GREET tutorial:

The purpose of this tutorial is to provide a step-by-step guide for checking GHG emission results for bio-ethanol production. It was designed with reference to the official training materials provided by Argonne National Laboratory. For the latest updates, please refer to this link:
https://greet.anl.gov/greet_train_the_trainer

Step 1 - Download R&D GREET 2024 Rev. 1

1. Go to Argonne's GREET Website: https://greet.anl.gov/greet_1_series.
1. Enter your information and select Submit.
2. Click on ***R&D GREET_2024 Rev1.zip*** and download the file.
3. Once the model is downloaded, extract the contents to any folder that is not the Downloads folder.
4. Right-click on each of the Excel files in your newly extracted folder, select properties, check "Unblock," then select "Apply".

When you open the folder, you will find the following files:

Name	Type	Compressed size	Password ...	Size
CCLUB_2024_Rev1	Microsoft Excel Macro-En...	16,266 KB	No	17,126 KB
R&D GREET1_2024_Rev1	Microsoft Excel Macro-En...	23,372 KB	No	24,570 KB
R&D GREET2_2024_Rev1	Microsoft Excel Macro-En...	5,152 KB	No	5,596 KB
STOCHASTIC	Microsoft Excel Add-In	527 KB	No	1,718 KB

- R&D GREET 1: fuel cycle (or WTW) model of vehicle technologies and transportation fuels.
- R&D GREET 2: vehicle manufacturing cycle model of vehicle technologies.
- CCLUB: land-use and land-management changes.
- Stochastic Toolkit: running stochastic analyses and determining error bars on LCA estimates.

We will use ***R&D GREET 1_2024_Rev1.xlsm***. Note: The Excel model should be opened as a macro-enabled file to ensure proper functionality.

Step 2 - GREET 1 Model Structure

1. **The overview sheet**

When you open the Excel file, the first sheet is the ***Overview***, containing the GREET copyright statement. It also presents a brief summary of each worksheet and is intended to provide a brief introduction to the functions of each sheet.

To become familiar with this sheet, watch the YouTube video "Bidges Case Study Resources - Aviation Fuel" from 0*2:35 to 06:33*.

In this tutorial, we will utilize the following sheets:

- The ***Input*** Sheet: presents key variables for various well-to-pump (WTP) and pump-to-wheels (PTW) scenarios, and specifies key parametric assumptions for GREET simulations.
- The ***Result*** Sheet: presents results for vehicle/fuel options included in the GREET model. The sheet consists of three sections: well-to-pump, well-to-wheels, and well-to-wheels energy Use and Emissions sections.
- The ***EtOH*** Sheet: calculates energy use and emission rates for ethanol production from various biomass feedstocks, covering farming, transportation, ethanol production, transportation, distribution, and storage of the ethanol fuel.

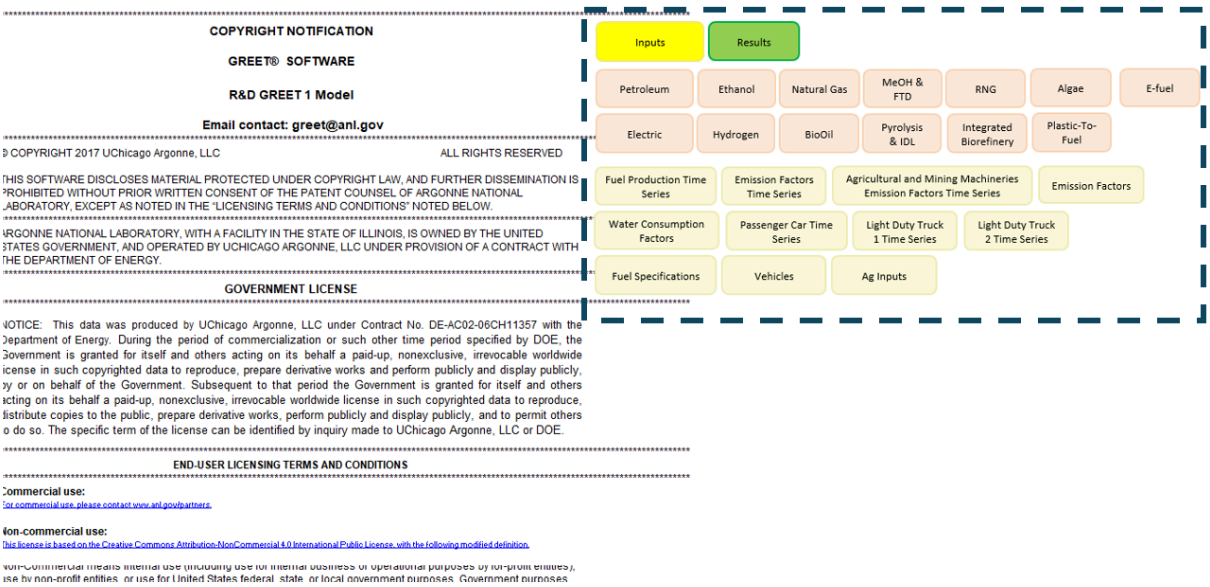


Figure 1: The overview of sheets in the GREET model.

Note: For more details on each sheet, please refer to the ***Operating Manual for GREET***, which can be downloaded here: https://greet.anl.gov/greet_1_series (see the Documents section).

Step 3 - Find the General Settings to Alter an Ethanol Pathway

1. Target year for simulation

When you open the 'Input' sheet, the first parameter you can modify is the '**Target Year for Simulation.**'

Since this GREET version is 2024, the default target year is set to 2024. You can also select the future year (e.g., 2030 or 2050) to simulate future scenarios, which are based on assumed changes in parameters such as the electricity generation mix, vehicle efficiency, and carbon capture implementation. These assumptions can be manually adjusted by users as needed.

In this tutorial, we use the default **2024** as the target year.

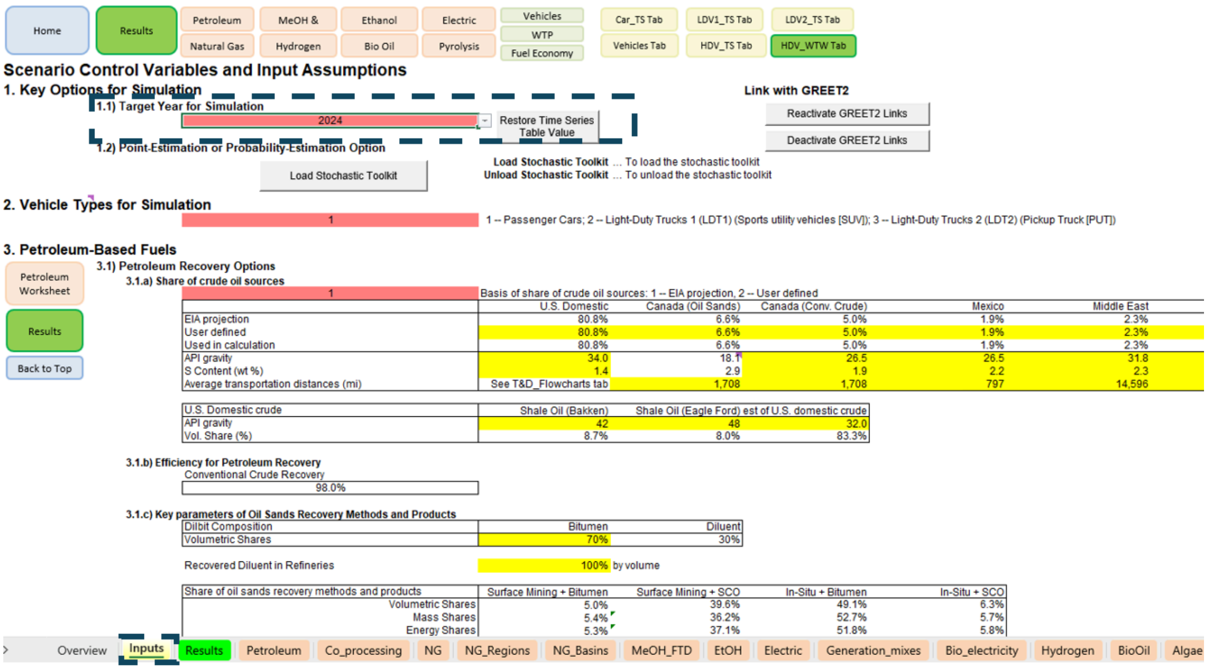


Figure 2: The selection of 'Target Year of Simulation'.

2. Ethanol production pathway

Next, click **'Ethanol'**. This will take you to the section in the Input sheet where you can modify parameters for ethanol production.

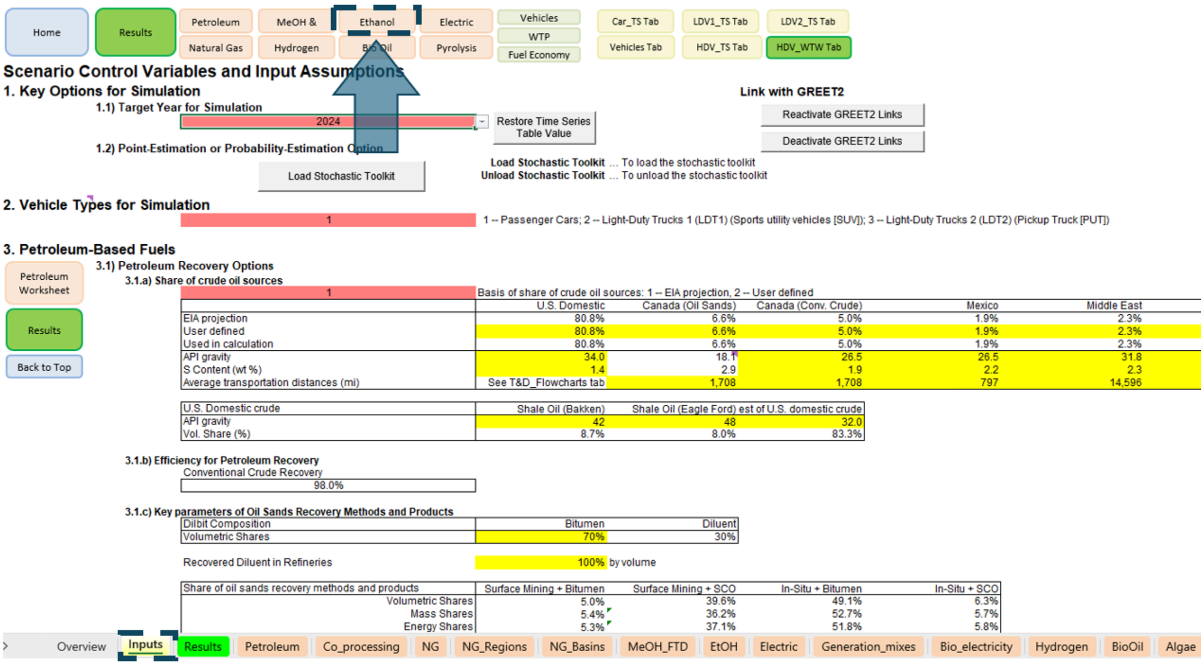


Figure 3: Button to access the 'Ethanol' section.

Bioethanol can be produced from various biomass feedstocks. In the **'Fuel Ethanol Pathway'** section, you can specify the percentage contribution of each feedstock from corn, cellulosic biomass, or sugarcane. For example, you can set corn to 100%, or switchgrass to 100%, or assign mixed shares (e.g., 50% corn stover and 50% wheat straw).

Here, we will explore ethanol production from five biomass feedstocks: **corn, sugarcane, corn stover, switchgrass,** and **miscanthus**. First, let's set the **100% share of corn** to ethanol production.

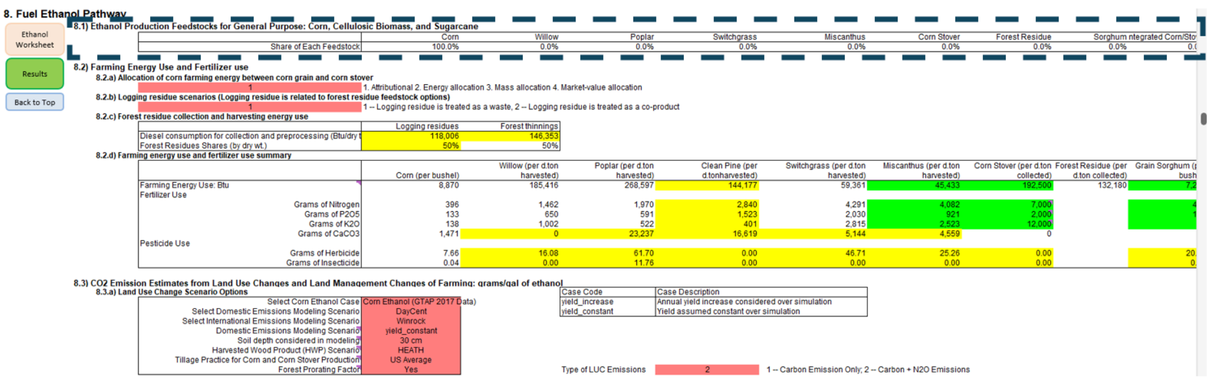


Figure 4: Setting the ethanol production feedstock shares.

Next, scroll down to Section **‘8.7.c Selection of Plant Type’**.

In this section, you can modify the configuration of the ethanol production plant. You can choose the type of **process fuel** used (e.g., natural gas, coal, or biomass) and specify whether the plant co-produces Distillers Dried Grains with Solubles (**DDGS**)—a high-protein animal feed derived from the fermentation residues.

Dry mill and **wet mill** refer to two different ethanol production technologies: a dry mill grinds the entire corn kernel and primarily produces ethanol and DDGS, while a wet mill separates the corn into its components (starch, fiber, oil, and protein) before fermentation and yields multiple co-products such as corn gluten meal, corn oil, and ethanol. Generally, the dry mill is a modern fuel ethanol plant design that is used for almost all corn-based ethanol in North America.

Here, let’s select **4 - Plant Specific: Dry Mill with only DDGS as co-product and NG as process fuel**.

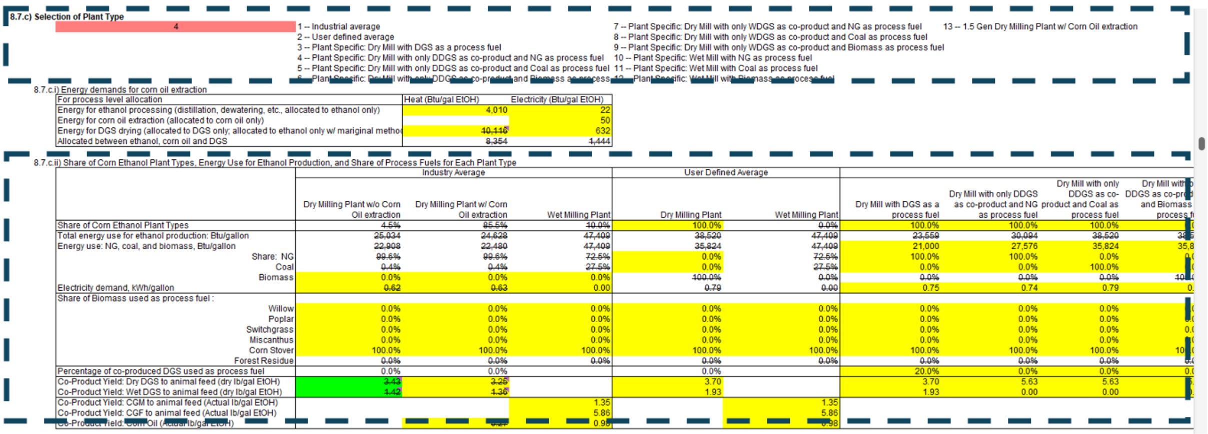


Figure 5: Selecting the ethanol plant type.

3. Further Explore Ethanol Scenarios

Click **‘EtOH’.** This will open the *EtOH* sheet, where you can further adjust ethanol production scenarios and calculate the associated energy use and emission rates.

Here are **four sections** for this sheet:

1) Scenario control and key input parameters. The values in this section derive primarily from the Inputs sheet. Thus, this section is the interactive link between the Inputs sheet and this sheet.
2) Shares of combustion processes for each stage, which are used for emission calculations;
3) Calculation of energy use and emissions for individual stages. In this section, GREET calculates energy use and emissions for each individual stage by considering energy and material use, energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) Summary of energy use and emissions. Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

1) Scenario Control and Key Input Parameters - This section links values from the *Inputs* sheet that define the feedstocks used for ethanol production (first row). Besides, you can modify the fraction of gasoline-blended ethanol (second row). Let's keep the default setting, which assumes that **all of the ethanol produced (100%)** is blended with gasoline.

1.1) Feedstock Farming - This section defines the feedstock farming options. In **'N2O Emissions Management Practices'**, you can choose among three options: BAU (Business-As-Usual), 4R (improved fertilizer management), or EEF (enhanced efficiency fertilizer technology). Here, we will use the default **BAU scenario**.

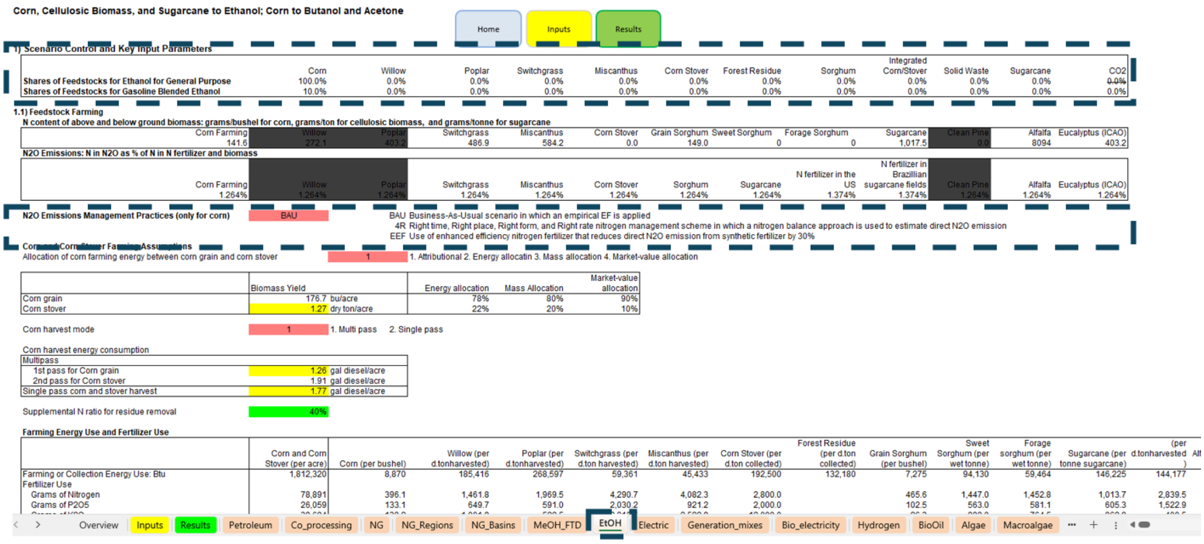


Figure 6: Setting feedstock and farming scenarios.

Then, scroll down to the bottom of the sheet to find **Section 4**, which provides a **summary of energy consumption, water consumption, and emissions** for different biomass ethanol pathways. *Note:* These results can also be viewed on the 'Results' page, so let's go there to check them.

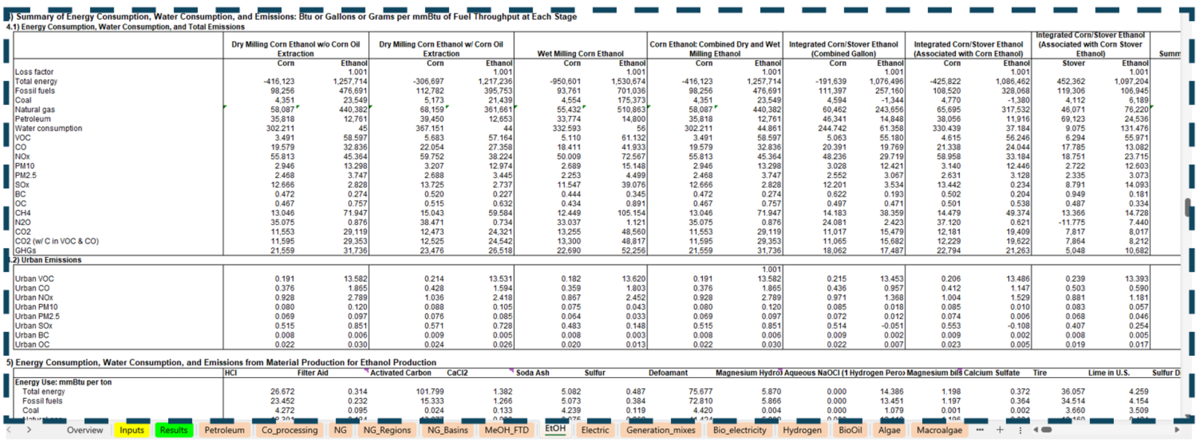


Figure 7: Checking the result.

Step 4 - Well-to-Wheel (WTW) GHG Emissions

1. Vehicle operations setting

To calculate well-to-wheels (WTW) GHG emissions, let's use a Dedicated Ethanol (EtOH) Spark-Ignition Internal Combustion Engine (**SI-ICE**) Light-Duty Vehicle fueled by 100% ethanol as an example. First, go to the **'Vehicle Operations'** section in the *Inputs* sheet and set the **Dedicated Vehicle Fuel** to **100% Ethanol**.

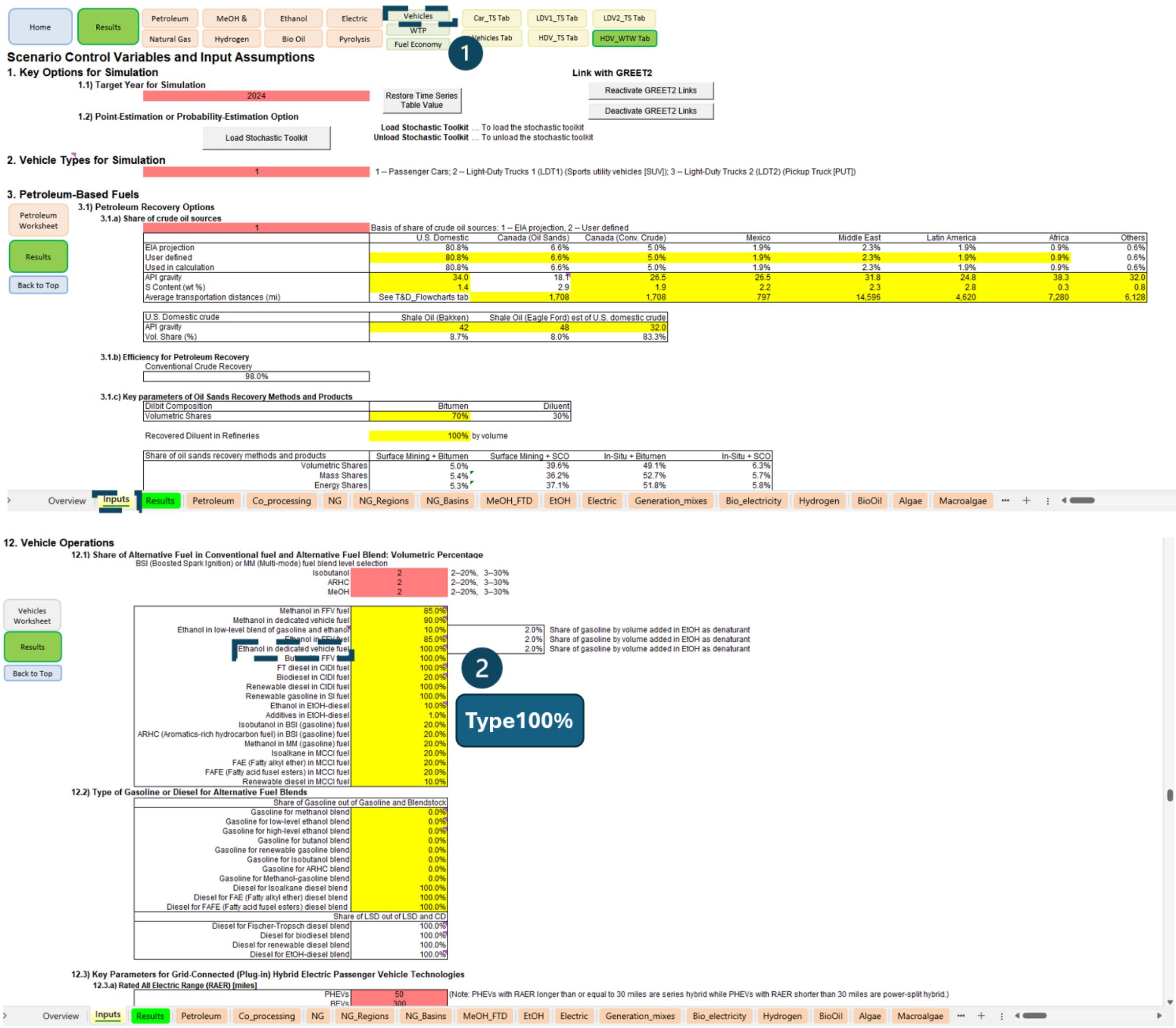


Figure 8: Setting the dedicated vehicle fuel.

2. Select the vehicle type and check the result

Then, go to the '**Results'** page. Under SI ICE Vehicles, select **'SI – Dedi. EtOH Vehicle'** as the vehicle type, and set the **emission unit** to **grams (g)** and the **energy functional unit** to **megajoules (MJ)**. Finally, click '**Go'** to review the WTW energy consumption, water consumption, and GHG emissions results for the selected scenario. These results cover the different life cycle stages of ethanol, including feedstock cultivation, fuel production, and vehicle operation.

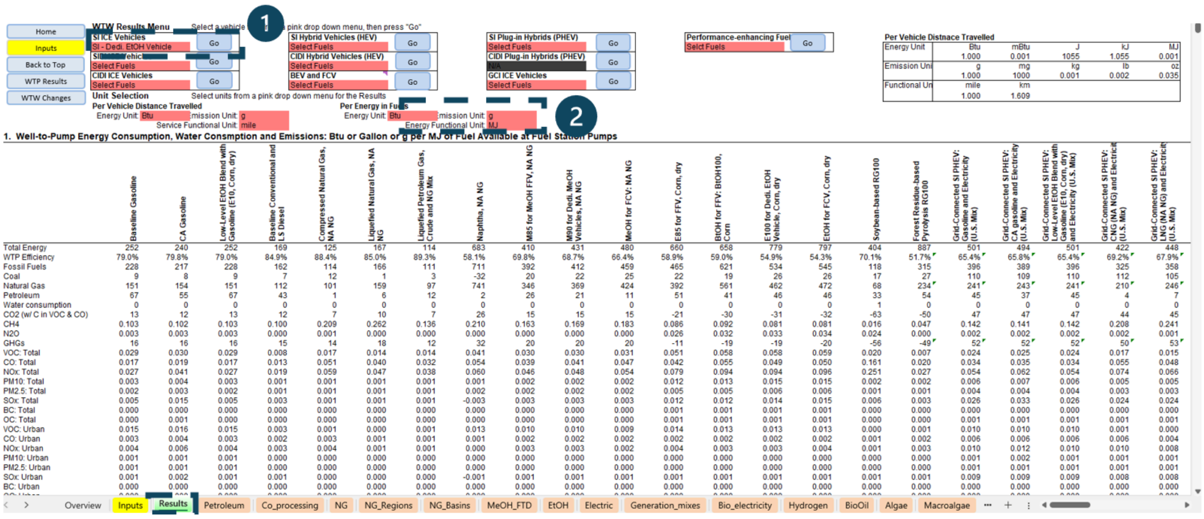
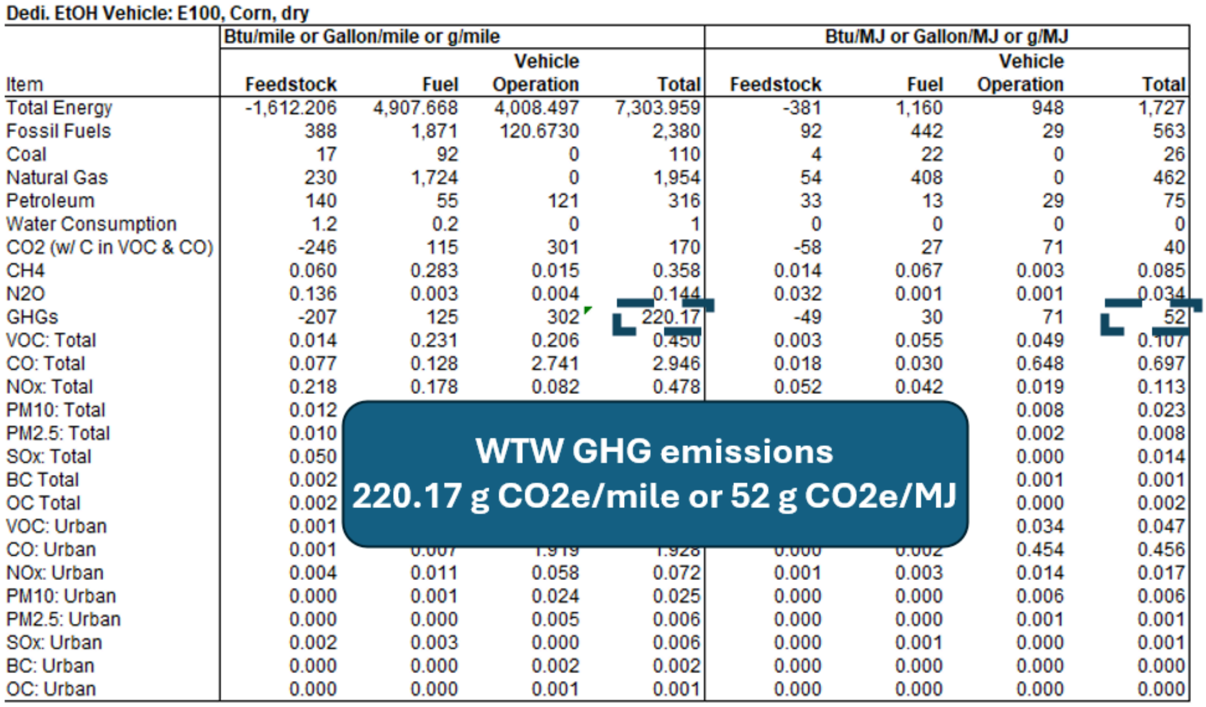


Figure 8: Setting the vehicle type.



Dedi. EtOH Vehicle: E100, Corn, dry

	Btu/mile or Gallon/mile or g/mile				Btu/MJ or Gallon/MJ or g/MJ			
Item	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	-1,612.206	4,907.668	4,008.497	7,303.959	-381	1,160	948	1,727
Fossil Fuels	388	1,871	120.6730	2,380	92	442	29	563
Coal	17	92	0	110	4	22	0	26
Natural Gas	230	1,724	0	1,954	54	408	0	462
Petroleum	140	55	121	316	33	13	29	75
Water Consumption	1.2	0.2	0	1	0	0	0	0
CO2 (w/ C in VOC & CO)	-246	115	301	170	-58	27	71	40
CH4	0.060	0.283	0.015	0.358	0.014	0.067	0.003	0.085
N2O	0.136	0.003	0.004	0.144	0.032	0.001	0.001	0.034
GHGs	-207	125	302	220.17	-49	30	71	52
VOC: Total	0.014	0.231	0.206	0.450	0.003	0.055	0.049	0.107
CO: Total	0.077	0.128	2.741	2.946	0.018	0.030	0.648	0.697
NOx: Total	0.218	0.178	0.082	0.478	0.052	0.042	0.019	0.113
PM10: Total	0.012						0.008	0.023
PM2.5: Total	0.010						0.002	0.008
SOx: Total	0.050						0.000	0.014
BC Total	0.002						0.001	0.001
OC Total	0.002						0.000	0.002
VOC: Urban	0.001						0.034	0.047
CO: Urban	0.001						0.454	0.456
NOx: Urban	0.004	0.011	0.058	0.072	0.001	0.003	0.014	0.017
PM10: Urban	0.000	0.001	0.024	0.025	0.000	0.000	0.006	0.006
PM2.5: Urban	0.000	0.000	0.005	0.006	0.000	0.000	0.001	0.001
SOx: Urban	0.002	0.003	0.000	0.006	0.000	0.001	0.000	0.001
BC: Urban	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.000
OC: Urban	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000

Figure 9: Checking the emission result.

Note: You can click Formulas -> Trace Precedents, or simply click on a cell's formula, to see how the results are calculated.

Repeat the above steps to check the WTW GHG emissions for ethanol produced from the other four biomass feedstocks - **sugarcane, corn stover, switchgrass, and miscanthus**. Discuss your observations and findings 😀.