U.S. DEPARTMENT OF ENERGY

Guidelines to Determine Life Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel Production Pathways using 40BSAF-GREET 2024

April 2024

Disclaimer

The current document describes the manner in which 40BSAF-GREET 2024 characterizes life cycle greenhouse gas (GHG) emissions of sustainable aviation fuel (SAF) production pathways that are included in the model and provides instructions for use of the model for the purpose of the SAF tax credit established in sections 40B and 6426(k) (40B tax credit) of the Internal Revenue Code (I.R.C). The U.S. Department of Energy (DOE) does not anticipate the need for significant revisions to the 40BSAF-GREET model. However, if the model is revised in the future, those future releases are expected to be accompanied with additional supporting documentation describing the revisions made. The model is specific to the calculation of GHG emissions for the 40B tax credit and thus its use would not be appropriate for other purposes, including for determining eligibility for other tax credits or other Federal programs.

Summary

This document describes the methodology to calculate life cycle GHG emissions of SAF production, and life cycle GHG emissions reduction percentage relative to conventional jet fuel, using the 40BSAF-GREET 2024 model that has been developed by Argonne National Laboratory (ANL) based on ANL's Research and Development (R&D) GREET model. As described in the Internal Revenue Service's (IRS) Notice 2024-37, the U.S. Department of the Treasury (UST) and the IRS will accept an emissions reduction percentage of a feedstock-specific SAF production pathway or combination of feedstock-specific SAF pathways calculated according to the 40BSAF-GREET 2024 model for the purpose of the 40B tax credit. 40BSAF-GREET 2024 is based on the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (R&D GREET®) model developed and maintained by ANL. 40BSAF-GREET 2024 was developed in collaboration with the Interagency Sustainable Aviation Fuels Lifecycle Analysis Working Group, with consideration of information provided by EPA in the December 13, 2023, letter regarding section 211(o) of the Clean Air Act,[1] and in consultation with the UST, for use in implementing the 40B tax credit. Unless otherwise specified, 40BSAF-GREET 2024 may only be used for the purposes of the safe harbor described in section 3 of Notice 2024-37.

40BSAF-GREET 2024 is available at: https://www.energy.gov/eere/GREET. 40BSAF-GREET 2024 is based on R&D GREET 2023 Rev 1, which is available at: Pursuant to Notice 2024-37, 40BSAF-GREET 2024 is an accepted methodology for the administration of the 40B tax credit and can be applied for SAF production in 2023 and/or 2024. The model includes features that make it easy to use for taxpayers, as well as SAF production pathways that are of sufficient methodological certainty to be appropriate for determining eligibility for the 40B tax credit.

The 40B tax credit is available for certain fuel mixtures containing SAF sold or used after December 31, 2022, and prior to January 1, 2025. The 40B tax credit is equal to the product of – (1) the number of gallons of sustainable aviation fuel in a qualified mixture, multiplied by (2) the sum of – (A) $1.25, plus (B) the "applicable supplementary amount"[2] with respect to such SAF. For a claimant to qualify for the 40B tax credit, the producer or importer of the SAF is required to be registered with the IRS. A claimant for the 40B tax

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[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 (December 13, 2023), available at https://home.treasury.gov/system/files/136/Final-EPA-letter-to-UST-on-SAF-signed.pdf.

[2] "Applicable supplementary amount" means, with respect to any sustainable aviation fuel, an amount equal to $0.01 for each percentage point by which the life cycle greenhouse gas emissions reduction percentage with respect to such fuel exceeds 50 percent. In no event shall the applicable supplementary amount determined…exceed $0.50."

credit also is required to provide the IRS with certification from an unrelated party demonstrating compliance with any general requirements, supply chain traceability requirements, and information transmission requirements of the methodology used to determine the GHG emissions of SAF. See I.R.C. section 40B for the statutory requirements for the 40B tax credit.

Guidance concerning registration, certification, and claims for the 40B tax credit is outside the scope of this document. Please refer to Notice 2024-37. See also Notice 2023-6, 2023-2 I.R.B. 328, and Notice 2024-6, 2024-2 I.R.B. 348, for additional IRS guidance on the 40B tax credit, including guidance on other methodologies used for the 40B tax credit.

This document refers to the current version of the California Air Resources Board's Low Carbon Fuel Standard (LCFS or California LCFS) and the verification bodies accredited under that regulatory system as of April 2024. Notice 2024-37 provides that taxpayers may use certification from accredited LCFS verifiers to provide certification of the requirements of 40B-SAF –GREET 2024, as required by I.R.C. section 40B(f)(2)(A). The descriptions in this document regarding the treatment of certain foreground data (i.e., data input by the user) reference the LCFS to enable the use of readily available certification.

This document has three sections:

Section 1: Introduction

Section 2: Methodology

Section 3: User Instructions

Table of Contents

List of Figures

List of Tables

Section 1. Introduction

40BSAF-GREET 2024 can be used to characterize SAF life cycle greenhouse gas (GHG) emissions through the point of use. "Emissions through the point of use" is defined as the aggregate life cycle GHG emissions related to SAF produced during the applicable taxable year at a SAF production facility. It includes emissions associated with feedstock growth/sourcing, gathering, processing, and delivery to a SAF 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 SAF production process, inclusive of the electricity, process fuel(s), and hydrogen used by the SAF production facility. Life cycle GHG emissions accounted for in 40BSAF-GREET 2024 also include transport, storage, and use of the SAF as part of an aviation fuel blend.[3]

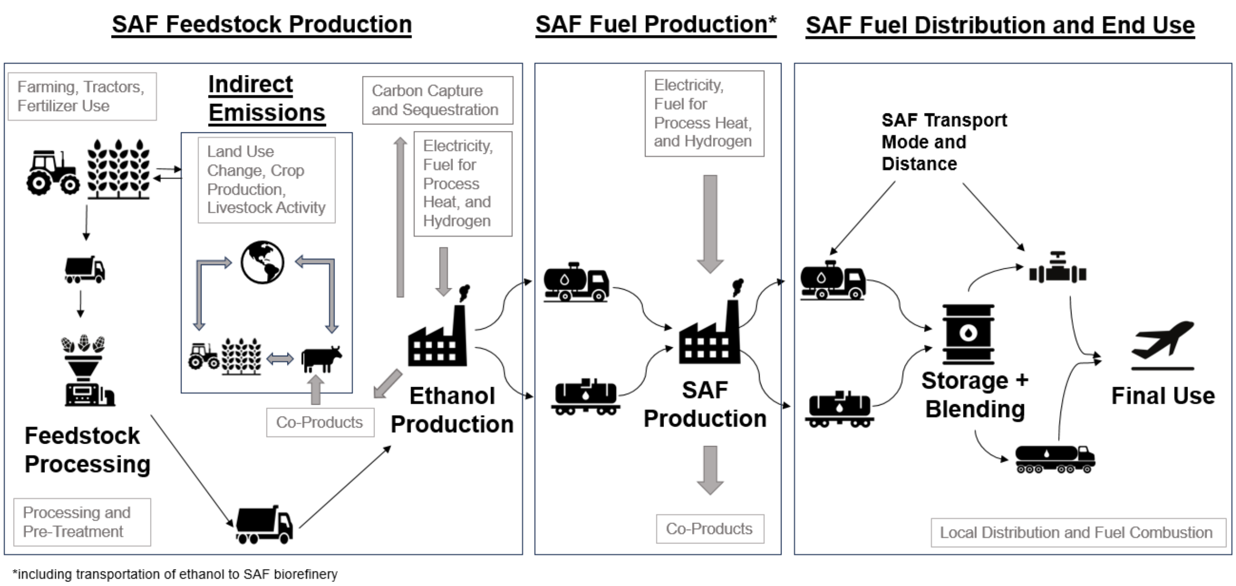

Figure 1. Examples of key activities related to life cycle GHG emissions within the system boundary for SAF production.

Certain parameters within 40BSAF-GREET 2024 are fixed (i.e., "background data") and may not be changed by the user. Background data is defined as parameters for which default average values based on the industry statistics and scientific literature are deemed

[3] For all bio-based SAF feedstocks, the biogenic CO_2 emitted during conversion and SAF combustion is assumed to be fully offset by the CO_2 sequestered in the biomass feedstock during its growth. Thus, neither the CO_2 uptake during feedstock growth nor biogenic CO_2 emitted during conversion and combustion is explicitly included. However, biogenic CO_2 capture and sequestration is modeled as a net emissions reduction strategy.

appropriate and bespoke inputs from SAF producers are unlikely to be independently verifiable with high fidelity, given the current status of verification mechanisms. Examples of background data in 40BSAF-GREET 2024 include direct emissions at soybean crushing facilities, methane leakage rates for the natural gas supply chain, and the fuel efficiency and carbon dioxide (CO_2) emission factors for individual transportation modes. Inputs for background data are itemized in the GREET dependency file in the 40BSAF-GREET 2024 package.

The user must enter all other parameters, considered foreground data. Examples of these parameters include feedstock type, the type and quantity of energy used for SAF production, and the quantity of SAF and other liquid fuels produced. Additional details can be found in Table 2.

Section 2. Methodology

This section presents the methodology used in 40BSAF-GREET 2024 to calculate the life cycle GHG emissions of SAF production pathways via technologies currently represented in the tool.

2.1 Functional Unit

Section 40B generally allows credit for each gallon of SAF that is blended with kerosene. The amount of the credit depends upon the reduction percentage of GHG emissions from a petroleum-based jet fuel (i.e., petroleum-derived kerosene-based jet fuel) baseline. For the purposes of 40BSAF-GREET 2024, one gallon of SAF is equivalent to a lower heating value (LHV)[4] of 126.37 megajoules (MJ). 40BSAF-GREET 2024 uses a functional unit of 1 MJ of fuel, on a LHV basis. This functional unit is used to calculate a SAF's life cycle GHG emissions and its reduction percentage relative to the baseline of 89 grams (g) CO_2-equivalent (CO_2e) per MJ of conventional aviation fuel. After the percent reduction in life cycle GHG-intensity achieved by the SAF is calculated on a g CO_2e/MJ basis relative to 89 g CO_2e/MJ, the amount of the tax credit to be claimed must be calculated on a per-gallon SAF basis.

2.2 Greenhouse Gases

40BSAF-GREET 2024 accounts for methane (CH_4), nitrous oxides (N_2O) and CO_2 in its representation of GHG emissions and uses the global warming potentials (GWP) of these gases to determine grams of CO_2e released per MJ of SAF produced and consumed (i.e., g CO_2e/MJ SAF). The model uses GWP values characterized on the basis of a 100-year

[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).

timeframe (i.e., GWP100) from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5). **Table 1** below presents GWPs of the three GHGs using AR5.[5,6]

Table 1. 100-Year Global Warning Potentials of CO_2, CH_4, and N_2O in IPCC Assessment Report

IPCC Assessment Report	CO_2	CH_4	N_2O
Assessment Report 5	1	28	265

2.3 Eligible SAF Pathways, Feedstocks, and Foreground Data

Section 40B defines SAF as liquid fuel the portion of which is not kerosene, that: (1) meets fuel quality standard ASTM International Standard D7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons)[7] or the Fischer Tropsch provisions of ASTM International Standard D1655, Annex A1; (2) is not derived from coprocessing monoglycerides, diglycerides, triglycerides, free fatty acids, or fatty acid esters (or materials derived from such materials) with a feedstock which is not biomass; and (3) is not derived from palm fatty acid distillates or petroleum. To qualify as SAF for the 40B tax credit, the liquid fuel must also be certified as having a life cycle GHG emissions reduction percentage of at least 50 percent relative to the petroleum-based jet fuel GHG emissions of 89 g CO_2e/MJ. Notice 2024-37 provides guidance on certification for taxpayers calculating the 40B tax credit using 40BSAF-GREET 2024. As noted, the model is specific to the calculation of GHG emissions for the 40B tax credit and thus its use is not appropriate for other purposes, including for determining eligibility for other tax credits or other Federal programs.

40BSAF-GREET 2024 calculates life cycle GHG emissions associated with SAF from two production routes: hydroprocessed esters and fatty acids (HEFA), as well as alcohol-to-jet using an ethanol feedstock (ATJ-Ethanol). HEFA corresponds to the HEFA-SPK, ASTM D7566,

[5] GWPs of GHGs are published periodically by the Intergovernmental Panel on Climate Change (IPCC). The Fifth Assessment Report GWPs 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. https://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. 40BSAF-GREET 2024 additionally accounts for radiative forcing impacts of carbon dioxide added to the atmosphere due to oxidation of fossil-based methane, which is depicted in 40BSAF-GREET 2024 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, https://www.ipcc.ch/report/ar5/syr/.

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

Annex A2 (approved in 2011 at a 50% blend limit with petroleum-derived jet fuel). ATJ-Ethanol corresponds to the ASTM-approved alcohol-to-jet fuel: ATJ-SPK, ASTM D7566, Annex A5 (approved in 2016 at a 30% blend limit). 40BSAF-GREET 2024 includes HEFA and ATJ-Ethanol as these production processes were identified as the most relevant through the end of 2024 – the timeframe during which the 40B credit is available. Based on current and likely near-term SAF production, seven relevant feedstocks were identified for the two SAF production technologies modeled in 40BSAF-GREET 2024. This results in seven distinct SAF pathways as shown below:

- U.S. soybean HEFA
- U.S. and Canadian canola/rapeseed HEFA
- Tallow HEFA
- Used cooking oil (UCO)[8] HEFA
- U.S. distillers corn oil HEFA
- U.S. corn ATJ-Ethanol
- Brazilian sugarcane ATJ-Ethanol.

All pathways are based on the assumption that SAF production occurs in the United States, but in some cases, a production pathway requires inputs that are sourced from outside the U.S. 40BSAF-GREET 2024 includes specific feedstocks and origins based on their likelihood to: (1) be claimed by applicants; and (2) be part of a fuel pathway that meets the 50% life cycle GHG reduction threshold. For example, the Brazilian sugarcane ATJ-Ethanol pathway assumes that sugarcane ethanol is produced in Brazil and imported to the U.S. for final conversion to SAF at domestic ATJ-Ethanol facilities. The U.S. corn ATJ-Ethanol pathway assumes ethanol is sourced from U.S. corn dry mill plants with corn oil extraction. Ethanol produced via wet milling process is not included in 40BSAF-GREET 2024, as ATJ-Ethanol pathways relying on ethanol produced by wet milling are unlikely to meet the minimum 50% life cycle GHG reduction threshold established in the 40B tax credit. Note that 40BSAF-GREET 2024 only includes soybean oil sourced from the U.S., distillers corn oil sourced from the U.S., and canola/rapeseed oil sourced from the U.S. or Canada. There are no specific restrictions on the origin of tallow or UCO, and applicants may use these pathways in 40BSAF-GREET 2024 regardless of tallow and/or UCO origin. Further information on relevant foreground data and selected background data is provided in Table 2.

[8] Used Cooking Oil (or UCO) means fats, oils, or greases of vegetable or animal origin, originating from commercial or industrial food processing operations, including restaurants. Feedstock characterized as UCO must contain only fats, oils, or greases that were previously used for cooking or frying operations.

Table 2. SAF Production Pathways Included in 40BSAF-GREET 2024 with Selected Foreground and Background Data.*

40BSAF-GREET 2024 Input Data				U.S. Corn ATJ-Ethanol		Brazilian Sugarcane ATJ-Ethanol		U.S. Soybean HEFA	Canola/ Rapeseed HEFA	Tallow/UCO/ DCO HEFA
				Ethanol production	SAF production	Ethanol production (Brazil)	SAF production (U.S.)	SAF production	SAF production	SAF production
GHG Mitigation Options	Energy Sources	Electricity Mix	Eligible RECs	🟢	🟢	N/A	🟢	🟢	🟢	🟢
			Brazilian mix	N/A	N/A	🔴	N/A	N/A	N/A	N/A
			27 US eGrid subregions (select 1)	🟢	🟢	N/A	🟢	🟢	🟢	🟢
		On-Site Fuel Source	Natural gas	🟢	🟢	🟢	🟢	🟢	🟢	🟢
			RNG (landfill gas via direct connection)	🟢	🟢	🟢	🟢	🟢	🟢	🟢
		Imported Hydrogen Source	Fossil natural gas derived H2	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			45V modeled H2 (enter GHG intensity)	N/A	🟢	N/A	🟢	🟢	🟢	🟢
	Carbon Capture and Sequestration			🟢	N/A	N/A	N/A	N/A	N/A	N/A
Other User Input Data	Intermediate Production (ethanol for ATJ-Ethanol and fats/oils for HEFA)		Grid average electricity consumption	🟢	N/A	🟢	N/A	N/A	N/A	N/A
			Electricity purchased from eligible RECs	🟢	N/A	N/A	N/A	N/A	N/A	N/A
			BTM electricity consumption	🟢	N/A	🟢	N/A	N/A	N/A	N/A
			Natural gas consumption	🟢	N/A	🟢	N/A	N/A	N/A	N/A
			RNG (landfill gas) consumption	🟢	N/A	🟢	N/A	N/A	N/A	N/A
			Coal consumption	🟢	N/A	🟢	N/A	N/A	N/A	N/A
			Intermediate yield	🟢	N/A	🟢	N/A	N/A	N/A	N/A
	Intermediate Transport to SAF Facility		Distance traveled by mode	N/A	🟢	N/A	🟢	🔴	🔴	🔴
	SAF Production		Intermediate input	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Grid average electricity consumption	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Electricity purchased from eligible RECs	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			BTM electricity consumption	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Natural gas consumption	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			RNG (landfill gas) consumption	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Imported H2 consumption	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Imported H2 transportation mode(s) and distance	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Total SAF production	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Total renewable diesel production	N/A	🟢	N/A	🟢	🟢	🟢	🟢
			Total gasoline/naphtha production	N/A	🟢	N/A	🟢	🟢	🟢	🟢
	SAF Transport to Blending Terminal		Distance traveled by mode	N/A	🟢	N/A	🟢	🟢	🟢	🟢
	SAF Transport from Blending Terminal to Airport		Distance traveled by mode	N/A	🔴	N/A	🔴	🔴	🔴	🔴

* Green dots indicate foreground data and red dots indicate selected background data. Most foreground data require numeric inputs by the user; drop-down menu options are indicated where relevant. Categories that are entirely background data (e.g., soybean crushing facilities) are not shown in the table. REC = Renewable Electricity Credit; RNG = renewable natural gas; BTM = behind-the-meter; SMR = steam methane reforming; ATJ = alcohol-to-jet; UCO = used cooking oil; DCO = distillers corn oil; HEFA = hydroprocessed esters and fatty acids.

2.4 Selected Foreground Data and Decarbonization Options

40BSAF-GREET 2024 requires users to enter foreground data specific to their facility in order to generate a GHG intensity for the purposes of the 40B tax credit. In the case of ATJ-Ethanol, foreground data includes inputs and outputs to the production and delivery of ethanol: feedstock inputs, energy consumption, ethanol yield, and the distance(s) and mode(s) for ethanol transportation to the ATJ-Ethanol facility. HEFA production pathways use background data to characterize GHG emissions associated with the production and delivery of oils/fats to the HEFA production facility. Details of oilseed crushing facilities and UCO, DCO, and tallow sources are not incorporated as foreground data because HEFA facilities are likely to purchase oils/fats from a large number of individual sources and requiring foreground data for each source would substantially expand the verification requirements for these facilities. For all pathways, feedstock and energy inputs to the SAF production facility are required foreground data. Users must also enter the transportation modes and distances for the finished SAF required to transport the fuel to its point of use. Users are not supplied with optional default values for any foreground data to ensure that life cycle GHG intensities accurately reflect operations of individual facilities. The full set of foreground data is provided in **Table 2**. This section discusses selected foreground data needed to run 40BSAF-GREET 2024.

It is important to note that Notice 2024-37 provides information on the supporting documentation associated with 40BSAF-GREET 2024. Users are encouraged to review Notice 2024-37 before entering foreground data into 40BSAF-GREET 2024.

2.4.1 Accounting for Electricity in 40BSAF-GREET 2024

When specifying the source of electricity consumed at SAF and ethanol production facilities, users may enter annual electricity consumption values (calculated for the taxable year) for one or more of three available options:

Option 1: grid electricity consumed, which will be assigned the average annual grid mix in the eGRID subregion where the facility is located (see **Figure 2**).

Option 2: electricity supplied to the facility from certain zero-carbon intensity (CI) generator(s) through the purchase of Renewable Electricity Credits (RECs) from those generators.

Option 3: behind-the-meter (BTM) electricity supplied and consumed on-site. Zero-CI Renewable Portfolio Standard (RPS)-eligible RECs as defined by the California LCFS[9] are assigned a GHG-intensity of zero. BTM electricity generation must be accounted for in the mass and energy balance of the facility if any fuel is required to supply on-site generator(s).

These three options are described in more detail below.

Option 1 - Grid power. For electricity that is consumed in the respective calendar year from source(s) other than those described in Options 2 and 3, the electricity has an emissions profile that reflects the annual average emissions intensity of electricity in the eGRID subregion (see **Figure 2**) that the facility is located in, as determined by 40BSAF-GREET 2024. This applies to both SAF production facilities and, in the case of ATJ-Ethanol pathways, ethanol production facilities because users must provide electricity consumption totals and source(s) as foreground data for these facilities. To align with California LCFS, 40BSAF-GREET 2024 characterizes the emissions of electricity supplied by eGRID subregions based on the share of electricity supplied by each type of power generator modeled in R&D GREET in the respective regions and an assumption that 4.9% of electricity generated is lost in transmission and distribution. The share of electricity supplied by each type of power generator in each eGRID subregion in 40BSAF-GREET 2024 is based on the EPA eGRID data.[10]

[9] Lookup Table pathways are listed in section 95488.1(b) of the California LCFS regulation. Zero-CI sources are specified in section 95488.1(b)(2)(A).
[10] Emission factors are based on 2021 eGRID data, which is consistent with the 2024 California Air Resources Board's *Proposed Amendments to the Low Carbon Fuel Standard Regulation.* eGRID data is available here: https://www.epa.gov/egrid

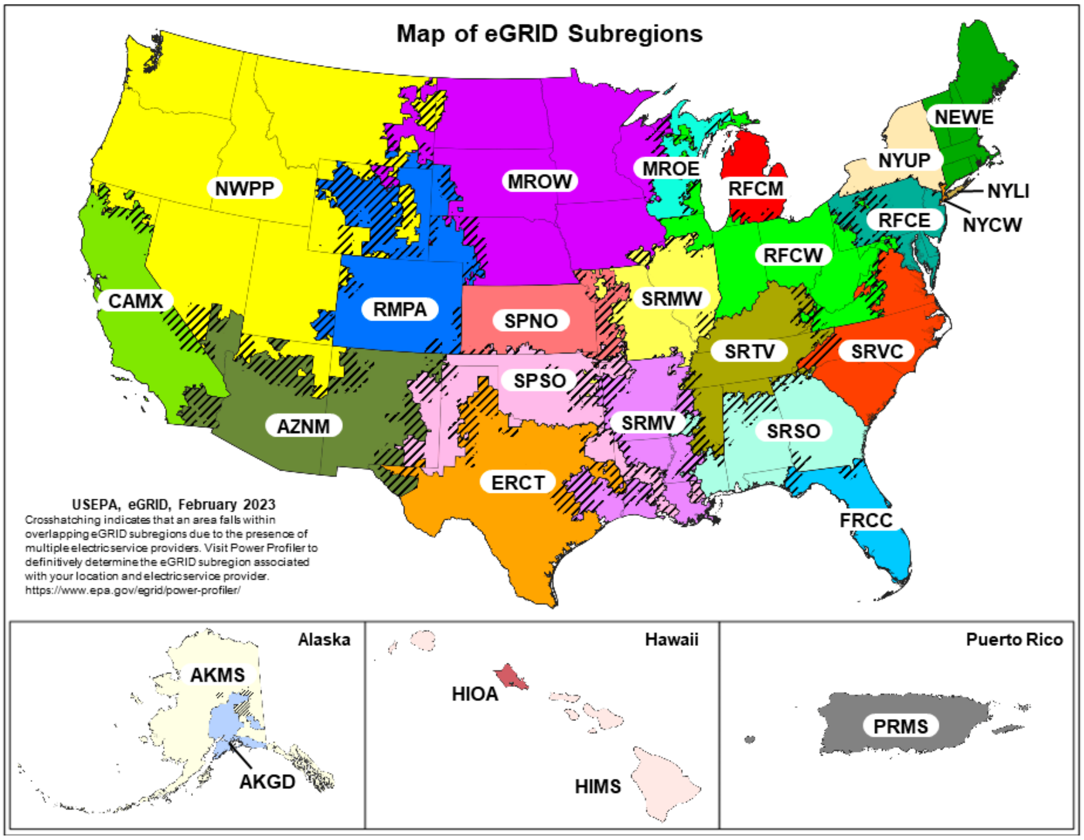

Figure 2: eGRID Subregions[11]

Option 2 – Specific source power. 40BSAF-GREET 2024 allows users to use an emissions rate associated with a given type of generator or combination of generators, provided that any electricity that is claimed to be sourced from the subject generator(s) in a given calendar year is verified via the purchase and retirement of RECs that meet specified criteria described in more detail below. These criteria align with the methodology established in the California LCFS (book-and-claim accounting for electricity is primarily addressed in CCR title 17, section 95488.8[I]). Eligible RECs are those purchased within a facility's local balancing authority from zero-CI RPS-eligible generators as defined in the California LCFS, which are assigned a GHG-intensity of zero in 40BSAF-GREET 2024. Specifically, this includes all California RPS-eligible generator types as defined in California Public Utilities Code sections 399.11-399.36 *except* biomass, biomethane, geothermal, and municipal solid waste, which are not considered zero-CI by the California LCFS. Generator types that are considered zero-CI RPS-eligible as defined in California LCFS include solar thermal, solar photovoltaic, wind, RPS-eligible hydroelectric generation, ocean wave, ocean thermal, and tidal current.

[11] Source: https://www.epa.gov/egrid/maps

Although California LCFS does offer a separate option for the purchases of RECs that include non-RPS-eligible generators (i.e., low-CI generators, such as nuclear power and fossil fuel-fired generators with carbon capture and sequestration), this requires applicants to pursue a Tier 2 LCFS pathway application process rather than the simpler Tier 1 LCFS process. Unlike the Tier 1 application process, which requires the submission of a discrete set of inputs in order to calculate the carbon intensity, the Tier 2 application process does not have a complete set of predetermined site-specific input fields and requires a detailed Life Cycle Analysis Report for the facility, as well as a public comment period.[12] Because of the short timeframe for the 40B tax credit relative to the timeline for the Tier 2 application process, users of 40BSAF-GREET 2024 are limited to zero-CI RPS-eligible generators only. As consistent with the California LCFS, the difference between electricity consumed and RECs purchased is calculated over a three-quarter (9 month) time period. A user-friendly guide to book-and-claim electricity accounting under the California LCFS is provided in LCFS Guidance 19-01.[13] In addition, in order to claim zero CI electricity in 40BSAF-GREET 2024, generators supplying power through RECs must have a commercial operations date (COD)[14] no earlier than 36 months prior to the placed in service (PIS)[15] date of the SAF (or ethanol) facility that is purchasing the RECs. In summary, before entering specified source power (RECs, in this case) into 40BSAF-GREET 2024, ethanol or SAF facilities must obtain and retire RECs from generators that:

- are located within the local balancing authority for the facility,
- have a COD no earlier than 36 months before the PIS date for the SAF (or ethanol) facility that is purchasing the RECs,
- are California RPS-eligible generators excluding biomass, biomethane, geothermal, and municipal solid waste (nuclear power and fossil fuel generators with CCS are also ineligible).

Option 3 – Behind-the-meter electricity. Accounting for behind-the-meter (BTM) renewable electricity generation also aligns with the California LCFS and requires monthly reporting of electricity generation and consumption, as described in the LCFS regulations (Cal. Code Regs. Tit. 17, § 95488.8, further described in guidance provided in LCFS Guidance 19-01[13]). Users may account for BTM power to the amount needed to meet 100% of a facility's needs, but users may not enter a net negative electricity consumption value, even if the

[12] Cal. Code Regs. Tit. 17, § 95488.7. Additional information on Tier 1 and Tier 2 application processes is provided by the California Air Resources Board: https://ww2.arb.ca.gov/resources/documents/apply-lcfs-fuel-pathway

[13] Low Carbon Fuel Standard Guidance 19-01 Book-and-Claim Accounting for Low-CI Electricity. https://ww2.arb.ca.gov/sites/default/files/2022-12/19-01_updated%20for%20WREGIS%20changes_ADA.pdf.

[14] The term commercial operations date or COD means the date on which a facility that generates electricity begins commercial operations.

[15] The placed in service (PIS) date of a facility is distinct from commercial operations date (COD).

facility is a net exporter of electricity. Any fuels consumed for generation of BTM electricity generation are included in the ethanol or SAF facility's energy balance as entered as user inputs to 40BSAF-GREET 2024. This ensures that BTM power supplied through an on-site combined heat and power system is properly accounted for in the facility's overall mass and energy balance. On-site solar and wind electricity generation that has a COD no earlier than 36 months before the PIS date of the SAF (or ethanol) facility for which the generation is behind the meter may also be included in reported BTM electricity supply and is treated as zero-emission within 40BSAF-GREET 2024.

2.4.2 Renewable Natural Gas

SAF production facilities typically require natural gas or renewable natural gas (RNG), which can be combusted to generate process heat and/or electricity. Natural gas or RNG can also be reformed to hydrogen via steam methane reforming (SMR). 40BSAF-GREET 2024 enables users to take credit for the use of directly supplied RNG (see **Table 2**), provided that the supplied RNG is sourced from landfill gas and constitutes the first productive use of that gas, as consistent with the proposed rules provided in the Notice of Proposed Rulemaking for the section 45V credit for production of clean hydrogen (45V NPRM).[16] Productive use is generally defined as any valuable application of biogas (to provide heat or cooling, generate electricity, or be upgraded and sold as RNG), and specifically excludes venting to the atmosphere or capture and flaring. Within 40BSAF-GREET 2024, only ethanol and SAF production facilities may claim credit for RNG use. Ethanol and SAF producers may not claim credit for a reduced GHG intensity associated with any RNG purchased via book-and-claim in 40BSAF-GREET, regardless of source. In summary, when claiming reduced GHG intensity due to RNG, enter RNG that meets the following three criteria into 40BSAF-GREET 2024:

- Originates from landfill gas.
- Originates from a source that has not previously used the methane portion of the biogas productively (to supply electricity or thermal energy on-site or sold to another entity).
- Is directly supplied to the ethanol or SAF facility (not supplied via book-and-claim).

In cases where RNG or biogas is consumed and does not meet all three of these requirements, include the quantity consumed in the natural gas user input for 40BSAF-GREET 2024. Creditable RNG that does meet all three requirements is entered in the RNG (landfill gas) user input.

2.4.3 Hydrogen

SAF production facilities require hydrogen as an input, which can be produced on-site or imported from a separate facility. Smaller facilities are more likely to import hydrogen,

[16] Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property. 88 Fed. Reg. 89220, 89238-39 (Dec. 26, 2023).

whereas larger SAF production facilities may operate a steam methane reformer or other hydrogen production system on-site. SAF production facilities purchasing hydrogen from an offsite facility will enter their hydrogen consumption as foreground data in 40BSAF-GREET 2024. The user may enter the quantity of hydrogen consumed from two possible sources: hydrogen derived from steam methane reforming (SMR) of fossil natural gas without carbon capture and sequestration, or hydrogen produced by a pathway represented in 45VH2-GREET. Any hydrogen from SMR without carbon capture and sequestration imported from an offsite production facility is entered in the fossil natural gas-derived hydrogen input cell. If a SAF producer intends to claim credit for purchasing hydrogen produced by any other approach at an offsite hydrogen production facility, the well-to-gate GHG intensity of that hydrogen must be calculated using the latest version of 45VH2-GREET[17] and entered as foreground data to 40BSAF-GREET 2024, along with the quantity imported. Users must also indicate the distance hydrogen is transported by each mode[18] from the hydrogen production facility to the SAF production facility. 40BSAF-GREET 2024 will use background data to calculate the emissions footprint for the transportation and additional compression, as required. If a SAF production facility generates its own hydrogen on-site, that quantity of hydrogen should not be entered separately into 40BSAF-GREET 2024 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, or RNG required for on-site hydrogen production is to be included in the reported facility energy consumption for the taxable year.

2.4.4 Carbon Capture and Sequestration

Carbon capture and geologic sequestration (CCS) is incorporated into 40BSAF-GREET 2024 for ethanol production facilities that supply ethanol as an intermediate to SAF production. CCS is included in 40BSAF-GREET 2024 for ethanol specifically because these facilities were deemed most likely to be capable of implementing CCS, in part because the fermentation of sugars to ethanol produces a relatively pure CO_2 stream that is comparatively inexpensive to capture and store. Total quantity of CO_2 captured and stored is a user input in 40BSAF-GREET 2024; users must enter the annual quantity of CO_2 captured and stored in U.S. Class VI wells (calculated for the taxable year). CO_2 capture and use in other applications, such as enhanced oil recovery or incorporation into a product, is not included as an option for reducing the GHG intensity of SAF in 40BSAF-GREET 2024.

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[17] https://www.energy.gov/sites/default/files/2023-12/greet-manual_2023-12-20.pdf

[18] Note that, if users enter any non-zero value for the share of tube trailer and/or liquid truck transport for hydrogen, regardless of the distance entered, 40BSAF-GREET 2024 will add the fixed energy and emissions footprint associated with compression and/or liquefaction of the hydrogen as applicable for the given mode(s).

2.4.5 Transportation Distances and Mode Share

40BSAF-GREET 2024 requires foreground data for the transport of ethanol to SAF production facilities (for ATJ-Ethanol pathways only), hydrogen from off-site production facilities to SAF production facilities (for all pathways that import hydrogen), and the transport of SAF to blending terminals. There are two types of input required for all foreground transportation data in 40BSAF-GREET 2024: 1) the distance traveled for each mode (e.g., barge, rail, truck) and 2) the share of input/product transported by that mode. For example, if 100% of the SAF product is transported by truck to a blending terminal 200 miles from the SAF production facility, the user would enter 100% in the share column of the transportation data table and 200 miles in the distance column of the table for truck transportation. If half of the SAF is transported by rail to a blending terminal 800 miles away and half of the SAF is transported by truck to a blending terminal 300 miles away, the user would enter a 50% share and the respective distances for each mode (truck and rail). Transportation distances and modes for fats and oils used in HEFA facilities are not included in foreground data in 40BSAF-GREET 2024 because HEFA facilities are likely to purchase these feedstocks from a larger number of facilities and the source locations and distance were determined to be burdensome to verify for the purposes of the 40B tax credit. Instead, 40BSAF-GREET 2024 includes national average assumptions for the transportation distance and modes.

2.4.6 Ethanol Production for Alcohol-to-Jet Pathways

Ethanol production facilities that supply ethanol for ATJ-Ethanol pathways are required to supply foreground data comparable to what is required of SAF production facilities. ATJ-Ethanol facilities are likely to source from a relatively small number of ethanol production facilities, most of which are already subject to the California LCFS verification process or another comparable verification process. Ethanol production facilities are also able to reduce their calculated life cycle GHG footprint in 40BSAF-GREET 2024 by pursuing many of the decarbonization options described above (RECs, BTM power, RNG, and CCS). Brazilian sugarcane ethanol facilities, however, may not claim the purchase of RECs or CCS in 40BSAF-GREET 2024 because the market for International Renewable Energy Credits (I-RECs) in Brazil is nascent and there is not yet a regulatory framework in Brazil for CO_2 injection wells comparable to Class VI wells in the U.S.

2.5 Additional Background Data in 40BSAF-GREET 2024

Background data in 40BSAF-GREET 2024 is itemized in the dependency file in the downloaded tool package. For convenience, examples of background data values are described in the subsequent sections.

2.5.1 Upstream Methane Emissions for Natural Gas

40BSAF-GREET 2024 assumes that methane leakage during the natural gas recovery process and subsequent gas processing and transmission sums to ~0.9% of methane consumed by the reformer. 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.[19]

2.5.2 Examples of Key Background Data in 40BSAF-GREET 2024

- All crop-based oil crushing facility data is assumed as background including energy and chemical inputs. SAF production facilities may draw from a variety of crushing facilities and verification of detailed practices at each facility is impractical for certification.
- Transport distances and modes for soybean oil, canola/rapeseed oil, and waste oils and fats used in HEFA production facilities are assigned with estimated national average values.
- All farm-based data for conventional farming practices in GREET are background data.
- Non-liquid fuel co-products and co-product yields are assumed to be background data based on facility models.

2.5.3 Indirect Effects GHG Emissions Modeling

The 40BSAF-GREET 2024 model relies on GHG emissions modeling of indirect effects from changes in activities from the GTAP-BIO model and emission profiles of activities from different sources. Indirect effects include induced land use changes (ILUC), changes in non-feedstock crop production (including rice paddy field methane emissions, which are reported separately), and changes in livestock production. New GTAP-BIO modeling runs were performed to serve as the basis for indirect emissions for the pathways in 40BSAF-GREET 2024 that include indirect effects, such as soy oil and canola oil HEFA, and corn and sugarcane ATJ-Ethanol. Therefore, these modeling runs were performed on U.S. corn, U.S. soybeans, U.S. and Canadian canola/rapeseed, and Brazilian sugarcane. The resulting emissions can be seen in the indirect effects field in 40BSAF-GREET 2024 and are summarized in Table 3a and Table 3b. Additional details on GTAP-BIO modeling and these emissions profiles can be found in ANL technical documentation, *Development of R&D GREET 2023 Rev1 to Estimate Greenhouse Gas Emissions of Sustainable Aviation Fuels for 40B Provision of the Inflation Reduction Act*, hereon referred to as the "R&D GREET 2023 Rev1 Technical Report," available at: https://greet.anl.gov/files/greet-2023rev1-summary.

[19] Wang et al. (2023). Summary of Expansions and Updates in R&D GREET 2023. https://greet.anl.gov/publication-greet-2023-summary.

Table 3a. Adjusted indirect effects for the SAF pathways in 40BSAF-GREET 2024 (in g CO_2e per bushel of corn/soybeans and g CO_2e per metric ton of canola/sugarcane)

	SAF Pathway (g CO_2e per unit feedstock)			
	Soy Oil HEFA	Canola Oil HEFA	Corn ATJ-Ethanol	Brazilian Sugarcane ATJ-Ethanol
ILUC	2,366.8	675,828.7	2,057.3	17,619.1
Non-Feedstock Crops (Excluding Rice Paddy Methane)	682.6	221,961.8	859.6	-5,005.0
Livestock	263.9	2,745.4	-322.8	-2,597.2
Rice Paddy Methane	-155.9	-12133.8	-67.8	-240.2
Total	3,157.4	888,402.0	2,526.2	9,776.6

Table 3b. Adjusted indirect effects for the SAF pathways in 40BSAF-GREET (estimated in g CO_2e per MJ SAF using sample yields for each pathway)

	SAF Pathway (g CO_2e per MJ SAF)			
	Soy Oil HEFA	Canola Oil HEFA	Corn ATJ-Ethanol	Brazilian Sugarcane ATJ-Ethanol
ILUC	12.2	18.1	9.0	10.6
Non-Feedstock Crops (Excluding Rice Paddy Methane)	3.5	5.9	3.8	-3.0
Livestock	1.4	0.1	-1.4	-1.6
Rice Paddy Methane	-0.8	-0.3	-0.3	-0.1
Total	16.2	23.7	11.1	5.9

Facility-level SAF conversion efficiency based on user inputs is applied to adjust the indirect effects to reflect facility-specific yields as documented in the R&D GREET 2023 Rev1 Technical Report.

2.6 Co-Product Allocation Methods

SAF production processes may yield co-products that are also valorized (i.e., sold by the oil, ethanol, or SAF producer or otherwise productively used). For those co-products that have actually been valorized, 40BSAF-GREET 2024 allows for users to account for certain co-products in the life cycle GHG emissions of the SAF production facility.

Users may only account for a co-product if it has been valorized in a process downstream of the SAF production facility; co-products that were produced but not valorized may not be allocated emissions in the life cycle GHG emissions calculation of produced SAF.[20] 40BSAF-GREET 2024 uses multiple allocation methods following the default assumptions in R&D GREET 2023, 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.[21] **Table 4** itemizes the co-products that can be simulated in 40BSAF-GREET 2024 and the approach used to account for them.

Table 4: Co-products in 40BSAF-GREET 2024 and accounting mechanisms

Production Process(es)	Co-Product	Accounting Mechanism
Corn ethanol for ATJ-Ethanol	Distillers grains	System expansion
Corn ethanol / distillers corn oil for HEFA	Distillers corn oil	Marginal approach, allocating only oil extraction burden to distillers corn oil
Soy/canola oil for HEFA	Oil and meals	Mass-based allocation
HEFA	Naphtha	Energy-based allocation
HEFA	Liquefied Petroleum Gas (LPG)	Energy-based allocation
HEFA	Propane	Energy-based allocation
HEFA	Diesel	Energy-based allocation

Section 3. User Instructions

40BSAF-GREET 2024 is available in Excel form at: https://www.energy.gov/eere/greet

3.1 40BSAF-GREET 2024 Setup

When the 40BSAF-GREET 2024 package is downloaded from Argonne, it will come in a compressed .zip package. To work with 40BSAF-GREET 2024, 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 40BSAF-GREET 2024 Excel file

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

and a subfolder "GREET1 Dependency," which contains the GREET1 model, entitled "GREET1_2023_Rev1," used to run the life cycle analysis (LCA) in 40BSAF-GREET 2024.

When the package is first downloaded, Excel will automatically be blocked from running macros. For 40BSAF-GREET 2024 to operate correctly, users need to right click the 40BSAF-GREET 2024 file and click "Properties." At the bottom of the opened properties window, the user should click "Unblock" and "Apply" to allow macros to run within the file (**Figure 3**). This step needs to be done only once, for both the 40BSAF-GREET 2024 and GREET1_2023_Rev1 files.

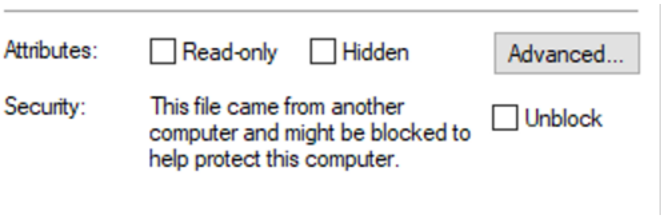

Figure 3. Unblocking file to allow macros

The first time the 40BSAF-GREET 2024 file is opened, users may need to enable editing and disable protected view. A message will appear as a yellow banner at the top of the Excel file. Click Enable Editing to allow the file to load properly (**Figure 4**).

Figure 4. Enable editing message

The 40BSAF-GREET 2024 and accompanying GREET1_2023_Rev1 file are sensitive to file name changes or file path changes. While the package can be moved, users should not remove the GREET1_2023_Rev1 file from the GREET1 dependency folder. The dependency folder must be placed in the same location as the 40BSAF-GREET 2024 file. In addition, neither the file nor the GREET1 dependency folder should be renamed, as 40BSAF-GREET 2024 relies on the naming conventions of the files to work correctly.

When 40BSAF-GREET2024 is loaded, it will attempt to load the GREET1_2023_Rev1 file and connect to it. If it cannot find the GREET1_2023_Rev1 file, a popup will warn users of the failed connection (**Figure 5**).

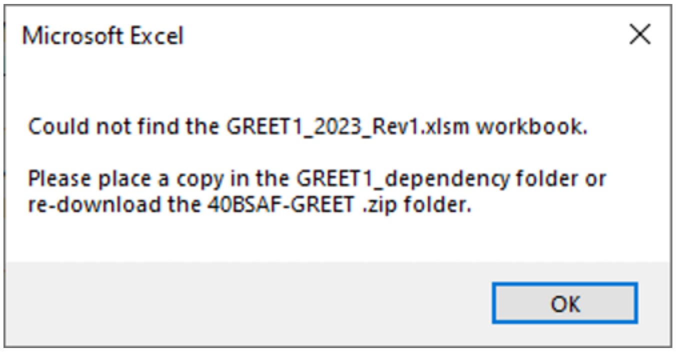

Figure 5. Error message warning that GREET1_2023_Rev1 file could not be located

If this occurs, users must exit 40BSAF-GREET 2024 and replace the GREET1_2023_Rev1 file located in the GREET1 dependency subfolder.

3.2 40BSAF-GREET 2024 Overview

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

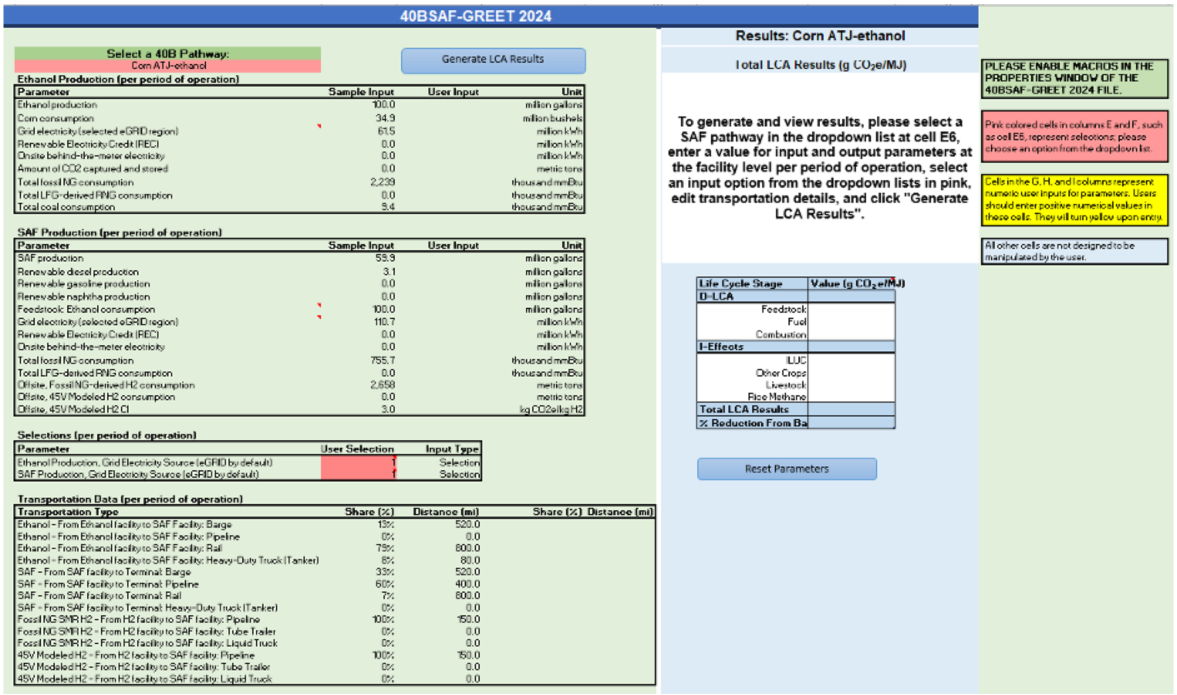

Figure 6. Dashboard, which serves as the user interface to control the model

3.2.1 Operation of 40BSAF-GREET 2024

40BSAF-GREET 2024 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 are not used in modeling in any way. Additionally, 40BSAF-GREET 2024 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 information and results, and are not to be modified by the user. These instructions are present on the righthand side of the model. To generate results for a pathway, users should follow the steps outlined below to input their data.

First, users select a pathway to load. Cell E6 provides a dropdown list of supported 40BSAF-GREET 2024 pathways: Corn and Sugarcane ATJ-Ethanol, and Distillers Corn Oil, Tallow, UCO, Canola, or Soybean HEFA (**Figure 7**). The User Input section will be populated with default inputs for the selected pathway. There is a small delay as Excel populates the User Input section; users should avoid interacting with Excel until the inputs are fully loaded.

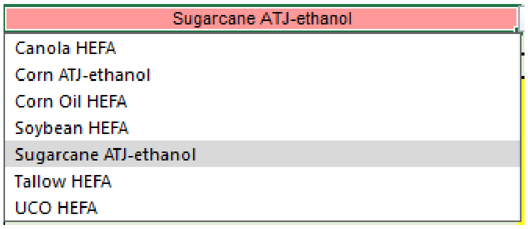

Figure 7. Dropdown list of available pathways in 40BSAF-GREET 2024

Users must input their own foreground data within the User Inputs section. For the purposes of the 40B tax credit, there is *no* option to take default foreground values (despite default values being displayed under "Sample Input"). Inputs are broken down into distinct categories: ethanol production, SAF production, pathway-wide selections, and transportation information. Note that ethanol production parameters are only available for the Corn ATJ-Ethanol and Sugarcane ATJ-Ethanol pathways. Additionally, all parameters are input as values per period of operation (which is the taxable year).

"Selections" consist of grid electricity source options for the ethanol (where applicable) and SAF production facilities. Selections consist of a Parameter name to describe what the specific selection applies to; a User Selection, including the GREET default input; and an Input Type that defines whether the input is a selection or a numerical entry.

Hovering over the input value of a pink dropdown list selection will provide a comment description indicating which numerical option corresponds to each eGRID region. All pathways include options for the SAF production facility electricity source. Corn ATJ-Ethanol also includes options for corn ethanol facility electricity production source (**Figure 8**). Note that the default electricity source is the AKGD eGRID subregion; eGRID subregion selection must be changed to the region where the applicable facility is located.

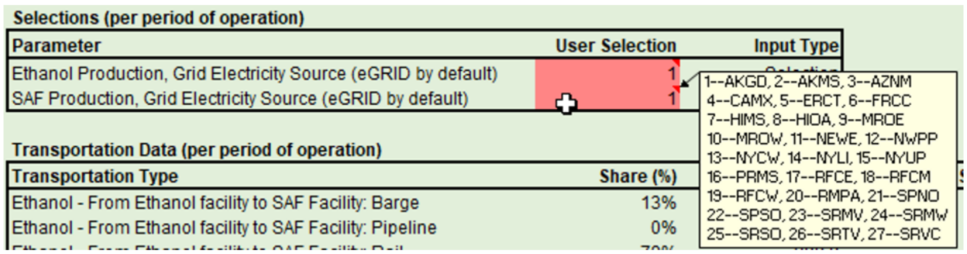

Figure 8. Selections available for the Corn ATJ-Ethanol process (hovering over the cells under "User Selection" reveals the available eGRID regions and corresponding numbers)

The "SAF Production" section requires users to input foreground life cycle inventory (LCI) data for the selected pathway (**Figure 9**) under "User Input". A list of GREET sample data points for reference and functionality testing *only* will be displayed under "Sample Input". The required unit of the user-provided parameter is displayed under "Unit". All values are per operational period (taxable year). Energy parameters for natural gas, RNG, coal, and residual oil consumption are to be entered on an LHV basis. Users have the option of sourcing natural gas from landfill gas (LFG) or fossil natural gas (NG), or a mixture of both. Hydrogen consumed can be sourced from fossil NG reforming without CCS or from a source with a user-defined carbon intensity as determined in accordance with the 45V NPRM using 45VH2-GREET ("45V Modeled H2"). As noted above, 45V Modeled H2 must have an associated carbon intensity (CI) obtained using the latest version of 45VH2-GREET. Users should make sure their inputs are in the correct units, as specified under "Unit" in the table.

SAF Production (per period of operation)			
Parameter	**Sample Input**	**User Input**	**Unit**
SAF production	59.9		million gallons
Renewable diesel production	3.1		million gallons
Renewable gasoline production	0.0		million gallons
Renewable naphtha production	0.0		million gallons
Feedstock: Ethanol consumption	100.0		million gallons
Grid electricity (selected eGRID region)	110.7		million kWh
Renewable Electricity Credit (REC)	0.0		million kWh
Onsite behind-the-meter electricity	0.0		million kWh
Total fossil NG consumption	755.7		thousand mmBtu
Total LFG-derived RNG consumption	0.0		thousand mmBtu
Offsite, Fossil NG-derived H2 consumption	2,658		metric tons
Offsite, 45V Modeled H2 consumption	0.0		metric tons
Offsite, 45V Modeled H2 CI	3.0		kg CO2e/kg H2

Figure 9. Inputs for SAF Production section for Corn ATJ-Ethanol

In addition to the foreground data required for SAF production, ATJ-Ethanol pathways also require foreground data for ethanol production. If ethanol is sourced from multiple production facilities, users should calculate inputs based on a weighted average across all production facilities based on the quantity of ethanol procured from each one. The Ethanol Production section (**Figure 10**) provides parameters for the user to specify information about the ethanol production process of these pathways. Note that different parameters may use different units. All parameters are per period of operation.

Ethanol Production (per period of operation)			
Parameter	**Sample Input**	**User Input**	**Unit**
Ethanol production	100.0		million gallons
Corn consumption	34.9		million bushels
Grid electricity (selected eGRID region)	61.5		million kWh
Renewable Electricity Credit (REC)	0.0		million kWh
Onsite behind-the-meter electricity	0.0		million kWh
Amount of CO2 captured and stored	0.0		metric tons
Total fossil NG consumption	2,239		thousand mmBtu
Total LFG-derived RNG consumption	0.0		thousand mmBtu
Total coal consumption	9.4		thousand mmBtu

Figure 10. Inputs for Ethanol Production for Corn ATJ-ethanol

40BSAF-GREET 2024 allows users to adjust transportation modes and distances for ethanol (where applicable) and SAF. Transportation information is included for SAF transportation from facility to the blending terminal (background data is used for transportation of SAF-containing blends to airports) (**Figure 11**). For hydrogen purchased from an off-site facility, transportation distances and modes are also included. If no hydrogen is imported from off-site facilities, the mode share percentages must still be populated with values that sum to 100% to prevent 40BSAF-GREET 2024 from generating an error message. Inputs are separated into two columns: Columns F and H include the volumetric share of SAF for the specific transportation type (samples and required user inputs, respectively), and columns G and I include the distance for that transportation type (samples and required user inputs, respectively). Note that share percentages should be entered as a percentage rather than a decimal value. (e.g., 55%, not 0.55 or 55). The transportation distance should be entered in miles.

Transportation Data (per period of operation)

Transportation Type	Share (%)	Distance (mi)	Share (%)	Distance (mi)
Ethanol - From Ethanol facility to SAF Facility: Barge	13%	520.0		
Ethanol - From Ethanol facility to SAF Facility: Pipeline	0%	0.0		
Ethanol - From Ethanol facility to SAF Facility: Rail	79%	800.0		
Ethanol - From Ethanol facility to SAF Facility: Heavy-Duty Truck (Tanker)	8%	80.0		
SAF - From SAF facility to Terminal: Barge	33%	520.0		
SAF - From SAF facility to Terminal: Pipeline	60%	400.0		
SAF - From SAF facility to Terminal: Rail	7%	800.0		
SAF - From SAF facility to Terminal: Heavy-Duty Truck (Tanker)	0%	0.0		
Fossil NG SMR H2 - From H2 facility to SAF facility: Pipeline	100%	150.0		
Fossil NG SMR H2 - From H2 facility to SAF facility: Tube Trailer	0%	0.0		
Fossil NG SMR H2 - From H2 facility to SAF facility: Liquid Truck	0%	0.0		
45V Modeled H2 - From H2 facility to SAF facility: Pipeline	100%	150.0		
45V Modeled H2 - From H2 facility to SAF facility: Tube Trailer	0%	0.0		
45V Modeled H2 - From H2 facility to SAF facility: Liquid Truck	0%	0.0		

Figure 11. Transportation data inputs for Corn ATJ-Ethanol

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 40BSAF-GREET 2024 and the GREET1_2023_Rev1 backend file to calculate the LCA results for the pathway. When results are calculated, a graph will appear in the blue Results section, and the results table will be populated (Figure 12). The results graph shows the Total LCA Results as a text box at the top of the column that includes both direct life cycle assessment (D-LCA) and Indirect Effects. To see the individual contribution of a particular life cycle stage, users can either hover over a color in the column graph or review the life cycle results in Figure 12 below. 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. The results graph and table are reported in g CO_2e/MJ total liquid fuel.

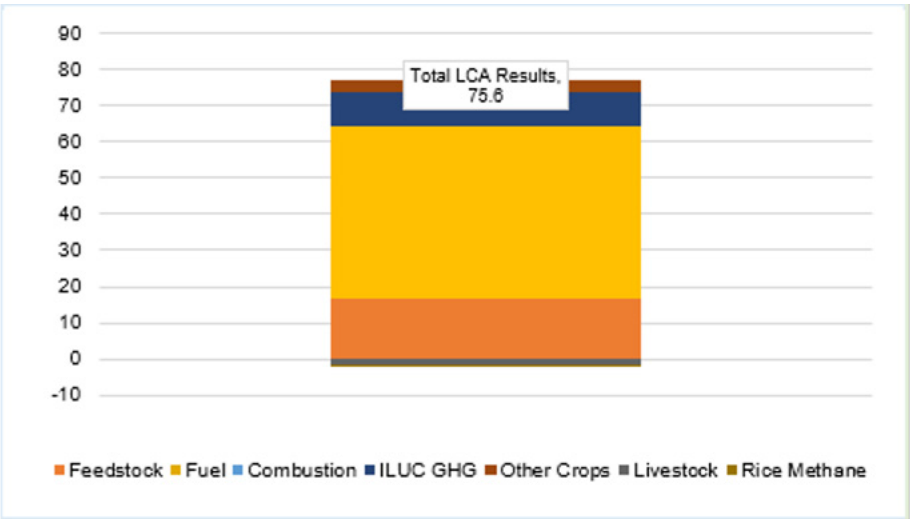

Figure 12. Sample results graph generated for the Corn ATJ-Ethanol pathway using all sample inputs as user inputs (the graph shows the total LCA result, but also has the breakdown of emissions based on life cycle stage)

The Life Cycle GHG Results Table (**Figure 13**) breaks the results down by life cycle stage. 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 SAF. 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 Fuel, Feedstock, and Combustion categories. “Feedstock” emissions include growing, harvesting, transporting, and processing primary feedstock material (e.g., corn for corn ethanol, soybeans for soybean oil HEFA). For Sugarcane ATJ-Ethanol and corn ATJ-Ethanol, ethanol production and transport are also included in the “Feedstock” category. The “Fuel” category includes the transport of intermediates to SAF facilities. Emissions associated with operating the SAF production facility itself are included in the “Fuel” category for all pathways. The “Fuel” category also includes transportation of the finished SAF to blending terminals and airports. The only component included in the “Combustion” category is the non-CO_2 emissions from SAF combustion.[22] The value for “Combustion” is non-zero, but typically very small and may appear to be zero depending on how many decimal points are shown in the cell. Note that waste fat/oil feedstocks (UCO and tallow) do not have

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

"Feedstock" emissions because 40BSAF-GREET 2024 does not assign any burdens to the production of these waste feedstocks and the transportation of these feedstocks to HEFA plants is included in the "Fuel" category. For Distillers corn oil from dry mill ethanol plants, the "Feedstock" emissions only include marginal emissions associated with the oil extraction process.

The indirect effects include four sources of modeled emissions for the four SAF feedstocks requiring dedicated land for production (i.e., corn, soybeans, canola, sugarcane). "ILUC" GHG emissions stem from new cropland being brought into production to meet demand for the SAF feedstock from other land cover types as well as market-driven shifts in the type and location of existing cropland. Other crops emissions include emissions from fertilizer inputs and on farm energy use associated with modeled changes in the production of crops other than the SAF feedstock. These emissions could be positive or negative depending on the net changes in the levels of production of other crops as well as the relative emissions intensities of production of those crops. Livestock emissions are CH_4 emissions from enteric fermentation and CH_4 and N_2O emissions from manure management corresponding to modeled changes in the amount and type of livestock in the agricultural system stemming from increased demand for SAF feedstocks. This effect may be positive or negative depending on each modeled scenario's estimate of the changes in livestock production. Rice methane emissions correspond to methane emissions from the flooding of rice paddy fields corresponding to modeled changes in rice production. This impact is negative in all cases as rice production is assumed to decrease in each scenario. R&D GREET 2023 Rev1 Technical Report[23] and accompanying appendices includes a detailed overviews of the four modeled scenarios and descriptions of results. The D-LCA and Indirect Effects results are summed together to give the Total LCA Results for the pathway. Note that Indirect Effects are only present for Corn ATJ-Ethanol, Soybean HEFA, Canola HEFA, and Sugarcane ATJ-Ethanol. Tallow HEFA, UCO HEFA, and Distillers Corn Oil HEFA do not have Indirect Effects because they are derived from byproducts/wastes rather than purpose-grown crops, and the corresponding section of the results table will be blank. The Results Table also includes a percentage reduction value from the Baseline CI of 89.0 g CO_2e/MJ.

[23] https://greet.anl.gov/files/greet-2023rev1-summary

Life Cycle Stage	Value (g CO_2e/MJ)
D-LCA	64.6
Feedstock	16.7
Fuel	47.8
Combustion	0.0
I-Effects	11.1
ILUC	9.0
Other Crops	3.8
Livestock	-1.4
Rice Methane	-0.3
Total LCA Results	75.6
% Reduction From Ba	15.0%

Figure 13. The Life Cycle GHG Results Table after running the Corn ATJ-Ethanol pathway using all sample inputs as user inputs. Results are shown by life cycle stage and summed to provide total emissions for the D-LCA, Indirect Effects (I-Effects), and the Total LCA Results

3.3 Other Supporting Features and Information

40BSAF-GREET 2024 includes several other features to assist users. 40BSAF-GREET2024 does include default values (Sample Inputs) *for the purposes of testing model functionality only.* These default values should not be used for the purposes of generating a user's life cycle GHG intensity. 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. This feature also resets the results, requiring the users to run 40BSAF-GREET 2024 again to show results. Also, if the user switches from one 40BSAF-GREET 2024 pathway to another, the GREET defaults will be restored. A pop-up message will inform the user as the model quickly resets to defaults. Users should avoid interacting with Excel while the module is restoring the GREET 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 40BSAF-GREET 2024 is closed, the GREET1_2023_Rev1 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. While the 40BSAF-GREET 2024 Excel file can be saved, it will restore to defaults for the selected pathway upon loading. Finally, users should NOT attempt to save the GREET1_2023_Rev1 Excel file after modeling. The GREET1_2023_Rev1 file is automatically closed without saving when the 40BSAF-GREET2024 Excel file is closed to preserve the GREET formulas and default data. If users accidentally save over the GREET1_2023_Rev1 file, they will need to replace it with the GREET1_2023_Rev1 file from the downloaded 40BSAF-GREET 2024 Package to restore default values and ensure accurate modeling.

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For more information, visit energy.gov/eere/greet

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