U.S. DEPARTMENT of ENERGY | Office of Critical Minerals and Energy Innovation

Guidelines To Determine Life Cycle Greenhouse Gas Emissions of Clean Transportation Fuel Production Pathways Using 45ZCF-GREET

Rev. September 2026

Disclaimer

This document describes how the 45ZCF-GREET model characterizes life cycle greenhouse gas (GHG) emissions of approved transportation fuel production pathways. Further, the manual provides guidance for using the model to determine emissions rates for clean fuel tax credits, as established in § 45Z (45Z tax credit) of the Internal Revenue Code. If the model is revised in the future, those releases may be accompanied with additional supporting documentation describing the revisions made. The model is specific to the calculation of GHG emissions for the 45Z tax credit. Therefore, its use would not be appropriate for other purposes, including determining eligibility for other tax credits or for federal programs.

Public Law 119-21, commonly referred to as the One Big Beautiful Bill Act, made certain amendments to § 45Z that impact the characterization of GHG emissions of transportation fuel production that are effective beginning Jan. 1, 2026. These amendments relate to the treatment of negative emissions values, the exclusion of emissions attributable to indirect (also referred to as induced) land use changes, the prohibition on non-North American feedstocks, and the use of distinct emissions rates with respect to fuel based on specific animal manure feedstock and apply to transportation fuel produced after Dec. 31, 2025. This document and the associated 2026 update to the 45ZCF-GREET model reflect emissions rates for transportation fuel produced prior to Jan. 1, 2026, and, where emission rates differ for fuels produced after Dec. 31, 2025, additional results are provided corresponding to certain amendments to § 45Z that take effect after Dec. 31, 2025. On Feb. 4, 2026, the Internal Revenue Service (IRS) published proposed regulations for determining clean fuel production credits, including credit eligibility rules, emissions rates, and certification and registration requirements (Notice of Proposed Rulemaking, Section 45Z Clean Fuel Production Credit, 91 FR 5160).

The U.S. Department of the Treasury and IRS subsequently issued Notice 2026-53, which provides additional guidance to clarify eligibility requirements and certain emissions accounting guidelines under § 45Z, such as foreign feedstock limitations, accounting for regenerative agriculture practices, and establishing distinct emissions rates for specific animal manure feedstocks.

List of Acronyms

ATJ	alcohol-to-jet
BTM	behind-the-meter
Btu	British thermal unit
CCLUB	Carbon Calculator for Land Use and Land Management Change from Biofuels Production
CFR	Code of Federal Regulations
CH_4	methane
CI	carbon intensity
CMM	coal mine methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DCO	distillers corn oil
D-LCA	direct life cycle assessment
DSO	distillers sorghum oil
EAC	energy attribute credit
FD-CIC	Feedstock Carbon Intensity Calculator
FOG	fats, oils, and greases
GGE	gallon gasoline equivalent
GHG	greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GTAP	Global Trade Analysis Project
GWP	global warming potential
HEFA	hydroprocessed esters and fatty acids

ILUC	induced land use change
IRS	Internal Revenue Service
LCA	life cycle analysis
LHV	lower heating value
MMBtu	million British thermal units
N_2O	nitrous oxide
R&D GREET	Research and Development Greenhouse gases, Regulated Emissions, and Energy use in Technologies
RNG	renewable natural gas
SAF	sustainable aviation fuel
SMR	steam methane reforming
T-DISC	Tillage Disturbance Index for Soil Carbon
UCO	used cooking oil
USDA	U.S. Department of Agriculture

Executive Summary

This document describes the methodology to calculate life cycle greenhouse gas (GHG) emissions of transportation fuel production using the 45ZCF-GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model (Sept. 2026 version) developed by Argonne National Laboratory. The model is titled "45ZCF-GREET" because it was developed in support of the clean fuel production tax credit authorized by § 45Z of the Internal Revenue Code. 45ZCF-GREET includes feedstock-specific fuel production pathways for sustainable aviation fuel (SAF) and non-SAF fuel. The SAF production pathways leverage those that were included in 40BSAF-GREET, which was developed in collaboration with the Interagency Sustainable Aviation Fuels Lifecycle Analysis Working Group, with consideration of information provided by the U.S. Environmental Protection Agency in the Dec. 13, 2023, letter regarding § 211(o) of the Clean Air Act,[1] and in consultation with the U.S. Department of the Treasury (Treasury Department), for use in implementing the 40B tax credit.

45ZCF-GREET is available at www.energy.gov/cmei/GREET. The 45ZCF-GREET model was developed as a specific version of the GREET® model to determine emissions rates that also meets three key parameters: (1) user-friendliness and consistency, (2) technical robustness of the pathways represented, and (3) consistency with the requirements of § 45Z. The model includes transportation fuel production pathways that are of sufficient methodological certainty to be appropriate for determining eligibility for the 45Z tax credit.

The 45Z tax credit is available for certain fuels that are suitable for use in a highway vehicle or aircraft produced domestically after Dec. 31, 2024, and sold prior to Jan. 1, 2030. The 45Z tax credit is equal to the product of (A) the applicable amount per gallon (or gallon equivalent) of a transportation fuel produced at a qualifying facility and (B) the emissions factor for such fuel. In 2025, the applicable amount (A) is $1.00 for non-SAF and $1.75 for SAF where applicable wage and apprenticeship requirements specified in § 45Z are met; and $0.20 for non-SAF and $0.35 for SAF if wage and apprenticeship requirements are not met[2] per gallon or gallon gasoline equivalent (GGE), as appropriate, of a transportation fuel produced at a qualifying facility. For fuels produced after Dec. 31, 2025, the applicable amount for SAF is equal to the applicable amount for non-SAF. The emissions factor (B) is calculated as the quotient of— **(I)** an amount equal to (aa) 50 kilograms (kg) of carbon dioxide equivalent (CO_2e) per million British thermal units (MMBtu), minus (bb) the emissions rate for such fuel, divided by **(II)** 50 kg of CO_2e per MMBtu. For a claimant to qualify for the 45Z tax credit, the producer of the transportation fuel is required to be registered with the Internal Revenue Service (IRS). In the case of SAF, a claimant for the 45Z tax credit is also required to provide the IRS

[1] Letter from Joseph Goffman, Principal Deputy Assistant Administrator for the Office of Air and Radiation, U.S. Environmental Protection Agency, to Lily Batchelder, Assistant Secretary for Tax Policy, U.S. Department of Treasury (Dec. 13, 2023). home.treasury.gov/system/files/136/Final-EPA-letter-to-UST-on-SAF-signed.pdf.

[2] Notice 2025-37 provides the calendar year 2025 inflation adjustment factor and applicable amounts for the 45Z tax credit.

with certification from an unrelated party demonstrating compliance with any general requirements, supply chain traceability requirements, and information related to transmission requirements for the methodology used to determine the GHG emissions rate of SAF.

Section 45Z generally divides transportation fuel into two categories: SAF transportation fuel and non-SAF transportation fuel, with different methods to determine emissions rates for SAF and non-SAF fuel. Section 45Z directs the Treasury Department to annually publish a table setting forth the emissions rates for similar types and categories of transportation fuels based on the amount of life cycle GHG emissions as described in § 211(o)(1)(H) of the Clean Air Act (42 U.S.C. 7545(o)(1)(H)), as in effect on Aug. 16, 2022, for such fuels, expressed as kilograms of CO_2e per MMBtu. The Treasury Department and the IRS issued Notice 2025-11 containing the initial table setting forth these emissions rates for purposes of the 45Z tax credit. The Treasury Department and the IRS subsequently issued Notice 2026-53, which provides an annual emissions rate table for calendar year 2026 that a taxpayer must use for purposes of § 45Z.

For certain types and categories of non-SAF transportation fuels, Notice 2025-11 directs taxpayers to determine the emissions rate of a fuel using the most recent version of the 45ZCF-GREET model.[3] For hydrogen, Notice 2025-11 directs taxpayers to calculate well-to-gate emissions using the most recent 45VH2-GREET model (the model used to determine emissions rates for the § 45V Clean Hydrogen Production Credit), then calculate the full well-to-wheel emissions using the most recent version of the 45ZCF-GREET model.

For certain categories of SAF, Notice 2025-11 directs taxpayers to determine the emissions rate using either the most recent version of the 45ZCF-GREET model or determinations from fuel pathways approved under the most recent Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Default Life Cycle Emissions Values for CORSIA Eligible Fuels (CORSIA Default) or CORSIA Methodology for Calculating Actual Life Cycle Emissions Values (CORSIA Actual). For other categories of SAF, taxpayers are directed to use the most recent CORSIA Default or CORSIA Actual.

If (1) a transportation fuel is a novel type of fuel not included in the applicable emissions rate table, or (2) the type of fuel is included in the emissions rate table, but such fuel is produced using a pathway/feedstock combination not included in the applicable emissions rate table, the taxpayer producing such fuel may file a petition with the Secretary of the Treasury for a provisional emissions rate.

Guidance concerning registration, certification, and claims for the 45Z tax credit is outside the scope of this document. Please refer to Notice 2024-49, Notice 2025-10,

[3] In Notice 2025-11, the Treasury Department and IRS determined that 45ZCF-GREET is the successor model to be used to calculate emissions rates for non-SAF transportation fuel; see also 91 FR 5160, 5171 (Feb. 4, 2026). With regard to SAF, in Notice 2025-11 the Treasury Department and IRS concluded that 45ZCF-GREET constitutes a methodology that is similar to the most recent CORSIA with the agreement of the United States and that also satisfies the criteria under § 211(o)(1)(H) of the Clean Air Act.

Notice 2025-11, 91 FR 5160, and Notice 2026-53, for guidance on rounding emissions factors and other methodologies used for the 45Z tax credit.

This document refers to the § 45V Regulations (Treasury Decision 10023) and 45VH2-GREET December 2025 user manual. As indicated in the notice of proposed rulemaking under § 45Z (91 FR 5160, 5171), the Treasury Department and the IRS intend to propose that rules similar to the rules established under § 45V would apply under § 45Z with respect to determining emissions associated with hydrogen (as a production input); natural gas alternatives (non-manure-derived); electricity; and carbon capture, utilization, and sequestration. For this reason, the manual provides guidance on how to use 45ZCF-GREET consistent with and through reference to the applicable rules established by the Treasury Department and the IRS under § 45V.

This document has three sections:

- Section 1: Introduction
- Section 2: Methodology
- Section 3: User Instructions.

Additionally, there are three appendices included: Appendix A, B, and C.

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1 Introduction

The 45ZCF-GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model (Sept. 2026 version) can be used to characterize transportation fuel life cycle greenhouse gas (GHG) emissions through the point of use. “Emissions through the point of use” is defined as the aggregate life cycle GHG emissions related to transportation fuel produced at a transportation fuel production facility. It includes emissions associated with feedstock growth/sourcing, gathering, processing, and delivery to a transportation fuel production facility, and can include estimates of indirect effects (abbreviated in the model as “I-Effects”) from land use change (conversion of new land to agricultural production), livestock activity changes, and crop production changes (see Figure 1). It also includes the emissions associated with the transportation fuel production process, inclusive of the electricity, process fuel(s), and hydrogen used by the transportation fuel production facility. Life cycle GHG emissions accounted for in 45ZCF-GREET also include transport, storage, and use of the transportation fuel as part of a neat fuel or fuel blend suitable for transportation. The One Big Beautiful Bill Act (Public Law 119-21) amended § 45Z, effective for fuels produced after Dec. 31, 2025, to prohibit use of feedstocks other than from the United States, Mexico, or Canada; exclude any emissions attributed to indirect land use change; adjust life cycle GHG accounting methods for transportation fuels derived from animal manures; and prohibit negative emissions rates for all pathways except transportation fuels derived from animal manures. Where applicable, 45ZCF-GREET (Sept. 2026 version) has been updated to display separate life cycle GHG emissions results for fuels produced in 2025 and fuels produced after Dec. 31, 2025. Where currently supported by available, creditable data, 45ZCF-GREET (Sept. 2026 version) has been updated to include pathways for transportation fuels that are derived from specific animal manure feedstocks, consistent with Notice 2026-53.

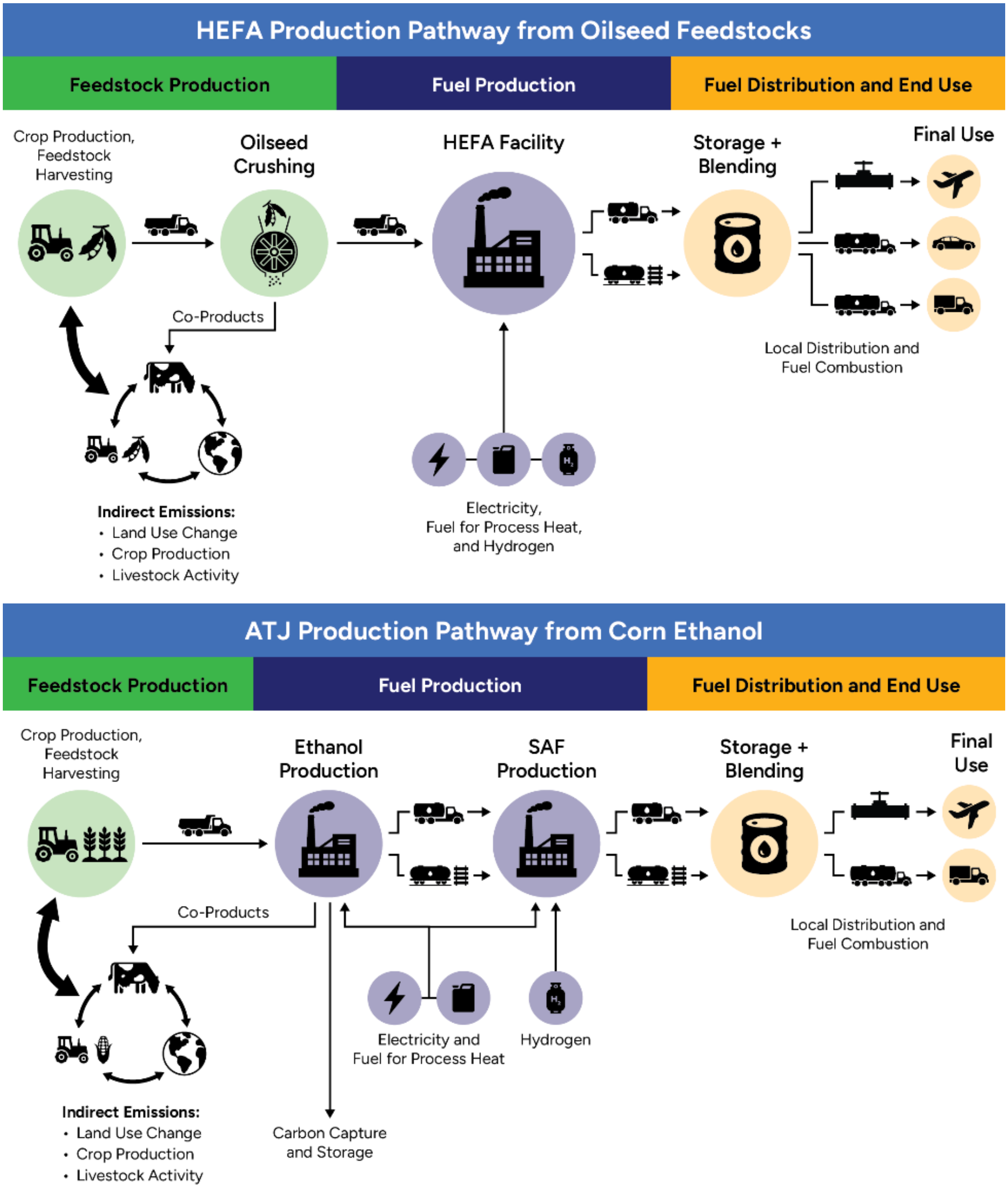

Figure 1. Examples of key activities related to life cycle GHG emissions, as calculated for fuels produced before Jan. 1, 2026, within the system boundary for transportation fuel production. The top diagram shows an example hydroprocessed esters and fatty acids (HEFA) pathway, and the bottom diagram shows an alcohol-to-jet (ATJ)-ethanol pathway, which coproduces both sustainable aviation fuel (SAF) and diesel. For fuels produced after Dec. 31, 2025, 45ZCF-GREET does not include indirect land use change emissions.

Certain parameters within 45ZCF-GREET are fixed (i.e., "background data") and may not be changed by the user. Background data are defined as parameters for which default average values based on industry statistics and scientific literature are deemed appropriate. Examples of background data in 45ZCF-GREET include direct emissions from operating farm equipment, methane leakage rates for the natural gas supply chain, and the transportation distances and carbon dioxide (CO_2) emissions factors for individual transportation modes. Inputs for background data are itemized in the GREET dependency file in the 45ZCF-GREET package.

The user must enter all other parameters, which are considered as foreground data. Examples of these parameters include feedstock type, the type and quantity of energy used for transportation fuel production, and the quantity of transportation fuel and other fuels produced. Additional details can be found in Table 5.

2 Methodology

This section presents the methodology used in 45ZCF-GREET to calculate the life cycle GHG emissions of transportation fuel production pathways via technologies currently represented in the tool.

2.1 Functional Unit

Section 45Z generally allows credit for each gallon (or, for fuels that are gaseous at ambient conditions, gallon gasoline equivalent [GGE]) of transportation fuel that has "practical and commercial fitness for use as a fuel in a highway vehicle or aircraft, or may be blended into a fuel mixture that has practical and commercial fitness for use as a fuel in a highway vehicle or aircraft," per 91 FR 5160. For fuels that are liquid at ambient conditions, the reported volume of fuel produced is measured in gallons at ambient conditions (60°F, 1 atmosphere [atm]). The amount of the credit depends in part upon the emissions rate, expressed as kilograms (kg) of carbon dioxide equivalent (CO_2e) per million British thermal units (MMBtu).[4] For gaseous fuels, the quantity of fuel produced is converted to GGE using a lower heating value (LHV) of 122.5 megajoules (MJ) (116,090 Btu) per GGE. 45ZCF-GREET uses a functional unit of 1 MJ of fuel on an LHV basis. This functional unit is used to calculate a transportation fuel's life cycle GHG emissions rate. The emissions rate is used to calculate the emission factor, for the purposes of § 45Z, which is equal to the quotient of **(I)** an amount equal to (aa) 47.4 grams (g) of CO_2e per MJ (50 kg of CO_2e per MMBtu), minus (bb) the emissions rate for such fuel, divided by **(II)** 47.4 g of CO_2e per MJ (50 kg of CO_2e per MMBtu).

For gaseous fuels, the amount of the tax credit to be claimed must be calculated on a per-GGE basis using the LHV per 91 FR 5160. Table 1 provides LHVs and GGEs for selected gaseous transportation fuels.

Table 1. LHV and GGE for Selected Transportation Fuels That Exist as a Gas at Ambient Conditions (60°F, 1 atm)

Fuel	LHV	Appropriate GGE
Gasoline (E0)	116,090 Btu/gallon (18,680 Btu/pound [lb])	1.00
Propane (liquefied petroleum gas)	19,873 Btu/lb	1 lb = 0.17 GGE
Propane fuel mix (from HEFA process)	18,568 Btu/lb	1 lb = 0.16 GGE
Compressed natural gas (including compressed natural gas from renewable natural gas [RNG] or coal mine methane [CMM])	20,267 Btu/lb	1 lb = 0.17 GGE
Liquefied natural gas (including liquified natural gas from RNG or CMM)	20,908 Btu/lb	1 lb = 0.18 GGE
Hydrogen	51,585 Btu/lb	1 lb = 0.44 GGE (1 kg = 0.98 GGE)

[4] LHV refers to the value of the heat of combustion of a fuel measured by allowing all products of combustion to remain in the gaseous state. This method of measure does not take into account the heat energy put into the vaporization of water (heat of vaporization).

2.2 Greenhouse Gases

45ZCF-GREET accounts for methane (CH_4), nitrous oxide (N_2O), and CO_2 in its representation of GHG emissions, and it uses the global warming potentials (GWPs) of these gases to determine grams of CO_2e released per megajoule of transportation fuel produced and consumed (i.e., g CO_2e/MJ fuel). The model uses GWP values characterized on the basis of a 100-year time frame (i.e., GWP100) from the Intergovernmental Panel on Climate Change's Fifth Assessment Report. Table 2 presents the reported GWPs of the three GHGs.[5,6]

Table 2. 100-Year GWPs of CO_2, CH_4, and N_2O in the Intergovernmental Panel on Climate Change Assessment Report[5]

CO_2	CH_4	N_2O
1	28	265

2.3 Eligible Transportation Fuels, Conversion Pathways, and Feedstocks

Section 45Z defines transportation fuel as a fuel that (1) is suitable for use as a fuel in a highway vehicle or aircraft, (2) has an emissions rate not greater than 47.4 g of CO_2e per MJ (50 kg of CO_2e per MMBtu), and (3) is not derived from coprocessing monoglycerides, diglycerides, triglycerides, free fatty acids, or fatty acid esters (or materials derived from such materials) with a feedstock that is not biomass. In addition to these requirements for all transportation fuels, for fuels produced before Jan. 1, 2026, § 45Z differentiates between SAF and non-SAF fuels with different rates for each. Section 45Z defines SAF as liquid fuel, the portion of which is not kerosene, that (1) meets fuel quality standard ASTM International Standard D7566 (*Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*)[7] or the Fischer-Tropsch provisions of ASTM International Standard D1655, Annex A1; and (2) is not derived from palm fatty acid distillates or petroleum.

As noted, the 45ZCF-GREET model is designed specifically to calculate GHG emissions rates for the 45Z tax credit, and thus its use is not appropriate for other purposes, including for determining eligibility for other tax credits or for federal programs except where specifically referenced in the provisions for such tax credits or programs.

[5] GWPs of GHG emissions are published periodically by the Intergovernmental Panel on Climate Change. The Fifth Assessment Report GWP data are currently utilized in reporting to the United Nations Framework Convention on Climate Change. See: Subsidiary Body for Scientific and Technological Advice. 2022. "Common metrics used to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks." United Nations Framework Convention on Climate Change. unfccc.int/sites/default/files/resource/sbsta2022_L25a01E.pdf.
[6] The GWP of methane per the Fifth Assessment Report, and agreed for use in the Paris Agreement and the U.S. Nationally Determined Contribution, is 28. Additionally, 45ZCF-GREET accounts for radiative forcing impacts of carbon dioxide added to the atmosphere due to oxidation of fossil-based methane, which is depicted in 45ZCF-GREET by increasing the GWP value by 2, consistent with alternative GWP values published in Table 8.A.1 of the Fifth Assessment Report, www.ipcc.ch/report/ar5/syr/.
[7] See www.astm.org/d7566-22.html.

45ZCF-GREET calculates life cycle GHG emissions associated with certain fuels and pathways that correspond to fuels that were identified in IRS Notice 2024-49, Notice 2025-10, Notice 2025-11, 91 FR 5160, and Notice 2026-53. Table 3 summarizes the definitions of the non-SAF fuels in 91 FR 5160 and identifies the relevant pathways listed in IRS Notice 2025-11 and included in 45ZCF-GREET. These fuels and pathways were selected based on current and expected near-term production of transportation fuels that are likely to meet the eligibility requirements for the 45Z tax credit. As shown in Table 3, fuels identified in IRS Notice 2024-49 and defined in 91 FR 5160 but not currently included in 45ZCF-GREET 2026 include butanol, dimethyl ether, and methanol.

Table 3. Definitions and Specifications That May Qualify as a Non-SAF Transportation Fuel

Non-SAF Fuel	Corresponding 45ZCF-GREET Fuel/Pathway(s)	Definition	Specification(s)
Biodiesel	Biodiesel (transesterification)	Monoalkyl esters of long-chain fatty acids	ASTM D6751
Butanol	N/A	Mixture of n-butyl, sec-butyl, and iso-butyl alcohols	ASTM D7862
Renewable diesel	Renewable diesel (HEFA, gasification and Fischer-Tropsch, and ATJ-ethanol)	Liquid fuel, including renewable diesel	ASTM D975
Dimethyl ether	N/A	Gaseous fuel, including renewable dimethyl ether	ASTM D7901
Ethanol	Ethanol (fermentation)	Ethyl alcohol that is a liquid fuel for blending with gasolines	ASTM D4806 ASTM D8651
Naphtha	Naphtha (HEFA)	Liquid fuel, including renewable gasoline	ASTM D4814
Hydrogen	Hydrogen (hydrogen)	Gaseous or liquid fuel	SAE J2719
Propane	Propane (HEFA)	Liquefied gases, including propane	ASTM D1835
Methanol	N/A	Methyl alcohol that is a liquid fuel	ASTM D1152/D5797
Alternative natural gas	RNG via anaerobic digestion (animal manures,[a] dairy manure,[b] swine manure,[b] wastewater sludge, food scraps, grain stillage, corn stover, and mixed feedstocks [c]), RNG from landfill gas, and CMM capture and upgrading	Natural gas suitable for use in transportation	ASTM D8080 [d]

[a] For fuels produced before Jan. 1, 2026.
[b] For fuels produced after Dec. 31, 2025.

[c] See Appendix A for a list of included feedstocks and categories.
[d] Except the compression requirements. Users enter the pressure of produced RNG/CMM upon exiting the upgrader (prior to any compression) into 45ZCF-GREET. The model will subsequently calculate any additional emissions associated with transport and compression of RNG or CMM to 4,800 pounds per square inch absolute (psia) when modeled for use a transportation fuel.

Under 91 FR 5160, if a taxpayer's taxable year began before the publication of 45ZCF-GREET (for example, on Jan. 1, 2025), the taxpayer must use 45ZCF-GREET for the entire taxable year. Additionally, if an updated version of the 45ZCF-GREET model becomes publicly available after the first day of the taxable year of production (but still within such taxable year), then the taxpayer may, in their discretion, treat such version as the most recent version of the 45ZCF-GREET model. However, taxpayers must use the version of well-to-wheel emissions rates that align with the year in which the fuel was produced. If a taxpayer's taxable year spans both 2025 and 2026, taxpayers are directed to run 45ZCF-GREET twice to calculate separate emissions rates: first for the portion of fuel produced in 2025, and second for the portion of fuel produced after Dec. 31, 2025.

For all fuels, 45ZCF-GREET calculates well-to-wheel emissions rates based on their use as a transportation fuel. Under 91 FR 516, to claim the 45Z tax credit for hydrogen production, claimants are directed to use the most recent version of the 45VH2-GREET model to calculate a well-to-gate emissions rate.

45ZCF-GREET offers a single pathway for hydrogen, which provides a space for users to enter a 45VH2-GREET-modeled emissions rate per kilogram of hydrogen produced at a pressure of 300 psia. Users may enter an emissions rate produced by 45VH2-GREET or as the result of a provisional emissions rate application through the 45V tax credit. 45ZCF-GREET then calculates the additional emissions resulting from hydrogen compression to 700 bar (10,152.6 psia) at a temperature of −40°C, delivery as a gas in tube trailers via truck with a distance of 200 miles, and additional precooling and compression at the fueling station to generate a well-to-wheel emissions rate per megajoule of hydrogen for the purposes of claiming the 45Z tax credit.

Several pathways in 45ZCF-GREET can be used to produce fuels from multiple primary feedstocks, which are enumerated in Notice 2026-53. Table 4 summarizes the primary feedstocks that are included in each GREET pathway. All pathways are based on the assumption that production of transportation fuel occurs in the United States or a U.S. territory as is required to qualify for the 45Z tax credit. In some cases, a production pathway may have inputs that are sourced from outside the United States. 45ZCF-GREET includes specific feedstocks and origins based on the availability of adequate data to quantify life cycle GHG emissions and their likelihood to be (1) claimed by applicants and (2) part of a fuel pathway that achieves an emissions rate below the threshold of 47.4 g CO_2e per MJ (50 kg CO_2e per MMBtu). For example, the Brazilian sugarcane ATJ-ethanol pathway assumes that sugarcane ethanol is produced in Brazil and imported to the United States for final conversion to SAF at domestic ATJ-ethanol facilities.

Table 4. Primary Feedstocks Included in 45ZCF-GREET by Conversion Pathway

Conversion Pathway	Primary Feedstock(s)
HEFA	U.S. soybean oil
	U.S./Canadian canola oil/rapeseed oil
	Used cooking oil (UCO) [a]
	Tallow [a]
	U.S. distillers corn oil (DCO)
	U.S. distillers sorghum oil (DSO)
	U.S. carinata oil (intermediate crop)
	U.S. camelina oil (intermediate crop)
	U.S. pennycress oil (intermediate crop)
Transesterification	U.S. soybean oil
	U.S./Canadian canola oil/rapeseed oil
	UCO [a]
	Tallow [a]
	U.S. DCO
	U.S. DSO
	U.S. carinata oil (intermediate crop)
	U.S. camelina oil (intermediate crop)
	U.S. pennycress oil (intermediate crop)
Fermentation	U.S. corn starch [b]
	U.S. sorghum grain
	Brazilian sugarcane (for use as feedstock for SAF-ATJ prior to Jan. 1, 2026, only)
	U.S. corn stover
ATJ	Ethanol (from fermentation pathways listed above) [c]
Gasification and Fischer-Tropsch	U.S. corn stover
Anaerobic digestion and biogas upgrading	U.S. wastewater sludge
	U.S. animal manures [d,e]
	U.S. dairy manure [d,f]
	U.S. swine manure [d,f]
	U.S. landfill gas

Conversion Pathway	Primary Feedstock(s)
	U.S. food scraps [g]
	U.S. corn stover
	U.S. grain stillage
	U.S. DCO
	U.S. DSO
	U.S. fats, oils, and greases (FOG) and septage
	U.S. mixed high-moisture organic wastes [h]
CMM capture and upgrading	U.S. CMM
Hydrogen (well-to-gate pathways as defined in the user manual for the most recent 45VH2-GREET model, gate-to-wheels as modeled in 45ZCF-GREET)	Hydrogen (well-to-gate, 300 psia), as defined in the user manual for the most recent 45VH2-GREET model [c]

[a] Per Notice 2026-53, transportation fuels produced from non-Canadian/Mexican imported UCO or tallow as a feedstock only receive an emissions date if the fuels are produced prior to Jan. 1, 2026. 91 FR 5160 reflects changes made in Section 70521 of Public Law 119-21 that amended § 45Z to limit eligibility to fuels produced from feedstocks produced or grown in the United States, Canada, and Mexico.

[b] Corn starch as a primary feedstock includes both starch and corn kernel fiber.

[c] Subject to the limitation in § 45Z(d)(5)(A)(iv).

[d] For the purposes of 45ZCF-GREET, manure is defined as feces, urine, or other excrement from livestock or poultry. Manure processed in anaerobic digesters may include water from sources such as precipitation, runoff, or wash water. The 45ZCF-GREET manure RNG pathway only generates accurate results for facilities that process manure mixed with up to 5% (mass fraction of total solids) non-manure material that is typically commingled with manure and cannot be practically separated, such as bedding materials, hay, compost, and animal carcasses.

[e] The pathway for anaerobic digestion of animal manures based on the national average of all animal waste management practices per Section 1.45V-4(f)(3)(v) must be used for fuels produced before Jan. 1, 2026, and cannot be used for fuels produced after Dec. 31, 2025.

[f] 45ZCF-GREET (Sept. 2026 version) has been updated to include pathways for transportation fuels that are derived from specific animal manure feedstocks for fuels produced after Dec. 31, 2025, consistent with Notice 2026-53.

[g] Food scraps are defined as the portion of municipal solid waste that consists of inedible or postconsumer food collected from residences, hospitality facilities, institutions, and grocery stores. Feedstocks that are not typically landfilled do not qualify as food scraps, which include FOG, liquids at the point of collection, and materials from industrial food manufacturing or processing facilities.

[h] See Appendix A.

Note that 45ZCF-GREET, except where otherwise noted, only includes feedstocks sourced from the United States. Specifically, canola/rapeseed oil is included for U.S. and Canadian sources. There are no specific restrictions on the origin of tallow or UCO for fuels produced before Jan. 1, 2026, and applicants may use these pathways in 45ZCF-GREET regardless of feedstock origin. Section 70521 of Public Law 119-21 amended § 45Z to limit eligibility, effective for fuels produced after Dec. 31, 2025, to fuels exclusively derived from feedstocks produced or grown in the United States, Mexico, or Canada. Effective for fuels produced after Dec. 31, 2025, only the portion of fuels produced from feedstocks sourced from the United States, Canada, and Mexico receive an emissions rate in 45ZCF-GREET.[8] For both UCO and tallow, users are directed to feedstock based on its origin as directed in the user interface. The model is configured to determine the volumes of eligible and ineligible fuels for the purposes of § 45Z. 45ZCF-GREET will provide emissions rate(s) corresponding to the eligible UCO and/or tallow inputs only.

2.4 Selected Foreground Data and Emission Reduction Options

45ZCF-GREET requires users to enter foreground data specific to their facility in order to generate an emissions rate for the purposes of the 45Z tax credit. 45ZCF-GREET does not offer any optional default values to use as foreground data. Users are encouraged to review 91 FR 5160, Notice 2025-10, and Notice 2025-11 before entering foreground data into 45ZCF-GREET. Foreground data for all pathways in 45ZCF-GREET include primary feedstock inputs, energy consumption related to the fuel production process, and fuel production outputs (see Table 5). Foreground data include multiple potential energy sources that may be used for process heat and power based on the relevance to the particular pathway and primary feedstock. For example, the corn ethanol fermentation pathway includes options to use coal and/or corn stover due to the current and potential use of these resources for heat and power, but these options are not included in all pathways. Certain pathways may also have foreground data that a user is required to enter due to unique characteristics/requirements of the fuel production process that may significantly impact a facility's emissions rate (e.g., the amount of methanol used in transesterification to produce biodiesel).

Several pathways in 45ZCF-GREET include an option to use more than one primary feedstock in the same facility—usually referred to as "mixed feedstock." Facilities that use more than one primary feedstock are directed to calculate separate GHG emissions rates corresponding to the quantity of fuel produced from each of those feedstocks. 45ZCF-GREET uses a mass balance allocation based on the relative mass of each primary feedstock. For example, a HEFA facility that converts a combination of soybean oil and DCO will generate two GHG emissions rates for each fuel it produces, corresponding to the portion of each fuel generated from soybean oil and the portion generated from DCO.

[8] Section 70521 of Public Law 119-21.

Table 5. Example Transportation Fuel Production Pathways in 45ZCF-GREET With Selected Foreground and Background Data

45ZCF-GREET Input Data		Ethanol Fermentation	ATJ-Ethanol	Transesterification	HEFA	Gasification and Fischer-Tropsch	RNG/CMM	Hydrogen
Primary Feedstock(s)								
	Feedstock amount(s)	▲	▲	▲	▲	▲	N/A	▲
Production Process								
Energy sources for heat and power	Grid electricity	▲	▲	▲	▲	▲	▲	N/A
	Integrated on-site behind-the-meter (BTM) electricity	▲	▲	▲	▲	▲	▲	N/A
	Non-integrated on-site BTM electricity: energy attribute credit (EAC)	▲	▲	▲	▲	▲	▲	N/A
	Imported renewable electricity: EAC	▲	▲	▲	▲	▲	▲	N/A
	Fossil natural gas	▲	▲	▲	▲	▲	▲	N/A
	45Z modeled RNG	▲	▲	▲	▲	▲	N/A	N/A
	45Z modeled CMM	▲	▲	▲	▲	▲	▲	N/A
	Coal	▲	N/A	▲	N/A	▲	N/A	N/A
	Agricultural residue	▲	N/A	N/A	N/A	N/A	N/A	N/A
Imported chemical inputs	Methanol	N/A	N/A	▲	N/A	N/A	N/A	N/A
	Off-site, fossil steam methane reforming (SMR) hydrogen	N/A	▲	N/A	▲	N/A	N/A	N/A
	Off-site, 45Z modeled hydrogen	N/A	▲	N/A	▲	N/A	N/A	N/A
Carbon capture and storage		▲	▲	N/A	N/A	▲	▲	N/A

45ZCF-GREET Input Data		Ethanol Fermentation	ATJ-Ethanol	Transesterification	HEFA	Gasification and Fischer-Tropsch	RNG/CMM	Hydrogen
Fuel Output								
SAF		N/A	▲	N/A	▲	▲	N/A	N/A
Non-SAF fuels	Ethanol	▲	N/A	N/A	N/A	N/A	N/A	N/A
	Biodiesel	N/A	N/A	▲	N/A	N/A	N/A	N/A
	Renewable diesel	N/A	▲	N/A	▲	▲	N/A	N/A
	Naphtha	N/A	N/A	N/A	▲	N/A	N/A	N/A
	Propane	N/A	N/A	N/A	▲	N/A	N/A	N/A
	RNG/CMM	N/A	N/A	N/A	N/A	N/A	▲	N/A
	Hydrogen (300 psia)	N/A	N/A	N/A	N/A	N/A	N/A	▲
Coproduct Outputs								
Non-fuel coproducts		●	N/A	▲	N/A	N/A	N/A	N/A
Transportation, Conditioning, and End Use								
Transportation	Feedstock and intermediate transport to fuel production facility	●	●	●	●	●	●	●
Conditioning	Fuel blending or conditioning for use in transportation	●	●	●	●	●	●	●
Transportation and end use	Finished fuel transportation and end use	●	●	●	●	●	●	●

Green triangles indicate foreground data, and red dots indicate selected background data. Most foreground data require numeric inputs by the user. Foregrounded options may vary based on pathway and feedstock. For example, Brazilian sugarcane ethanol assumes a Brazilian grid mix and does not provide certain emission reduction options, such as carbon capture, utilization, and sequestration. Most inputs are listed as N/A for hydrogen because users are directed to provide inputs to the 45VH2-GREET model, as 45ZCF-GREET does not model them directly, and input the result into the 45ZCF-GREET hydrogen pathway for hydrogen as a process fuel.

Upstream emissions from feedstock production are calculated from background data. Likewise, emissions from transporting the feedstock and/or intermediates to the production facility are also calculated from background data for several reasons. Feedstock transport emissions are typically a small fraction of a fuel's life cycle GHG emissions rate (<5 g CO_2e/MJ), even in cases where feedstock is sourced internationally, because of the comparatively low energy intensity of marine shipping relative to truck or rail. Including feedstock transport modes and distances in foreground data inputs increases the complexity of modeling and could lead to unintended effects (e.g., transport distances for biofuel feedstocks may become shorter while distances for other uses such as food/feed could become longer).

Emissions associated with conditioning the fuel for transportation use are also calculated from background data. For example, background data are used to calculate emissions associated with compressing RNG and CMM for transportation use. Lastly, emissions associated with transporting the finished fuel to the point of use and the emissions from its end use are also calculated from background data. The background data for gate-to-wheels are based on typical logistics for each fuel's use in a transportation application. 45ZCF-GREET also includes any compression and/or cooling necessary to transport gaseous fuels and make them suitable for final vehicle fueling. Including gate-to-wheels emissions as background data avoids the requirement for users to track the final use of each fuel and also avoids unintentionally advantaging fuels sold and used for non-transportation purposes if such applications result in lower emissions (e.g., due to reduced compression requirements for gaseous fuels not delivered to vehicle fueling stations).

As stated in 91 FR 5160, clean fuel producers may use low-carbon inputs consistent with the guidelines established in the 45V Regulations to reduce the GHG emissions rate of their fuel. 45ZCF-GREET aligns with this guidance and includes the ability to use electricity from zero or minimally emitting sources directly or through the use of EACs, as well as natural gas alternatives (through a direct pipeline connection to a supplier of natural gas alternatives or documentation of other physical methods of exclusive delivery).[9] Where relevant, certain pathways also include options to use clean hydrogen as a chemical input (e.g., HEFA), and carbon capture, utilization, and sequestration (e.g., fermentation) to achieve a lower GHG emissions rate, if consistent with the rules established under the 45V Regulations.

2.4.1 Accounting for Electricity in 45ZCF-GREET

The accounting of electricity in 45ZCF-GREET aligns with the 45Z notice of proposed rulemaking, which generally aligns with the 45V Regulations. This alignment reflects a shared statutory direction to account for life cycle GHG emissions as described in 42 U.S.C. 7545(o)(1)(H). When specifying the source of electricity consumed, users may represent either (1) electricity from a specific generator or combination of generators, or

[9] Under the final regulations, use of gas EACs (i.e., RNG book-and-claim) under certain conditions may become available in future years upon a determination by the Secretary of the Treasury. Until such determination is made and the Treasury Department and the IRS issue further guidance, taxpayers may not use gas EACs.

(2) the average annual grid mix in the region where the transportation fuel production facility is located. Regions within 45ZCF-GREET are depicted in alignment with the 45V Regulations. A third option has been added in the Sept. 2026 version of 45ZCF-GREET to accommodate facilities that operate integrated BTM power generator(s) and also purchase EACs. These three options are described below. Note that any electricity that is procured from the grid and is not substantiated via the Treasury Department and the IRS's requirements for qualifying EACs must be assumed to be sourced from the facility's grid region (Option 2) and input into 45ZCF-GREET accordingly. Users may also exercise a combination of Options 1 and 2 representing the portion of electricity consumption that meets the criteria for each option and enter the corresponding electricity consumption values into 45ZCF-GREET accordingly.

Option 1: Specific source power. This option allows users to enter power that was either generated BTM or purchased from a specific source. Imported power, labeled "Imported Renewable Electricity: Energy Attribute Credit (EAC)," allows users to specify an amount of electricity purchased from one or more specific sources along with matching qualifying EACs. The current version of 45ZCF-GREET allows users to enter certain purchases of electricity from sources that are modeled as zero emission in 45VH2-GREET, specifically solar, wind, and hydroelectricity. Other electricity sources modeled in 45VH2-GREET are not currently available in 45ZCF-GREET. We intend for future updates to include additional generator types, allowing users to use an emissions rate associated with additional types of generators (i.e., geothermal; nuclear; natural gas turbines with and without carbon capture, utilization, and sequestration; coal; and/or residual oil combustion) or a combination of generators, provided that (1) an emissions profile is available for the subject generator(s) in 45ZCF-GREET, and (2) any electricity that is claimed to be sourced from the subject generator(s) in a given calendar year is verified via the purchase (or generation, in the case of non-integrated BTM power) and retirement of qualifying EACs, which are EACs that meet specified criteria provided in the 45V Regulations.

There are two types of BTM power that may be entered into 45ZCF-GREET: integrated and non-integrated. Integrated BTM power, labeled "Onsite Behind-the-Meter (BTM) Electricity: Integrated" refers to generation that is interdependent on the fuel production facility, either by combusting a portion of inputs that are reported as overall facility inputs in 45ZCF-GREET (e.g., natural gas), combusting intermediate/waste products from the facility (e.g., biogas or residual solids), or through heat integration with the facility. One such example of "integrated BTM power" is a BTM combined heat and power unit that is used to provide process heat to the fuel production facility and also generates electricity that is used by the same facility. Integrated BTM power can be included when calculating and entering the facility's net grid electricity requirements, regardless of whether EACs have been generated and retired for that electricity.

For non-integrated BTM power generation, defined as generation that does not include heat integration with the facility or rely on any fuel production facility inputs/intermediate products (e.g., BTM solar or wind), EACs must be generated and retired as described above. Users enter the quantity of EACs generated and retired from power generated on-site in the input cell titled "Onsite Behind-The-Meter Electricity (BTM): EAC."

Any fuels consumed for generating BTM electricity are included in the transportation fuel production facility's energy balance and entered as user inputs to 45ZCF-GREET. This ensures that BTM electricity supplied through an on-site combined heat and power system is properly accounted for in the facility's overall mass and energy balance. Users may account for BTM electricity up to the amount needed to meet 100% of a facility's needs, but users may not enter a BTM electricity value that exceeds the facility's gross electricity consumption, even if the facility is a net exporter of electricity. Users may not enter a negative value in any electricity consumption input cell in 45ZCF-GREET.

As further described in the 45V Regulations, the criteria specified in the 45V Regulations are important guardrails to ensure that the transportation fuel producer's electricity use can be reasonably deemed to reflect the emissions associated with the specific generators from which the EACs were purchased and retired.[10] The criteria include:

- Deliverability: The electricity generator is located in the same region as the transportation fuel producer (as discussed in the Electricity Grid Regions section).
- Temporal matching: The electricity generation occurs at a relevant time in relation to the time of consumption, as defined in the 45V Regulations.
- Incrementality: The generator meets criteria designed to ensure the electricity is incremental, as defined in the 45V Regulations.

Additional details regarding these criteria are provided in the 45V Regulations.

Option 2: Grid power. For electricity that is consumed in the respective calendar year from source(s) other than those described in Option 1, users must assume that the electricity has an emissions profile that reflects the annual average GHG emissions intensity of electricity in the grid region in which the qualified facility is located, as determined by the 45ZCF-GREET model. Users are directed to select the appropriate choice in the "Needs Region Electricity Source" drop-down menu and enter the amount of electricity consumed in the "Electricity: Grid Consumption" input cell. The emissions factors for electricity consumption from each region (kg CO_2e/kilowatt-hour [kWh]) are based on (1) 2024 U.S. Energy Information Administration reporting identifying the amount of electricity generated by specific types of generation in each region,[11] (2)

[10] It is important to note that 45ZCF-GREET includes estimates of emissions associated with electricity generation from specific power generator types by using an attributional life cycle analysis (LCA) approach in conjunction with a basic representation of consequential/induced grid considerations. Per the latter, 45ZCF-GREET requires that any electricity that users input from specific power generator types meet the requirements for temporal matching, regional matching, and incrementality defined in the 45V Regulations, thereby characterizing via proxy the life cycle GHG emissions, including potential induced grid emissions, associated with electricity consumption.

[11] U.S. Energy Information Administration. 2024. "Form EIA-923 detailed data with previous form data (EIA-906/920)." www.eia.gov/electricity/data/eia923/.

emissions factors from the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID) 2023[12] to estimate direct emissions from each type of generator, (3) emissions factors from R&D GREET 2025 Rev. 1 to estimate upstream emissions associated with each type of feedstock consumed, and (4) estimates of transmission and distribution losses within each region, based on state-level reporting to the U.S. Energy Information Administration. More information describing the analysis that yielded emissions factors for each region is available in the technical report.[13]

Option 3: Integrated BTM power matched with specific source power. Facilities generating integrated BTM power as described in Option 1 may purchase and retire EACs equivalent to a maximum of the electricity generated by the integrated BTM power generator in the calendar year. Users are directed to enter the heat rate of the integrated BTM power generator, which is used to calculate the portion of total fuel consumption and emissions attributable to integrated BTM power generated. Users are also directed to enter the EACs purchased and retired in the "EACs Matched to BTM Electricity: Integrated" input cell up to a maximum of the reported integrated BTM power generated. If the value entered in "EACs Matched to BTM Electricity: Integrated" exceeds the value reported in "Onsite BTM Electricity: Integrated," the model will produce an error message. The portion of emissions attributable to integrated BTM power that is matched with EACs will be subtracted from the facility's total emissions. If the integrated BTM power generated has a higher emission factor per kilowatt-hour produced than the regional grid average emission factor (see Table 7), the subtracted emissions will be set to the grid average emission factor. Option 3 is currently implemented in 45ZCF-GREET only for natural-gas-fired integrated BTM power in the ethanol pathways using corn and/or sorghum as a feedstock.

Electricity Grid Regions

Deliverability of electricity in 45ZCF-GREET is treated in a manner that aligns with the 45V Regulations, which specify that an EAC meets the deliverability requirements if the electricity represented by the EAC is generated by a source that is in the same U.S. region as the qualified transportation fuel production facility. The guidance further defines the term "region," as depicted in Table 6. These regions and corresponding emissions factors are represented in 45ZCF-GREET.

Consistent with the 45V Regulations, the location of a generation source and the location of a transportation fuel production facility is based on the U.S. balancing authority to which it is electrically interconnected, with each balancing authority linked to a single region. The Midcontinent Independent System Operator (MISO) balancing authority is an exception because it is split into two U.S. regions, as shown in Table 6.

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[12] U.S. Environmental Protection Agency. 2025. *The Emissions & Generation Resource Integrated Database: eGRID Technical Guide with Year 2023 Data*. www.epa.gov/egrid/egrid-technical-guide.
[13] Z. Lu, A. Elgowainy, P. Vyawahare, and C. Ng. 2024. *Development of Life Cycle Greenhouse Gas Emission Intensities of Electricity by National Transmission Needs Study Region*. Lemont, IL: Argonne National Laboratory. ANL/ESIA-24/26. greet.anl.gov/publication-ele_ci_needs.

Though not depicted in Table 6, as per the 45V Regulations, Alaska and Hawaii are treated as two additional regions within the context of the EAC deliverability requirements, with one covering the entirety of Hawaii and the other covering the entirety of Alaska. Similarly, as per the 45V Regulations, each U.S. territory is considered a separate region.

Table 6. U.S. Balancing Authorities Linked to Grid Regions

Balancing Authority	Grid Region
Balancing Authority of Northern California	California
California Independent System Operator (Balancing Authority)	California
Imperial Irrigation District	California
Los Angeles Dept. of Water & Power	California
Turlock Irrigation District	California
Midcontinent ISO (Balancing Authority): South	Delta
Duke Energy Florida Inc.	Florida
Florida Municipal Power Pool	Florida
Florida Power & Light	Florida
Gainesville Regional Utilities	Florida
Homestead (City of)	Florida
JEA	Florida
New Smyrna Beach Utilities Commission	Florida
Reedy Creek Improvement District	Florida
Seminole Electric Coop Inc.	Florida
Tallahassee FL (City of)	Florida
Tampa Electric Co.	Florida
East Kentucky Power Coop Inc.	Mid-Atlantic
LG&E & KU Services Co.	Mid-Atlantic
Ohio Valley Electric Corp.	Mid-Atlantic
PJM Interconnection	Mid-Atlantic
Associated Electric Coop Inc.	Midwest
Electric Energy Inc.	Midwest
GridLiance Heartland	Midwest
Midcontinent ISO (Balancing Authority): North	Midwest
NaturEner Power Watch LLC (GWA)	Mountain

Balancing Authority	Grid Region
NaturEner Wind Watch LLC	Mountain
Nevada Power Co.	Mountain
Northwestern Energy	Mountain
PacifiCorp East	Mountain
Public Service Co. of Colorado	Mountain
WAPA Rocky Mountain Region	Mountain
WAPA Upper Great Plains West	Mountain
New England ISO (Balancing Authority)	New England
Northern Maine	New England
New York ISO (Balancing Authority)	New York
Avangrid Renewables LLC	Northwest
Avista Corp.	Northwest
Bonneville Power Administration	Northwest
Gridforce Energy Management LLC	Northwest
Idaho Power Co.	Northwest
PacifiCorp West	Northwest
Portland General Electric	Northwest
PUD No. 1 of Chelan County	Northwest
PUD No. 1 of Douglas County	Northwest
PUD No 2. of Grant County	Northwest
Puget Sound Energy Inc.	Northwest
Seattle City Light	Northwest
Tacoma Power	Northwest
Southwest Power Pool (Balancing Authority)	Plains
Southwestern Power Administration	Plains
Alcoa Power Generating Inc. Yadkin Division	Southeast
Duke Energy Carolinas LLC	Southeast
Duke Energy Progress East	Southeast
Duke Energy Progress West	Southeast
PowerSouth Energy Coop	Southeast
South Carolina Electric & Gas Co.	Southeast
South Carolina Public Service Authority	Southeast

Balancing Authority	Grid Region
Southeastern Power Administration (Southern)	Southeast
Southern Co. Services Inc.	Southeast
Tennessee Valley Authority	Southeast
Arizona Public Service Co.	Southwest
Arlington Valley LLC	Southwest
El Paso Electric	Southwest
Gila River Power LLC	Southwest
Griffith Energy LLC	Southwest
New Harquahala Generating Co. LLC	Southwest
Public Service Co. of New Mexico	Southwest
Salt River Project	Southwest
Tucson Electric Power Co.	Southwest
WAPA Desert Southwest Region	Southwest
ERCOT ISO (Balancing Authority)	Texas

Emissions factors associated with each of these regions are itemized in Table 7.

Table 7. Emissions Factors Corresponding to Each Grid Region per Kilowatt-Hour at the Point of Consumption

Grid Region	Emissions Factor (kg CO_2e/kWh)
California	0.23
Delta	0.44
Florida	0.43
Mid-Atlantic	0.41
Midwest	0.58
Mountain	0.62
New England	0.31
New York	0.28
Northwest	0.16
Plains	0.46
Southeast	0.37
Southwest	0.39
Texas	0.40
Alaska	0.57
Hawaii	0.76

2.4.2 Natural Gas Alternatives as an Input to Transportation Fuel Production

Transportation fuel production facilities typically require natural gas, which can be combusted to generate process heat and/or electricity. Natural gas can also be used to produce hydrogen via SMR. 45ZCF-GREET enables users sourcing natural gas alternatives (including RNG or CMM) as an input for fuel production to claim the emissions profile of externally sourced alternative natural gas that is directly supplied (see Table 5). RNG sources currently included in 45ZCF-GREET are (1) landfill gas, (2) wastewater sludge, (3) animal manures (prior to Jan. 1, 2026, only), (4) dairy manure (after Dec. 31, 2025, only), (5) swine manure (after Dec. 31, 2025, only), (6) food scraps, (7) grain stillage, (8) corn stover, and (9) mixed feedstocks (full list included in Appendix A). In the case of landfill gas, the gas is captured via a collection system and upgraded to RNG. With all other feedstocks, these materials are fed into anaerobic digesters where biogas is generated and captured for upgrading to RNG. 45ZCF-GREET also includes alternative natural gas from CMM capture and upgrading.

If biogas, CMM, or RNG is produced *and* used on-site as a process input/fuel at a transportation fuel production facility (e.g., methane/biogas produced on-site and combusted as a process fuel), the resulting energy use and emissions are included in the facility-level energy and mass balances entered as foreground data in 45ZCF-GREET. The biogas, CMM, or RNG produced and used on-site is not entered as a separate input because it is not externally sourced. For facilities whose primary product is RNG or CMM, only the amount of RNG or CMM sold should be reported in the total production. Biogas, CMM, or RNG produced and consumed on-site should not be entered into 45ZCF-GREET.

Users are directed to calculate the emissions rate for externally sourced RNG and/or CMM by running 45ZCF-GREET for the applicable RNG and/or CMM pathway(s), selecting “Model Pipeline RNG as a Process Fuel” or “Model Pipeline CMM as a Process Fuel” as the end use of the RNG/CMM within the “Selections” section of the model to obtain emissions rates for each source of RNG/CMM, which are subsequently entered into 45ZCF-GREET (GHG intensity entered in “45Z Modeled RNG CI” or “45Z Modeled CMM CI”) along with the quantities consumed (entered in “45Z Modeled RNG” or “45Z Modeled CMM”). If users purchase RNG and/or CMM as a process fuel from multiple external sources, the total quantity can be entered along with a mass-weighted average carbon intensity (CI) value for all applicable RNG/CMM. Consistent with the 45V Final Rule, any RNG and/or CMM modeled as a process fuel must be physically consumed (i.e., cannot be consumed via book-and-claim).

Under 91 FR 516, any negative emissions rates calculated for CMM and non-manure-derived RNG must be adjusted up to 0 kg of CO_2e per MMBtu for fuels produced after Dec. 31, 2025. This applies to RNG and CMM used as process fuels in addition to RNG and CMM as transportation fuels. Users are directed to enter any other external natural gas or natural gas alternative source (e.g., propane that is imported to the facility) for which a 45ZCF-GREET pathway is not available in the total natural gas consumption user input. For natural gas that is metered on a volumetric basis, users are directed to convert the volume of natural gas consumed to its LHV using a conversion factor of

890.402918 Btu/standard cubic feet (scf; volume at standard temperature and pressure of 60°F and 1 atm, respectively). If natural gas is metered on a mass basis, a density of 19.818463 g/scf can be used for the conversion.

Consistent with 91 FR 5160, 45ZCF-GREET aligns with guidance in the 45V Final Rule regarding counterfactual scenarios (with the exception of dairy and swine manure RNG) and distinct modeling of each process (i.e., not modeling "blended" CIs of final products).

2.4.3 Hydrogen as an Input to Transportation Fuel Production

Some transportation fuel production facilities, including HEFA and ATJ facilities, require hydrogen as an input, which can be produced on-site or sourced from a separate facility. Transportation fuel production facilities purchasing hydrogen from an off-site facility will enter their hydrogen consumption as foreground data in 45ZCF-GREET. The user may enter the quantity of hydrogen consumed from two possible sources:

- Hydrogen produced off-site from fossil gases (including natural gas) without carbon capture, utilization, and sequestration (user input titled "Offsite, Fossil SMR Hydrogen"). Any hydrogen purchased from an off-site production facility that does not have a modeled 45V CI is entered in the "Offsite, Fossil SMR Hydrogen" input cell, regardless of how it was produced.
- Hydrogen that has been modeled using 45VH2-GREET or has received a CI as the result of a provisional emissions rate application. To obtain a value for "Offsite, 45Z Modeled Hydrogen CI," users are first directed to navigate to the hydrogen production pathway in 45ZCF-GREET. The user-entered CI in this pathway is based on output from 45VH2-GREET or the result of a provisional emissions rate application through the 45V tax credit ("45V Modeled Hydrogen CI"). Users enter the appropriate CI and select "Model Hydrogen as a Process Fuel" in the "Selections" table, which adds emissions associated with hydrogen transportation and compression. The "Total LCA Results" value can then be used in the "45Z Modeled Hydrogen CI" user input for the main fuel production pathway. If the production facility purchases multiple hydrogen sources with different CIs, a mass-weighted average of the individual CIs is entered along with the sum of hydrogen purchased. 45ZCF-GREET uses background data to estimate transportation distances and calculate the GHG emissions footprint for the transportation and additional compression, based on an assumption of pipeline transportation and a distance of 150 miles.
- Under 91 FR 516, any negative emissions rates calculated for hydrogen must be adjusted up to 0 kg of CO_2e per kg H_2 for fuels produced after Dec. 31, 2025. This applies to hydrogen used as a process fuel in addition to hydrogen as a transportation fuel.

If a transportation fuel production facility generates its own hydrogen on-site for use as a process input, that quantity of hydrogen should not be entered separately into 45ZCF-GREET as hydrogen consumption. Instead, the inputs for this hydrogen production are to be included in the overall mass and energy balance of the facility. Thus, any electricity, natural gas, other fossil gases, or RNG required for on-site hydrogen production are to be included in the reported facility energy consumption for the calendar year in which the fuel production occurred.

2.4.4 Carbon Capture, Utilization, and Sequestration

Carbon capture, utilization, and sequestration is incorporated into 45ZCF-GREET for domestic ethanol pathways, RNG pathways, and gasification with Fischer-Tropsch synthesis pathways. The total quantity of CO_2 captured and stored is a user input in 45ZCF-GREET; users are directed to enter the annual quantity of CO_2 captured and stored in U.S. Class VI and/or Class II wells (calculated for the calendar year in which the fuel production occurred). Users may not enter a value for CO_2 captured and stored that exceeds the value of their total fossil and biogenic CO_2 emissions. CO_2 capture and use in other applications, such as incorporation into a product, are not included as options for reducing the GHG emissions rate of transportation fuels in 45ZCF-GREET.

2.4.5 Agricultural Residues as Process Fuel for Transportation Fuel Production

45ZCF-GREET provides the option for entering agricultural residues that are used as an alternative process fuel for generating heat and electricity at transportation fuel production facilities. For the current version, users may enter the total intake of two specific crop residues: corn stover and sorghum stubble. Corn stover and sorghum stubble quantities are summed and entered as an annual total, along with the mass-weighted average moisture content of delivered biomass, in the “Agricultural Residue Input” and “Agricultural Residue Moisture Content” input cells, respectively. This material may be combusted as a solid fuel or gasified to syngas that is ultimately combusted. The option of using crop residues as an alternative fuel is available in corn and sorghum ethanol pathways. The use of bagasse in Brazilian sugarcane ethanol is incorporated as background data. Although transportation fuel producers may choose to export excess electricity or steam generated using these residues, 45ZCF-GREET does not apply a displacement credit for excess electricity or steam exported from the facility. 45ZCF-GREET accounts for additional fertilizer inputs and fuel use specifically associated with the collection and removal of agricultural residues from the field. It assumes that crop residues are sourced in a manner that does not result in significant emissions from the diversion of crop residues from other productive uses.

2.4.6 Regenerative Agriculture Practices Modeled in 45ZCF FD-CIC

45ZCF-GREET has been updated to incorporate emissions adjustments for regenerative agricultural practices for corn, sorghum, soybeans, and canola. These emissions adjustments are only available for crops grown in the United States. Consistent with 91 FR 5160 and Notice 2026-53, the 45ZCF-GREET package now includes a 45Z-specific version of the Feedstock Carbon Intensity Calculator (45ZCF FD-CIC). Users are directed to model regenerative practices in 45ZCF FD-CIC based on the location and practices of each feedstock producer, and the outputs of 45ZCF FD-

CIC can be entered into 45ZCF-GREET for inclusion in the calculation of fuel-specific emissions rates. The agricultural practices included in 45ZCF FD-CIC are cover crops, tillage practices, application of nitrification inhibitors, and application of manure.

45ZCF FD-CIC can be run using the linked interface, which will automatically populate 45ZCF-GREET with the calculated feedstock emissions intensity. Alternatively, 45ZCF FD-CIC can be run separately, after which users can manually input the resulting emissions intensity of the feedstock into 45ZCF-GREET. If an emissions intensity of a feedstock is entered, either automatically or manually, that is outside the expected range of values, 45ZCF-GREET will produce an error, prompt the user to confirm that the 45ZCF FD-CIC input values have been entered correctly, and will not generate an emissions rate for the final fuel(s).

2.4.7 Manure-Derived Renewable Natural Gas

The animal manures pathway, described in Section 2.5.2, applies to fuel produced prior to Jan. 1, 2026. For fuels produced after Dec. 31, 2025, 45ZCF-GREET has been updated to incorporate two new pathways for manure-derived RNG: dairy manure and swine manure. Each pathway accommodates digesters that process one type of livestock manure exclusively, either dairy or swine manure. There are no pathways currently available in 45ZCF-GREET for digesters that process mixtures of manure (e.g., a mixture of swine and dairy manure, swine and poultry manure, beef and dairy manure).

To determine the counterfactual emissions associated with farm-specific prior manure management practices, users enter the annual average number of animals by type and annual average share of manure managed using each prior practice, measured based on the fraction of total volatile solids in the manure. It is recommended that users calculate these annual average shares based on relative time each animal spends in areas of the farm with certain manure management practices. As defined in Notice 2026-53, a “farm” is any animal feeding operation, with or without a nutrient management plan, or other animal operation with a nutrient management plan. Per Notice 2026-53, prior practices are defined as the manure management practices in place immediately preceding the earlier of (1) the commencement date of any anaerobic digester operation or (2) September 8, 2026. If a farm diverted manure to an off-farm anaerobic digester prior to September 8, 2026, the commencement date is the date the farm first began diverting manure to any off-site anaerobic digester.

Prior practices are to be entered by the user in the user input section entitled “Prior Manure Management Practices.” Prior practices included for the dairy manure RNG pathway include solid storage; pasture, range, or paddock; liquid/slurry; deep pit (>1 month); daily spread; uncovered anaerobic lagoon; and dry lot. Users only enter the share of practices applicable to dairy cows. Typical management of heifer, bull, and dairy calf manure is included in background data. Prior practices included for the swine manure RNG pathway include solid storage; pasture, range, or paddock; liquid/slurry; deep pit (>1 month); deep pit (<1 month), and uncovered anaerobic lagoon. Users only enter the share of practices applicable to average grow/finish swine. Typical management of nursery swine and breeding swine manure is included in background data.[14]

In the 45ZCF-GREET user input sections entitled “Products (per period of operation),” “Process inputs (per period of operation),” and “RNG Project Scenario,” users are directed to enter details of their operations during the calendar year. This includes total RNG production, fuel(s) and electricity consumed for *both* anaerobic digestion and biogas upgrading to RNG, and the share of current manure management practices. Current manure management practices include the same set of options available for documenting prior manure management practices, with additional entries for users to indicate the share of manure (on a mass volatile solids fraction basis) from each animal type that is diverted to an anaerobic digester. Users are also directed to indicate the type of anaerobic digester used (covered lagoon or enclosed vessel).

45ZCF-GREET accommodates several configurations for managing manure and biogas across multiple sites. In the simplest case, Scenario A (see Figure 2), a single digester accepts manure from one farm, and the resulting biogas is sent to a dedicated upgrader (which can be located on the farm or on a separate site). The instructions included above are sufficient for Scenario A. In Scenarios B and C, the quantities of RNG produced and the emissions rates calculated in 45ZCF-GREET correspond to each individual digester.

In Scenario B, multiple farms transport the same type of manure (entirely swine or entirely dairy) to a single centralized digester. The resulting biogas can be upgraded to RNG that is assigned a single emissions rate. Provided the farms feeding the digester all supply a manure of the same type, the user is directed to:

1. Select the appropriate pathway (swine manure RNG or dairy manure RNG) and the type of anaerobic digester (covered lagoon or enclosed vessel) and RNG upgrader used.

2. Enter the total RNG produced by the upgrader, provided the upgrader only processes biogas from the single centralized digester.

3. Determine the prior practices applicable to each farm (noting that each farm may have a different date on which prior practices are established, per Notice 2026-53).

4. Enter the cumulative head by animals by type across all applicable farms for both the prior practices scenario and RNG project scenario.

5. Using the number of head by animal type at each farm, calculate and enter the weighted average share of manure managed using each practice across all farms

[14] Typical practices as documented in B. Leonhardt, J. Englander, M. Wang, and H. Cai. 2026. *Updates to Anaerobic Digestion Pathways for Animal Manure in R&D GREET 2025 Rev.1*. Lemont, IL: Argonne National Laboratory. ANL-26/15. greet.anl.gov/publication-manure_update_2025r1.

(on a fraction of mass volatile solids basis) for both the prior practices scenario and RNG project scenario.

6. Enter all other required inputs and run the model to generate a single emissions rate corresponding to the total quantity of RNG produced.

In cases where multiple digesters transport biogas to a centralized RNG upgrader via pipeline (Scenario C), quantities of RNG and their associated emissions rates correspond to individual digesters. Users are directed to run 45ZCF-GREET using the inputs applicable to an individual digester and the farm(s) supplying manure to each digester. This pathway is only applicable for digesters that exclusively process one type of manure (swine or dairy). However, 45ZCF-GREET can accommodate configurations in which a single upgrader accepts biogas from different types of digesters and manure. Users are instructed to:

1. Obtain the centralized upgrader's total RNG production, electricity and fuel input(s), and total biogas input by mass, calculated for the calendar year.

2. Calculate the individual digester's share of total upgrader biogas input as a fraction of the upgrader's total biogas input in the calendar year.

3. Multiply the upgrader's electricity input(s), fuel input(s), and RNG output by the fractional biogas share calculated in Step 2 to determine the RNG produced and upgrading inputs corresponding to the individual digester.

4. Select the appropriate pathway (swine or dairy manure RNG) and the type of anaerobic digester (covered lagoon or enclosed vessel) and RNG upgrader used. Enter the calculated RNG production corresponding to the individual digester. Sum the digester's fuel(s) and electricity inputs with the calculated share of upgrader fuel(s) and electricity inputs to determine the entries for total fuel(s) and electricity consumption.

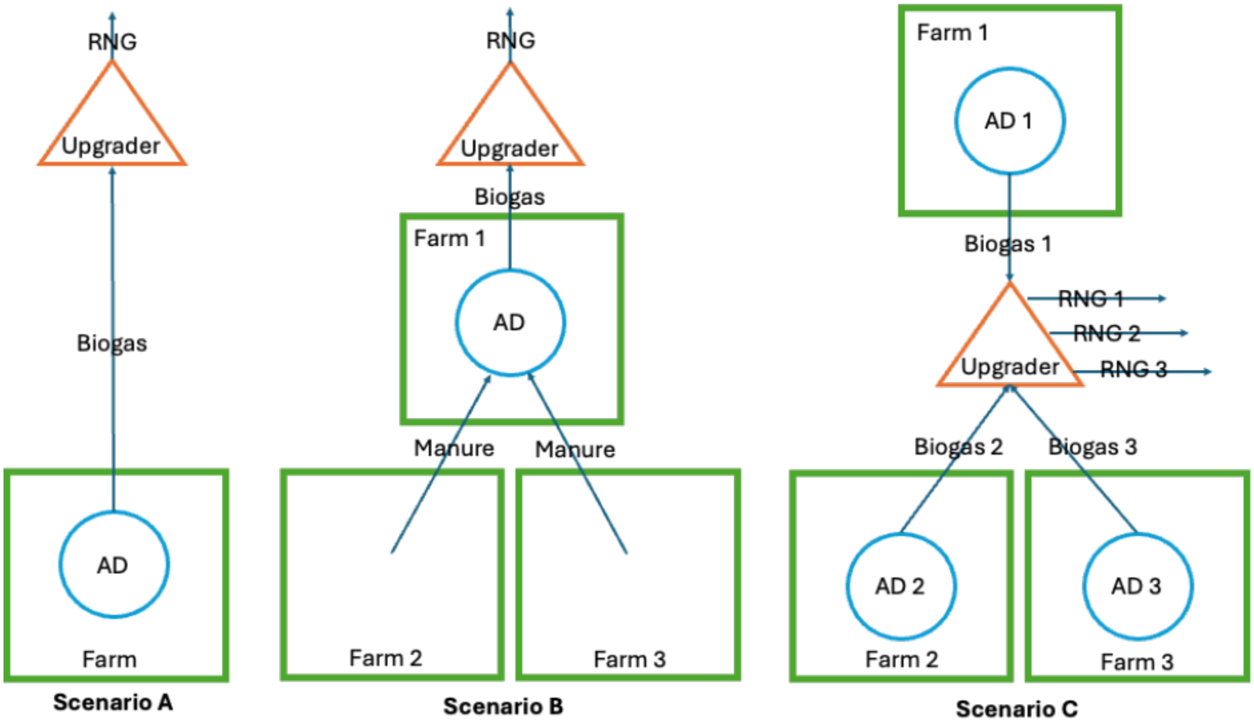


Figure 2. Farm, digester, and upgrader configurations applicable to swine manure and dairy manure RNG pathways. AD = anaerobic digester.

2.5 Additional Background Data in 45ZCF-GREET

Background data in 45ZCF-GREET are itemized in the dependency file in the downloaded tool package. For convenience, examples of background data values are described in the following sections.

2.5.1 Upstream Methane Emissions for Natural Gas

45ZCF-GREET assumes that methane leakage during the natural gas recovery process and subsequent gas processing and transmission sums to ~0.8% of methane consumed. Fugitive methane emissions resulting from methane slip in specific combustion technologies (e.g., industrial boilers, gas turbines, and SMR) are accounted for separately in the model. These emissions are described further in other GREET documentation.[15]

2.5.2 Counterfactuals for Organic Waste, Agricultural Residue, Manures, Biogas, and Coal Mine Methane

45ZCF-GREET relies on assumed counterfactuals for solid, liquid, and gaseous wastes/residues when calculating the net GHG emissions (or avoidance) resulting from their diversion to transportation fuel production. 45ZCF-GREET relies on the assumption that landfill gas would typically be captured and flared. Biogas from

[15] A. Burnham. 2024. *Updated Natural Gas Pathways in GREET 2024*. Lemont, IL: Argonne National Laboratory. greet.anl.gov/publication-update_ng_2024.

wastewater sludge anaerobic digesters is assigned a counterfactual consistent with incumbent wastewater sludge management practices. These default wastewater treatment practices are defined such that approximately 55% of biogas is combusted to heat the digester, 44% is flared, and 0.16% is emitted directly to the atmosphere. Agricultural residues are assumed to be left on the field, and food scraps are assumed to be landfilled in the counterfactual. The counterfactual assumptions for residue/waste materials are shown in Table 8.

Table 8. Residue/Waste Counterfactual Assumptions

Material	Counterfactual	Relevant 45Z Pathway(s)
Manure (before Jan. 1, 2026)	National average manure management as defined in *A Generic Counterfactual Greenhouse Gas Emission Factor for Life-Cycle Assessment of Manure-Derived Biogas and Renewable Natural Gas*	Animal manures RNG
Dairy manure (after Dec. 31, 2025)	Farm-specific dairy manure management (foreground)	Dairy manure RNG
Swine manure (after Dec. 31, 2025)	Farm-specific swine manure management (foreground)	Swine manure RNG
Landfill gas	Landfill gas collection and flaring	Landfill gas RNG
Wastewater treatment sludge and digester biogas	Incumbent wastewater sludge and biogas management practices	Wastewater sludge RNG
Agricultural residues	Left on field	Ethanol, corn stover RNG, mixed feedstocks RNG, gasification and Fischer-Tropsch
Food scraps	Landfilled	Food scraps RNG, mixed feedstocks RNG
Grain stillage	Animal feed	Grain stillage RNG, mixed feedstocks RNG
CMM	Methane collection and flaring	CMM capture and upgrading

To calculate the emissions rates applicable to fuel produced before Jan. 1, 2026, 45ZCF-GREET uses a counterfactual GHG emissions value for manure-derived biogas based on the average national manure types and management practices and resulting GHG emissions, further detailed in a white paper entitled *A Generic Counterfactual Greenhouse Gas Emission Factor for Life-Cycle Assessment of Manure-Derived Biogas and Renewable Natural Gas*.[16] Consistent with the direction in 91 FR 5160, which

[16] U.S. Department of Energy. 2025. *A Generic Counterfactual Greenhouse Gas Emission Factor for Life-Cycle Assessment of Manure-Derived Biogas and Renewable Natural Gas*. Washington, D.C. www.energy.gov/45vresources.

references the 45V Regulations, 45ZCF-GREET uses an upstream GHG emissions value of −51 g CO_2e/MJ (LHV) of biomethane contained in untreated biogas produced from the manure digester. This value includes emissions associated with operating the manure digester, as well as the transport of manure and liquid/solid digestate. This value is incorporated with downstream impacts associated with biogas upgrading to RNG, compression, and transport of the RNG to fueling stations (where applicable) in 45ZCF-GREET to calculate the GHG emissions rate of manure-derived RNG produced prior to Jan. 1, 2026. For fuels produced after Dec. 31, 2025, the animal manures pathway is no longer applicable, and there are two new pathways in which counterfactual manure management practices have been foregrounded: swine manure RNG and dairy manure RNG. Section 2.4.7 describes these new pathways in greater detail.

45ZCF-GREET assumes that the counterfactual scenario for pipeline-quality gas derived from CMM is that the gas being consumed would otherwise have been flared. This counterfactual scenario aligns with the 45V Final Rule to include estimates of (1) methane emissions associated with incomplete combustion of CMM during flaring, (2) N_2O emissions associated with CMM flaring, and (3) any other non-CO_2 emissions that result from combustion (e.g., carbon monoxide). The CO_2 emissions generated from reforming CMM-derived gas are treated as 0, assuming they represent CO_2 emissions that would otherwise have been generated via flaring in the counterfactual.

2.5.3 Examples of Key Background Data in 45ZCF-GREET

- All crushing facility data for crop-based oil are incorporated as background, including energy and chemical inputs. Transportation fuel production facilities may draw from a variety of crushing facilities; therefore, verification of detailed practices at each facility is impractical for certification.
- All transport distances for feedstocks, intermediates, and final fuels are assigned with estimated national average values.
- Emissions associated with fuel conditioning that is necessary to make fuels suitable for use in transportation are based on estimated national average values. Examples include compression of alternative natural gas from CMM, RNG, or hydrogen when the producers of these fuels intend to claim the 45Z tax credit.[17]
- All farm-based data for conventional farming practices (not including regenerative agriculture practices) in 45ZCF-GREET are background data.
- Non-liquid fuel coproducts and coproduct yields are assumed to be background data based on facility models.

[17] 45ZCF-GREET automatically deducts these emissions when alternative natural gas/RNG and/or 45V-modeled hydrogen are used as inputs to transportation fuel production.

2.5.4 Market-Mediated Effects GHG Emissions Modeling

Market-mediated, also referred to as "indirect," effects include:

- Induced land use change (ILUC; included only for fuels produced in 2025): Emissions from ILUC, typically resulting in a one-time pulse of emissions when new cropland is brought into production or market-driven shifts in the type and location of existing cropland occur.
- Other crops: Longer-term net GHG emissions (potentially positive or negative) resulting from sustained changes in non-feedstock crop production (including on-farm energy use, fertilizer inputs, N_2O emissions, and rice paddy field CH_4 emissions) in response to shifts in agricultural commodity prices/demand.
- Livestock: Longer-term net GHG emissions (potentially positive or negative) from sustained changes in livestock and poultry production driven by shifts in agricultural commodity prices/demand (including CH_4 emissions from enteric fermentation and emissions of CH_4 and N_2O from manure management).

45ZCF-GREET includes indirect effects for original feedstocks that require dedicated land for production (i.e., corn, sorghum, soybeans, canola/rapeseed, sugarcane). Indirect effects for crop residues and intermediate crops were not assessed in 45ZCF-GREET because they were determined to not be potentially significant. The results per unit of original feedstock are shown in Table 9, and illustrative values per megajoule of fuel are shown in Table 10. As previously noted, the net GHG emissions for "Other Crops" are negative when an increase in demand for feedstocks results in a broader shift away from emissions-intensive crop production, particularly rice cultivation because of the CH_4 emissions that occur during flooding of rice paddy fields. Negative GHG emissions also occur in the livestock category, driven by model-predicted shifts in the type and number of livestock and poultry produced.

The 45ZCF-GREET model relies on GHG emissions modeling of these indirect effects from changes in activities generated from the GTAP-BIO model (Global Trade Analysis Project) and emission profiles of activities from different sources. This aligns with the approach previously used to estimate indirect emissions for the 40BSAF-GREET 2024 model,[18] which was developed in support of the 40B SAF Production Tax Credit, but utilizes the GTAP database version 11 (v11) featuring a 2017 reference year (whereas 40BSAF-GREET 2024 used the GTAP database v10 featuring a 2014 reference year). 45ZCF-GREET also expands the scope of this modeling to include non-SAF transportation fuels and feedstocks. Additional model updates or alternative approaches to assess indirect effects may be considered in future efforts, such as the use of different models in a multi-model, or ensemble, approach.

New GTAP-BIO modeling runs were performed to serve as the basis for estimating indirect emissions for the pathways in 45ZCF-GREET that include indirect effects, such

[18] A user manual, downloadable version of the model, and additional documentation for 40BSAF-GREET 2024 are available at www.energy.gov/cmei/greet.

as soy oil and canola oil HEFA; soy and canola biodiesel; and corn, sorghum, and sugarcane ethanol. These modeling runs were performed on U.S. corn, soybeans, and sorghum; U.S. and Canadian canola/rapeseed; and Brazilian sugarcane.

Estimates of land use changes from GTAP-BIO were combined with a series of emissions factors included in the Carbon Calculator for Land Use and Land Management Change from Biofuels Production (CCLUB) to generate land use change emissions estimates. For U.S. grassland and cropland-pasture conversion, emissions factors are derived from simulations run in the DayCent model.[19] For U.S. forestland conversion and all international land use change, emissions factors from AEZ-EF v54 (Agro-ecological Zone Emission Factor) were applied.[20] The resulting emissions are shown in the indirect effects field in 45ZCF-GREET and are summarized in Table 9 and Table 10.

Details on GTAP-BIO modeling and emissions factors can be found in Argonne National Laboratory technical documentation on the CCLUB module, *Expansion of Carbon Calculator for Land Use and Land Management Change from Biofuels Production (CCLUB) to Address Induced Land Use Changes and Other Indirect Effects of Clean Fuel Production for R&D GREET® 2024*, hereafter referred to as the "CCLUB 2024 Update," available at greet.anl.gov/publication-cclub_update_2024.

Because modeling of land use change effects is sensitive to the geographic location of feedstock production, new modeling would be necessary if feedstocks are sourced from regions that are not represented in this analysis. For example, if U.S. clean fuel producers import feedstocks that are not represented in the R&D GREET 2025 technical report, new modeling runs in GTAP-BIO and/or other models would be necessary to estimate the indirect emissions resulting from that pathway.

Table 9. Adjusted Indirect Effects for the Clean Fuel Pathways in 45ZCF-GREET.

Results are presented in grams CO_2e per bushel of corn/soybeans/sorghum and grams CO_2e per wet metric ton of canola/sugarcane.

45Z Clean Fuel(s): Pathway	Feedstock	Total	ILUC [a]	Livestock	Other Crops
Ethanol: fermentation	U.S. corn starch	1,054	1,324	−363	93
Ethanol: fermentation	Brazilian sugarcane	6,230	22,045	−10,252	−5,563
Ethanol: fermentation	U.S. sorghum grain	1,063	1,709	−460	−186
Biodiesel: transesterification	U.S. soybean oil	2,511	2,559	−110	63
Renewable diesel, SAF: HEFA	Soybean oil	2,462	2,502	−97	57

[19] One exception is for land use change to canola grown in the United States and Canada, for which estimates from AEZ-EF v54 are used. Canola is not represented in DayCent.
[20] CCLUB also includes land use change emissions factors from other sources that are not used in 45ZCF-GREET analyses.

45Z Clean Fuel(s): Pathway	Feedstock	Total	ILUC [a]	Livestock	Other Crops
Biodiesel: transesterification	U.S./Canadian canola/rapeseed oil	260,922	237,816	−13,865	36,970
Renewable diesel, SAF: HEFA	U.S./Canadian canola/rapeseed oil	265,519	241,408	−13,143	37,254

[a] ILUC is excluded for fuels produced after Dec. 31, 2025.

Table 10. Adjusted Indirect Effects for the Clean Fuel Pathways in 45ZCF-GREET.

For illustrative purposes only; results are estimated in grams CO_2e per megajoule of fuel using sample yields for each pathway.

45Z Clean Fuel(s): Pathway	Feedstock	Total	ILUC [a]	Livestock	Other Crops
Ethanol: fermentation	U.S. corn starch	4.58	5.75	−1.58	0.41
Ethanol: fermentation	Brazilian sugarcane	3.70	13.10	−6.09	−3.31
Ethanol: fermentation	U.S. sorghum grain	4.61	7.42	−2.00	−0.81
Biodiesel: transesterification	U.S. soybean oil	11.68	11.9	−0.51	0.29
Renewable diesel, SAF: HEFA	U.S. soybean oil	13.35	13.57	−0.53	0.31
Biodiesel: transesterification	U.S./Canadian canola/rapeseed oil	16.58	15.11	−0.88	2.35
Renewable diesel, SAF: HEFA	U.S./Canadian canola/rapeseed oil	18.30	16.64	−0.91	2.57

[a] ILUC is excluded for fuels produced after Dec. 31, 2025.

Facility-level transportation fuel conversion efficiency based on user inputs is applied to adjust the indirect effects to reflect facility-specific yields as documented in the CCLUB 2024 Update.

2.6 Coproduct Allocation Methods

Transportation fuel production processes may yield coproducts that are also valorized (i.e., sold by the oil, ethanol, or other transportation fuel producer or otherwise productively used). For those coproducts that have been valorized, 45ZCF-GREET allows for users to account for certain coproducts in the life cycle GHG emissions of the transportation fuel production facility.

Users may only account for a coproduct if it has been valorized in a process downstream of the transportation fuel production facility; coproducts that were produced but not valorized may not be allocated emissions in the life cycle GHG emissions calculation of produced transportation fuel.[21] For example, if liquefied petroleum gas/propane is produced by the facility but used on-site as a process fuel (as opposed

[21] Allocation of emissions to valorized coproducts is standard practice in LCA, including in previously published GREET models and related publications.

to sold to another party), that quantity of liquefied petroleum gas/propane should *not* be entered as a product.

For net electricity exports, 45ZCF-GREET does not allocate any GHG burden to electricity sold by the fuel production facility to the grid or another entity. For all other coproducts, 45ZCF-GREET uses multiple allocation methods following the default assumptions in R&D GREET 2025, including system expansion (also known as the displacement method) and energy- or mass-based allocation. System expansion and physical allocation methods are described further in the International Organization for Standardization's ISO 14044:2006.[22] System expansion is used when it is straightforward to identify the conventional product displaced by the coproduct (e.g., soybean meal demand that can be met by distillers grains) and the quantity of the coproduct is small relative to the main fuel product(s). Energy-based allocation is used to allocate burdens across multiple fuel outputs because it is a reasonable measure of their relative function and is not subject to price fluctuations that can impact market-value-based allocation. 45ZCF-GREET allocates the burdens of oilseed crop production and crushing to oil and meals using mass-based allocation because energy content is not an appropriate proxy for the functional value of oils and meals (used for animal feed), and market-value-based allocation is subject to instability and uncertainty caused by price fluctuations. Market-value-based allocation is used to assign burdens to glycerin as a coproduct from transesterification to biodiesel because neither mass nor energy content are adequate proxies for the relative function or value of biodiesel and glycerin, and additional supply of glycerin resulting from biodiesel production has meaningfully impacted glycerin's market value. Table 11 itemizes the coproducts that can be simulated in 45ZCF-GREET and the approach used to account for them. Consistent with the allocation mechanisms included in Table 11, emissions reductions calculated for regenerative agricultural practices in 45ZCF FD-CIC are allocated entirely to ethanol when produced from corn and/or sorghum in dry or wet mill ethanol facilities. For oilseed crops, emissions reductions calculated in 45ZCF FD-CIC are allocated by mass to oil and meals produced during oilseed crushing.

Table 11. Coproducts in 45ZCF-GREET and Accounting Mechanisms

Production Process(es)	Potential Coproduct(s)	Accounting Mechanism
Dry mill corn grain ethanol, sorghum grain ethanol	Distillers' grains	System expansion
Dry mill corn grain ethanol, sorghum grain ethanol	DCO or sorghum oil	Marginal approach, allocating only oil extraction burden to oil
Wet mill corn grain ethanol	Distillers' grains, dextrose, germ, corn gluten meal, corn gluten feed/fiber, high-fructose corn syrup/other sweetener, DCO,	Mass-based allocation

[22] International Organization for Standardization. 2006. *Environmental management — Life cycle assessment — Requirements and guidelines*. ISO 1044:2006. www.iso.org/standard/38498.html.

Production Process(es)	Potential Coproduct(s)	Accounting Mechanism
	hydrolyzed corn protein, dry starch	
Any pathway/process	Electricity	No displacement credit for exported electricity
Oilseed crushing	Oil and meals	Mass-based allocation
ATJ-ethanol	SAF, diesel	Energy-based allocation
HEFA	Naphtha/gasoline, liquefied petroleum gas/propane, diesel, SAF	Energy-based allocation
Gasification and Fischer-Tropsch	Diesel, SAF	Energy-based allocation
Transesterification	Glycerin, heavy distillation bottoms, and free fatty acids	Market-value-based allocation

3 User Instructions

45ZCF-GREET is available at www.energy.gov/cmei/greet.

3.1 45ZCF-GREET Setup

Throughout this section, the version of 45ZCF-GREET released in Sept. 2026 is referred to as “45ZCF-GREET,” and the file name for this version is “45ZCF-GREET 2026.” When the 45ZCF-GREET package is downloaded, it will come in a compressed .zip package. To work with 45ZCF-GREET, users should unzip the package into a subfolder. **We recommend unzipping the package into a folder that is not synced to a cloud service (e.g., OneDrive, Google Drive, or Dropbox); otherwise, the model may not run properly.** For example, storing the package in the “Downloads” folder, which typically does not sync to a cloud, typically works. The unzipped package contains the 45ZCF-GREET 2026 Excel file and a subfolder “GREET1 Dependency,” which contains the GREET1 model, entitled “GREET1_2025” used to run the LCA in 45ZCF-GREET.

When the package is first downloaded, Excel will automatically be blocked from running macros. For 45ZCF-GREET to operate correctly, users need to right-click the 45ZCF-GREET file and click “Properties.” At the bottom of the opened properties window, the user should click “Unblock” and “Apply” to allow macros to run within the file (Figure 3). This step needs to be done only once, for both the 45ZCF-GREET 2026 file and GREET1_2025 file.

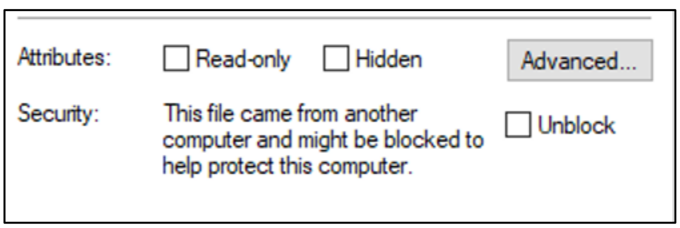


Figure 3. Unblocking file to allow macros

The first time the 45ZCF-GREET file is opened, users may need to enable editing and disable protected view. A message will appear as a yellow banner at the top of the Excel file. Click “Enable Editing” to allow the file to load properly (Figure 4).

Figure 4. Enable editing message

The 45ZCF-GREET 2026 file and accompanying GREET1_2025 files are sensitive to file name changes or file path changes. While the package can be moved, users should not remove the GREET1_2025 file from the GREET1 dependency folder. The dependency folder must be placed in the same location as the 45ZCF-GREET 2026 file. In addition, neither the file nor the GREET1 dependency folder should be renamed, as 45ZCF-GREET relies on the naming conventions of the files to work correctly.

When the 45ZCF-GREET 2026 file is loaded, it will attempt to load the GREET1_2025 file and connect to it. If it cannot find the GREET1_2025 file, a pop-up will warn users of the failed connection (Figure 5).

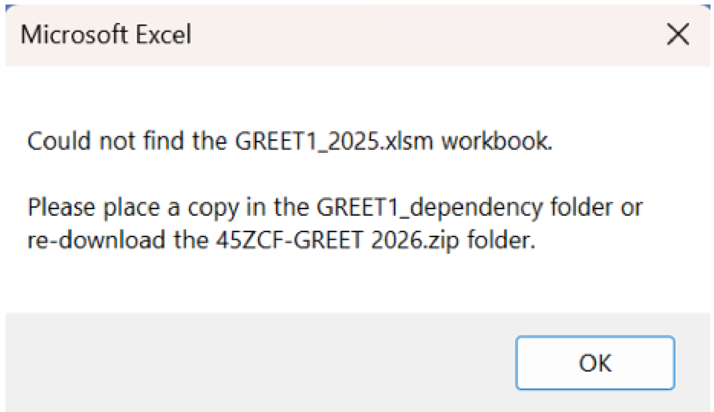


Figure 5. Error message warning that the GREET1_2025 file could not be located

If this occurs, users must exit 45ZCF-GREET and replace the GREET1_2025 file located in the GREET1 dependency subfolder.

3.2 45ZCF-GREET Overview

The dashboard worksheet serves as the user interface, allowing the user to select a pathway to model, change key model parameters, and view modeled results (Figure 6).

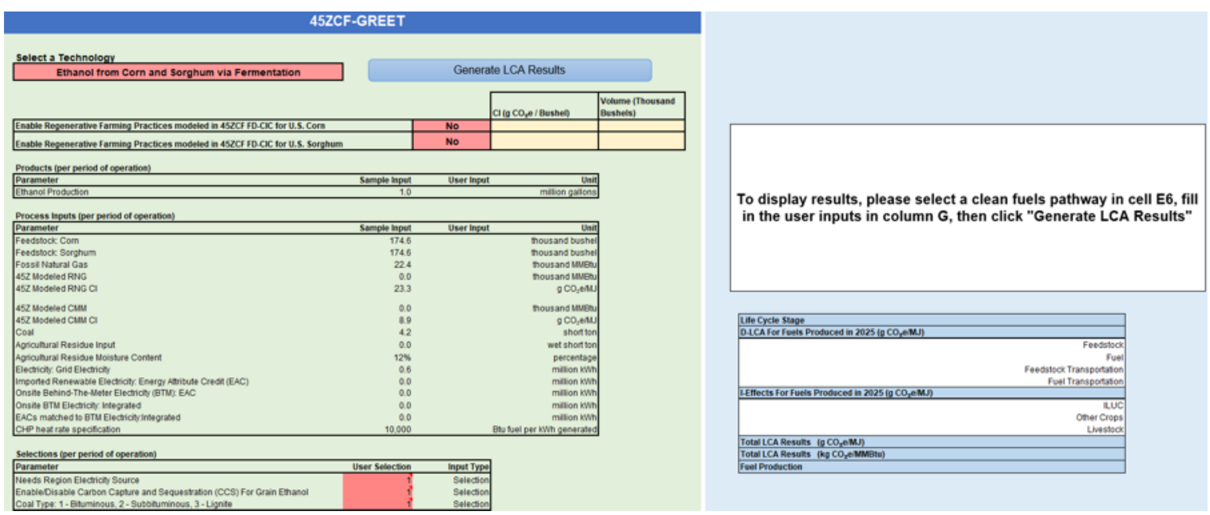


Figure 6. Dashboard, which serves as the user interface to control the model

3.2.1 Operation of 45ZCF-GREET

45ZCF-GREET allows all user interaction through the dashboard. There are two sections to the dashboard: the green user input side on the left, and the results section on the right. All user inputs are managed on the green, left-hand side of the model. *Sample inputs are provided as an example for the user and to test model functionality; these parameters are not used in modeling*. Additionally, 45ZCF-GREET uses a consistent color scheme: Pink cells include drop-down lists from which users select an option. The “User Input” columns will turn yellow when a valid parameter is entered. White and other colored cells include instructions and results and are not to be modified by the user. These instructions are present on the right-hand side of the model. To generate results for a pathway, users should follow the steps outlined in this section to input their data.

First, users select a pathway to load. Cell E6 provides a drop-down list of supported 45ZCF-GREET pathways (Figure 7). The User Input section will be populated with default inputs for the selected pathway. There is a small delay as Excel populates the User Input section; users should avoid interacting with Excel until the inputs are fully loaded.

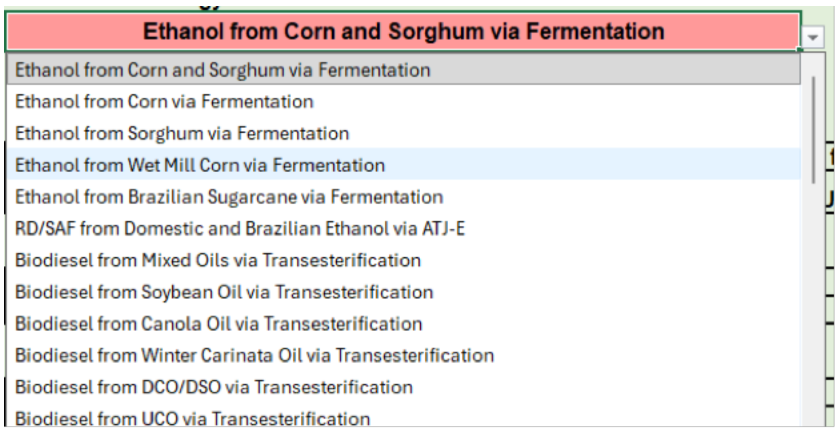


Figure 7. Drop-down list of pathways in 45ZCF-GREET. More pathways can be seen by scrolling down using the scroll bar.

Users must input their own foreground data within the User Input section. For the purposes of the 45Z tax credit, there is *no* option to take default foreground values (despite values being displayed under “Sample Input”).

Inputs are organized into three distinct categories: “Products,” “Process Inputs,” and “Selections” (described in the following text). All energy parameters are to be entered on an LHV basis. Additionally, all parameters should be input as total values per period of operation (i.e., the calendar year).

The “Products” section (Figure 8) allows the user to specify the quantity of fuels and coproducts produced per period of operation. All inputs include an input name to define what the input is, a sample input for an example value, a User Input column for the user to enter their facility-specific value, and a column with the unit of the input. Note that the User Input column will highlight yellow when filled out correctly.

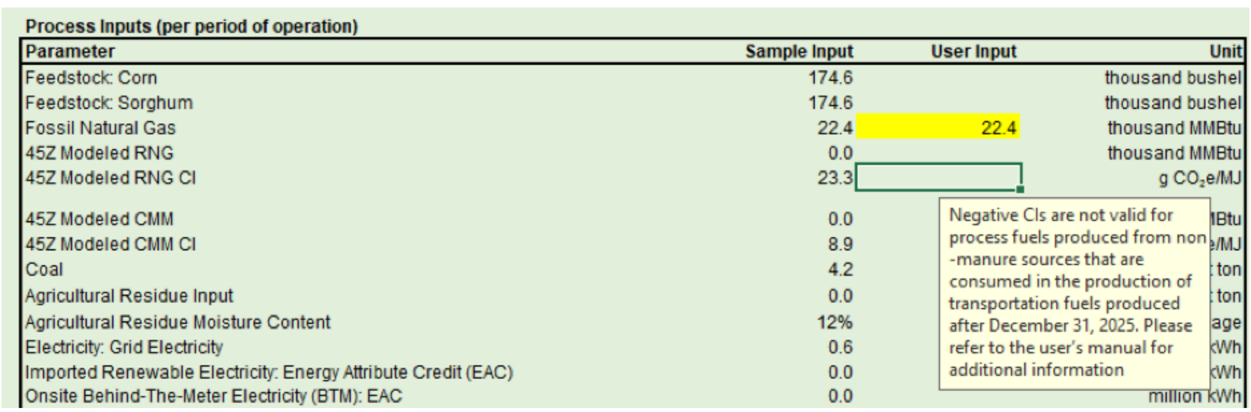
Products (per period of operation)

Parameter	Sample Input	User Input	Unit
Ethanol Production	1.0	1.0	million gallons

Figure 8. The Products section for ethanol from corn and sorghum via fermentation

The “Process Inputs” section (Figure 9) includes foreground data for inputs for the fuel production process, inputted as values per period of operation (calendar year). These inputs are always numerical inputs. All inputs include an input name to define what the input is, a sample input for an example value, a User Input column for the user to enter their value, and a column with the unit of the input. Note that the User Input cell will highlight yellow when filled out correctly. Users have the option of sourcing fossil natural gas, RNG, or a mixture of both (see Section 2.4.2 for more details on using RNG). Hydrogen consumed for certain pathways can be sourced from fossil natural gas reforming without carbon capture and sequestration (“Offsite, Fossil SMR Hydrogen”) or from a source with a user-defined GHG intensity as determined in accordance with the 45V Regulations (“Offsite, 45Z Modeled Hydrogen”; see Section 2.4.3 for more details on requirements vis-à-vis 45V). Users can also enter combinations of multiple feedstocks as inputs in the following pathways:

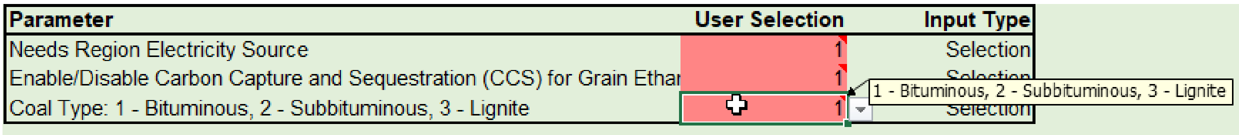
- Ethanol from corn and sorghum via fermentation.
- Renewable diesel/SAF from domestic and Brazilian ethanol via ATJ-ethanol.
- Biodiesel from mixed oils via transesterification.
- Renewable diesel/SAF from mixed oils via HEFA.


Process Inputs (per period of operation)

Parameter	Sample Input	User Input	Unit
Feedstock: Corn	174.6		thousand bushel
Feedstock: Sorghum	174.6		thousand bushel
Fossil Natural Gas	22.4	22.4	thousand MMBtu
45Z Modeled RNG	0.0		thousand MMBtu
45Z Modeled RNG CI	23.3		g CO_2e/MJ
45Z Modeled CMM	0.0		MBtu
45Z Modeled CMM CI	8.9		e/MJ
Coal	4.2		ton
Agricultural Residue Input	0.0		ton
Agricultural Residue Moisture Content	12%		age
Electricity: Grid Electricity	0.6		kWh
Imported Renewable Electricity: Energy Attribute Credit (EAC)	0.0		kWh
Onsite Behind-The-Meter Electricity (BTM): EAC	0.0		million kWh

Figure 9. The Process Inputs section for ethanol from corn and sorghum via fermentation. Note that the User Input cell will highlight yellow when filled out correctly.

The “Selections” section (Figure 10) contains additional parameters such as the grid electricity source; carbon capture, utilization, and sequestration options; capture rate (when enabled); coal type used; and more. Selections consist of a parameter name to describe what the specific selection applies to, a user selection, and an input type that defines whether the input is a selection (i.e., a choice from a drop-down menu) or a numerical entry (described as “Value”). Hovering over the input value of a pink drop-down list selection will provide a comment description indicating which numerical option corresponds to each needs region. All pathways include a selection for the clean fuel production facility’s needs region electricity source. Note that the California needs region is initially selected, but users are directed to select the needs region where the applicable facility is located.



Parameter	User Selection	Input Type
Needs Region Electricity Source	1	Selection
Enable/Disable Carbon Capture and Sequestration (CCS) for Grain Ethar	1	Selection
Coal Type: 1 - Bituminous, 2 - Subbituminous, 3 - Lignite	1	Selection

Figure 10. Additional parameters for ethanol from corn and sorghum via fermentation

When all user inputs are entered correctly, users can generate results using the “Generate LCA Results” button located at the top of the User Inputs section. Excel will run the calculations in the 45ZCF-GREET 2026 file and the GREET1_2025 back-end file to calculate the LCA results for the pathway. When the results are calculated, one or more graphs will appear in the blue Results section, and the results table will be populated. The results graph and table are reported in g CO_2e/MJ total dispensed fuel on an LHV basis. In the table, the results are also reported in kg CO_2e/MMBtu.

The results graph shows the total LCA results for fuels produced in 2025 as a text box at the top of the column that includes both direct life cycle assessment (D-LCA) and indirect effects, if relevant (Figure 11). Some stages can contribute substantially smaller impacts than others, making them difficult to view in the graph. In this case, we recommend a tabular view.

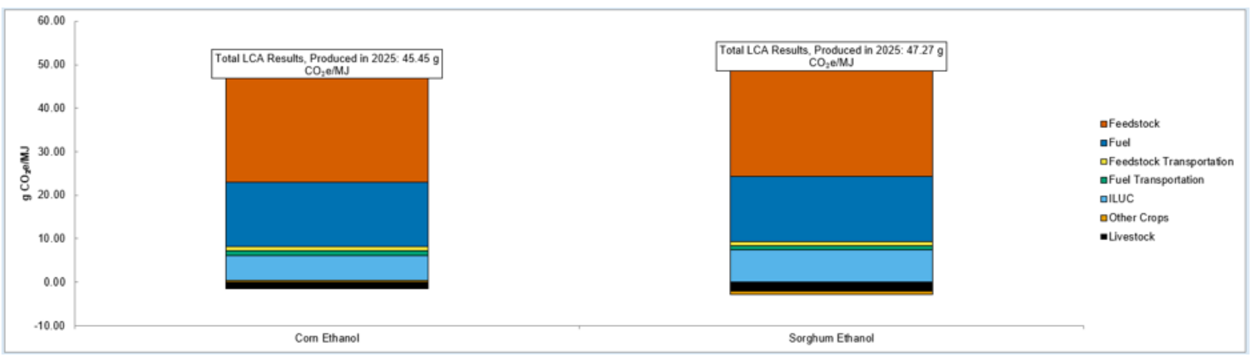


Figure 11. Total LCA results bar chart displayed for ethanol from corn and sorghum via fermentation using sample inputs

The life cycle GHG results table (Figure 12) breaks the results down by life cycle stage. When more than one feedstock is combined in a mixed pathway, as in the calculations used to generate Figure 11, the results will be separated by feedstock. The results are also designated as applying to fuels produced in 2025 or those produced after Dec. 31, 2025, which account for amendments made to § 45Z by the One Big Beautiful Bill Act. Each stage has an associated emissions value, in g CO_2e/MJ. The D-LCA results include direct and upstream (supply chain) emissions associated with producing a clean fuel. D-LCA results do not include market-mediated effects (referred to here as indirect effects), which are included in the separate indirect effects values. Within the D-LCA results, net emissions values are separated into categories that depend on the fuel of interest. For most pathways, there will be feedstock, fuel, and transportation categories shown. For some pathways, feedstock will be broken down by an “Original” and “Intermediate” feedstock category. “Original Feedstock” emissions include growing, harvesting, and processing original feedstock material (e.g., corn, soybeans). “Intermediate Feedstock” emissions include conversion of original feedstocks into intermediate feedstocks (e.g., soybean crushing and extraction to soybean oil). “Fuel” emissions include the conversion of intermediate feedstocks into finished fuel (e.g., soy oil conversion into renewable diesel). Emissions from fuel combustion—which are typically very small—are allocated to the fuel category.[23] Each category has a dedicated transportation category (e.g., “Feedstock Transportation,” “Fuel Transportation”) associated with transportation emissions during that life cycle stage.

Life Cycle Stage	Corn Ethanol	Sorghum Ethanol
D-LCA For Fuels Produced in 2025 (g CO_2e/MJ)	**40.87**	**42.66**
Feedstock	24.06	25.85
Fuel	14.84	14.84
Feedstock Transportation	0.96	0.96
Fuel Transportation	1.01	1.01
I-Effects For Fuels Produced in 2025 (g CO_2e/MJ)	**4.58**	**4.61**
ILUC	5.75	7.41
Other Crops	0.41	-0.81
Livestock	-1.58	-1.99
Total LCA Results For Fuels Produced in 2025 (g CO_2e/MJ)	**45.45**	**47.27**
Total LCA Results For Fuels Produced in 2025 (kg CO_2e/MMBtu)	**47.95**	**49.87**
Total LCA Results For Fuels Produced After December 31, 2025 (g CO_2e/MJ)	**39.70**	**39.85**
Total LCA Results For Fuels Produced After December 31, 2025 (kg CO_2e/MMBtu)	**41.89**	**42.05**
Fuel Production	**500000 Gallons**	**500000 Gallons**

Figure 12. The life cycle GHG results table after running the sample inputs for ethanol from corn and sorghum via fermentation

Note that UCO, tallow, and DCO/DSO do not have “Original Feedstock” emissions. For UCO and tallow, this is because 45ZCF-GREET does not assign any burdens to the production of these waste feedstocks. For DCO/DSO from dry mill ethanol plants, the marginal emissions associated with the oil extraction process are categorized within “Intermediate Feedstock.”

For RNG, an “Avoided” category represents the GHG emissions credits from avoiding GHG emissions in the counterfactual scenario (see Table 8 for more details on counterfactual scenarios in 45ZCF-GREET).

In the “Hydrogen Production” pathway, users must enter their well-to-gate GHG result for hydrogen that is consistent with 45V Regulations into the User Input section to calculate the “Gate-to-Wheels” GHG emissions (see Section 2.4.3 for more details on requirements vis-à-vis 45V)—i.e., GHGs associated with transportation and use of hydrogen as a transportation fuel. Results will be broken down by “Hydrogen Production” and subsequent stages related to hydrogen transport and vehicle refueling.

The indirect effects (“I-Effects”) include three sources of modeled GHG emissions (ILUC, other crops, and livestock), as discussed in greater detail in Section 2.5.4. These effects are included for pathways using dedicated land for feedstock production (i.e., corn, sorghum, soybeans, canola/rapeseed, and sugarcane). The D-LCA and I-Effects results are summed together to give the total LCA results for the pathway. Note that ILUC is not included in the total LCA results for fuels produced after Dec. 31, 2025, due to amendments made to § 45Z by the One Big Beautiful Bill Act. I-Effects are not included for corn stover, tallow, UCO, DCO/DSO, landfill gas, wastewater sludge, food scraps, grain stillage, FOG and septage, mixed high-moisture organic wastes, manures,

[23] For all bio-based feedstocks, the biogenic CO_2 emitted during conversion and fuel combustion is assumed to be fully offset by the CO_2 sequestered in the biomass feedstock during its growth.

or selected intermediate crops (i.e., carinata, camelina, pennycress), as these feedstocks are not considered to have significant I-Effects in 45ZCF-GREET, and the corresponding section of the results table will be blank. Additional purpose-grown feedstocks may be considered for inclusion in future updates to 45ZCF-GREET, such as switchgrass, miscanthus, willow, and poplar pending further assessment of their potential I-Effects.

3.2.2 Modeling Feedstock Using Regenerative Farming Practices

Corn, sorghum, soybeans, and canola/rapeseed farmed in the United States can be modeled using regenerative farming practices for fuel pathways that use these feedstocks. When a relevant pathway is loaded, the inputs to enable and control regenerative farming practice modeling will be shown above the Products section of the dashboard (Figure 13).

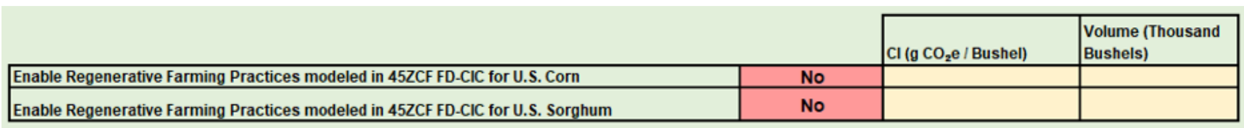


Figure 13. The regenerative farming practices section

Regenerative farming practices can be enabled or disabled per feedstock. To enable, click the drop-down selector corresponding to the appropriate feedstock and select “Yes.” A pop-up will ask the user whether they want to open 45ZCF FD-CIC (Figure 14) where regenerative farming practices are modeled. If the user already knows the CI and volume from modeling the feedstock separately in 45ZCF FD-CIC, they can select “No” and directly enter these values in the corresponding input fields of the same table.

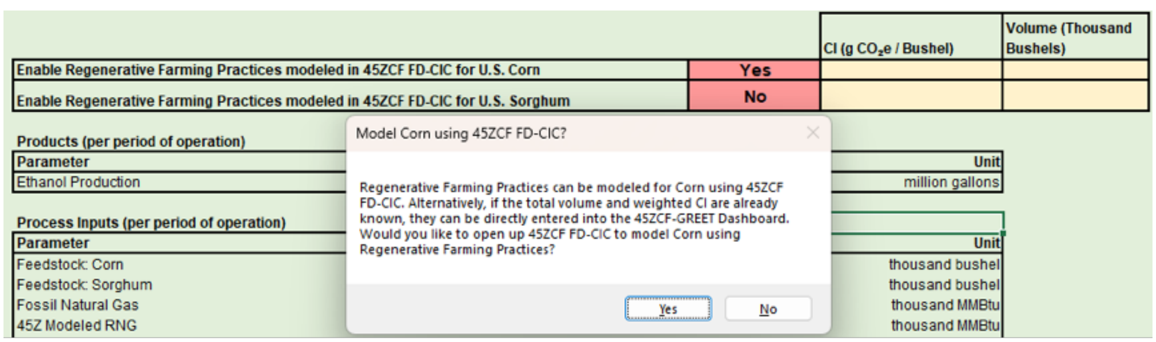


Figure 14. The message box asking users if they want to model regenerative farming practices using 45ZCF FD-CIC

3.2.3 Modeling Regenerative Farming Practices in 45ZCF FD-CIC

When selecting “Yes” to the message box shown in Figure 14, a copy of 45ZCF FD-CIC will be opened. Copies of 45ZCF FD-CIC are made per feedstock and per pathway being modeled, to support having multiple feedstocks being modeled in separate instances of 45ZCF FD-CIC. Each 45ZCF FD-CIC file will be named marking the pathway and feedstock being modeled and are organized in a folder labeled “45ZCF FD-CIC User Work.”

Upon loading 45ZCF FD-CIC, the 45Z Connection tab will be opened (Figure 15). This tab allows the user to model multiple feedstock producers, each with one or more management units.

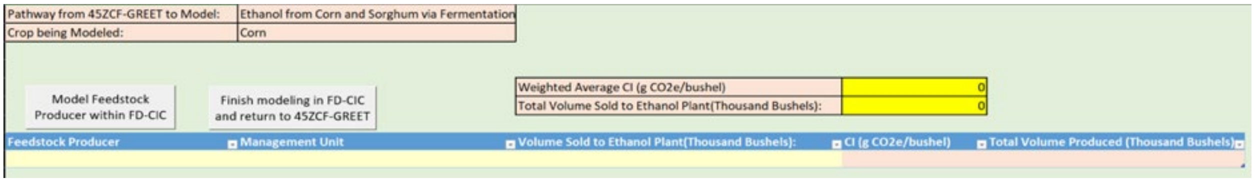


Figure 15. The 45Z Connection tab

The pathway and crop being modeled from 45ZCF-GREET are shown in Cells A1:B2 for the user's reference. The table starting at cell A9 contains information on the feedstock producers being modeled. To begin, the user should enter one or more feedstock producers, and between 1 and 10 management units per feedstock producer. Note that feedstock producers must each have a unique name, and management units must have a unique name within each feedstock producer.

To model a feedstock producer, users click on the "Model Feedstock Producer within FD-CIC" button, located above the Feedstock Producer column. This will open a user form for the user to select which feedstock producer to model. Users should select a feedstock producer from the drop-down and click "Model Feedstock Producer" to continue (Figure 16).

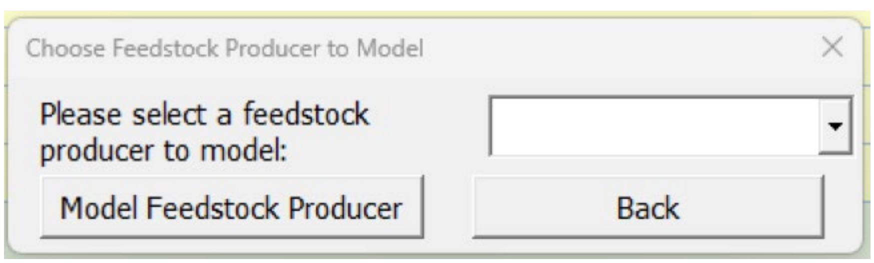


Figure 16. The feedstock producer selection user form

After selecting a feedstock producer, the Crop Inputs tab will be opened. See Appendix C for step-by-step instructions required to operate 45ZCF FD-CIC.

When finished modeling in the Crop Inputs tab, click the "Save Calculations and Return to 45Z Overview" button to return to the 45Z Connection interface and save the yield and CI for each modeled management unit. This will populate Columns D and E with the CI and total volume produced for each management unit (see example in Figure 17). Finally, the user should fill in Column C with the volume sold to ethanol plant per management unit. Note that the volume sold should be less than the total volume produced for each management unit. As the total volume sold is entered, the weighted average CI and total volume sold to the ethanol plant will automatically update in Cells D4 and D5.

Feedstock Producer	Management Unit	Volume Sold to Ethanol Plant(Thousand Bushels):	CI (g CO2e/bushel)	Total Volume Produced (Thousand Bushels)
Producer A	MU 1	50	4985.895773	160
Producer A	MU 2	50	1971.813716	160
Producer A	MU 3	50	2400.275118	160
Producer B	MU 1	15	4650.783156	16
Producer B	MU 2	15	4548.918081	17.5
Producer B	MU 3	15	4280.337711	20

Figure 17. An example of the feedstock producer table for two producers with three management units each

When finished, the user should click the “Finish Modeling in FD-CIC and return to 45ZCF-GREET” button. This will return them to 45ZCF-GREET and automatically send the weighted average CI and total volume sold to the dashboard. Note that if any errors are present, such as the total volume sold being more than the total volume produced for a given management unit, they will be shown to the user, and the user will be prompted to correct those errors.

After either (1) modeling regenerative farming practices in 45ZCF FD-CIC or (2) entering the CI and volume manually, the user can model the rest of the pathway as normal (see Section 3.2.1). Note that feedstock inputs in the Process Inputs section are the total feedstock amount for the period of operation, including feedstock modeled using regenerative farming practices.

After all other user inputs are entered, the user may run the model by clicking “Generate LCA Results.” The feedstock will be modeled using the regenerative farming practices user inputs for CI and volume first, and any remaining feedstock included in the process inputs will be modeled using GREET default data for conventional farming practices. Note that the feedstock modeled using regenerative farming practices should be less than the total feedstock entered in the Process Inputs section. If this is not the case, a warning will be shown directing the user to correct the error.

After generating results, in addition to the results shown for pathways, a feedstock breakdown table will be shown displaying the CI and the amount of feedstock coming from regenerative farming practices, the CI and the amount of feedstock coming from conventional farming practices data, and the weighted average of the two used in calculations (Figure 18).

Feedstock Modeling Method:	Weighted Average CI (g CO2e/Bushel)	Total Volume (Thousand Bushels)
Corn modeled using Regenerative Farming Practices (45ZCF FD-CIC):	3436.41	195.00
Corn modeled using Conventional Farming Practices (45ZCF-GREET):	6040.54	154.20
Total	4586.34	349.20

Figure 18. The feedstock breakdown table in the results to show the amount of feedstock coming from regenerative or conventional farming practices

3.3 Other Supporting Features and Information

45ZCF-GREET includes several other features to assist users. It includes default values (sample inputs) *for the purposes of testing model functionality only.* These default values should not be used to generate a user’s life cycle GHG emissions rate. If users wish to save their results, we recommend saving the results table to an external Excel file. Also, if the user switches from one 45ZCF-GREET pathway to another, the GREET defaults will be restored. A pop-up message will inform the user as the model quickly resets to the defaults. Users should avoid interacting with Excel while 45ZCF-GREET is restoring the defaults. When the defaults are fully restored, the inputs for the selected pathway will become visible, and the user can begin editing the next pathway.

When the 45ZCF-GREET 2026 file is closed, the GREET1_2025 file will automatically be closed as well. If users wish to save their results, we recommend saving the results table to an external Excel file. Although the 45ZCF-GREET 2026 Excel file can be saved, it will restore the defaults for the selected pathway upon loading. Finally, users should *not* attempt to save the GREET1_2025 Excel file after modeling. The GREET1_2025 file is automatically closed without saving when the 45ZCF-GREET 2026 Excel file is closed to preserve the formulas and default data. If users accidentally save over the GREET1_2025 file, they will need to replace it with the GREET1_2025 file from the downloaded 45ZCF-GREET package to restore the default values and ensure accurate modeling.

Appendix A

Table A-1. Feedstocks for Mixed Feedstock Anaerobic Digestion and Inclusion in 45ZCF-GREET

Feedstock	Description	Category in 45ZCF-GREET
Wastewater treatment sludge	Solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.	Sludge
Food scraps	The portion of municipal solid waste that consists of inedible or postconsumer food collected from residences, hospitality facilities, institutions, and grocery stores. Feedstocks that are not typically landfilled do not qualify as food scraps, which include FOG, liquids at the point of collection, and materials from industrial food manufacturing or processing facilities.	Food scraps
Corn stover	Stalks, leaves, husks, and cobs left after corn grain harvest	Corn stover
FOG	UCO, animal fats, and greases from commercial and industrial sources	FOG and septage
Septage	Direct-haul septage waste that does not enter a treatment works prior to enter the anaerobic digester	FOG and septage
Dairy dissolved air flotation waste	Suspended solids, fats, and other contaminants removed from dairy wastewater during dissolved air flotation	Mixed high-moisture organic wastes
Acid whey	Whey remaining after acid coagulation in the production of dairy products, such as yogurt and soft cheeses	Mixed high-moisture organic wastes
Pomace	Residue containing skins, seeds, pulp, and/or stems from olive, tomato, grape, and other fruit processing operations	Mixed high-moisture organic wastes
Brewery and distillery waste	Spent grain, yeast, and/or hops	Mixed high-moisture organic wastes
Grain stillage	Stillage from grain-to-ethanol facilities, including corn and sorghum ethanol production	Grain stillage
DCO	Distillers corn oil	DCO/DSO
DSO	Distillers sorghum oil	DCO/DSO

Feedstock	Description	Category in 45ZCF-GREET
Poultry and livestock blood	Poultry, swine, beef, and sheep blood from animal processing operations, including slaughterhouses	Mixed high-moisture organic wastes
Rendering waste	Wastewater, solid waste, and FOG produced from animal rendering operations	Mixed high-moisture organic wastes
Other industrial wastewater	Wastewater from industrial food and beverage manufacturing or processing facilities, pharmaceutical manufacturing facilities, and other industrial operations that is liquid at the point of collection	Mixed high-moisture organic wastes
De minimis other inputs	Feedstocks not included in this table (amount must be at or below 5% of total solids input)	Other feedstocks (≤5% of total solids)

Appendix B

Table B-1. Glossary of Terms for 45ZCF FD-CIC

Term	Description
Management unit size	Management unit is defined as a field, group of fields, or other land units of the same land use and having the same management.
Actual average yield per acre	The actual crop yield for the management unit.
Expected yield per acre	1. For feedstock producers holding a crop insurance policy covering the reduced-CI crop for the current crop interval, feedstock producers must provide the yield used to establish coverage on their crop insurance policy. 2. For feedstock producers that do not hold a crop insurance policy, a feedstock producer may utilize the transitional yield or Agriculture Risk Coverage county benchmark yield for their county published by the U.S. Department of Agriculture (USDA) Risk Management Agency or Farm Service Agency.
Synthetic N	Industrially manufactured nitrogen fertilizer applied to soils to support crop growth.
Nitrification inhibitor	A chemical compound that slows down the conversion of ammonia to nitrate in soil, a process called nitrification. Nitrification inhibitors can be added to fertilizers and can help reduce nitrogen losses and N_2O emissions.
Manure	Feces, urine, other excrement, and bedding produced by livestock including dairy, swine, beef, and poultry that may have been collected and stored but has not been actively managed as compost.
Cover Crop	
Cover crop	Seasonal vegetative cover (grasses, legumes, and forbs) not intended for harvest, planted between production crops.
Cover crop with grazing	A cover crop that is grazed by livestock during its growth period.
No cover crop	No vegetative cover was planted between production crops.
Tillage Practice	
Reduced till	The implementation of a tillage system that limits disturbance to soil from mixing or inversion throughout the crop interval but allows minimal tillage and soil disturbance. Feedstock producers are directed to use the Tillage Disturbance Index for Soil Carbon (T-DISC) to determine a tillage value: www.usda.gov/t-disc. The resulting T-DISC value of the tillage system is no greater than 0.252.
No till	The implementation of a tillage system that limits the amount of disturbance to soil from mixing or inversion, creating only minor disturbances to the upper layers of soil throughout the crop interval. Feedstock producers are directed to use T-DISC to determine a tillage value: www.usda.gov/t-disc. The resulting T-DISC value of the tillage system is no greater than 0.075.

Term	Description
None of the above	The tillage method used does not meet the criteria for reduced till or no till.
Applied Manure	
Manure applied	Manure that is applied to the management unit. Applied manure options in the tool include beef cattle manure (solid or liquid), dairy cattle manure (solid or liquid), swine manure (solid or liquid), and poultry manure (solid or liquid).
Amount of manure applied	Feedstock producers applying solid or liquid manure may not exceed application rates stated in their nutrient budget and also must get a manure test for each type of manure applied. The manure test must be collected during the current crop interval and provide information on nitrogen and phosphorus content of the manure.
N content of manure applied	Farmers should reference the results of their manure test for the correct nitrogen content of applied manure to their management unit.

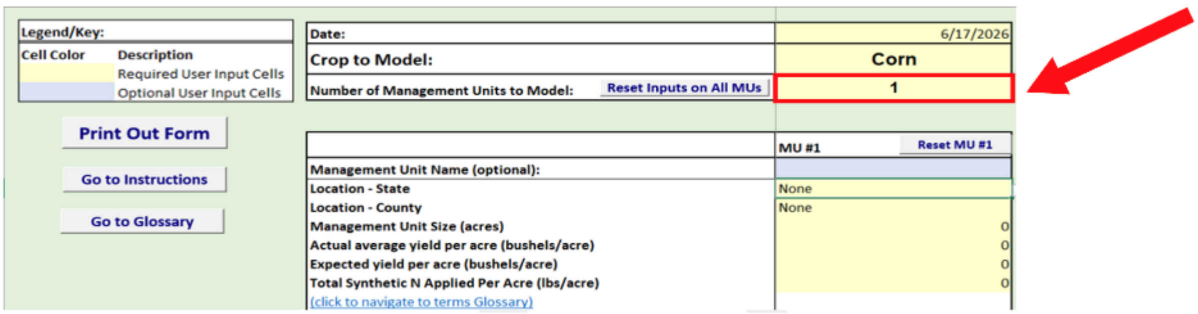
Appendix C

This appendix provides instructions for operating 45ZCF FD-CIC.

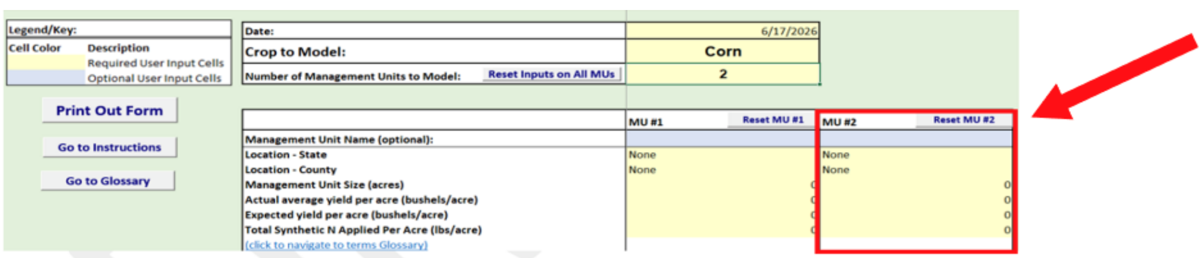
Getting Started

Ensure that Excel is functioning properly by following these steps:

1. Ensure that the tool is saved on your device in a desktop or documents folder.
2. Open the Excel workbook from the saved location.
3. If you see a security warning, select “Enable Content” or “Yes” (see example security warning dialogue image in Step 6).
4. Click into the “Crop Inputs” tab. In Cell C5, change the value to “2.”



5. If new content appears in Column D (see below), Excel is functioning properly; continue to “Step-by-Step Instructions.”

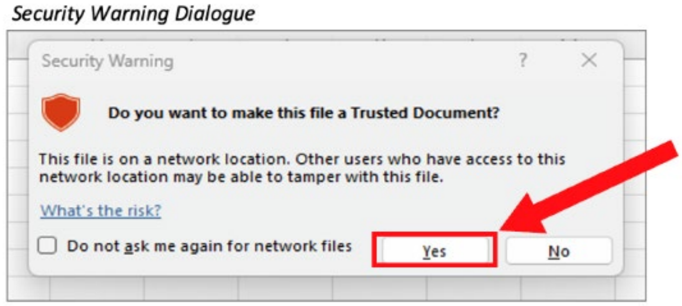


6. If the input number of management units did not expand to additional input columns, you will need to adjust a setting in Excel to enable the “macros” feature. To enable macros in Excel, please follow these steps:
   a. Confirm that the tool is saved on your device in a desktop or documents folder.
   b. Open the Excel workbook from the saved location.
   c. If you see a security warning, select “Enable Content” or “Yes” (see example security warning dialogue image).
   d. Alternatively, go to File → Info → Security Warning → Enable Content → Advanced Options to enable macros for one session.

e. For more permanent changes, go to Excel Options → Trust Center → Macro Settings and activate the "Enable VBA Macros" option.

f. For more information, follow the instructions to enable or disable macros in Microsoft 365 files here: support.microsoft.com/en-us/office/enable-or-disable-macros-in-microsoft-365-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6.

Security Warning Dialogue



g. Once the second management units table appears (indicating the Excel macros are working), please reset the tool by clicking the "Reset Inputs on All MUs" button in Cell B5 or manually change Cell C5 back to "1."

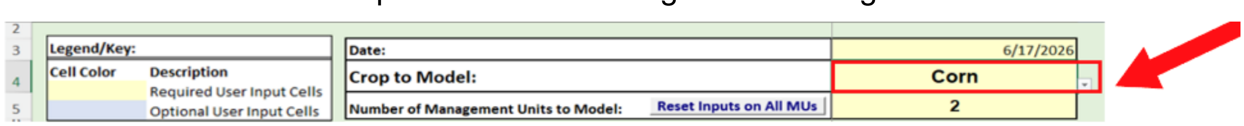
Legend/Key:	
Cell Color	**Description**
	Required User Input Cells
	Optional User Input Cells

Details of the legend/key and cell coloration:

- In the "Crop Inputs" tab, cells highlighted in pale yellow are required user inputs. Please ensure all pale yellow cells are filled in for your operation.
- All pale blue cells are optional user entry cells.

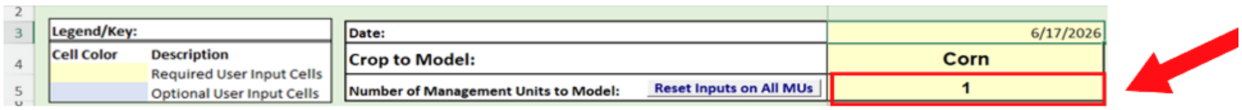
Step-by-Step Instructions

1. Select the crop type and number of management units to model.
2. Choose "Crop to Model" by clicking the pale yellow cell (C3). Using the gray drop-down arrow to the right of the cell, select the feedstock from the options provided (corn, sorghum, soybeans, or spring canola). 45ZCF FD-CIC can only generate CI scores for one crop at a time. See images below for guidance.



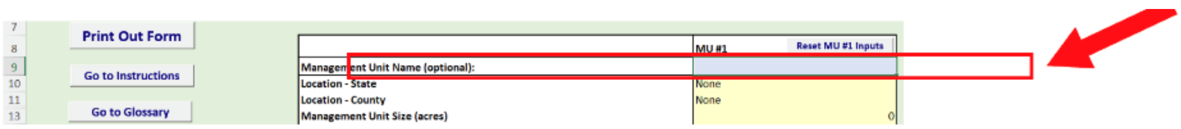
Select crop type to model (Cell C3)

a. Enter the number of management units (Cell C5) for which you plan to calculate CI score(s). A management unit is defined as a field, group of fields, or other land units of the same land use and having the same management.

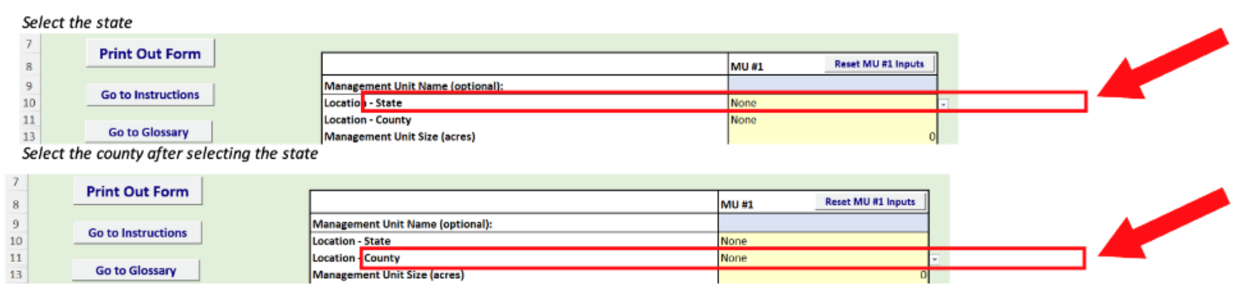


Select number of management units to model (Cell C5)

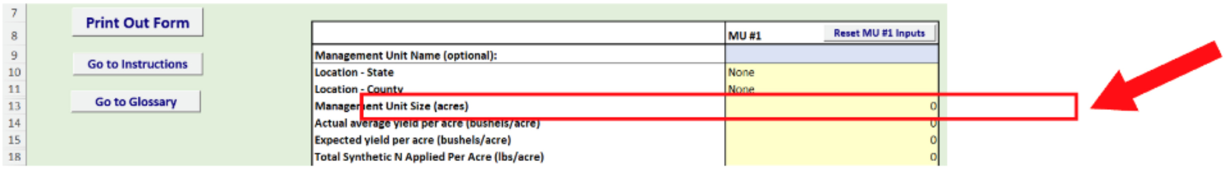
3. Once the user has entered the number of management units to model, 45ZCF FD-CIC will automatically generate one column per management unit. Each column contains options for selecting the relevant low-carbon practices implemented on that management unit, including cover crop, tillage, and fertilizers.
4. (Optional) In Row 9, users can enter a name for each management unit (MU), if useful for tracking purposes.
    a. For MU 1, enter a management unit name or description in Cell C9. For MU 2, enter the second management unit name or description in Cell D9, and so on.



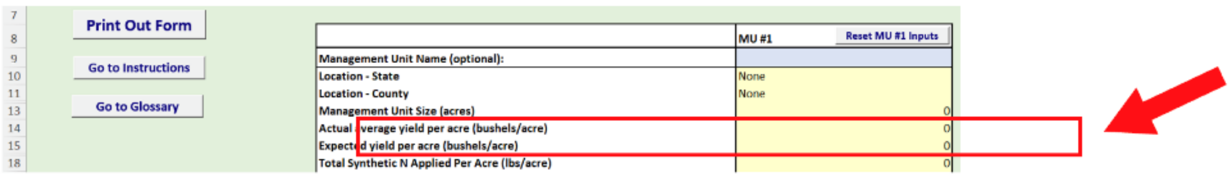
5. Select the location for each management unit.
    a. Select the state and county for the location of the management unit using the drop-down arrow to the right of the input cell. Users must select state first, and then county. For MU 1, this corresponds to Cells C10 and C11 for state and county, respectively.



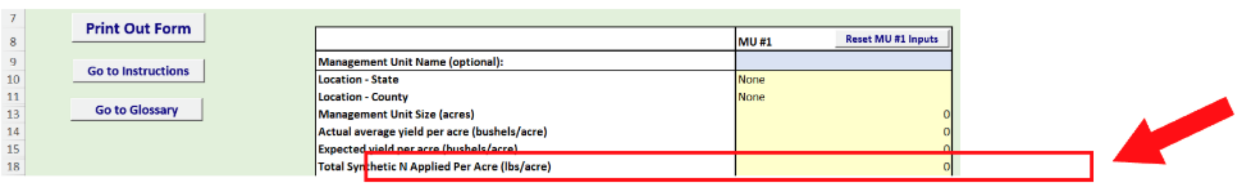
6. Enter the management unit size.
    a. Users must enter the size of the management unit (in acres) for which the CI will be calculated. A management unit is defined as a field, group of fields, or other land units of the same land use and having the same management. For additional information, consult the user manual or glossary.



7. Enter crop yield information for the management unit.
    a. Users must enter the actual and expected yield (in units of bushels/acre) for each management unit. For additional information, consult the user manual or glossary.



8. Enter the total synthetic nitrogen (N) applied per acre.
    a. Users must enter the total synthetic nitrogen applied per acre (in units of lb/acre) in Cell C18.



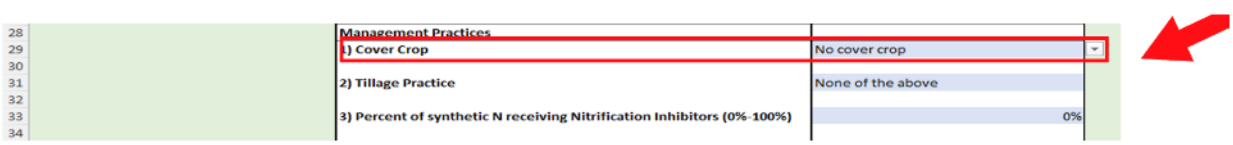
9. Select applicable management practices for each management unit.

    Once management unit information for all mandatory cells (pale yellow shading) are input by the user, users may then select applicable management practices for each management unit.

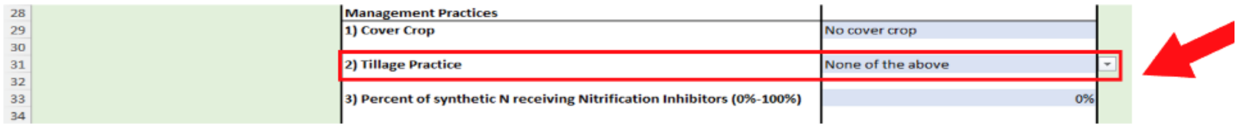
    If crops are grown on management units without the management practices included in the tool (Rows 33–59), users should leave the default selections unchanged.

    All management units growing the crop specified in Cell C3 that will be used as reduced-CI feedstocks as defined in 7 CFR § 2100 should be included.

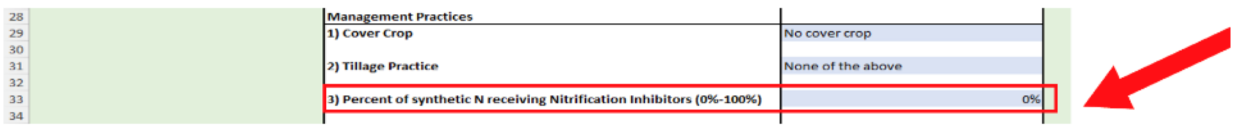
    a. Enter cover cropping practice using the drop-down in Cell C29. Choices are cover crop, cover crop with grazing, or no cover crop (default).



    b. Enter tillage practice using the drop-down in Cell C31. Choices are reduced till, no till, or none of the above (default). The tillage designation should be based on results of the T-DISC calculator found on the USDA website: www.usda.gov/t-disc.

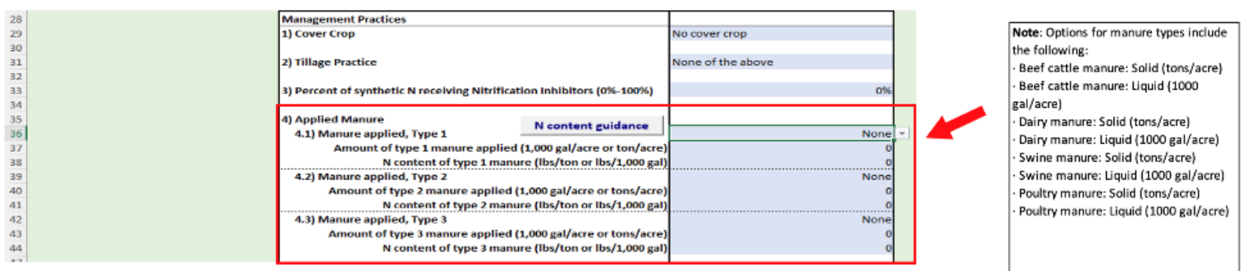


c. If applicable, enter the percent of synthetic nitrogen receiving nitrification inhibitors using the drop-down in C33. Enter the percentage of synthetic nitrogen applied jointly with nitrification inhibitors. Input value should be between 0% and 100% of applied synthetic fertilizer.



d. If applicable, select up to three types of applied manure. Start by selecting the first manure type by using the drop-down arrow to the right of the cell (C36).

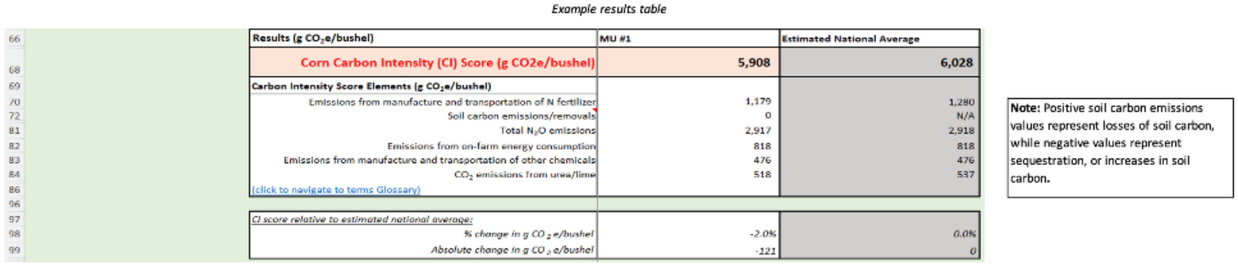
e. Next, enter the amount of manure applied (units of tons/acre or 1,000 gal/acre) in Cell C37. Add the total nitrogen content of the manure (in lb N/ton or lb N/1,000 gal) in Cell C38. Repeat for each additional applied manure type to the management unit. To reset the manure type, select "None" in the drop-down menu in Cell C36, C39, or C42.



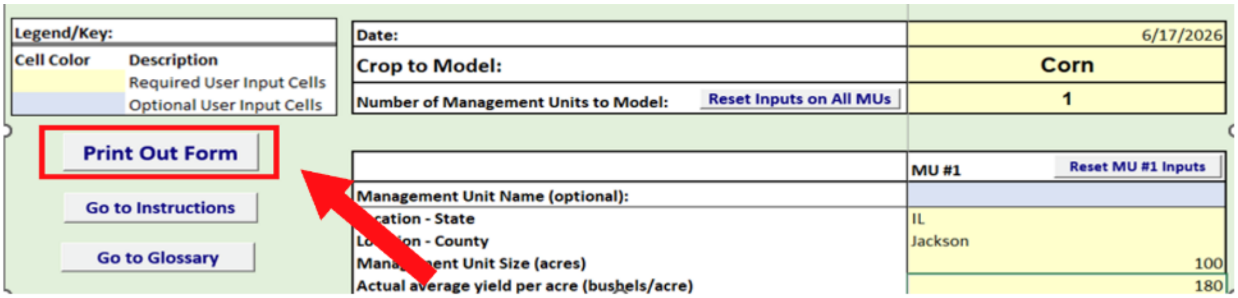
10. Review management unit CI results.

a. The results table starts at Row 66. The results table provides the management unit CI score in grams of CO_2e per bushel. The estimated national average CI score is also displayed for reference. Please see the glossary for more details.

Example results table



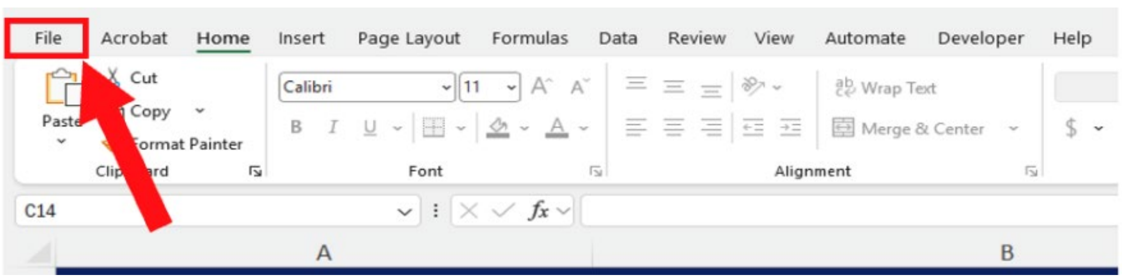
b. Save your results by either generating a PDF copy *or* by saving a copy of the tool to your computer. To generate a printable form, click the "Print Out Form" button and save or print the generated PDF.



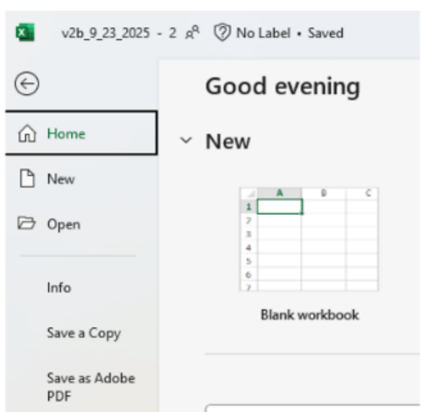
Click the "Print Out Form" button to print your results.

Another save option is to save the tool file as a new name in a user-designated folder location to be accessed at another time or shared with others:

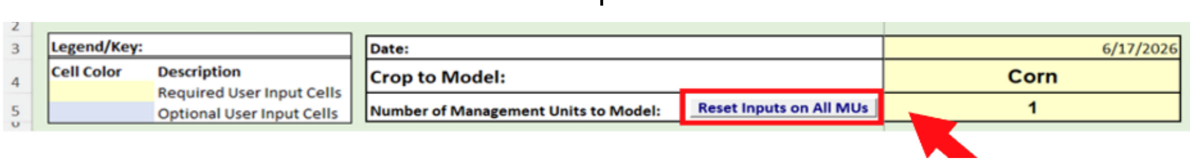
In the top left corner of your Excel browser, click "File"



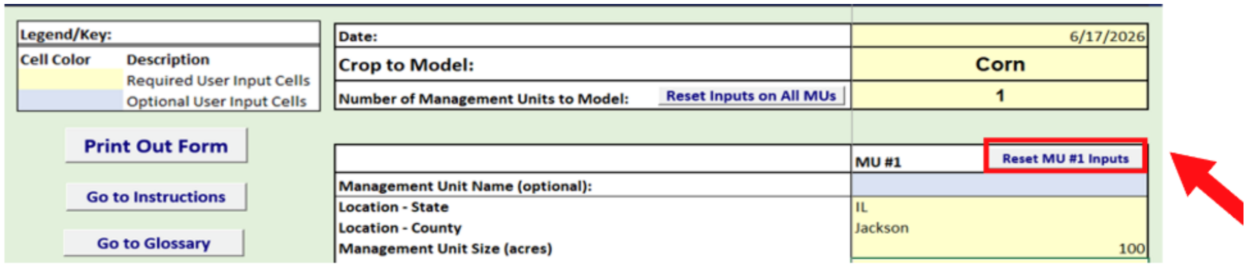
From the menu that appears, select "Save a Copy." A pop-up menu will appear, allowing you to save this version file to your computer.



11. Use the "Reset" button to start over.
    a. Scrolling back up to the top of the Crop Inputs tab, identify the gray button in Cell B5 that reads "Reset Inputs on All MUs."



b. Or reset just one management unit's input data in Row 8 using the corresponding "Reset MU #1 Inputs" button.



Management Practice Standards

If adhering to the voluntary guidelines established in 7 CFR Part 2100 "Technical Guidelines for the Production of Regenerative Agricultural Biofuel Feedstocks," farm producers must meet all of the applicable practice standards as follows:

- For reduced till or no till, 7 CFR § 2100.051, "Tillage management."
- For cover crops, 7 CFR § 2100.052, "Cover crop management."
- For synthetic nitrogen applied, 7 CFR § 2100.060, "General nutrient management."
- For nitrification inhibitors, 7 CFR § 2100.061, "Nitrification inhibitor standards."
- For applied manure, 7 CFR § 2100.062, "Manure application standards."