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Farm-Level Carbon Intensity Improvements and the Inflation Reduction Act

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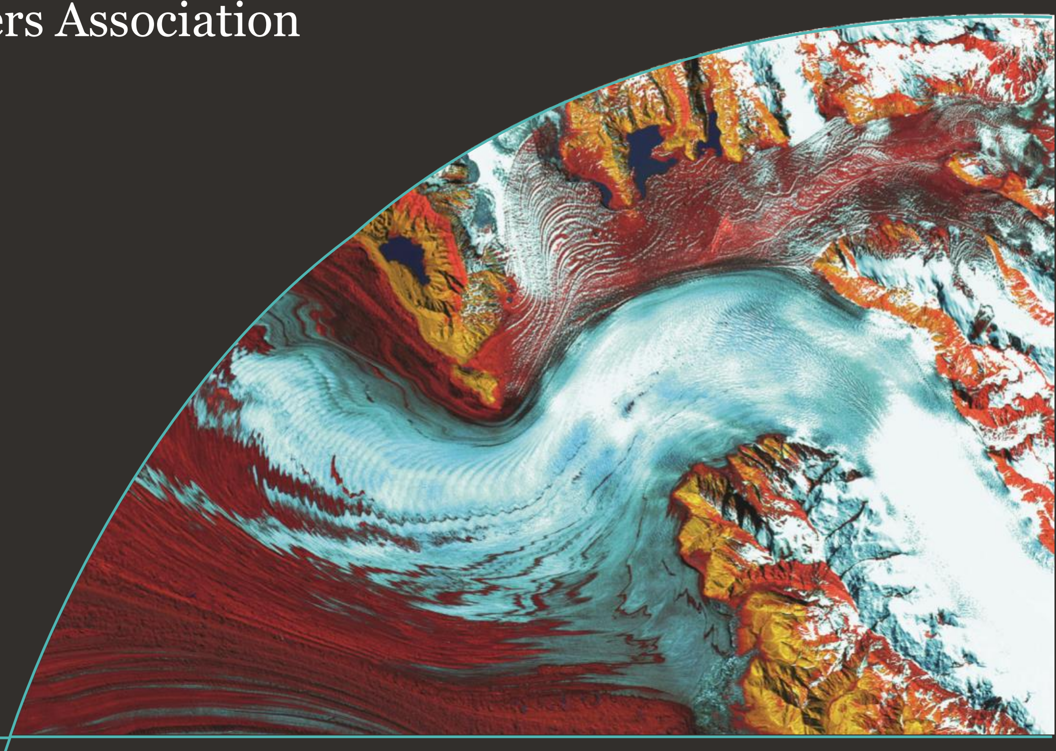
Topic 1 Report



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	Acronyms and Abbreviations
AGSs	Automated Guidance Systems
ANL	Argonne National Laboratory
CA-LCFS	California Low Carbon Fuel Standard
CCLUB	Carbon Calculator for Land Use and Land Management Change from Biofuels Production
CFPC	Clean Fuels Production Credit
CI	Carbon Intensity
CRFs	Controlled-Release Fertilizers
EEFs	Enhanced Efficiency Fertilizers
EFs	Emission Factors
ERS	Economic Research Service
EU	European Union
FD-CIC	Feedstock Carbon Intensity Calculator
FSA	Farm Service Agency
GPS	Global Positioning System
GREET	Greenhouse Gases, Regulated Emissions, and Energy use in Technologies
IBDU	Urea-Isobutylidene Diurea
IRA	Inflation Reduction Act
LPG	Liquefied Petroleum Gas
LUC	Land-Use Change
MRV	Monitoring, Reporting, and Verification
NASS	National Agricultural Statistics Service
OCE	Office of the Chief Economist
RFA	Renewable Fuels Association
RMA	Risk Management Agency
SOC	Soil Organic Carbon

SOM	Soil Organic Matter
	Acronyms and Abbreviations
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
VRTs	Variable Rate Technologies

Section 1: Executive Summary

Inflation Reduction Act (IRA) Section 45Z tax incentive measures provide strong motivation to lower the carbon intensity (CI) of ethanol produced in the U.S. Corn farming plays a substantial role in the final CI of ethanol, contributing 29.3 g CO_2e/MJ of the national average ethanol CI of 57 g CO_2e/MJ as calculated in ANL_GREET_2022. Farming practices such as cover cropping, reduced and no-till production, manure injection, and the Four "Rs" of fertilizer management can lower the CI of corn production, as shown below in Table E1.

Table E.1: Average CI-Reduction Range for Farm-Practice Changes

Farm Practice	CI Reduction (g CO_2e/MJ) from the Baseline Practice CI of 30.2	CI Score with various Farm Practices (Baseline Practice CI at 30.2 g CO_2e/MJ)
Manure	-8.8	21.4
Cover Crops	-15.2	15
Manure + Cover Crops	-22.2	8
Reduced Tillage	-3.2	27
No-Till	-4.3	25.9
Reduced Tillage + Cover Crops	-20.3	9.9
No-Till + Cover Crops	-25.4	4.8

Manure + Reduced Tillage + Cover Crops	-25.8	4.4
Farm Practice	**CI Reduction (g CO_2e/MJ) from the Baseline Practice CI of 30.2**	**CI Score with various Farm Practices (Baseline Practice CI at 30.2 g CO_2e/MJ)**
Manure + No-Till + Cover Crops	-30.5	-0.3

– *EcoEngineers modeling performed in FD-CIC for multiple states and counties.*

Capturing the potential benefits of these improvements in farm practices requires a number of changes by regulators, ANL, farmers, and the supply chain. Regulators need to be able to accept differentiated feedstocks from the current national average values. ANL would need to adopt alternate datasets for crop data and release more frequent GREET model updates reflecting improvements in farming. Farmers would need to adopt several farming practice changes and participate in reporting and tracking requirements for regulators, ANL, and the supply chain. The supply chain needs to update practices for feedstock traceability and identity-preserved mass-balance accounting.

Adopting a differentiated corn-farming production system may introduce unintended consequences. Higher CI corn in a differentiated system would likely be diverted to other corn markets such as food and feed. This may undermine the emission reductions achieved. Changes to modeling practices and data update cycles may not be feasible given the need for quality assurance and quality control (QA/QC). Results on soil organic carbon (SOC) exhibit higher uncertainty due to variations in soil properties, geography, differences in the precipitation patterns across the geography, crops grown, and land management practices. Measures to address this high uncertainty, such as more frequent SOC sampling at the field level, can be costly to implement. Making all these changes in time to take advantage of the 2025-2027 crediting periods may also be a heavy ask of the industry at large.

Section 2: Introduction

There is an interest expressed by the industry to determine if improved crop production practices can be recognized within the GREET model for specific applications by ethanol production facilities seeking to generate Clean Fuel Production Credits (CFPC) under IRA Section 45Z to lower the carbon intensity (CI) of their product. The GREET model, specifically the released Feedstock Carbon Intensity Calculator (FD-CIC), allows users to model the CI of crop production under various scenarios with embedded SOC change estimation using the parameterized CENTURY model. The tools exist, but questions remain about whether the datasets are sufficient, whether the data is accurate, and whether the modeled values represent real-world harvest performance indicators. The obstacle to monetizing low-CI corn's potential in the supply chain remains. Monetization of low-CI corn properties depends on the supply chain's capacity to maintain the traceability of the low-CI characteristics and transfer those properties to ethanol facilities. Doing so requires documentation practices like those practiced for exporting oilseeds to the European Union (EU) but are not commonly employed within the corn commodities market.

The current methodology presents unique challenges and opportunities in agricultural CI modeling, particularly for corn. The national average CI for corn, used in evaluating crop contributions to fuel life cycles, is derived from U.S. Census Bureau data collected in five-year cycles and supplemented with additional targeted datasets. While this approach offers a uniform platform for all crop producers, it inherently relies on data that could be up to five years old at the time of model development. Such a time lag raises questions about the relevance and time correlation of the data used.

Using a national average based on these five-year data cycles primarily aims to reduce the variability or "noise" from the factors influencing crop CI. It is an artifact of the frequency of agricultural survey data. More frequent data collection needs are balanced against the time spent processing data and the time requirements of survey respondents. This averaging approach also ensures a level playing field among crop producers by treating all equally, regardless of individual farm characteristics or local growing conditions. However, this method has drawbacks, particularly in rapidly evolving agricultural practices and environmental conditions.

Updating models at only semi-regular intervals is a pragmatic choice to minimize the extensive workload of renewing CI applications for numerous fuel producers and their myriad feedstock suppliers. Each supplier potentially has unique farm characteristics that could lead to a highly variable CI if considered individually. The schedule of updates, while reducing administrative burden, might not fully capture the dynamic nature of agricultural practices and environmental factors impacting crop CI.

The debate on the granularity of data used in CI modeling is critical. More frequent data collection and regional disaggregation could lead to increased signal noise and more significant variation, potentially disrupting the current status quo in the commodity market. However, the current approach of using a national average also masks substantial differences in farm performance due to factors like soil quality and growing conditions. Using farm-specific data turns a non-differentiated commodity into a potentially fractured one, necessitating more complex measures like traceability and supply chain management, similar to those employed for oilseed crops destined for EU markets.

There is also the issue of what occurs with higher emitting or higher-CI farms and counties; permitting them to continue to use an undifferentiated average may mask actual emission reductions. If differentiation does happen, the disaggregated approach must be applied equally to all counties. This is further complicated due to the multiple markets for commodity grains, which will cause higher CI products to be shunted to undifferentiated markets. Further policy consideration is required to limit the ancillary impacts created by this implementation.

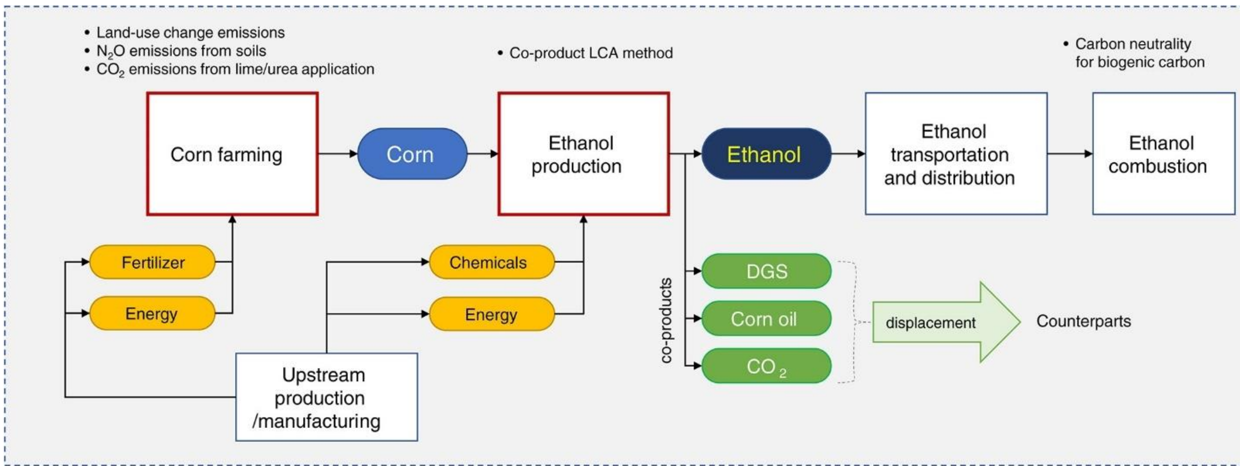
The crux of the issue lies in the intersection of agricultural practices, carbon footprint reduction, and economic incentives. Current tax incentives, such as those under the CFPC or IRA Section 45Z, encourage the production of low-carbon fuels by basing incentives on the final CI of the fuel, which is significantly influenced by crop production. The current system, while functional, overlooks the potential for recognizing and monetizing the CI-reduction efforts of farmers. If accurately acknowledged, these efforts could enhance the tax incentives for low-carbon fuel producers, encouraging more sustainable agricultural practices and resulting in a quicker transformation of reduced greenhouse gas (GHG) emissions from agriculture.

This paper aims to delve into the complexities of agricultural CI modeling, exploring the balance between data accuracy, administrative feasibility, and the ability to capture economic incentives. It will examine potential pathways for recognizing and monetizing the CI-reduction efforts in crop production, thereby contributing to a more sustainable and economically viable agricultural and energy production sector.

Section 3: Context

Figure 3.1 shows the typical life cycle boundaries, feedstocks, primary contributing emissions sources, and products produced from the fuel ethanol production lifecycle. This area focuses on the contributions of the corn-farming stage. Figure 3.2 shows the breakdown of significant contributions to the CI of the corn from the corn-farming stage. Emission sources include the production and use of fertilizers, nitrogen emissions from cropping practices, farm fuel use, and other minor contributors. The current average has no net soil carbon emissions.

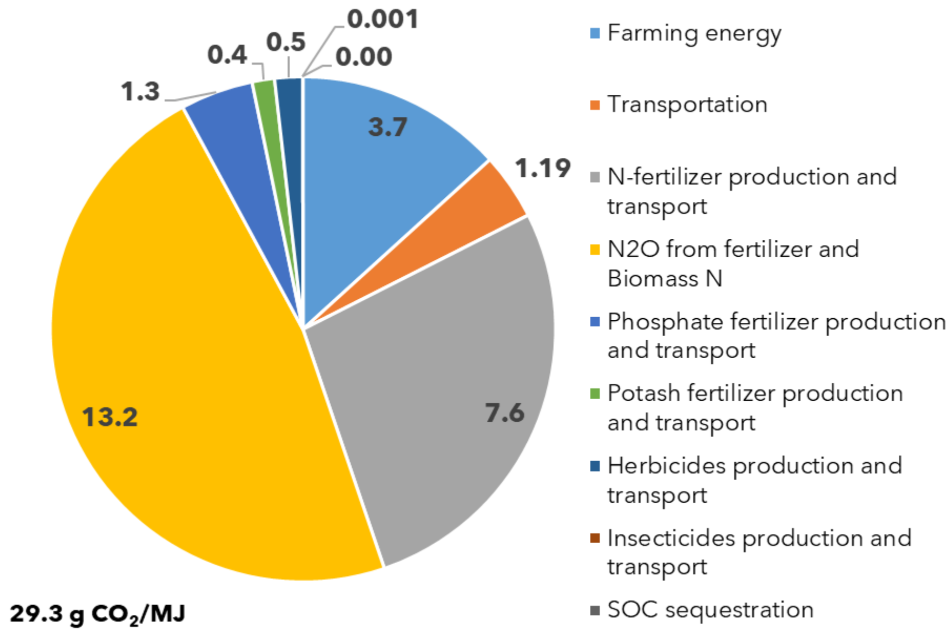
Figure 3.1: Life-Cycle Boundary for Corn-Ethanol Production[1]



– Argonne National Laboratory

[1] Argonne National Laboratory. *Biofuels, Bioprod. Bioref.* 15:1318–1331 (2021); DOI: 10.1002/bbb.2225)

Figure 3.2: Significant Contributors to the CI of Corn at the Farm Gate[2]



Section 4: Overview of Key Provisions of the IRA Section 45Z or the Clean Fuels Production Credit (CFPC)

This section provides an overview of key provisions within the IRA, focusing on the Section 45Z measure,[3] which is a straightforward production incentive. The IRA Section 45Z provision is designed to encourage the production of fuels with a lower CI. The incentive scales according to the degree of CI reduction achieved in the final fuel product, promoting fuel alternatives with lower net emissions. Additionally, the IRA includes a multiplier that rewards production facilities for meeting specific apprenticeship and wage targets, further incentivizing responsible and sustainable production practices. It is important to note that the credit is accrued directly to the fuel producer. Consequently, any transfer of this value to the farm level hinges on contractual agreements and maintaining a low CI (LowCI) corn identity within the supply chain.

Furthermore, for any credit to be generated with LowCI corn, the U.S. Environmental Protection Agency (USEPA), the U.S. Department of Energy (USDOE), the California Low

[2] ANL GREET Midwest Average from the Presentation by Ron Alverson to Dakota Ethanol Board of Directors.

[3] 26 U.S. Code § 45Z - Clean fuel production credit | U.S. Code | US Law | LII / Legal Information Institute (cornell.edu)

Carbon Fuel Standard (CA-LCFS), or the Canadian CFR must recognize the changes made in LowCI corn production. This recognition must affirm that farm, county, region, or state-level alterations are verifiable and accurate and that the data utilized is accepted. A significant challenge here is that most policies currently treat corn as a non-differentiated bulk commodity product, which overlooks the nuances of LowCI corn production and its potential environmental benefits. This treatment of corn CI is a policy choice impacted by multiple social and political factors beyond the scope of the science of Life-Cycle Analysis (LCA) and is beyond the scope of this work.

The CFPC, or IRA Section 45Z, is available from 2025 through 2027. Key provisions are:

- The fuel must be produced in the U.S. and have a CI lower than 50 kg CO_2e/MMBtu.
- For non-aviation fuels, the credit is US$0.02 per gallon (/gal) for each kg CO_2e/MMBtu reduction, up to $1.00/gal.

Table 4.1: Estimated IRA Section 45Z Clean Fuel Production Credit Values[4]

IRA Section 45Z Sample Targets (Rounding to 5 kg/MMBtu)	Sample Targets Converted to g CO_2e/MJ	Sample Emissions Factor Multiplier	Incentive US$/gal	Emissions Factor Multiplier
50 kg GHG/MMBtu	47.4 g CO_2e/MJ Ethanol	0	0	0
40 kg GHG/MMBtu	37.9 g CO_2e/MJ Ethanol	0.2	0.04	0.20
25 kg GHG/MMBtu	23.7 g CO_2e/MJ Ethanol	0.5	0.10	0.50
10 kg GHG/MMBtu	9.5 g CO_2e/MJ Ethanol	0.8	0.16	0.80

[4] Adapted from Congressional Research Service, titled "The Section 45Z Clean Fuel Production Credit", IF12502 (congress.gov)

0 kg GHG/MMBtu	0 g CO_2e/MJ Ethanol	1.0	0.20	1.00

With the national average ANL GREET 2022 value of ~53.4 g CO_2e/MJ, no facilities qualify for IRA Section 45Z credits as the emission-reduction targets have not been reached. IRA Section 45Z allows for rounding to the nearest 5 kg CO_2e/MMBtu, meaning the first credit generation occurs at 45 kg CO_2e/MMBtu or 42.7 g CO_2e/MJ. Facilities need to demonstrate at least a 10.7 g CO_2e/MJ reduction from this baseline value to qualify for the lowest tier of credit generation.

Corn feedstock production, as currently modeled using the ANL GREET Midwest Average, accounts for 29.3 g CO_2e/MJ of that national average value, making it a logical place to look for deep reductions required for credit generation. Several factors influence the CI of the corn crop, and the most relevant ones are detailed in the following sections.

Section 5: What We Know About Current Methods of Reducing On-Farm CI

Reducing the carbon footprint of crop production is crucial for sustainable agriculture. Some methods have been evaluated at various points in time within the agricultural sector. Adoption of any given practice is dependent on location and soil condition. Some of these methods are incorporated into the ANL GREET FD-CIC model and may be modeled for various state and county levels.

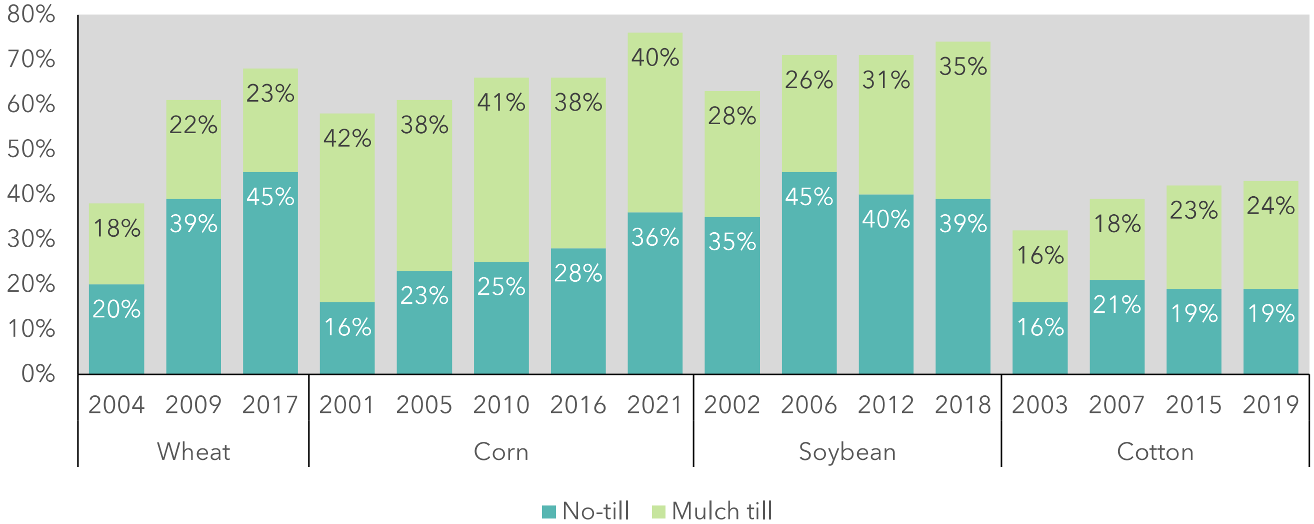
Chapter 5.1: Conservation Tillage

Traditional tillage practices can release significant amounts of carbon dioxide (CO_2) into the atmosphere. Conservation tillage techniques, such as no-till or reduced tillage, disturb the soil less and help retain more organic matter. This not only sequesters carbon in the soil but also improves soil structure and water retention.

Conservation tillage practices, including no-till, strip-till, and mulch-till, are widely used across crops and regions in the U.S. These practices can enhance soil health, reduce soil erosion, and potentially sequester carbon.

The adoption rates of conservation tillage practices vary widely by crop. In representative surveys, farmers reported employing conservation tillage on the majority of acres of wheat (68%), corn (76%), and soybeans (74%). However, many farmers are “partial” adopters, meaning they adopt these conservation practices on some but not all acres of their farm.

Figure 5.1: Percentage of Mulch-Till and No-Till Planted Acreage for Select Crops[5]



The potential GHG impacts of conservation tillage on the production of a bushel of corn are significant. It has been shown that there is potential for a substantial (up to 30%) reduction in GHG emissions by simply moving to no-till, as the resulting changes in the soil structure help reduce GHG emissions. Minimizing tillage also dramatically cuts diesel consumption linked to crop production.[6]

Given U.S. farmers' high adoption rate of no-till and mulch-till scenarios, the ongoing use of conventional tillage as the default scenario in modeling may require revision. This change would likely lower the national average CI value due to SOC playing a more significant role in the calculation. However, this exacerbates the issue of allowing those with higher emitting production scenarios to receive credit from the average without adopting improved practices. The use of a weighted average among tillage scenarios may mitigate this effect.

[5] Data Adapted from the U.S. Department of Agriculture (USDA) Economic Research Service ERS (USDA ERS - Chart Detail)

[6] Mooney, S.J., Sjogersten, S. Greenhouse gas emissions rise due to tillage. Nat Food 3, 246 (2022). https://doi.org/10.1038/s43016-022-00491-1

Chapter 5.2: Cover Cropping

Planting cover crops when the main crop is not growing can provide multiple benefits. Cover crops help prevent soil erosion, enhance soil fertility, improve water quality and absorption, and contribute to sequestering carbon. They also promote biodiversity and can suppress weeds, reducing the need for herbicides.

Cover cropping is a practice that has seen remarkable growth in every crop-producing region of the U.S. It involves using crops grown for the protection and enrichment of the soil rather than for harvest. These cover crops can include various plant species, including grasses, legumes, and others.

According to the 2017 U.S. Department of Agriculture's (USDA) Census of Agriculture, over 150,000 farms reported using cover crops.[7] The use of cover crops increased by 50% between 2012 and 2017.[8] The acreage of cover crops on U.S. farmland has also grown significantly from 10.3 million acres in 2012 to an estimated 20 million acres in 2020. However, despite these increases, cover crops have only been adopted on 6% of harvested annual cropland as of 2017, indicating a significant potential for future adoption.[7]

The potential GHG impacts of cover cropping on the production of a bushel of corn are significant. Cover crops can help reduce GHG emissions by sequestering carbon in the soil and lowering the amount of CO_2 in the atmosphere.

In a study comparing trace gas fluxes in a no-till maize field over the entire growing season in 2018, it was found that different types of cover crop systems have the potential to mitigate climate change. Specifically, the living mulch (LM) system using white clover showed the lowest net-carbon equivalent, indicating its potential for reducing GHG emissions.[9]

Moreover, adopting conservation tillage, reducing nitrogen fertilizer use, and implementing cover crops can reduce GHG emissions per unit of corn produced compared to a baseline scenario of a corn-soybean rotation.

[7] 2017 Census of Agriculture, United States Department of Agriculture. Issued April 2019.

[8] National Cover Crop Survey Report 2022-2023, Sustainable Agriculture Research and Education (SARE), American Seed Trade Association (ASTA) and Conservation Technology Information Center (CTIC), August 2023.

[9] Agricultural Greenhouse Gas Fluxes Under Different Cover Crop Systems. Wang, Y., Saikawa, E., Avramov, A., and Hill, N. Front. Clim., 04 January 2022. Sec. Climate Risk Management Volume 3 - 2021 | https://doi.org/10.3389/fclim.2021.742320

Chapter 5.3: Crop Rotation

The continuous cultivation of the same crop can deplete soil nutrients and increase the need for fertilizers. Crop rotation involves alternating different crops in a specific sequence, which helps break pest and disease cycles, improve soil health, and reduce the reliance on synthetic inputs. Healthy soils sequester more carbon.

Crop rotation is a common practice in the U.S. that involves sequencing different crops over time on the same field. This practice is not unique to organic systems; many conventional farmers also practice it.

According to the USDA, most of the cropland across the U.S. uses crop rotation. The most widely adopted rotation is a two-year rotation of corn and soybeans, though wheat is also commonly added into the mix. However, less than 24% of the respondents use diversified cropping—about two-thirds are diversifying via a three-crop rotation plan, and the remainder via four or more crops.[10]

The potential GHG impacts of crop rotation on the production of a bushel of corn are significant. Crop rotation practices can help reduce GHG emissions by improving soil health, managing, and conserving nutrients, and breaking crop pest cycles. Currently, GREET modeling assumes the default scenario of a corn/soybean rotation. Additional options include a limited number of cover crops. Comparing the corn phase of a corn-soybean rotation to continuous corn showed an average yield benefit of more than 20% and a cumulative reduction in nitrous oxide (N_2O) emissions of approximately 35%.[11] Moreover, adding a single tiny grain crop can reduce fossil fuel use, pollution, and damage by about one-half.[12] More diverse rotation systems used 56% less fossil fuels, generating 54% fewer GHG emissions.[9]

[10] Wade, Tara, Roger Claassen, and Steven Wallander. Conservation-Practice Adoption Rates Vary Widely by Crop and Region, EIB-147, U.S. Department of Agriculture, Economic Research Service, December 2015.

[11] Gevan D. Behnke et al, Long-term crop rotation and tillage effects on soil greenhouse gas emissions and crop production in Illinois, USA, Agriculture, Ecosystems & Environment (2018). DOI: 10.1016/j.agee.2018.03.007

[12] Fossil Energy Use, Climate Change Impacts, and Air Quality-Related Human Health Damages of Conventional and Diversified Cropping Systems in Iowa, USA. Natalie D. Hunt, Matt Liebman, Sumil K. Thakrar, and Jason D. Hill. Environmental Science & Technology 2020 54 (18), 11002-11014 DOI: 10.1021/acs.est.9b06929

Chapter 5.4: Precision Agriculture

Precision agriculture technologies, such as GPS-guided tractors and sensors, enable farmers to optimize the use of resources like water, fertilizers, and pesticides. By precisely applying these inputs where and when they are needed, farmers can reduce excess usage and associated emissions. This approach improves overall efficiency in the farming system.

Precision agriculture is implemented on corn farms in the U.S. through various digital technologies. Here are some of the key technologies used and their impact on GHG emissions:

- **Automated Guidance Systems (AGSs) and GPS Mapping:** These technologies are used by up to 80% of the largest U.S. corn farms (over 2,900 acres). They help in precise steering and mapping of yields, leading to more efficient resource use and reduced GHG emissions.[13]
- **Variable Rate Technologies (VRTs):** These technologies allow for site-specific application of inputs such as fertilizers and pesticides. They are used by 30%-40% of the largest U.S. corn farms.[14] By optimizing inputs, VRTs can reduce the amount of fertilizer needed, thereby decreasing GHG emissions.
- **Yield Maps and Soil Maps:** These technologies have been adopted on a substantial portion of corn acreage for many years.[15] They provide detailed information about the variability within fields, which can be used to optimize input use and reduce GHG emissions.[16]
- **Precision Physical Weeding:** This technology reduces the need for chemical herbicides by using high-tech equipment to remove weeds, which can result in lower GHG emissions. The technology is largely in the demonstration phase.
- **Strip Tillage:** Precision agriculture and the increased use of AGSs and GPS mapping allow farmers to accurately place fewer nutrients in the soil in a narrower tillage area and increase their crop yields.

[13] Jonathan McFadden, Eric Njuki, and Terry Griffin. February 2023. Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms, EIB-248, U.S. Department of Agriculture, Economic Research Service.

[14] Agricultural Greenhouse Gas Fluxes Under Different Cover Crop Systems. Wang, Y., Saikawa, E., Avramov, A., and Hill, N. Front. Clim., 04 January 2022. Sec. Climate Risk Management

Volume 3 - 2021 | https://doi.org/10.3389/fclim.2021.742320

[15] Xinyu Liu et al 2020 Environ. Res. Lett. 15 084014

[16] Jonathan McFadden, Eric Njuki, and Terry Griffin. February 2023. Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms, EIB-248, U.S. Department of Agriculture, Economic Research Service.

The adoption of these technologies has been increasing in recent years, driven by factors such as pricing, soil variability, USDA programs, labor-saving benefits, expected productivity impacts, and the availability of consultant services. However, the effect of these technologies on GHG emissions can vary based on specific farm conditions and practices.

Chapter 5.5: Renewable Energy Sources

Implementing renewable energy sources on the farm, such as solar or wind power, can reduce the carbon footprint associated with energy consumption. Solar panels on farm buildings or wind turbines in suitable locations can generate clean energy, offsetting the use of fossil fuels and reducing GHG emissions. Additionally, using renewable fuels in vehicles and farm implements lowers GHG emissions at the farm gate and on to the delivery of the crop to the end user.

Chapter 5.6: The Four "Rs" of Enhanced Efficiency, Fertilizers, and Special-Use Crop Chemicals

The four "Rs" of fertilizer application in agriculture, including corn farming, are:

Right Source: This involves choosing a fertilizer that provides the appropriate nutrients for the crop. For corn farming, this means selecting a fertilizer that includes nitrogen, phosphorus, potassium, and other micronutrients essential for corn growth.

Right Rate: This is about applying the correct amount of fertilizer. For corn, this rate depends on factors such as soil fertility, previous crop management, and expected yield. Over-application can lead to nutrient runoff and under-application can result in poor crop performance.

Right Time: Timing the application to match the crop's nutrient uptake. In corn farming, nitrogen is often applied in the spring before planting and sometimes supplemented during the growing season to meet the crop's changing nitrogen needs.

Right Place: This refers to applying fertilizer where the plants can easily access it. In corn farming, this might mean banding the fertilizer near the seed at planting or side-dressing nitrogen along the rows of growing corn.

Each of the four "Rs" can be altered by the farmer according to their local conditions and needs. Soil testing for nutrient content, zone mapping, and other testing data provide farmers with the information they need to make appropriate choices for managing crop yield, health, and effectively its CI at the farm gate.

Chapter 5.7: Enhanced Efficiency Fertilizers (EEFs)

EEFs are a category of fertilizers designed to increase nutrient availability to plants and reduce environmental nutrient losses. They work by altering the fertilizer release rate or stabilizing the nutrients, thus improving efficiency. There are several types of EEFs, each working in different ways:

Controlled-Release Fertilizers (CRFs): These fertilizers encapsulate nutrients in a polymer coating. The release of nutrients is controlled by the properties of the coating, which allows for a slow and steady release over time. This more closely matches the nutrient uptake pattern of the plant, reducing the risk of leaching or runoff.

Slow-Release Fertilizers: Unlike CRFs, slow-release fertilizers rely on physical and chemical processes within the fertilizer material to slow down nutrient release. They typically involve urea-formaldehyde, urea-isobutylidene diurea (IBDU), or sulfur-coated urea.

Stabilized Fertilizers: These fertilizers include additives that inhibit or delay specific biochemical reactions in the soil, specifically those involving nitrogen. For example, nitrification inhibitors slow the conversion of ammonium to nitrate, which is more prone to leaching and denitrification. Urease inhibitors slow the conversion of urea to ammonia, reducing volatilization losses.

Customized Fertilizers: These are tailor-made for specific soil types, crop varieties, and environmental conditions. They might combine technologies (like slow-release and stabilization) to suit requirements.

The main benefits of EEFs include:

- **Increased Nutrient Use Efficiency:** By aligning nutrient release with crop demand, more nutrients are absorbed by the plant, thereby reducing waste.
- **Reduced Environmental Impact:** They minimize nutrient runoff and leaching, which can lead to water pollution.
- **Flexibility in Application Timing:** Because of their controlled release, there's less need for precision timing in fertilizer application.
- **Potential Cost Savings:** While EEFs might be more expensive upfront, they can lead to cost savings by reducing the amount of fertilizer needed and minimizing the need for multiple applications.

Using EEFs requires understanding the crop's nutrient needs, soil characteristics, and environmental conditions to maximize their benefits.

Chapter 5.8: The Use of Manure or Green Ammonia

The GREET model contains datasets showing that livestock manure can dramatically reduce GHG emissions and sequester nutrients and carbon when properly applied. Nitrogen produced from a renewable energy source also significantly reduces direct and indirect emissions. However, using manure in the farming system can induce additional emissions due to energy consumption during manure application and additional N_2O emissions from applied manure.

The changes in GHG emissions due to "green ammonia" are mainly attributed to conventional ammonia production relying heavily on fossil fuels (primarily natural gas) to produce required hydrogen and provide process heat. Alternatively, potential solutions to reduce GHG emissions from the "green hydrogen" are due to:

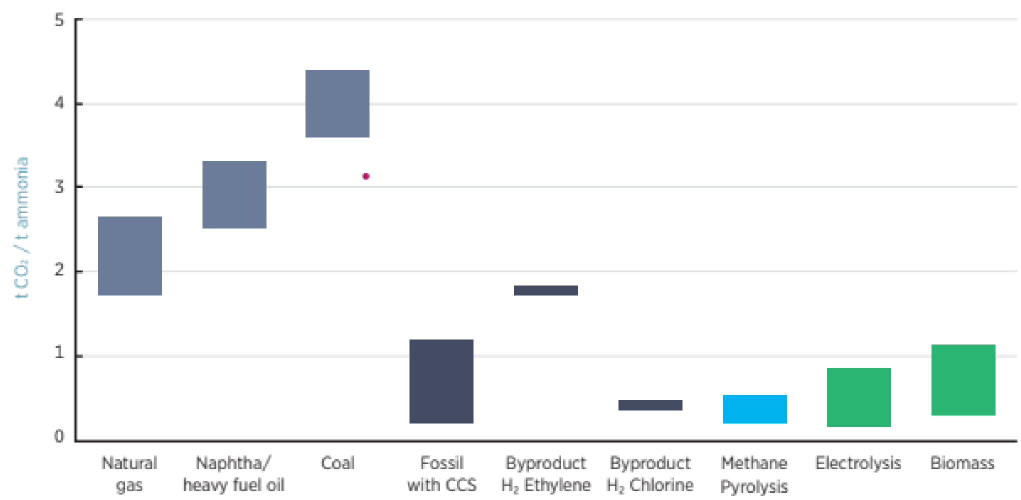
- Production of clean hydrogen for ammonia synthesis, which can be carried out through multiple pathways (e.g., carbon capture and storage) or electrolysis with renewable electricity;
- Improvement in the technology performance (e.g., electrolyzer efficiency); and
- Diversifying the fuel-switching (e.g., biomass).

The high prices for natural gas (experienced in 2021 due to shortage) provide tremendous opportunity for renewable ammonia.[17] Renewable ammonia is expected to reduce global GHG emissions in the following manner:

- Ammonia production generates around 0.5 gigatons (Gt) of CO_2-equivalent annually, accounting for 1% of global GHG emissions. These emissions are mainly attributed to the extensive consumption of fossil fuel in the conventional hydrogen production and ammonia synthesis processes, as discussed above. The use of clean energy can mitigate these emissions.
- GHG-gas emissions from fossil-based ammonia production vary depending on the feedstock (e.g., natural gas generates at least 1.6 metric tons (MT)) of CO_2 per MT of ammonia, and coal generates around 4.0 MT of CO_2 per MT of ammonia).
- Additional GHG emissions occur at the upstream (with embedded emissions and fugitive methane) and downstream (during storage, transport, and distribution) stages.
- Including upstream and downstream emissions, renewable ammonia from electrolysis could have a carbon footprint below 0.1 MT of CO_2 per MT of ammonia by 2050.

[17] International Renewable Energy Agency (IRENA 2022) IRENA, 2022. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf?rev=50e91f792d3442279fca0d4ee24757ea

Figure 5.2: Illustrative Ranges of Estimated GHG Emissions of Ammonia Production from Various Feedstock[17]



Chapter 5.9: Crop Stimulants and Biological Products

In corn farming, particularly in the U.S. Midwest, farmers often use a variety of crop stimulants and biological products to improve crop yields and overall plant health. These products enhance nutrient uptake, improve soil health, and protect against pests and diseases. Some of the common types of stimulants and biologicals used include:

1. **Biostimulants:** These substances or microorganisms are applied to plants or soils to enhance nutrient uptake, stress tolerance, and crop quality. They include:
    - Humic and fulvic acids: Natural compounds that improve soil structure and nutrient availability.
    - Seaweed extracts: Rich in micronutrients and growth-promoting substances that enhance plant growth and stress tolerance.
    - Beneficial bacteria and fungi such as rhizobacteria and mycorrhizae, form symbiotic relationships with plant roots, aid nutrient absorption, and protection against pathogens.
2. **Biofertilizers:** These microbial inoculants promote plant growth by increasing the availability of primary nutrients to the host plant. Common examples include:

[17] International Renewable Energy Agency (IRENA 2022) IRENA, 2022. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf?rev=50e91f792d3442279fca0d4ee24757ea

- Nitrogen-fixing bacteria: Such as rhizobium, form nodules on roots and fix atmospheric nitrogen.
- Phosphate solubilizing microorganisms: These bacteria and fungi convert insoluble soil phosphate into forms more easily taken up by plants.

3. **Plant Growth Regulators (PGRs):** These chemicals influence plant growth and development. They can be natural or synthetic and include substances like:
    - Auxins: Promote root development and cell elongation.
    - Cytokinins: Stimulate cell division and shoot growth.
    - Gibberellins: Influence seed germination, stem growth, and fruit development.
4. **Soil Amendments:** While not biological, organic matter like compost and manure is often added to improve soil health, structure, and nutrient content. They also support the growth and activity of beneficial soil microorganisms.
5. **Cover Crops:** Planting cover crops like legumes, grasses, or crucifers during the off-season can enhance soil health, prevent erosion, and improve nutrient cycling, indirectly benefiting the subsequent corn crop.
6. **Microbial Soil Inoculants:** These preparations contain beneficial microorganisms like Trichoderma or bacillus species, which can improve soil health and nutrient uptake and provide disease resistance.

The application of these products is guided by soil and tissue testing, local climate conditions, and specific crop requirements. These stimulants and biologicals are vital in sustainable and efficient agricultural practices by enhancing nutrient uptake, improving soil health, and stimulating plant growth. Data on yield improvement, soil health improvement, and increased SOC storage using stimulants and biologicals is more diverse, showing that lower-productivity soils and more degraded conditions benefited more from these interventions than healthier, more productive soils. They likely require more extensive testing and monitoring on a farm-by-farm basis based on local conditions.

Chapter 5.10: Summary of On-Farm Practices

In modern corn farming, multiple levers can be used to alter the yield of the crop and the CI thereof. Tillage practices, including no-till and reduced-till, are already being implemented on over 75% of corn acres planted. Other practices such as cover crops, manure application, and fertilizer applications are used to varying degrees with varying results.

This includes using GPS-guided equipment to apply fertilizers more accurately, soil testing to determine the exact nutrient needs, and sometimes even sensors and drones to monitor crop health and adjust fertilizer application in real time. These methods help optimize fertilizer use, enhance crop yields, and minimize environmental impact.

It is important to note that the effectiveness of these methods can vary depending on the specific context of the farm, including its location, climate, soil type, and the crops grown. A combination of these practices, tailored to the local conditions, can significantly reduce the carbon footprint of crop production. Additionally, ongoing research and collaboration within the agricultural community can help identify and implement new strategies for sustainable farming.

Now that we have established an understanding of the various CI levers and practices within the farmer's ability to influence, we need to determine which levers to pull to achieve the targeted reductions required and how to make the determination of these reductions accurate, verifiable, and the properties traceable within the system.

Section 6: Feedstock Carbon Intensity Calculator (FD-CIC) Comparison of Multiple Counties While Varying Farm Practices

Several tools and models quantify the GHG emissions or total CI of crop production. By testing varying practices with these models, we hope to narrow down the options available to provide the best result for effort. ANL has been working on the GREET model for several years to expand its use and utility in modeling the feedstock production phase of the fuel's lifecycle. This has resulted in the development of the Feedstock Carbon Intensity Calculator (FD-CIC). Due to the acceptance of the GREET model for use in the Renewable Fuel Standard (RFS) and its adoption within the CA-LCFS, work will focus on using this model. This is not to say there are no other options; some are perhaps better tuned to the agriculture sector. This study does not aim to contrast or compare other available modeling options.

Chapter 6.1: The GREET FD-CIC

In addition to biofuel conversion processes, feedstock production also substantially contributes to the lifecycle GHG emissions of the biofuel supply chain. Various farming practices lead to significant CI variations for feedstocks. To provide evidence-based research findings, the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) has supported the Systems Assessment Center of the Energy Systems Division at ANL to examine CI variations of different farming practices to grow crops for biofuel production. Meanwhile, the ARPA-E has launched the Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management (SMARTFARM) program to develop technologies and data platforms that enable an accurate measurement of key farming parameters that can help robust accounting of the GHG benefits of sustainable, low-carbon agronomic practices at the farm level. With the ARPA-E support, ANL has developed a tool: the FD-CIC.

The first version of FD-CIC was released with the GREET model in 2020 (Wang et al., 2020) so that corn feedstock producers can use this publicly available tool[18] to quantify corn grain CIs with farm-level input data and management practices. More expansions were made in FD-CIC at different time spans to accommodate various feedstocks such as soybeans, sorghum, and rice. Currently, dynamic and standalone versions of FD-CIC are available. The dynamic version interacts with the GREET model by directly reading the life-cycle inventory (LCI) data of key farming inputs from it.

This version is well suited when users want to change the GREET default settings that affect the GHG-emission intensities of farming inputs. For example, suppose users wish to assess the impact of using a regional electricity grid mix to produce key farming inputs instead of the U.S. average grid mix. In that case, they can modify the grid mix in the GREET model and utilize the interacting feature in the FD-CIC to re-read the updated CI values for those key farming inputs. The interacting feature also updates the CI values with the annual GREET release. The standalone version is built for users who are not familiar with the GREET model and contains the GREET default LCI data for key farming inputs.

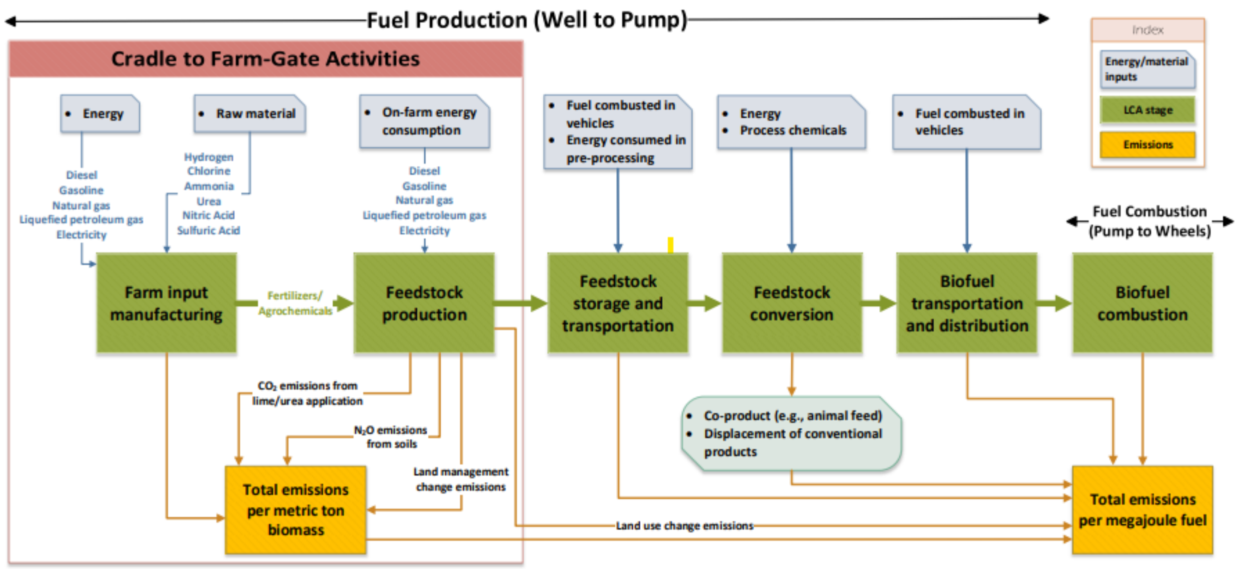
The system boundary of FD-CIC covers the cradle-to-farm-gate activities, including upstream emissions related to farming input manufacturing and feedstock production (see Figure 6.1). Farming inputs and on-farm energy consumption are the main LCI data required to estimate the GHG emissions associated with their upstream manufacturing and on-farm use. In FD-CIC, users must enter the usage amount per acre for fertilizer/chemical inputs and common energy carriers – i.e., diesel, gasoline, natural gas, liquefied petroleum gas (LPG), and electricity. If farms have not used a specific energy/fertilizer type, as defined in FD-CIC, the value for the particular type should be set to zero. The GREET default farming input data are also provided as the reference, which is based on results from USDA's major survey programs such as the National Agricultural Statistics Service (NASS), the Economic Research Service (ERS), and the Office of the Chief Economist (OCE) reports.

Regarding emission factors, two sources of nitrogen inputs to soil are considered in GREET and FD-CIC: nitrogen from fertilizer application and nitrogen in crop residues left in the field after harvest. As with GREET, FD-CIC calculates soil N_2O emissions associated with feedstock production using empirically derived emission factors (EFs), which assume a linear relationship between soil N_2O emissions and nitrogen inputs. FD-CIC 2021 adopts the direct soil N_2O EFs disaggregated by climate zones (i.e., wet or dry), according to a meta-analysis of field experiment data collected from nine major corn-producing states. FD-CIC accounts for the potential impacts of SOC changes associated with changes in farming practices on the feedstock CI accounting. The SOC impacts on corn and soybean CI are evaluated by modeling the county-level SOC changes under corn-soybean rotation prevalent in most of the U.S. Midwest. As an essential component in biofuel LCA, land-use change (LUC)-induced emissions have been incorporated into biofuel CI calculation that accounts for the SOC changes due to shifts in land use and land cover for large-scale biofuel feedstock production.

[18] https://greet.es.anl.gov/tool_fd_cic

However, since the FD-CIC focuses on cradle-to-farm-gate activities, it does not include LUC emissions in CI calculation. Still, it has a lookup table for SOC sequestration potentials of diverse farming practices to address great opportunities for CI reductions. LUC-induced direct and indirect emissions are included in the Carbon Calculator for Land Use and Land Management Change from Biofuels Production (CCLUB) module of the GREET model.[19]

Figure 6.1: The Cradle-to-Farm Gate System Boundary of FD-CIC Within an Ethanol Production System[20]



Chapter 6.2: Using the FD-CIC Calculator to Test Various Corn-Farming Production Scenarios

Several comparative analyses were undertaken using the FD-CIC calculator to better understand the CI impacts of applying specific farm practices to corn production. Changes in farming practices could alter SOC, where the primary focus was due to the variability in soil conditions from farm to farm and even county to county. The application of manure, use of cover crops, and the use of reduced till or no-till scenarios were tested alone and then in combinations. This is similar to the work of Liu et al., 2020, which used ANL GREET1_2018

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[19] Kwon, H., Liu, X., Dunn, J. B., Mueller, S., Wander, M. M., & Wang, M. (2020). Carbon Calculator for Land Use and Land Management Change from Biofuels Production (CCLUB). Argonne National Laboratory (ANL), Argonne, IL (United States).

[20] Liu, X., Kwon, H., & Wang, M. (2021). Feedstock Carbon Intensity Calculator (FD-CIC) Users' Manual and Technical Documentation. Argonne National Laboratory (ANL), Argonne, IL (United States).

and is discussed in the next section. Not all potential counties or states were examined; counties were selected to represent low-, medium-, and high-baseline CIs before application of the various test conditions. All other factors within the model, such as yield, were held constant. These changes would tend to stimulate a yield response. Calculating actual on-farm values using the FD-CIC calculator should be corrected to the actual yield of corn for the given year the farming practices were altered.

Figures represent the modeled values for various counties in different states subject to the combinations of other land management and cropping condition changes described. The lowest CI results are due largely to modeled changes in SOC and come from the combined practices of manure application, use of a cover crop, and no-till farming. The individual counties' values, however, vary widely.

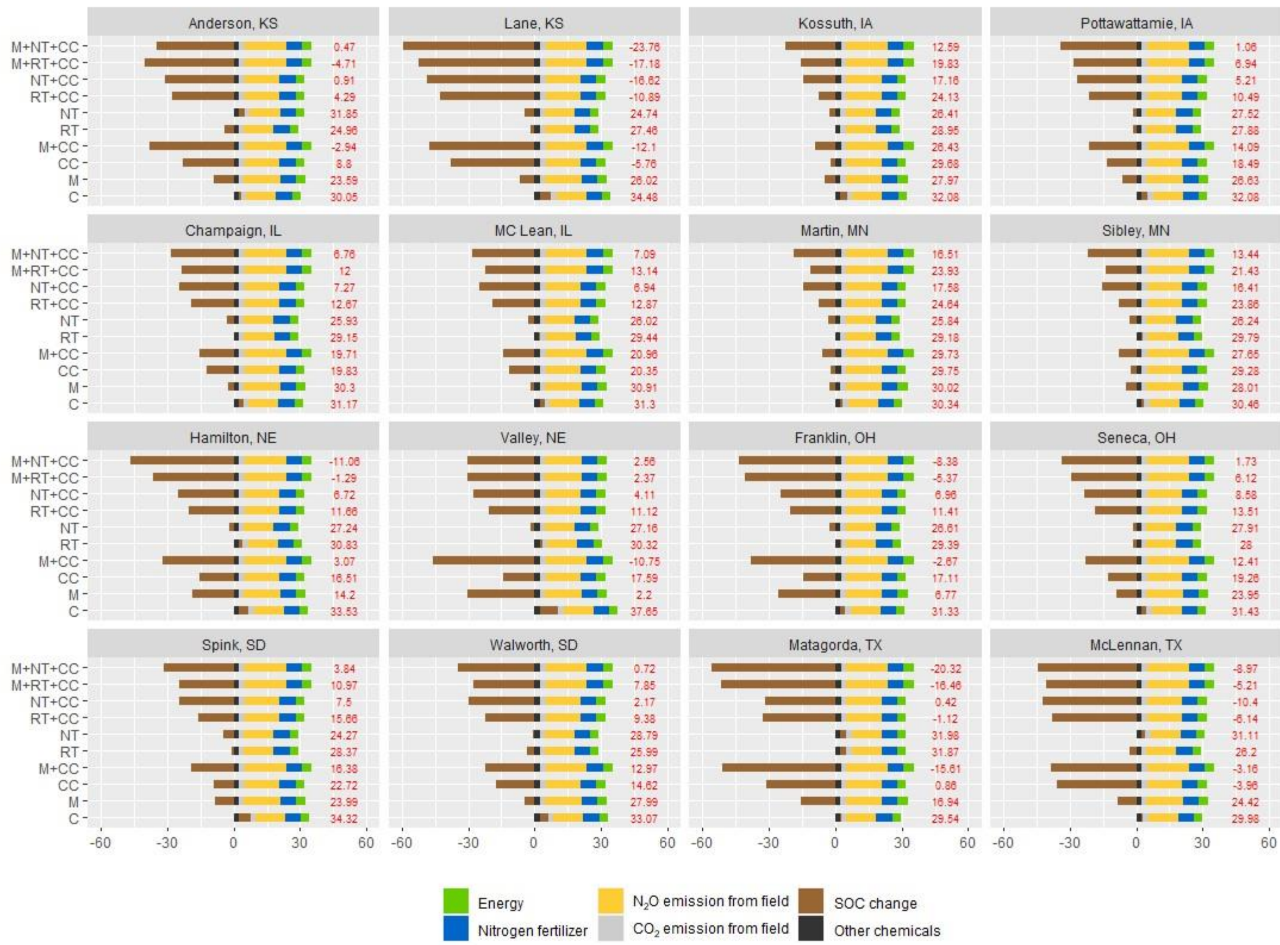
Table 6.1: Default Values Used for the Farm Inputs in the CI Calculation Using the FD-CIC Tool[21]

Parameters Considered in the Evaluation	Default Values from FD-CIC
Farm size (acre)	1000
Corn yield (bushels/acre)	178.4
Diesel use (gal/acre)	7.2
Gasoline use (gal/acre)	1.3
Natural gas (cu. ft/acre)	87
Liquified petroleum gas (gal/acre)	2.2
Electricity (kWh/acre)	69.3
N-Fertilizers (lbs N/acre)	
Ammonia	49.0
Urea	36.3
Ammonium Nitrate	3.2

[21] Liu, Xinyu, Kwon, Hoyoung, and Wang, Michael. Feedstock Carbon Intensity Calculator (FD-CIC): Users' Manual and Technical Documentation. United States: N. p., 2022. Web. doi:10.2172/1891321.

Parameters Considered in the Evaluation	Default Values from FD-CIC
Ammonium Sulfate	3.2
Urea-ammonium nitrate solution	50.5
Mono-ammonium Phosphate	6.3
Di-ammonium phosphate	9.5
Phosphorous-Fertilizers (lbs P_2O_5/acre)	
Mono-ammonium Phosphate	29.6
Di-ammonium phosphate	29.6
Potash fertilizer (K_2O) (lbs K_2O/acre)	59.9
Lime ($CaCO_3$) (lbs/acre)	573
Herbicides (g/acre)	1044.2
Insecticides (g/acre)	2.2
Manure (if considered)	
Swine (tons /acre)	1.9
Dairy (tons/acre)	3.3
Cattle (tons/acre)	1.7
Chicken (tons/acre)	0.9
Manure application energy (Btu/acre)	221,366
Manure transport distance (miles)	0.37
Manure transportation energy (Btu/ton/manure/mile)	10,416

Figure 6.2: CI of Corn Feedstock Across Various U.S. Regions (g CO_2e/MJ)



– EcoEngineers modeling in FD-CIC

Interpretation Matrix for Crop CI: C =Conventional, M = Manure, CC = Cover Crop, RT = Reduced Tillage, NT = No-till

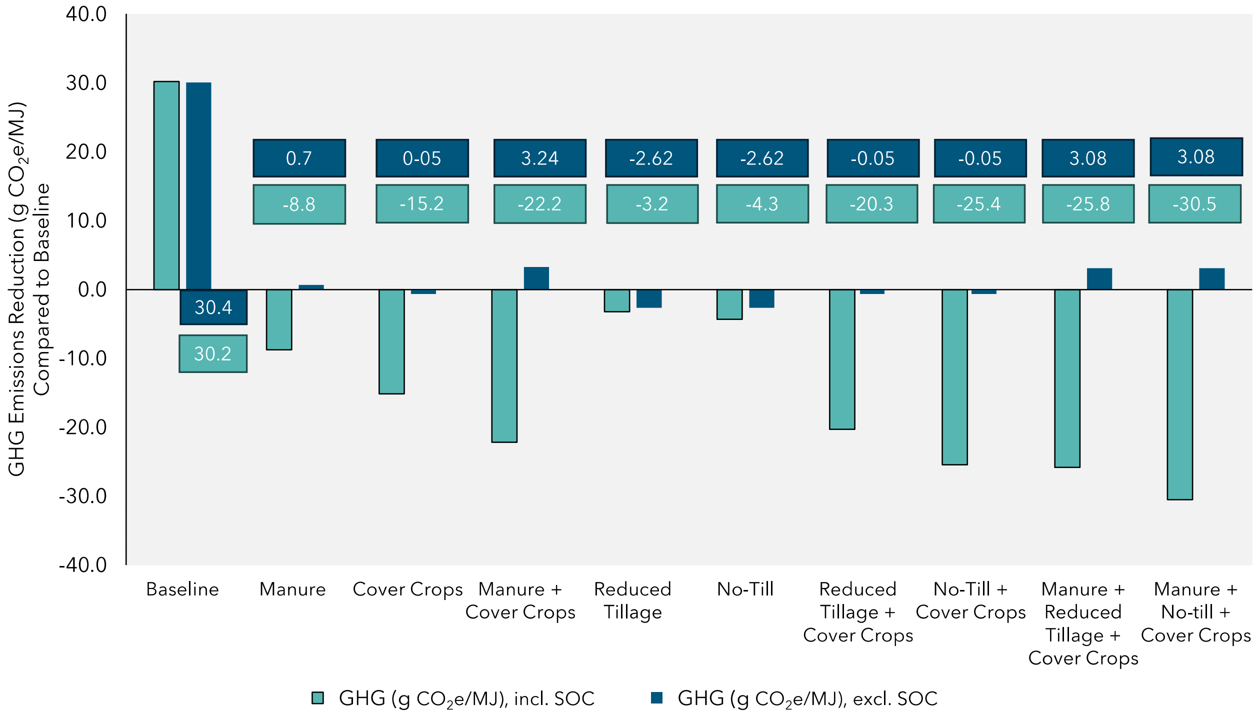
Chapter 6.3: What Does This Information and Data Comparison Tell Us?

First, we can consider whether the observed SOC differences discussed in this section are real or an artifact of modeling. The FD-CIC tool uses analyses from the parameterized Century model to estimate SOC changes. The Century model is built based on SOC sampling and a variety of other soil parameters from several studies. The U.S. has vast farming lands that are in very different geographies, with varied topography, varied soil types, varied microbial communities, and varied precipitation patterns. Century and FD-CIC attempt to model all these various impacts. The results observed are somewhat due to limitations in the modeling, and very likely are due to the highly variable nature of the farmlands being modeled. Farmlands are very much living systems in constant states of flux. The modeling available is the best approximation of how the system will respond to any change in activity but may not always prove true under real-world test conditions.

The various modeling scenarios demonstrate the large county-to-county variability that would be observed by going from using a single national average value to using farm-specific or farming county values. A single county can apply various practice changes and realize a benefit in reduced CI of the corn produced. Not all counties are equal; some counties are above the national average of 29.3 g CO_2e/MJ when using the baseline condition sets of conventional tillage and no cover cropping. SOC sequestration, and SOC generally, is a large source of variation between counties.

As shown in Figure 6.3, a substantial reduction in GHG emissions is expected from the scenario with SOC changes included in the net CI assessment. However, when only emissions from the farm inputs are accounted for (i.e., excluding the SOC change), a reduction in GHG emissions can be expected from management practices using reduced and no-till options and manure incorporation with cover crops. Without the SOC change included, and with manure applied, it is expected that the CI could increase due to the additional use of fuel for manure application and additional N_2O emissions from the manure. The magnitude of the CI increase depends on the amount of manure applied, the timing of the application, and soil-in situ characteristics.

Figure 6.3: GHG Emission Reductions Calculated for Different Management Practices



– EcoEngineers modeling in FD-CIC

Using Lane County, Kanas as a test case, the different management practices in Figure 6.3 resulted in a minimum CI value of -23.76 g CO_2e/MJ, suggesting that substantial SOC sequestration may be possible while producing corn crops for ethanol production. If corn were differentiated from the national average, an ethanol plant receiving this LowCI corn could shift from a CI of 49.8 g CO_2e/MJ (CA-LCFS average after iLUC is removed) to -3.26 g CO_2e/MJ (a net carbon sequestration scenario) with no further actions taken at the plant level. This would qualify for the highest IRA Section 45Z credit of $0.20/gal or $1.00/gal (with wage and apprenticeship targets met).

Under the baseline case (normal tillage, no cover crops, and no manure application), the highest local CI value observed from the counties tested was 37.65 g CO_2e/MJ, which included a contribution of modeled SOC loss. If corn were to be differentiated from the national average of 29.3 g CO_2e/MJ, a facility receiving this corn would see its CI shift from the average of 49.8 g CO_2e/MJ to 58.55 g CO_2e/MJ, putting the IRA Section 45Z credits further out of reach.

Chapter 6.4: Considerations

One item that should be considered is whether differentiation of the corn crop based on CI would create more problems than it is intended to solve. A farm producing higher CI corn is not required to supply that corn into the fuel ethanol sector. It can opt to sell to feeds and chemical markets where CI is not currently tracked with the same rigor. When only a fraction of production is covered by a policy, it creates potential holes where emissions can occur without consequence. Differentiating corn crops into LowCI and other grades potentially opens this door; this is a common issue in LCA studies known as problem shifting.

The GHG emission reductions are there for the taking if system traceability is enabled. Ongoing testing to prove SOC sequestration and validate model values will be required. Tracking of farm practices and regular SOC sampling at a statistically relevant frequency by accredited laboratories, followed by audit and verification practices to ensure data integrity would be required on a growing season or yearly basis. This may be a task more appropriate for a certification scheme of some sort, as the data collection, interpretation, and validation needs may exceed capacity at the farm or county level. Once SOC values become traceable and verifiable, the data will need to be transferred to the production facility along with the feedstock. In the event of aggregators or local elevators, this would require the management of multiple feedstock supplier CIs with supporting evidence. The production facility will need to be able to manage the data load, along with the increased purchasing sophistication to enable contracting of environmental attributes, feedstock tonnage, and transportation. Remaining within an annual operational CI range for output products could become logistically difficult if the CI of incoming feedstock is highly variable.

This has a follow-on effect of making CI calculation at the ethanol plant much more complicated as it needs to account for the weighted average of all incoming CIs as another variable in the system requiring a relatively large paper trail. Farmers may not be best suited to use FD-CIC individually to calculate their crop-specific CIs. However, passing on the farm-specific data required for those calculations to their customers could be a concern for disclosing competitive advantages they do not wish to share.

Undertaking the changes in practices and the administrative burden to include traceability within the system will require substantial monetization. Individual farmers will have to negotiate product premiums unless some established industry association negotiates standard premium rates for LowCI corn properties. That type of price discovery and support is beyond the scope of this analysis.

From the standpoint of the regulatory body responsible for administering a regulation with a fully disaggregated feedstock supply chain, it becomes a resource issue to ensure adequate auditing for system integrity and adherence to the regulation. From a model developer standpoint, there are several potential issues: high-frequency data collection, data validation, and publication are resource-intensive activities. Adjusting and publishing updated model databases, or adjusting values in spreadsheet models, ensuring functionality and annual publication is currently beyond the capacity of many organizations. Some of the resource constraints could be eased if the model structure or system were to change to allow for periodic model updates as needed while providing the ability to import databases are they are released. A redesign of existing models such as GREET to accommodate this type of dataset import would require additional efforts.

Chapter 6.5: Comparison to Prior Study by ANL on Shifting Agricultural Practices to Produce Sustainable, LowCI Feedstocks for Biofuel Production

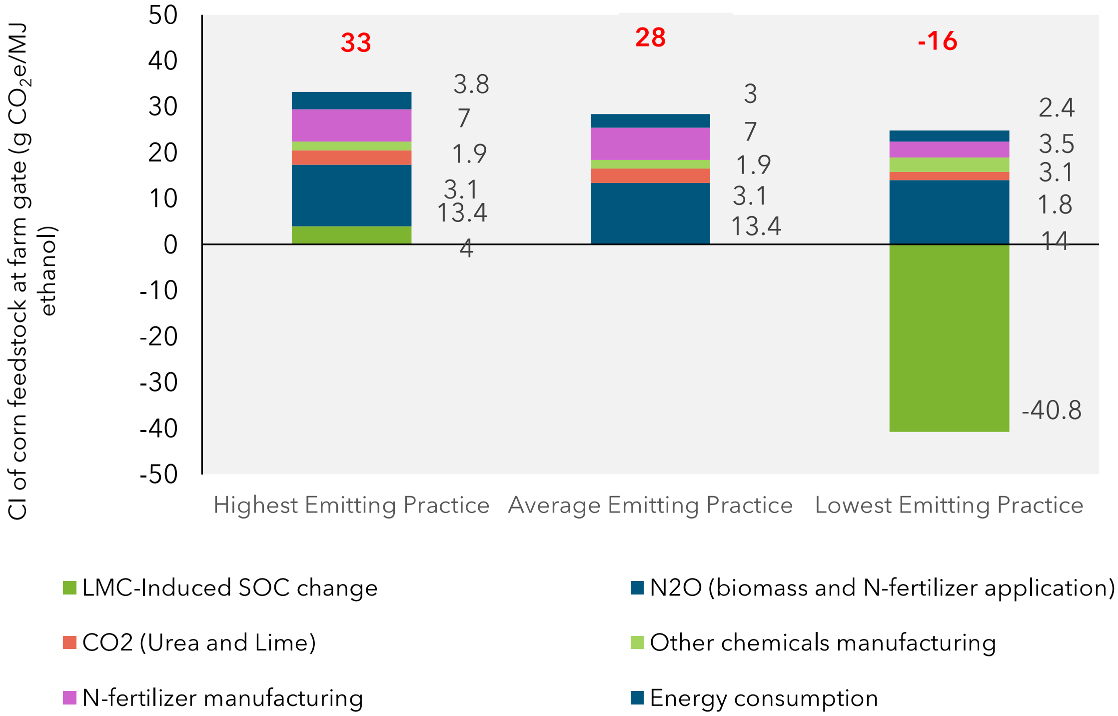
The work completed above is very similar to work undertaken by ANL in significant studies on reducing corn ethanol emissions by lowering the CI of corn feedstock. The difference is that the FD-CIC calculator had not yet been released and the work was completed in the full GREET_2018 model. In the ANL study, a variety of test conditions were run across multiple counties in nine states, though individual county results were not directly compared as the primary interest was the overall trends observable. For similar condition sets, namely tillage choice, manure application, and use of cover crops, results trend similarly between the EcoEngineers and ANL studies. This is largely anticipated as ANL's body of work contributed to the development of the FD-CIC calculator and tested the same assumptions.

Results can be complicated to interpret as the values seen are the final sum CI values resulting from complex calculations in sub-models, including the CENTURY SOC model (Figure 6.4).

The overall trends of note are as follows:

- The highest emitting practice set shows a net depletion of SOC.
- The average emitting practice set shows a value similar to the national average value of 29.3 g CO_2e/MJ, which makes sense if a farm uses a mix of average emitting practices.
- The lowest emission practice set provides net carbon sequestration of SOC, lowers fertilizer production emissions, and increases farm yield. Farm energy consumption is also reduced compared to the highest and average emitting cases.

Figure 6.4: Highest-, Average-, and Lowest-Emitting Practices[22]



In Figure 6.4, spatially explicit SOC EFs were calculated using the process-based model (i.e., parameterized CENTURY model) that simulates SOC dynamics under various land management changes (LMC). The SOC change was evaluated under 192 scenarios against a baseline scenario (i.e., business-as-usual scenario).

The CI of feedstock production is shown as the highest-, average- (i.e., baseline), and lowest-emitting practices using a national average inventory from the 192 practices. With the average-emitting practices, N_2O emissions contribute 47% to the cradle-to-farm-gate GHG emissions (due to higher Global Warning Potential, or GWP, of N_2O compared to CO_2 (265 g CO_2e per g N_2O)). N_2O emissions are from fertilizer input and the N-content in the biomass (C/N ratio and decay of biomass play roles during the mineralization of nitrogen in soil). Therefore, reducing N-fertilizer input while maintaining the yield is a highly effective way to minimize the feedstock's GHG emissions. The results for the lowest-emission scenario show that increased SOC can offer great opportunities for CI reductions.

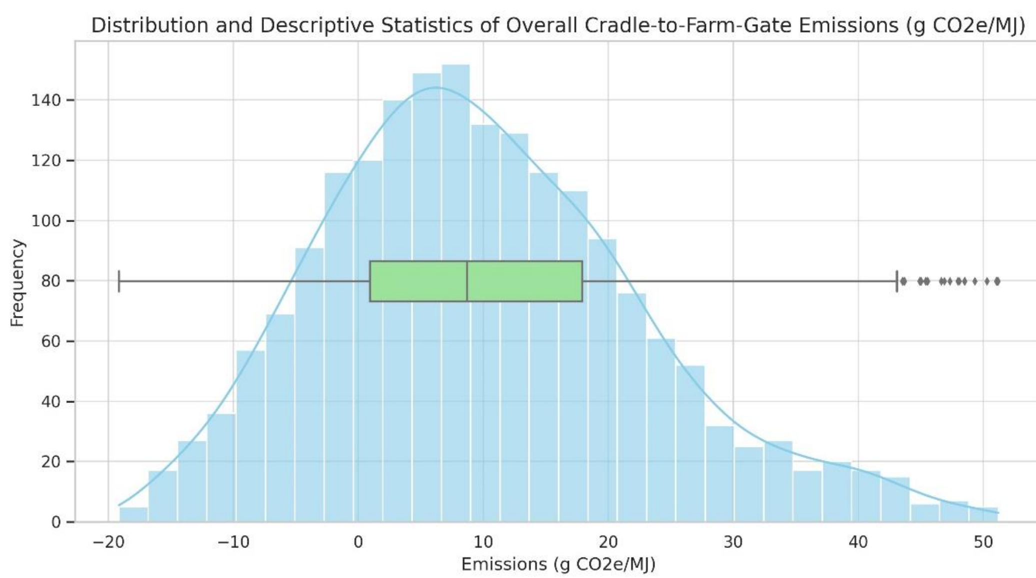
Furthermore, the lowest-emitting practices also constitute the trade-off between N_2O loss and SOC accumulation; it has more N_2O emissions, even after considering the N-benefits from the vetch cover crop. This finding is mainly due to the return of additional cover crop

[22] Liu, X., Kwon, H., Northrup, D., & Wang, M. (2020). Shifting agricultural practices to produce sustainable, low carbon intensity feedstocks for biofuel production. Environmental Research Letters, 15(8), 084014.)

biomass to the soil, which increases the amount of N-input in the soil and leads to more N_2O emissions. All other emissions (i.e., soil emissions from urea, lime, etc.), including those from the production of agrochemicals and fuel usages, are quantified concerning the amount of each input used in the respective scenarios. With the reduction of inorganic N-fertilizer (in the related alternative scenario), there will be a reduction in the upstream emissions resulting from their production, and the same applies to the decrease in the emissions (in reduced tillage and no-till) due to the shift from conventional tillage.

The LMC features, as discussed above, are summarized in Table 6.2. Influences of each alternative management practice (compared to baseline) are quantified for changes in N_2O, SOC, and CO_2 emissions (direct and indirect). Changes in tillage practices lead to changes in the crop biomass turnover to the soil, thus resulting in SOC change and soil nutrient availability, as well as changes in fuel consumption due to a shift from conventional tillage to reduced tillage and no-tillage. (Note: mulch tillage is grouped in a single category, i.e., reduced tillage.)

Figure 6.5: 1920 Test Conditions Across Nine States Showing the Distribution of Modeled Results[23]



Looking at the entire modeled dataset, which included both baseline scenario cases, as well as improved practice scenarios intended to increase SOC sequestration, with all the various

[23] Liu, X., Kwon, H., Northrup, D., & Wang, M. (2020). Shifting agricultural practices to produce sustainable, low carbon intensity feedstocks for biofuel production. *Environmental Research Letters, 15*(8), 084014.

test parameters from a statistical viewpoint, you can see how the variation could play out across the country. The average emissions scenario value represents the mean of all the test condition sets and not actual datasets from survey data. The value of 9.94 g CO_2e/MJ suggests that significant SOC storage and avoided emissions are possible across multiple soil conditions and locations under various scenarios. However, the standard deviation of these results of 12.81 g CO_2e/MJ demonstrates the high variability in the achievable results.

An individual farm practicing a farm scheme with the specific intent of lowering the CI of the output corn should be possible in many counties currently producing corn. A few outliers require improved practices to bring down CIs well above the national average.

Statistical observations of the tested dataset follow:

Count: 1,920 test scenarios were calculated.

Mean: The average emissions are 9.94 g CO_2e/MJ.

Standard Deviation: There is a considerable variation in the data with a standard deviation of about 12.81 g CO_2e/MJ.

Minimum: The lowest emission value is around -19.15 g CO_2e/MJ, indicating some scenarios result in negative emissions (possibly carbon sequestration).

25th Percentile: 25% of the observations are below approximately 0.93 g CO_2e/MJ.

Median (50th Percentile): The median value is around 8.69 g CO_2e/MJ.

75th Percentile: 75% of the observations are below approximately 17.91 g CO_2e/MJ.

Maximum: The highest observed emission is around 51.19 g CO_2e/MJ.

The Liu et al. study included additional parameters not assessed in the prior set to reduce the complexity of the study matrix. These included N-fertilizer application rates, crop genetics, and the use of EEF fertilizers. The study matrix is below. The LMC scenarios comprised various farming interventions, as shown in Table 6.2.

Table 6.2: Parameters Considered in the Evaluation for the CI Ranges (Highest-, Average-, and Lowest-Emitting Practices, as Shown in Figure 6.4) [24]

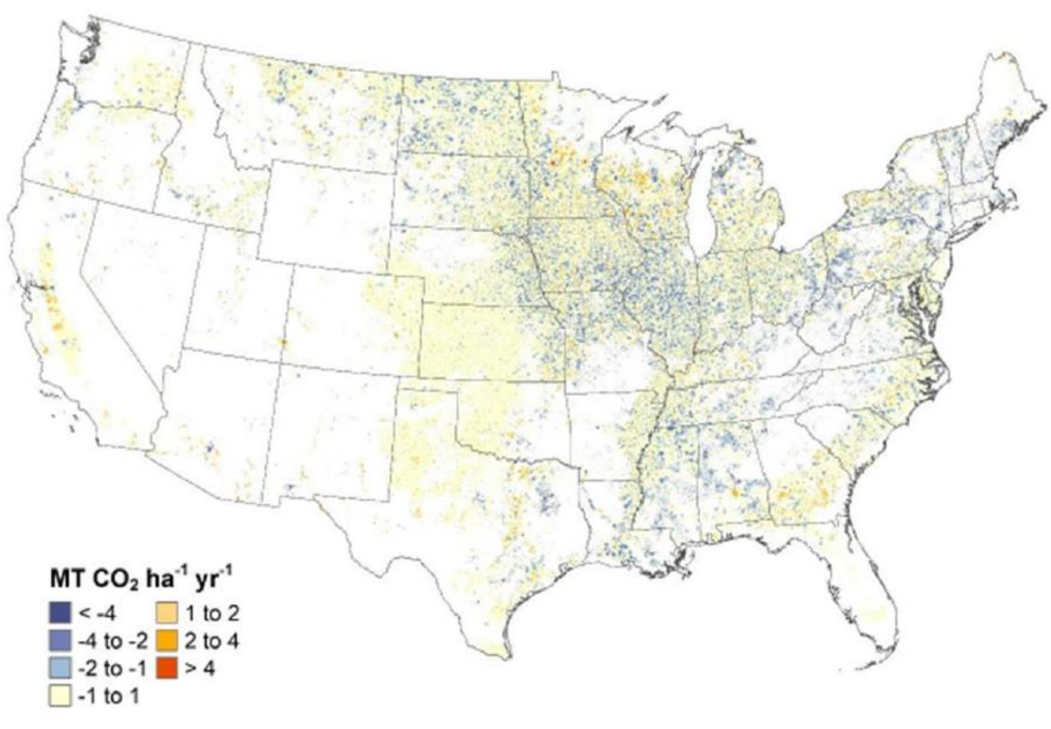
Farm Management	Baseline	Alternative Management (LMC) Scenarios	Benefits of LMC
Crop Rotation	Corn-soy (year 1 and 2)	Corn/rye-soybean Corn/rye-soybean/vetch	More crop residues and soil nutrients (+ erosion control).
Crop Yield	Average of 2006-2015 (constant)	Increase (a historical trend from 1951 to 2015)	Increased residue carbon and nutrients in soils (county-level yields).
N-Fertilizer Use	National average	Account for N-credit (45 kg/ha-from vetch legume cover crop).	Reduced nitrogen emissions from fields.
Manure Application	No	Yes	County-level manure application rate and type. The trade-off between SOC accumulation and N_2O emissions for manure application is captured.
Tillage Type	National average	CT, RT, and NT	Related to SOC sequestration and energy use (e.g., energy use in conventional tillage is about 3.5 times higher than no-till).
Genetics	No	Deep-rooting corn	Improved productivity and nutrient use efficiency.
EEF	No	Yes	Increased yield by 7% and reduced N_2O emissions from fertilizer by 30%.

[24] Liu, X., Kwon, H., Northrup, D., & Wang, M. (2020). Shifting agricultural practices to produce sustainable, low carbon intensity feedstocks for biofuel production. Environmental Research Letters, 15(8), 084014.)

Chapter 6.6: Supporting Evidence for SOC-Level Increases Across Multiple Corn-Farming Geographies

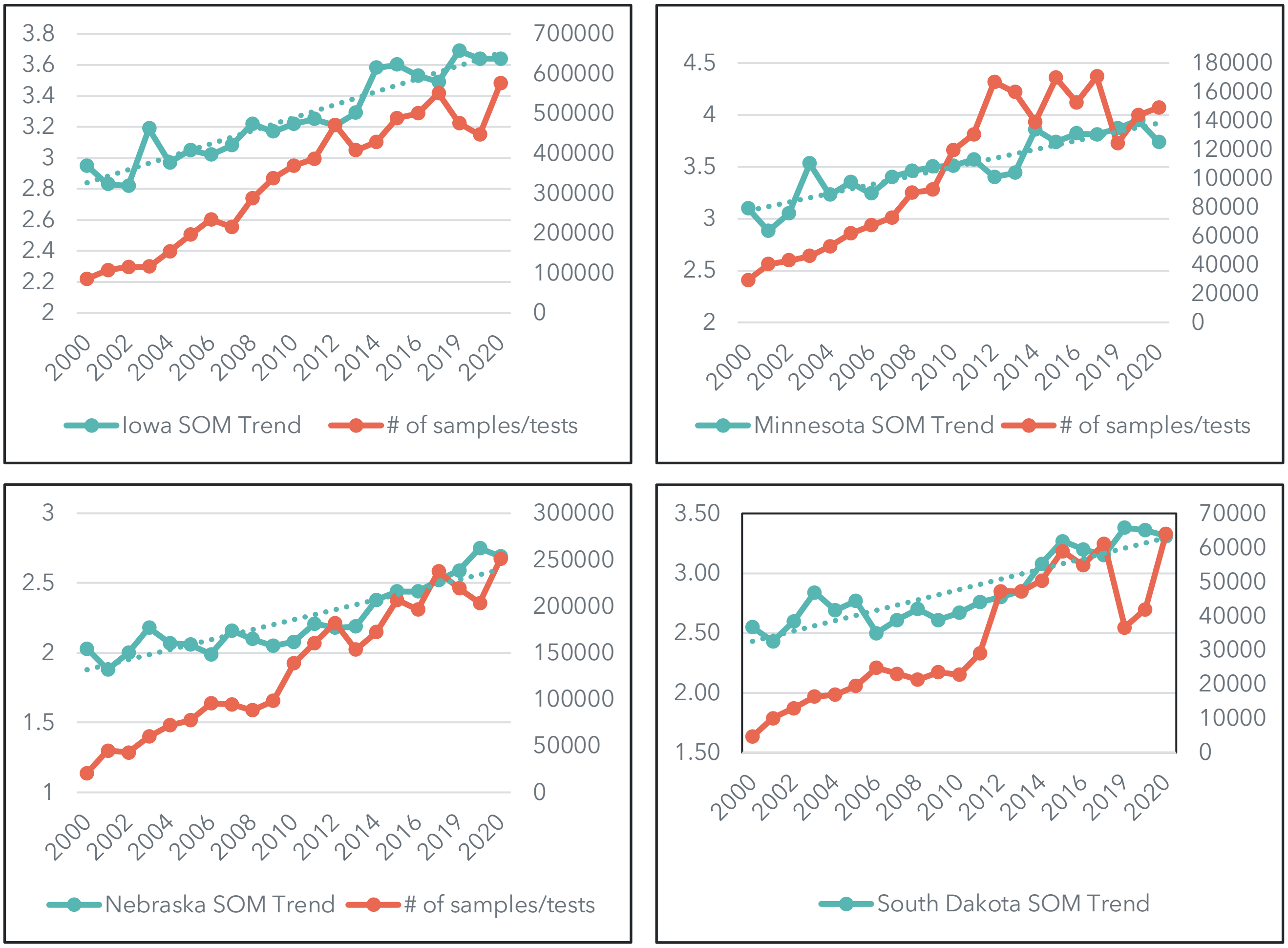
Modeled values without real-world scenario-supporting evidence can be viewed skeptically. However, improved farming practices such as reduced-till and no-till have been increasing in use for some time. USEPA annual GHG inventory data collected shows net SOC sequestration/accumulation in farming regions producing corn in the U.S. An ongoing effort by U.S. Midwest laboratories tracking thousands of soil organic matter (SOM) samples across multiple states also supports this SOC accumulation. SOM may be used as a proxy for SOC accumulation, and up to 50% of SOM may convert to SOC accumulation. Data for the four states below shows the increase in sampling rates and the gradual increases in SOM levels in regions corresponding to corn crop production.

Figure 6.6: USEPA 2021 National GHG Inventory Showing SOC Levels Increasing Across Corn-Producing Regions



– USEPA

Figure 6.7: Soil Organic Matter Content Across Four States[25]



[25] Jim Fasching, Mid-West Laboratories, Omaha, NE. SOM trends in testing used as a surrogate for SOC accumulation in soils. Presentation: The Road to Zero Carbon Corn EtOH in Low-Carbon Fuel Markets.

Chapter 6.7: Results from FD-CIC Analyses

All analyses in this section were performed with constant yields at the national average value. Using actual yield data for specific counties for a given year with different cropping practices will influence the result, with lower yields increasing the CI values and higher yields reducing the CI values.

In general, fuel use for farming emits 3.8 g CO_2e/MJ. Replacing diesel with renewable fuels to operate farm equipment can reduce emissions resulting from tillage operations. Studies showed that if 100% of petroleum-based diesel is substituted by soybean-based biodiesel, fuel-related emissions can be reduced by 63%.

Grain drying is another contributing source of emissions from farm operations. On average, approximately 0.22 g CO_2e/MJ is related to drying grains, which can be partially mitigated with renewable sources, like solar or wind-based electricity, or through natural drying processes that allow corn to dry more rapidly in the field.

As shown in Figure 6.2, the total CI of feedstock production can be decreased by 59% with the use of reduced tillage, and introduction of cover crops. The reduction is mainly due to SOC change from cover crops and reduced tillage adoption in farming practices. Compared to the same reference case, corn production with cover crop and no-till can further reduce the CI by about 77%.

Further emissions reductions can be achieved by lowering upstream emissions relating to the production of N-fertilizers. For instance, a shift to green ammonia that uses low-CI electricity during production can reduce the EF related to N-fertilizer production compared to fossil fuel-based production systems.[24] The adoption of the four "Rs" (right time, right place, right form, and right rate) and EEF (enhanced efficiency fertilizer) approaches in fertilizer management can help to improve nitrogen use efficiency, thus reducing nutrient leaching. These interventions also help mitigate fertilizer production emissions and total soil-induced N_2O emissions.

Studies have also shown that biochar-amended soil (at 10 tons/acre every 10 years) could increase corn yields by 10%. This is expected to reduce N_2O emissions from fertilizer and biomass by 10% and sequester soil carbon at an effective rate of 0.95 lbs CO_2e/lb biochar.[26,27,28]

[26] Drawdown. (2020). Biochar Production: Technical Summary. https://drawdown.org/solutions/biochar-production/technical-summary.

[27] Xiao, Q., Zhu, L. X., Zhang, H. P., Li, X. Y., Shen, Y. F., & Li, S. Q. (2016). Soil amendment with biochar increases maize yields in a semi-arid region by improving soil quality and root growth. Crop and Pasture Science, 67(5), 495-507

[28] Xu, X., Cheng, K., Wu, H., Sun, J., Yue, Q., & Pan, G. (2019). Greenhouse gas mitigation potential in crop production with biochar soil amendment—a carbon footprint assessment for cross-site field experiments from China. GCB Bioenergy, 11(4), 592-605

Chapter 6.8: Using Collaboration and GREET to Immediately Impact Midwest Average and Site-Specific Confidence

Based on the information discussed in prior sections of this study and the extensive research being completed to document the emission reductions created by certain practices, it is evident how vital it is to keep the dataset as current as possible to reflect the Midwest Average. Using current-year information for the primary CI-influencing factors can be one of the best methods to move the industry to monetize carbon through ethanol facilities.

A focus on using the most recent public and validated methods for calculating the Midwest Average will improve public and private sector collaboration. Using public funds to incentivize improved tillage, nitrogen usage, and cover-crop incentives for water quality could be layered into a carbon program by the inherent way it is captured through the GREET model. The monitoring, reporting, and validation (MRV) for a water quality program of a watershed could be captured if the reporting agency was part of the shared datasets. Collaboration and the use of already existing datasets that are part of the carbon inventory schemes will strengthen the accuracy and confidence of all programs and will eliminate the concerns of double counting, additionality, and shifting or shuffling.

The following are some areas of potential collaboration demonstrating how the separate programs being conducted today could contribute to documented improvement to the Midwest Average and the site-specific attributes the facilities could use to improve their CI:

- **USDA and Natural Resources Conservation Service (NRCS) Farm Program** – The use of the program information from the USDA Farm Service Agency (FSA) and the NRCS agencies is critical for reporting information by standardized field and tract information (NRCS and FSA already use several practices for environmental attribute qualification). The reporting structure and the qualified attribute should be relied upon for processing, monitoring, and standardizing field and tract information. As producers work with public programs, the reporting and monitoring of those programs should be part of the database used to supply site-specific information at the field level for practices being accounted for. The USDOE should review the validation in place for applicability and effectiveness, and it would not need further review if the parameters outlined by USDOE/ANL are met.
- **Farm Compliance and Sustainability** – Farmers have reporting and compliance requirements for USDA government program compliance. Annually, the cooperating farmer must certify their efforts toward stewardship that are similar to the program compliance of public and private incentivized programs. Having farmer approval for farms and tracts to be included in the GREET database could create a common baseline for all programs that establish the baseline platform to be built upon.
- **Yearly Yield Reporting/Updating** – There are several ways that yield could be updated annually. There are self-attestations with external audit processes in place by insurance and the FSA that could be utilized (with producer acceptance) to update grain production annually. Yield certification and auditing of the yield are already

being performed and standardized by FSA tract numbers. Alternatively, other agencies within the USDA could be utilized for similar information.

- **Private and Public Environmental Attribute Programs** – Many public and private sector outcomes programs use real-time and machine-generated data for reporting specifics on practices. These practices are validated by forensics and satellites through private programs. Simple techniques of taking a picture of a practice with georeferencing allow farms to be validated efficiently and effectively in the year the practices are being completed.
- **Importance of Collaborating with Farmers to Implement These Practices** – It is important to note the collaboration can be swift because the farmer is already reporting practices, timing, and necessary information for participation in other programs. The reporting and auditing process is already in place, and several of these processes include extensive historical data. Accepting or creating a standard baseline for programs could be the most critical first step in creating an all-encompassing carbon accounting program that transcends all platforms to capture practices at site-specific levels.

Chapter 6.9: How Does Potential Low-CI Corn Travel in the Grain-Handling System?

There are two significant methods of differentiating commodities:

- **Physical Segregation:** A case for organic certifications is costly and inefficient as it requires the installation of new storage silos, bins, and other grain-handling equipment. There is a high chance user error via cross-contamination can lead to higher-value LowCI corn being sold at reduced bulk commodity pricing.
- **Identity-Preserved Mass-Balance Accounting:** This is largely a paper exercise to maintain the visibility of a trait or characteristic. It is cost-effective but requires supply chain visibility and a willingness to cooperate. Attestations, identification of characteristics, and the ability to track properties within the supply chain need to be well established and require verification of mass balancing activities to prevent abuse of the system and double accounting for the exact attributes. There are lessons learned in several industries that can be applied here to reduce risk.

Data collection needs and supply chain handling of data to enable appropriate accounting will require the following:

- Audits and verification, supply chain management, traceability.
- The value passed through to the farmer must be commensurate with the effort to create LowCI corn and perform reporting.
- Mass and material balancing at elevators are necessary to preserve LowCI identity; otherwise, material segregation is costly.

Section 7: Conclusion

Several current practices in farming can reduce the CI of the output crops that are not currently recognized by regulatory bodies, even though the basis for their incorporation into LCA modeling has already been explored and is improving. However, the frequency of data collection through survey data and subsequent incorporation into models suffers from a severe time lag effect.

Individual farm yields have a dramatic effect on the CI of corn. The ability to tie actual yield in the calculations of farm-level CIs should be an essential area of focus. National average values versus Midwest Averages do not always adequately represent the conditions in most ethanol plants due to the relatively short distances from farm to facility and the concentration of facilities in the Midwest, which is close to corn production. SOC values currently represent the largest source of variability and uncertainty in calculating a crop CI due to the involvement of biological processes, multiple soil types, precipitation, and seasonal variations among other factors. However, there is credible evidence of SOC storage improvements in various states using these enhanced farm practices.

The average CI of corn in the baseline comparison was 30.2 g CO_2e/MJ for the tested counties using conventional practices, which is slightly higher than the national average value of 29.3 g CO_2e/MJ. The potential CI reduction due to the adoption of improved farm management practices is shown in Table 7.1. A maximum reduction was shown to be achieved with manure application, no-tilling, and cover crops, which reduces the CI by 30.5 g CO_2e/MJ from the baseline value. The minimum reduction was found for the scenario of reduced tillage only, which reduced the CI by 3.2 g CO_2/MJ from the baseline value.

Table 7.1: Average CI-Reduction Range for Farm Practice Changes

Farm Practice	CI Reduction (g CO_2e/MJ) from the Baseline Practice CI of 30.2	CI Score with various Farm Practices (Baseline Practice CI at 30.2 g CO_2e/MJ)
Manure	-8.8	21.4
Cover Crops	-15.2	15
Manure + Cover crops	-22.2	8
Reduced Tillage	-3.2	27
No-Till	-4.3	25.9
Reduced Tillage + Cover Crops	-20.3	9.9
No-Till + Cover Crops	-25.4	4.8
Manure + Reduced Tillage + Cover Crops	-25.8	4.4
Manure + No-Till + Cover Crops	-30.5	-0.3

– EcoEngineers modeling in FD-CIC

In a system that differentiates corn, each farm will have its own rolling CI score. This will dramatically increase the amount of paperwork/administrative burden in the system. CI characteristics will need to be described and passed through the supply chain and facilities will need to be able to process and manage the individual CI data. Facility CIs will be even more variable yearly and there is a concern that they will not be able to process a mass balance CI application, or a weighted average CI based on receipts.

Many of the data management concerns could be mitigated if a third-party certification scheme or other qualified entity collects and manages the data from the farm, manages the verification and audit process, and transfers those values through the production facility and regulatory bodies in a single electronic monitoring system. No such entity currently exists despite several companies wanting to function in that space. Having multiple competing systems that are not standardized, organized, and don't transmit information in the same format can hamper adoption.

Regulatory bodies and government agencies need to modernize to accept, access, and interact with complex multi-user cloud-based systems. This is currently not a strength of these groups and the procurement systems that support them. A number of privacy and data security issues would need to be addressed and universal standards applied. Farmers, aggregators, production facilities, and regulators all have different information needs, and not all information needs to flow through all participants. Developing a data-sharing protocol that can be enacted by all users of such a system would be challenging, but industry associations are in key positions to negotiate the terms among users.

There is a difference in opinion between industry and farmers. Farm associations often cite the regulatory and administrative burdens of participating in government programs. The financial incentives are often deemed insufficient for the level of effort required to complete the large amount of paperwork and provide the body of evidence required to prove CI claims. The information required for these programs can also be deemed as business confidential information. Farm associations often express discontent at perceived government overreach in seeking data and information to support farm claims. Given this, it can be challenging for an ethanol plant to get clear direction on how to incentivize farm-level practices.

Short-term ethanol facilities can begin to prepare their purchasing and supply chain processes to enable the systemic changes required to support the data requirements. Indicating a need for environmental attribute retention within the supply chain, along with key points of origin information, is an important first step to transitioning feedstock producers to the new data needs. Basic data collection on farming practices, farm yields, and key farm inputs will need to become commonplace and standard industry practice. Consistent formats, units, file types, etc. will be necessary to ease the transition pains. The current farm reporting structure could be used with some improvement, but verification will need to be intensified.

Medium-term development of a multiple industry data management and data sharing cloud solution will be required. The system must respect business confidential information while supporting the requirements of production facilities and regulatory bodies. Adapting modeling methods to accommodate more frequent database updates while maintaining the scientific validity of results is a longer-term initiative. Regulations are slow to change, and without regulatory guidance, tool development, and modeling method changes cannot occur.

Chapter 7.1: Summary

ANL's GREET model is a tool that considers several scenarios for crop production and the tool maintenance and modification process is regimented with heavy scrutiny and oversight. The use of the GREET model for monetizing farm practices can be completed efficiently with the tools and calculations embedded in the model. Farm-level CI through the processing system should be captured effectively as agriculture advances toward more sophisticated methods for aggregating field-level data.

There is concern today about SOC and the amount that farms can effectively sequester through cropping systems. However, long-term statistics and samples indicate that farm ground profiles reflect increased organic matter and SOC in the soil. Using GREET as the platform for introducing change and calibrations will standardize an acceptably conservative SOC accounting methodology and assist in addressing all science-based scrutiny with a real-time model.

Based on the studies and facts presented in this study, the following are suggestions on how GREET can incorporate farm-level practices into the ethanol supply chain.

- Continually improve upon updating and keeping the datasets as current as possible.
- Collaborate with the public and private sectors for best practices of MRV farm practices.
- Utilize machine-based, georeferenced, or satellite-provided datasets whenever possible. Eliminating the human element is critical to the successful scale-up of the industry.
- Separate what is accepted within GREET from where there is disagreement.
    - Where there is an agreement, move forward with a phased approach.
    - Where there is disagreement, create the path to improvement or wait to address the process until it can be developed based on sound science.
    - Specifically addressing the SOC discourse is paramount to successfully including the farm practices as a method for lowering CI at the ethanol facility. Buffers could be placed in the model to address the disparity in the results, or intentional "holdbacks" could be included in the tables.
- Use a phased approach for the implementation of GREET.
    - To fully capture the capabilities of the GREET model, extensive resources (money and human capital) should be dedicated to the sole purpose of updating and integrating all possible datasets to the most current information. Further, for modeling at the county or district crop reporting level, primary environmental attributes at the tract level should be updated based on the standard reports and data assembled by agencies of the federal government or standard reporting service. This improved dataset should capture the net CI of the crop at the most granular level or assemble to the revised Midwest Average. The aggregation would take place during the year, with the final dataset input coming from yield.
    - Every year, the dataset would be continually updated and driven to a more granular result for the industry. The result would be creating an option for the

facilities to report CI values that are related to their facilities. This would also encourage the inclusion of climate-smart practices by all producers because the CI improvement will be more determinant from the actual practices related to fuel and food production.

Table 7.2 illustrates how the evolutionary implementation could take place relatively quickly by utilizing existing processes in the public and private sectors. Further, we must emphasize the importance of resource allocation to the public sector to improve the datasets and to provide human capital or digital infrastructure to support the activities required to implement.

Table 7.2: Suggested GREET Implementation Schedule for Farm-Level CI

Calendar Year	2025	2026*	2027	2028	2029 - Forward
IRA Tax Year	2024	2025	2026	2027	2028
Crop Year	Oct 23 - Sep 24	Oct 24- Sep 25	Oct 25 – Sep 26	Oct 26 – Sep 27	Oct 27 and Beyond
Farm Practices	Midwest Average 2014-2016 Data	Midwest Average 2024 Data	State Average 2025 Data	County or District Average 2026 Data	County or District or Site Specific 2027 on Data
Collaborative Actions Necessary	Improve Dataset-Reporting Requirements	Data Validation and Facility Supply Chain	Dataset, Supply Chain, MRV	Farm Level Validation	Continuous Improvement

*Denotes first reporting year. – *EcoEngineers*

The overriding theme of this approach to monetizing the carbon reduction practices farmers are implementing is to use the existing reporting structure and build upon a process that would allow the different public and private sectors to collaborate toward an effective long-term sustainable program. This process would also set the precedent to evolve toward a more granular position every year. Finally, this protocol would take our existing supply chain and existing relationships to build climate-smart accounting practices for the future.

Chapter 7.2: Suggested Roadmap for the Implementation of Site-Specific Farm Practices

- Focus on the improvement of GREET to reflect the most current representation of emissions.
- Standardize the reporting at the tract and field level.
- Collaborate with public and private sectors to improve the dataset.
- Focus on the primary drivers of CI:
    - Geography
    - Yield
    - Tillage
    - Nitrogen (the four "Rs" or EFFs)
    - Cover Crop
- Agree on the "best" statistically sound validated dataset.
- Annually, calculate the Midwest Average.
- Annually, improve upon the Midwest Average.

Chapter 7.3: Suggested Roadmap for State-Level or Crop-Reporting District Implementation

- Use standardized information in GREET tables to provide county-level CI values for calculations by crop.
- State and federal agencies should estimate the primary factors required to calculate CI.
- Calculate reporting-level weighted averages via collaboration across the USDA, FSA, Risk Management Agency (RMA), USDOE, and the Internal Revenue Service (IRS).
- Repeat annual calculations.
- Determine the appropriate CI value from a table driver by the location of the processing facility.
- Develop a process for locations to notify the IRS in advance of intent to certify at a state level.

Chapter 7.4: Suggested Roadmap for County-Level Implementation

- Use standardized information in GREET tables to provide county-level CI values for calculations by crop.
- Processor supply chains establish county “draw” percentages with traceable farm origins (one step upstream).
- Include county-weighted averages into standardized tax forms to prevent those with higher emitting production scenarios from receiving credit based on the average without adopting improved practices. An example is shown in Table 7.3.
- Perform annual calculations and validations.

Table 7.3: Sample County-Level Implementation

County	Bushels of Corn	Carbon Intensity[29]
Johnson	10 Million	18 kg CO_2e/MMBtu
Linn	75 Million	16 kg CO_2e/MMBtu
Cedar	5 Million	20 kg CO_2e/MMBtu
Iowa	10 Million	12 kg CO_2e/MMBtu
	Weighted Average	**16 kg CO_2e/MMBtu**

– EcoEngineers

Chapter 7.5: Site-Specific Accumulation Utilizing Mass Balance or Identity-Preserved Corn

- Use GREET to calculate the entire supply chain average CI using primary factors of renewable fuel or crush facility aggregates to develop the facility baseline CI.
- Processors certify their baseline through IRS-approved validation protocols and receive tax credits based on the crop year.
- Enroll individual farms and calculate the CI of all bushels.
- Compare the individual CI values to the baseline CI to determine specific producer premiums to be charged based on deliveries.

[29] 1 MMBtu = 1055.056 MJ

Chapter 7.6: Final Thoughts

As climate-smart methods become more prevalent, tables and site-specific accounting methods must be promptly developed to recognize these practices so that commercial processing facilities are incentivized to implement them. Agricultural programs at scale can be more quickly monetized and measured with accurate and standardized MRV programs that allow for third-party verification.

The focus needs to be on database development and the ability for farm-level information to feed into such a system. Certification and validation of the data need to occur, and key parties need to have access to the data. The tools exist, but standardizing inputs and determining hosting, access, usability, etc., are all barriers.

Risks exist to managing such a system. Examples of concepts and challenges to consider in the implementation phase follow:

- Quality data on farming practices, fertilizer application, fuel consumption, and farm yields will need to be stored in an electronic system for transmission to production facilities for real-time CI determinations and modeling.
- Farm-level data, including the location of the farm, will be submitted to a database management system for use by production facilities. State or federal enforcement agencies may require access to this granular data to determine if fertilizer and setback rules have been followed in proximity to waterways to limit eutrophication effects.

Chapter 7.7: Major Regulatory Acceptance Hurdles to Overcome

1. **The Administrative Burden:** Regulators are often besieged by industry and lobbyist groups that change regulations often, including additional red tape that may make participation more difficult.
    a. The solution to this problem should be industry-led. The industry should propose the plan, and show how data collection, data management, and reporting will benefit both the industry and regulators. A government-led initiative can be time-consuming and oftentimes is not in sync with industry practices. Industry leadership in implementation is essential for success.
2. **Problem Shifting:** If a unit of low-CI-certified corn is sold into the ethanol industry, how does that translate into the CI scores of the feed, food, and chemicals industries? If all low-CI corn flows into the industry providing the incentive, but overall, the national average value of corn does not decrease, all that was accomplished is problem shifting. The industry needs to decide if it will apply the same CI accounting to all units of feedstocks produced and demonstrate that supplying low-CI feedstock to one industry reduces the average CI values of all units produced for use in all industries. Transparency, data monitoring, and reporting to regulators are needed. The national average CI of the feedstock needs to be visibly reduced consistently to combat this

problem-shifting perception. This should be done on a national level initially. If other industries using agriculture feedstocks decide to import cheaper non-CI-certified feedstocks for use, it will undermine the effort. Longer-term policy setting should occur to secure the space for low-CI feedstock production and not allow problem shifting and emissions leakage to occur. Regulators need to see the industry is ready to engage at the forefront of the discussion. Solutions need to be industry-focused and industry-led.

Chapter 7.8: Timeline Constraints

It is unlikely that necessary data collection, data validation and certification, data management, and data access by all involved parties can be accomplished in time for the beginning of IRA Section 45Z credit generation. Participation in 2026 may be feasible with concerted efforts by all parties.

This is a longer-term effort needed to drive down emissions and CI of fuels produced and used. If steps are not taken to lay the groundwork for this effort in the short term it will stall and open the industry up to further emission scrutiny.

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