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. June 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. Thus, this document and the associated 2026 update to the 45ZCF-GREET model reflects emissions rates for transportation fuel produced prior to Jan. 1, 2026 and some specific additional results corresponding to certain amendments to § 45Z that take effect after Dec. 31, 2025. Further revisions are necessary to fully align with amendments in Public Law 119-21, and will be incorporated into a subsequent update.

Additionally, on Feb. 4, 2026, the Internal Revenue Service 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 (Feb. 4, 2026).

List of Acronyms

AR5	Fifth Assessment Report (IPCC)
ATJ	alcohol-to-jet
BTM	behind-the-meter
CCLUB	Carbon Calculator for Land Use and Land Management Change from Biofuels Production
CCUS	carbon capture utilization and sequestration
CH_4	methane
CI	carbon intensity
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CMM	coal mine methane
DCO	distillers corn oil
D-LCA	direct life cycle assessment
EAC	energy attribute credit
GGE	gallon gasoline equivalent
GHG	greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GWP	global warming potential
HEFA	hydroprocessed esters and fatty acids
ILUC	induced land use changes
IPCC	Intergovernmental Panel on Climate Change
IRS	Internal Revenue Service
LCA	life cycle analysis
LHV	lower heating value

LPG	liquefied petroleum gas
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
UCO	used cooking oil

Executive Summary

This document describes the methodology to calculate life cycle greenhouse gas (GHG) emissions of transportation fuel production using the 45ZCF-GREET model (Jun. 2026 version) developed by Argonne National Laboratory (ANL). The model is titled "45ZCF-GREET" because it was developed in support of the clean fuel (CF) 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 (EPA) 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 (UST or 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 section 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; $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 equivalents (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

[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), available at 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.

the IRS 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 lifecycle GHG emissions as described in § 211(o)(1)(H) of the Clean Air Act (42 U.S.C. 7545(o)(1)(H))(CAA), as in effect on Aug. 16, 2022, for such fuels, expressed as kg of CO_2e per MMBtu. The Treasury Department and the IRS have issued Notice 2025-11 containing the initial table setting forth these emissions rates for purposes of the § 45Z credit.

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 using 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 a transportation fuel is (1) a novel type of fuel not included in the applicable emissions rate table, or (2) if 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 (PER).

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 Internal Revenue Service determined that 45ZCF-GREET is the successor model to be used to calculate emissions rates for non-sustainable aviation fuel (SAF) transportation fuel. *See also* 91 FR 5160, 5171 (February 4, 2026). With regard to SAF, in Notice 2025-11 the Treasury Department and the 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, and 91 FR 5160 including for guidance on rounding emissions factors and other methodologies used for the 45Z tax credit.

This document refers to the § 45V Regulations [TD 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 (as a production input or as the qualified transportation fuel produced), 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.

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1 Introduction

The 45ZCF-GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model (Jun. 2026 version) can be used to characterize transportation fuel lifecycle greenhouse gas (GHG) emissions through the point of use. “Emissions through the point of use” is defined as the aggregate lifecycle 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, as well as 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. Lifecycle 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 (P.L. 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 lifecycle 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. These changes will be fully implemented in a future release. Where possible, 45ZCF-GREET (Jun. 2026 version) has been updated to display separate lifecycle GHG emissions results for fuels produced in 2025 and fuels produced after Dec. 31, 2025.

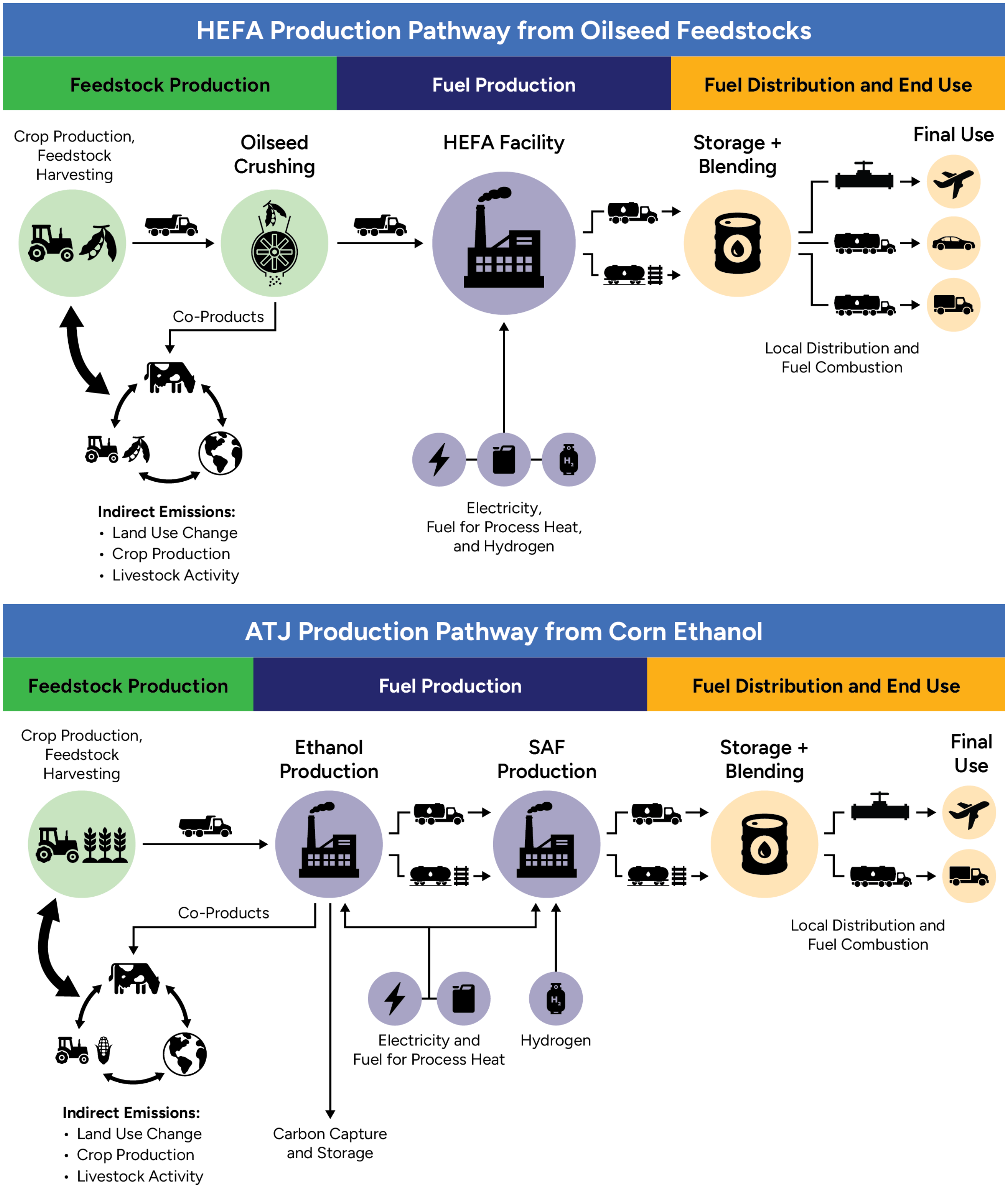

Figure 1. Examples of key activities related to life cycle GHG emissions, as calculated for fuels produced before Jan. 1, 2026, within the system boundary for transportation fuel production. The top diagram shows an example hydroprocessed esters and fatty acids (HEFA) pathway and the bottom diagram shows an alcohol-to-jet-ethanol (ATJ-ethanol) pathway, which co-produces both sustainable aviation fuel (SAF) and diesel.

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 kilogram (kg) of CO_2e per MMBtu[4]. For gaseous fuels, the quantity of fuel produced is converted to GGE using a lower heating value (LHV) of 122.5 megajoule (MJ) (116,090 Btu) per GGE. 45ZCF-GREET uses a functional unit of 1 MJ of fuel, on a LHV basis. This functional unit is used to calculate a transportation fuel's lifecycle 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. Lower Heating Value and Gallon Gasoline Equivalent for Selected Transportation Fuels That Exist as a Gas at Ambient Conditions (60°F, 1 atm)

Fuel	Lower Heating Value	Appropriate Gallon Gasoline Equivalent
Gasoline (E0)	116,090 Btu/gallon (18,680 Btu/pound [lb])	1.00
Propane (liquefied petroleum gas [LPG])	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	20,267 Btu/lb	1 lb = 0.17 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).

Fuel	Lower Heating Value	Appropriate Gallon Gasoline Equivalent
[RNG] or coal mine methane [CMM])		
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)

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 (GWP) of these gases to determine grams of CO_2e released per MJ 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 (IPCC) Assessment Report 5 (AR5). Table 2 presents the GWPs of the three GHGs using AR5.[5,6]

Table 2. 100-Year Global Warming Potentials of CO_2, CH_4, and N_2O in the IPCC 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 which is 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

[5] Global warming potential (GWP) of greenhouse gas emissions (GHGs) are published periodically by the Intergovernmental Panel on Climate Change (IPCC). 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, "Common metrics used to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks," UNFCC; 2022, Sharm el-Sheikh. unfccc.int/sites/default/files/resource/sbsta2022_L25a01E.pdf.

[6] The GWP of methane per IPCC AR5, 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 in Chapter 8 of the IPCC AR5 report, www.ipcc.ch/report/ar5/syr/.

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.

45ZCF-GREET calculates lifecycle 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, and 91 FR 5160. 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	Specifications
Biodiesel	Biodiesel (transesterification)	Monoalkyl esters of long-chain fatty acids	ASTM D6751
Butanol	Not applicable (N/A)	Mixture of n-butyl, sec-butyl, and iso-butyl alcohols	ASTM D7862
Renewable Diesel	Renewable diesel (HEFA, gasification and Fischer-Tropsch, alcohol-to-jet [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

[7] See www.astm.org/d7566-22.html.

Non-SAF Fuel	Corresponding 45ZCF-GREET Fuel/Pathway(s)	Definition	Specifications
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 (anaerobic digestion and upgrading: animal manures, wastewater sludge, landfill gas), coal mine methane (CMM) capture and upgrading	Natural gas suitable for use in transportation	ASTM D8080[a]

[a] 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 PER 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 2025-11. 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 lifecycle GHG emissions and their likelihood to: (1) be claimed by applicants; and (2) be part of a fuel pathway that achieves an emissions rate below the 47.4 g CO_2e per MJ (50 kg CO_2e per MMBtu) threshold. 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)
Hydroprocessed Esters and Fatty Acids (HEFA)	U.S. soybean oil
	U.S./Canadian canola oil/rapeseed oil
	Used cooking oil (UCO)[a]
	Tallow
	U.S. distillers corn oil (DCO)
	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
	Used cooking oil (UCO)[a]
	Tallow
	U.S. distillers corn oil (DCO)
	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)

Conversion Pathway	Primary Feedstock(s)
	U.S. corn stover
Alcohol-to-Jet (ATJ)	Ethanol (from fermentation pathways listed above)
Gasification and Fischer-Tropsch	U.S. corn stover
Anaerobic Digestion and Biogas Upgrading	U.S. wastewater sludge
	U.S. animal manures[c]
	U.S. landfill gas
Coal Mine Methane (CMM) Capture and Upgrading	U.S. coal mine methane (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

[a] Per Notice 2025-10, pathways that use imported UCO as a feedstock for transportation fuel prior to Jan. 1, 2026 are not available in the 45ZCF-GREET model. 91 FR 5160 reflects changes made in section 70521 of Pub. L. 119-21 that amended § 45Z to limit eligibility to fuels produced from feedstocks produced or grown in the United States, Canada, and Mexico. For fuels produced after Dec. 31, 2025, users are instructed to enter the total UCO input quantity and the share of total UCO that is sourced from the United States, Canada, and/or Mexico. For fuels produced before Jan. 1, 2026, users are instructed to enter the total UCO input and the share of UCO sourced from the United States. 45ZCF-GREET will provide emissions rate(s) and fuel volume(s) corresponding to the applicable UCO input only.
[b] Corn starch as a primary feedstock includes both starch and corn kernel fiber.
[c] 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 co-mingled with manure and cannot be practically separated, such as bedding materials, hay, compost, and animal carcasses.

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 were no specific restrictions on the origin of tallow in 2025, and applicants may use these pathways in 45ZCF-GREET regardless of tallow origin in 2025. Effective for fuels produced after Dec. 31, 2025, only feedstock from the United States, Canada, and Mexico is included in 45ZCF-GREET.[8] Users must enter U.S./Canada/Mexico tallow and other imported tallow separately, and 45ZCF-GREET will identify the emissions rate only for the fuels produced with tallow from the United States, Canada, and Mexico.

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. Based on Notice 2025-10, fuels produced before Jan. 1, 2026 from imported (non-U.S.) used cooking oil (UCO) cannot receive an emissions rate in 45ZCF-GREET, although facilities that use a combination

[8] Section 70521 of Pub. L. 119-21

of imported and domestic UCO may receive an emissions rate for the portion of fuel output attributable to the domestic UCO feedstock. For fuels produced after Dec 31, 2025, UCO is an eligible feedstock and can be modeled in 45ZCF-GREET if it is sourced from the United States, Canada, and/or Mexico. 45ZCF-GREET includes UCO, but differentiates between domestic, Canada and/or Mexico-sourced, and other imported UCO. Due to the potential for aggregators and clean fuel producers to mix domestic and imported UCO, users are directed to separately enter volumes of domestic UCO, UCO imported from Canada and Mexico (eligible after Dec. 31, 2025), and imported UCO from other countries (ineligible). 45ZCF-GREET will identify the fuel volume(s) and emissions rate(s) for only the fuels produced with eligible UCO, consistent with Notice 2025-11, 91 FR 5160, and the amendments to § 45Z.

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 distillers corn oil (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.

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 renewable natural gas (RNG)	▲	▲	▲	▲	▲	N/A	N/A
	45Z modeled coal mine methane (CMM)	▲	▲	▲	▲	▲	N/A	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
Fuel Output								

45ZCF-GREET Input Data		Ethanol Fermentation	ATJ-Ethanol	Transesterification	HEFA	Gasification and Fischer-Tropsch	RNG/CMM	Hydrogen
Sustainable aviation fuel (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	▲
Co-Product Outputs								
Non-fuel co-products		●	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.

ATJ = Alcohol-to-Jet, HEFA = Hydroprocessed Esters of Fatty Acids, RNG = Renewable Natural Gas, CMM = Coal Mine Methane

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 lifecycle GHG emissions rate (<5 gCO_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 energy attribute certificates (EACs), and 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 45V Regulations, reflecting a shared statutory direction to account for lifecycle 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 (2) the average annual grid mix in the region that the

[9] Under the final regulations, use of gas energy attribute certificates (i.e., renewable natural gas [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 energy attribute certificates.

transportation fuel production facility is located in. Regions within 45ZCF-GREET are depicted in alignment with the 45V Regulations. These two options are described below.

Option 1–Specific source power. This option allows users to enter power that was either generated behind-the-meter (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. 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 (CCUS), coal, and/or residual oil combustion) or a combination of generators, provided that (a) an emissions profile is available for the subject generator(s) in 45ZCF-GREET, and (b) that 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.

For BTM power generation entered into 45ZCF-GREET, there are two types of BTM power: integrated BTM power and non-integrated BTM power. 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 percent 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) 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

[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 lifecycle analysis 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 lifecycle GHG emissions, including potential induced grid emissions, associated with electricity consumption.
[11] www.eia.gov/electricity/data/eia923/
[12] www.epa.gov/egrid/egrid-technical-guide

describing the analysis that yielded emissions factors for each region is available in the technical report.[13]

Any imported electricity that 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.

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.

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

[13] greet.anl.gov/publication-ele_ci_needs

Balancing Authority	Grid Region
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
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

Balancing Authority	Grid Region
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
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 steam methane reforming (SMR). 45ZCF-GREET enables users sourcing natural gas alternatives (including renewable natural gas [RNG] or coal mine methane [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, and 3) animal manures. In the case of landfill gas, the gas is captured via a collection system and upgraded to RNG. With wastewater sludge and animal manures, 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. These sources are modeled in 45ZCF-GREET in alignment with the 45V Regulations.

If biogas, CMM, or RNG is produced *and* used on-site 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. All other requirements for externally sourced RNG and CMM are consistent with the 45V Regulations. 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 December 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.

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 CCUS (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 PER 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 PER 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 680 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 December 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, 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

CCUS 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.

2.5 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 ~0.9% 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.[14]

2.5.2 Counterfactuals for Organic Waste, Biogas, and Coal Mine Methane

45ZCF-GREET relies on assumed counterfactuals for organic waste and biogas 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 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. 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	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*	Manure RNG
Landfill gas	Landfill gas collection and flaring	Landfill gas RNG

[14] Burnham, A. 2024. Updated Natural Gas Pathways in GREET 2024. https://greet.anl.gov/publication-update_ng_2024.

Material	Counterfactual	Relevant 45Z Pathway(s)
Wastewater treatment sludge and digester biogas	Incumbent wastewater sludge and biogas management practices	Wastewater sludge RNG
Agricultural residues	Left on field	Ethanol, gasification, and Fischer-Tropsch
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*.[15] Consistent with the direction in 91 FR 5160, which 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. For fuels produced after Dec. 31, 2025, these calculations will be replaced with new methods that incorporate values for specific animal manure types and the updated pathways will be made available in a subsequent 45ZCF-GREET update.

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 (a) methane emissions associated with incomplete combustion of CMM during flaring, (b) N_2O emissions associated with CMM flaring, and (c) 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 is 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.

[15] 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, DC, available at https://www.energy.gov/45vresources.

- 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.[16]
- All farm-based data for conventional farming practices in 45ZCF-GREET are background data.
- Non-liquid fuel co-products and co-product yields are assumed to be background data based on facility models.

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 induced land use changes, 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, 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 MJ 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

[16] 45ZCF-GREET automatically deducts these emissions when alternative natural gas/RNG and/or 45V-modeled hydrogen are used as inputs to transportation fuel production.

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 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,[17] 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 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 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.[18] For U.S. forestland conversion and all international land use change, emissions factors from AEZ-EF v54 were applied.[19] 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 ANL 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: https://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

[17] User manual, downloadable version of the model, and additional documentation for 40BSAF-GREET 2024 is available at https://www.energy.gov/cmei/greet.
[18] 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.
[19] CCLUB also includes land use change emissions factors from other sources that are not used in 45ZCF-GREET analyses.

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

45Z Clean Fuel(s) – Pathway	Feedstock	Total	ILUC[20]	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
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

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

Table 10. Adjusted Indirect Effects for the Clean Fuel Pathways in 45ZCF-GREET (for illustrative purposes only)

45Z Clean Fuel(s) – Pathway	Feedstock	Total	ILUC[21]	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

Results are estimated in grams CO_2e per megajoule of fuel using sample yields for each pathway.

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.

[20] Induced land use change (ILUC) is excluded for fuels produced after Dec. 31, 2025.
[21] ILUC is excluded for fuels produced after Dec. 31, 2025.

2.6 Co-Product Allocation Methods

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

Users may only account for a co-product if it has been valorized in a process downstream of the transportation fuel production facility; co-products that were produced but not valorized may not be allocated emissions in the lifecycle GHG emissions calculation of produced transportation fuel.[22] For example, if LPG/propane is produced by the facility but used on-site as a process fuel (as opposed to sold to another party), that quantity of LPG/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, as consistent with the 45V Regulations and 45VH2-GREET. For all other co-products, 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/mass-based allocation. System expansion and physical allocation methods are described further in the International Organization for Standardization (ISO) 14044:2006.[23] System expansion is used when it is straightforward to identify the conventional product displaced by the co-product (e.g., soybean meal demand that can be met by distillers grains) and the quantity of the co-product 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 co-product 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 co-products that can be simulated in 45ZCF-GREET and the approach used to account for them.

[22] Allocation of emissions to valorized co-products is standard practice in life cycle analysis, including in previously published GREET models and related publications.
[23] https://www.iso.org/standard/38498.html

Table 11. Co-products 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, hydrolyzed corn protein, dry starch	Mass-based allocation
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, LPG/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 Jun. 2026 is referred to as “45ZCF-GREET” and the filename 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.** 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 life cycle analysis (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 2). This step needs to be done only once, for both the 45ZCF-GREET 2026 file and GREET1_2025 file.

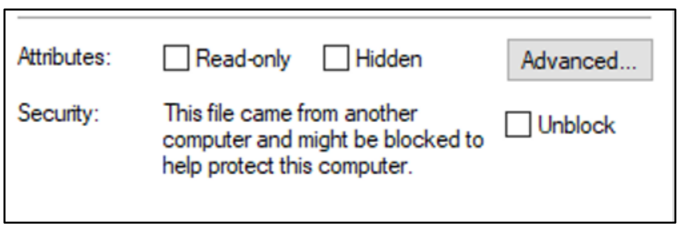

Figure 2. Unblocking file to allow macros

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 3).

Figure 3. 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 popup will warn users of the failed connection (Figure 4).

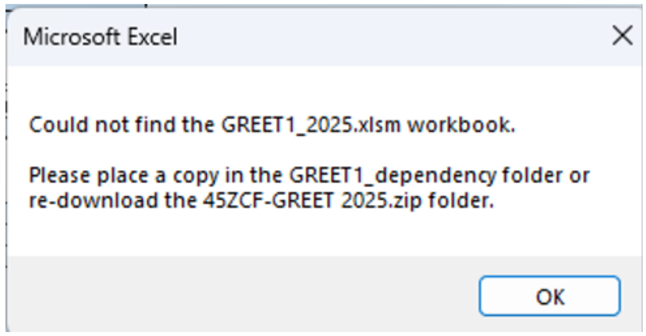

Figure 4. Error message warning that the GREET1_2025 file could not be located

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 5).

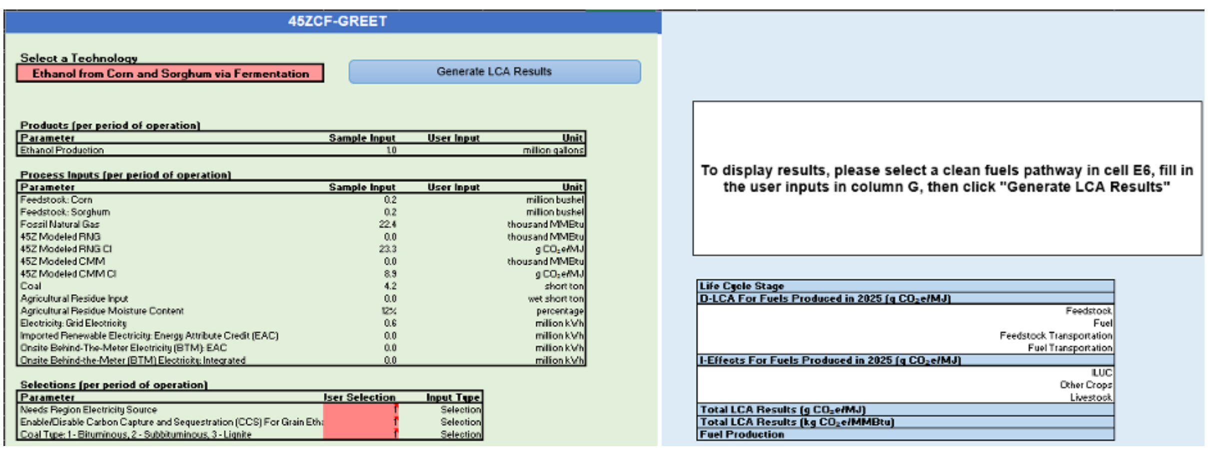

Figure 5. Dashboard, which serves as the user interface to control the model

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 dropdown 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 dropdown list of supported 45ZCF-GREET pathways (Figure 6). 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.

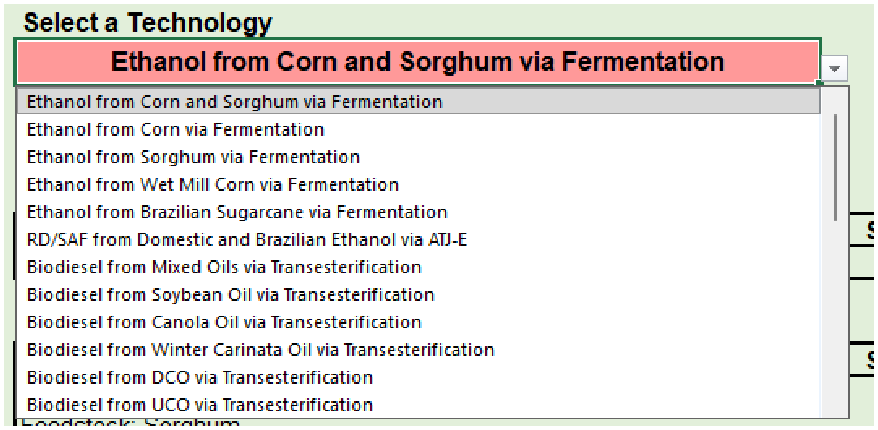

Figure 6. Drop-down list of pathways in 45ZCF-GREET. More pathways can be seen by scrolling down using the scroll bar.

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 7) allows the user to specify the quantity of fuels and co-products 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 column User Input 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 7. The Products section for ethanol from corn and sorghum via fermentation

The “Process Inputs” section (Figure 8) 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 column User Input 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 (NG), renewable 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 NG reforming without CCS ("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-E
- 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	0.2		million bushel
Feedstock: Sorghum	0.2		million 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		
45Z Modeled CMM CI	8.9		
Coal	4.2		
Agricultural Residue Input	0.0		
Agricultural Residue Moisture Content	12%		
Electricity: Grid Electricity	0.6		
Imported Renewable Electricity: Energy Attribute Credit (EAC)	0.0		
Onsite Behind-The-Meter Electricity (BTM): EAC	0.0		
Onsite Behind-the-Meter (BTM) Electricity: Integrated	0.0		million kWh

Negative CIs are not valid for process fuels produced from non-manure sources that are consumed in the production of transportation fuels produced after December 31, 2025. Please refer to the user's manual for additional information

Figure 8. 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 9) contains additional parameters such as the grid electricity source, carbon capture utilization and sequestration options and 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 dropdown menu) or a numerical entry (described as "Value"). Hovering over the input value of a pink dropdown 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

1 - Bituminous, 2 - Subbituminous, 3 - Lignite

Figure 9. 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 backend file to calculate the LCA results for the pathway. When the results are calculated, one or more graph(s) 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 lifecycle assessment (D-LCA) and Indirect Effects, if relevant (Figure 10). 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.

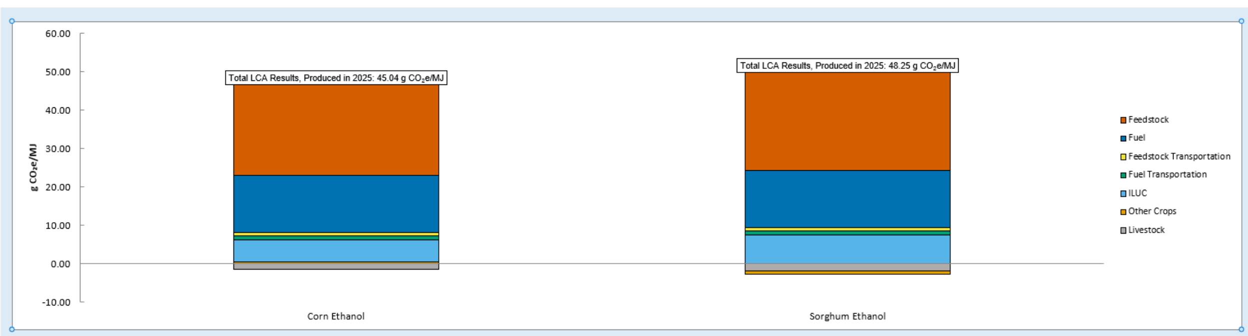

Figure 10. Total LCA Results bar chart displayed for ethanol from corn and sorghum via fermentation using sample inputs

The Lifecycle GHG Results Table (Figure 11) breaks the results down by lifecycle 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 a "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.[24] Each category has a dedicated transportation category (e.g., “Feedstock Transportation” and “Fuel Transportation”) associated with transportation emissions during that lifecycle stage.

Life Cycle Stage	Corn Ethanol	Sorghum Ethanol
D-LCA For Fuels Produced in 2025 (g CO_2e/MJ)	**40.88**	**42.67**
Feedstock	24.06	25.85
Fuel	14.85	14.85
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)	**45.46**	**47.28**
Total LCA Results For Fuels Produced in 2025 (kg CO_2e/MMBtu)	**47.96**	**49.88**
Total LCA Results For Fuels Produced After December 31, 2025 (g CO_2e/MJ)	**39.71**	**39.87**
Total LCA Results For Fuels Produced After December 31, 2025 (kg CO_2e/MMBtu)	**41.90**	**42.06**
Fuel Production	**500000 Gallons**	**500000 Gallons**

Figure 11. The Lifecycle GHG Results Table after running the sample inputs for ethanol from corn and sorghum via fermentation

Note that UCO, tallow, and DCO 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 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, U.S. UCO, DCO, or selected intermediate crops (i.e.,

[24] 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.

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.

3.3 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 lifecycle GHG emissions rate. Users can restore the scenario to the GREET defaults by clicking the “Reset Parameters” button located below the results table to return to the defaults for a selected pathway. Note that this feature also resets the results. 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.

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U.S. DEPARTMENT *of* ENERGY

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