GREET Marine Module Introduction and Instructions

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1. Introduction

The marine sector is amongst the largest users of fossil fuels and with increasing global trade, maritime shipping is anticipated to grow significantly. Maritime shipping contributed 2.9% of all anthropogenic greenhouse gas (GHG) emissions in 2018 and demand for maritime transport work is projected to increase by 30 to 100% of 2018 levels by 2050. With this increase, greenhouse gas emissions are projected to increase as much as 45% above 2018 levels even considering current GHG policies.[1] Thus, there is a significant need for low carbon alternatives for marine energy. In response to pressure to address GHG emissions from maritime shipping, the International Maritime Organization (IMO) has instituted measures to reduce the carbon intensity of individual ships and set targets for reducing the carbon intensity of and total GHG emissions from the international maritime shipping sector. These measures come soon after other policies targeting reductions in sulfur oxide and particulate matter emissions from fuel combustion. In the near term, alternative, low-carbon fuels offer a means of reducing the life cycle GHG emissions from vessels. And it has been noted that some of these alternative fuels also offer an inherently low sulfur content.

Marine energy pathways have been developed in the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET®) model to support decisions regarding future energy sources and propulsion systems. The pathways added to date reflect outcomes of projects sponsored by the U.S. Department of Energy, Bioenergy Technologies Office and the U.S. Department of Transportation, Maritime Administration. They include conventional, fossil fuel pathways as well as new biofuel pathways developed specifically for marine applications, such as biooils and partially upgraded biocrudes from pyrolysis and hydrothermal liquefaction and Fischer-Tropsch fuels from biomass and fossil feedstocks. The pathways also include those leveraging other work on renewable diesel, natural gas, green ammonia, and e-fuels. The GREET marine energy pathways are being further developed through ongoing studies targeting battery-electric energy systems for marine vessels.

[1] IMO. 2020. 'Fourth IMO Greenhouse Gas Study.' International Maritime Organization. London, United Kingdom.

The standalone GREET Marine Module leverages the GREET marine energy pathways to facilitate user access to fuel-cycle and trip-specific LCA results and to enable interaction with underlying model parameters. The GREET Marine Module sends and retrieves data from GREET 2022 as users modify model parameters and update results for fuel pathways and trips. This first version of the GREET Marine Module includes all of the marine fuel pathways included in GREET 2022 and will be expanded over time add new parameter interactions and new pathways as they are added in future versions of GREET.

The results presented in the GREET Marine Module reflect the full life cycle of fuel production and use based on a life cycle analysis (LCA) framework as described in the ISO 14040 series of standards. LCA is a well-established and standardized method for evaluating impacts across all stages of a product's life cycle—starting from raw material collection to the final use and disposal of a product. Argonne's GREET model has been developed and maintained through ongoing support from U.S. Department of Energy program offices and other sponsors for over 25 years. The GREET Marine Module draws on the detailed, transparent, and publicly-available datasets provided in GREET to provide complete and current results. The GREET Marine Module presents results for any of the impact categories provided by GREET including greenhouse gas emissions as a characterized global warming potential (GWP) impact and by type (CO_2, CH_4, N_2O), criteria air pollutant emissions (SO_x, NO_x, $PM_{2.5}$, PM_{10}, CO, VOC, black carbon), water consumption, and primary energy consumption by type (petroleum, natural gas, coal, renewable). The GREET model is updated annually by Argonne National Laboratory.

This instruction manual provides a brief introduction to inform the use of the GREET Marine Module including the structure, features, calculation processes, and connection to GREET. The first release of the GREET Marine Module is connected to GREET 2022, and the GREET Marine Module will be updated with future GREET releases. Questions regarding the GREET Marine Module can be sent by email to greet@anl.gov.

2. Goal and Scope

The goal of the GREET Marine Module is to provide harmonized comparisons between marine energy systems for life cycle metrics. The interactive interface enables users to cater the pathways to specific cases or to perform sensitivity analysis by modifying key parameters and viewing their effect on results. The GREET Marine Module supports two functional units fuel energy content and tonne-kilometers or trip total based on vessel and trip characteristics. The fuel energy content functional unit is suitable for comparing across fuels for use in internal combustion engines when the fuels do not affect engine efficiency. Users can select between energy units including MJ, kJ, J, MMBTU, BTU, and kWh. The functional unit based on tonne-kilometers or trip total provides another perspective. When the vessel-cycle is added to the GREET Marine Module in a future release, the tonne-kilometers and trip total functional units will be suitable for comparing between vessel energy systems, such as a drivetrain based on an internal combustion engine versus one based on a battery electric system.

The system boundary covers all stages of the supply chain of marine fuel production pathways, including feedstock production, feedstock transportation, fuel production, fuel transportation and distribution, and fuel combustion. Currently, the scope of the GREET Marine Module is limited to the fuel-cycle or well-to-wake results. Based on the outcomes of ongoing studies, the vessel-cycle (vehicle-cycle) may be added in a future version. Based on the underlying GREET models, results presented in the GREET Marine Module include all significant emissions from each stage in the production of the input energy and materials used throughout the life cycle of the marine fuels. Results are presented by life cycle stage. For waste feedstocks such as manure or corn stover, upstream impacts are attributed to the primary product and therefore waste feedstock impacts are tracked from the point they are collected for use. In cases where there are coproducts, impacts are allocated based on the GREET default coproduct management method (ie. system expansion/displacement or allocation by mass or energy).

The environmental metrics that the marine module covers are the same as those in the GREET model. The LCA results can be generated for GHG emissions including CO2, CH4, and N2O; criteria pollutant emissions including sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM2.5, PM10), carbon monoxide (CO), and volatile organic compounds (VOC); energy use by type including petroleum, natural gas, and coal; and water consumption. For total GHG emissions, results are presented in grams of CO2 equivalent (gCO2e) based on the global warming potential (GWP) characterization factors from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report for a 100-year time horizon (IPCC 2013). Biogenic carbon is considered carbon neutral in the results presented and therefore not included in CO2 results and assigned a GWP of zero in GHG totals.

3. Marine Module Structure

The GREET Marine Module is designed as a user interface that interacts directly with the GREET model in the background. It provides the user with an interface for manipulating relevant parameters for marine fuels production and viewing the effect on results based on the most recent version of the GREET model. When a user updates parameter values, the marine module updates those values within the background GREET model, recalculates results, and displays them to the user (Figure 1). Pathway results can be reviewed without an active connection to GREET, however manipulation of input parameters requires a local copy of the GREET model, which is provided as part of the GREET Marine Module package. The primary dashboard is shown in Figure 2. Further instructions for use are provided in Section 4.

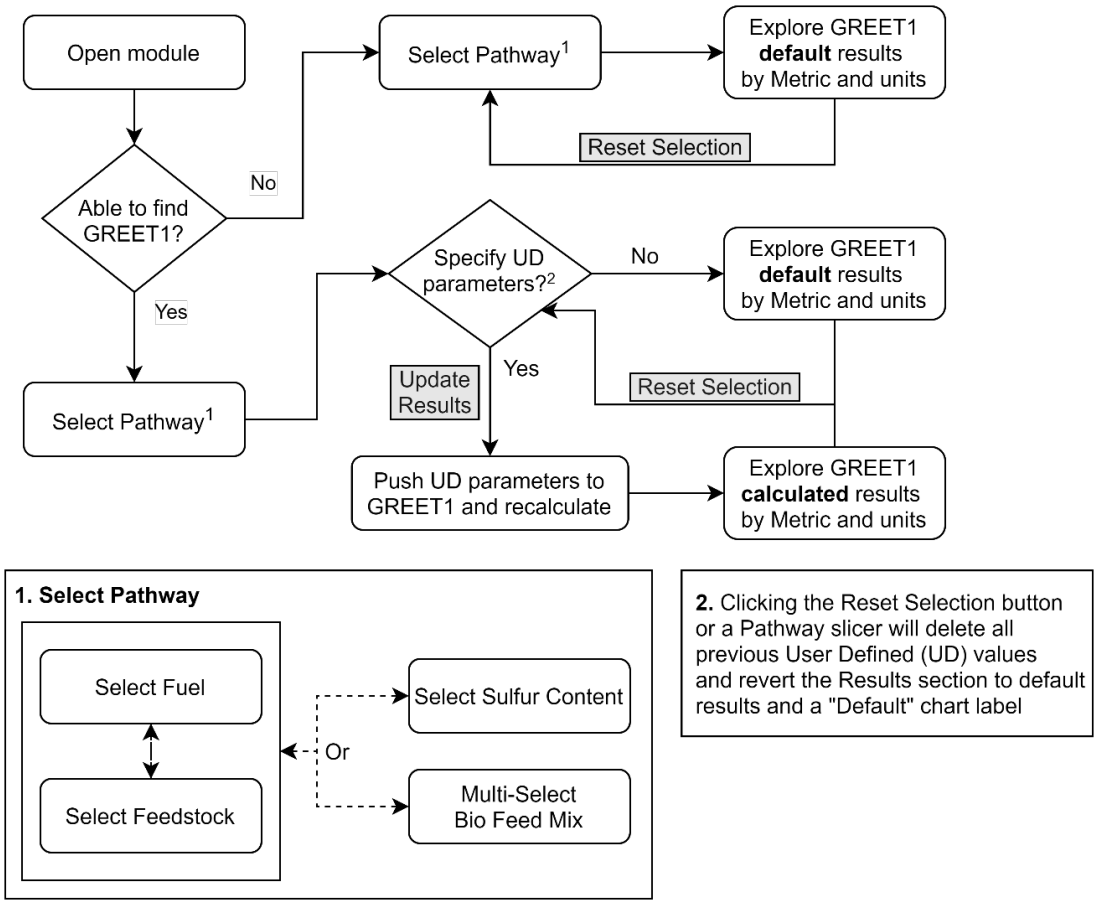


Figure 1. Schematic of data flow for the GREET Marine Module.

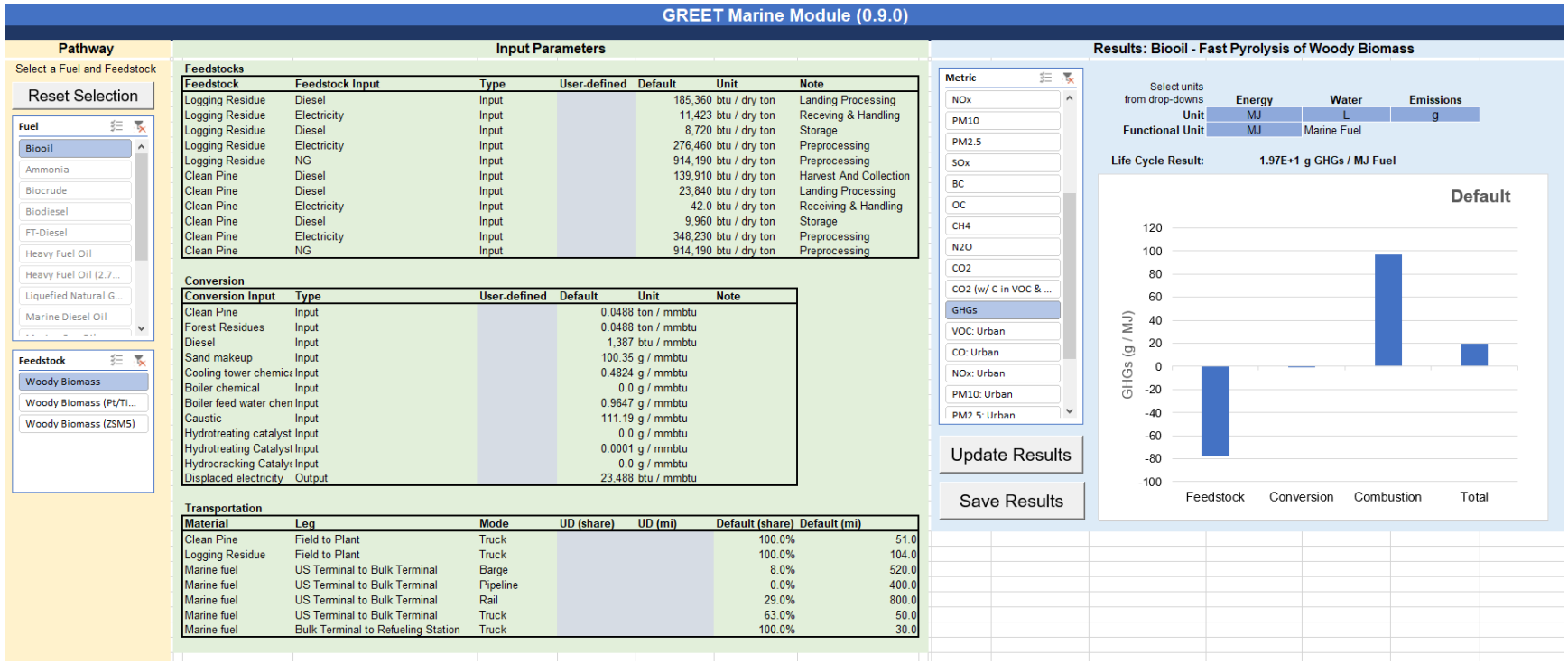


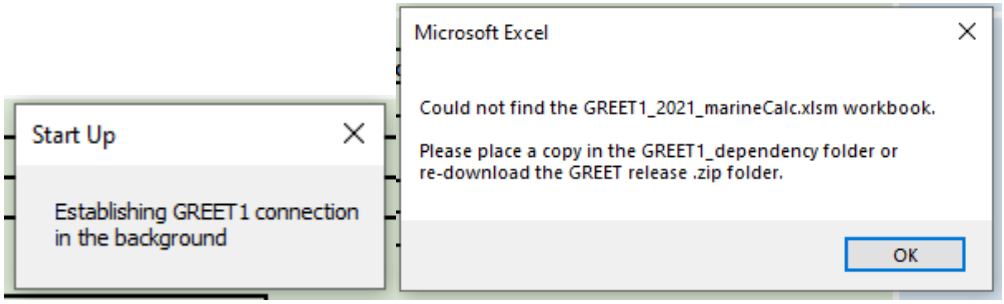
Figure 2. Primary user dashboard.

4. Instructions for Use

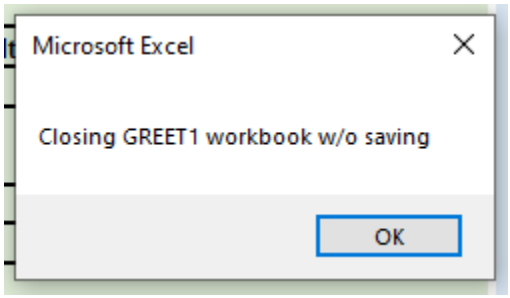
Upon opening the file, if Excel displays a red SECURITY RISK banner, please click the "Learn More" button (link here) and follow the instructions under "Unblock a single file".

GREET1 Connection

When opening the module, one of two start-up messages will appear. If the module finds GREET, then an "establishing GREET1 connection" message will pop up and then automatically resolve itself. If the module is unable to find GREET, a "could not find" message notifies the user of the issue and suggests replacing the GREET1_2022_marineCalc file or re-downloading the entire GREET_Marine_Module_2022_v1.zip model file.



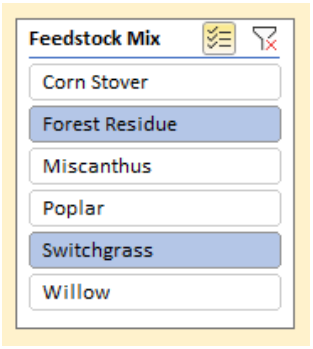
Upon closing the module, if a successful connection to GREET1 was established, users should see the following disconnection message:

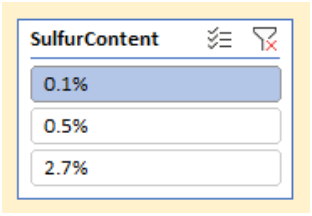


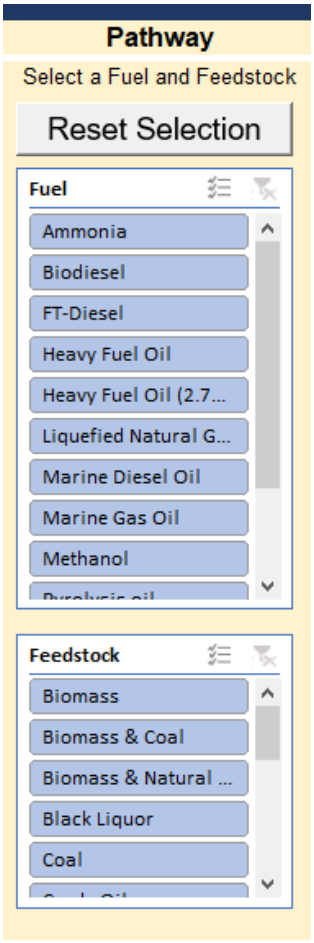
Even if the GREET1 connection is not established, users can still explore the default results embedded within the module. However, they cannot provide user-defined parameters and generate new sets of results.

Pathway Selection

Looking first at the Pathway section of the *Dashboard* tab, a list of available fuels and feedstocks is provided. To initiate selection of a pathway, both a fuel and a feedstock must be selected from the available options. For some pathways, additional selections appear once the fuel and feedstock are selected.







The list of choices will update dynamically based on the options selected, with available combinations shown first in the list. After a pathway is selected, results will appear in the figure in the "Results" section of the dashboard. If the figure does not appear, ensure that an option has been selected from all the available categories (i.e., fuel, feedstock, feedstock mix, etc.). When only a single option is available, that selection must still be clicked by the user.

Clicking the "Reset Selection" button will reset all choices and allow the user to select a new pathway.

Parameter Specification

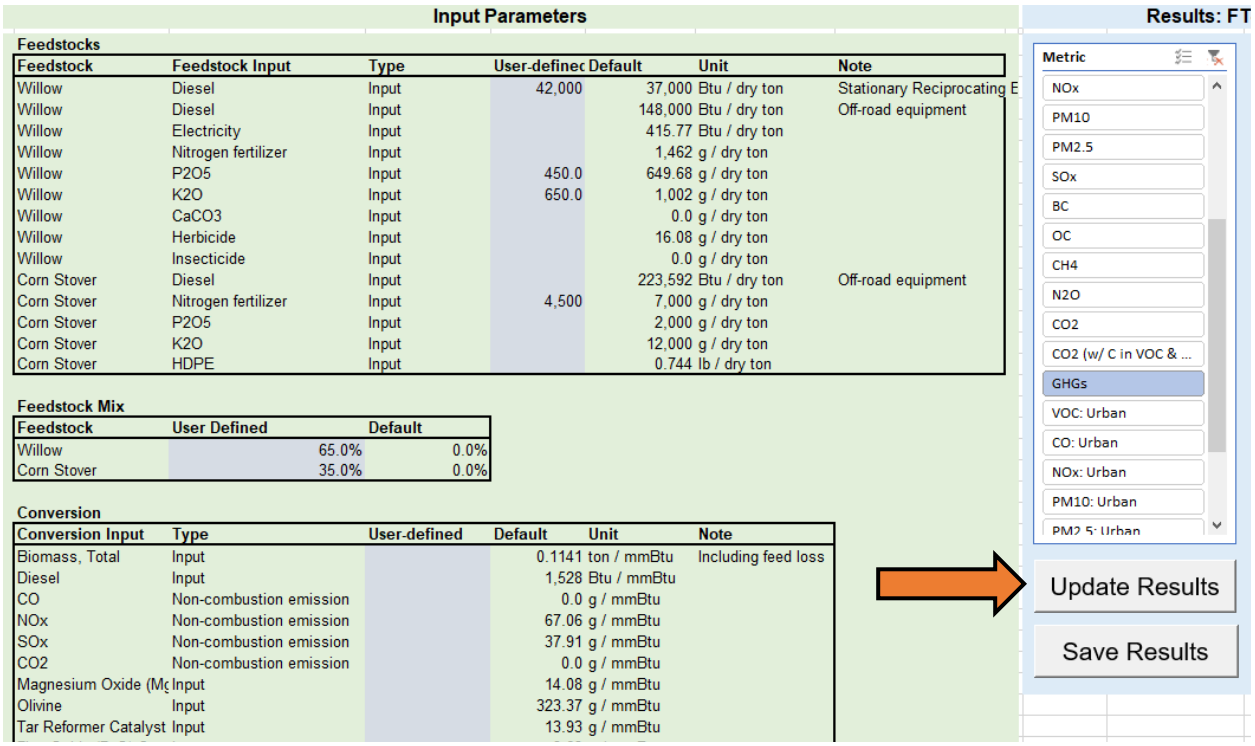
Input parameters and their default values are displayed for feedstock production, fuel conversion, and transportation. For some pathways additional selections are made available to the user. These values are sourced directly from GREET. Users may change the values for any provided parameters by entering new values within the User Defined column of the appropriate table. Values may be entered for any number of parameters. User defined parameter values are can be deleted by pressing the "Reset Selection" button or any button within a Pathway selection menu.

Input Parameters

Feedstocks

Feedstock	Feedstock Input	Type	User Defined	Default	Unit	Note
Willow	Diesel	Input		37,000	Btu / dry ton	Stationary Reci
Willow	Diesel	Input		148,000	Btu / dry ton	Off-road equipr
Willow	Electricity	Input		415.77	Btu / dry ton	
Willow	Nitrogen fertilizer	Input		1,462	g / dry ton	
Willow	P2O5	Input		649.68	g / dry ton	
Willow	K2O	Input		1,002	g / dry ton	
Willow	CaCO3	Input		0.0	g / dry ton	
Willow	Herbicide	Input		16.08	g / dry ton	
Willow	Insecticide	Input		0.0	g / dry ton	
Corn Stover	Diesel	Input		223,592	Btu / dry ton	Off-road equipr
Corn Stover	Nitrogen fertilizer	Input		3,183	g / dry ton	
Corn Stover	P2O5	Input		2,273	g / dry ton	
Corn Stover	K2O	Input		13,641	g / dry ton	
Corn Stover	HDPE	Input		0.744	lb / dry ton	

To update the results after entering user defined parameter values, click the "Update Results" button. This will insert the user defined values into GREET, recalculate, and then pull the new results back into the GREET Marine Module.

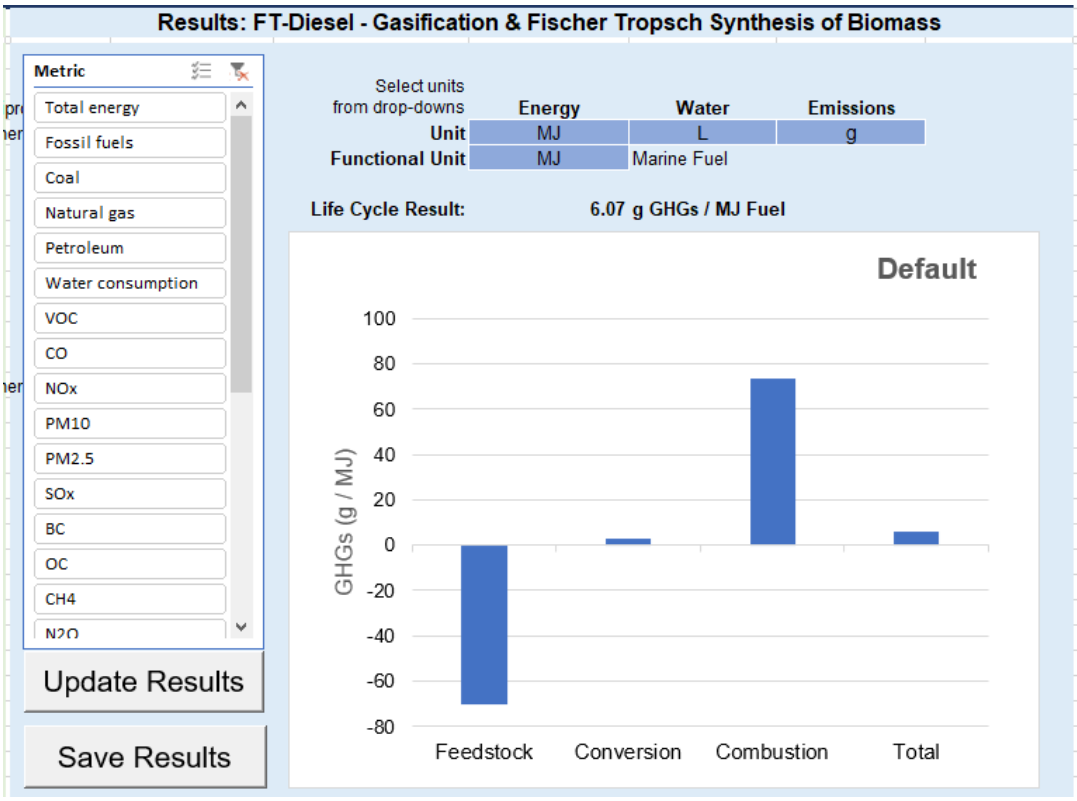


Successful connection with GREET and updated results will be reflected by the graph displaying "Calculated" instead of "Default".

Results Figure Options

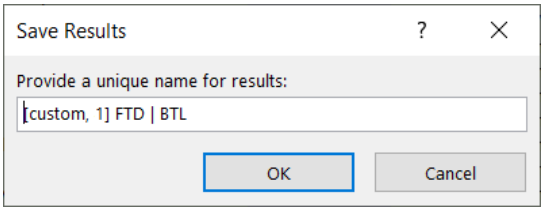
Any of the available GREET metrics can be selected in the "Metric" selection menu and rendered in the figure pane. Units for display can be altered via drop-down menus for energy, water, and emissions, as well as the functional unit of the fuel in energy units. The "Energy" unit selection will affect the figure when an energy-related metric is selected including those from

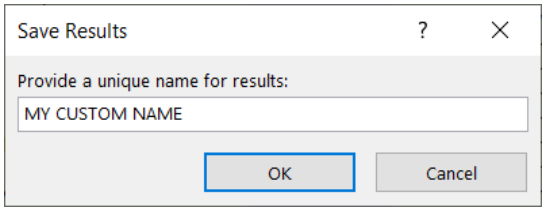
"Total energy" through "Petroleum"; "Water" corresponds to "Water consumption"; and "Emissions" units affect all metrics from "VOC" through "OC: Urban".



Saving and Comparing Results

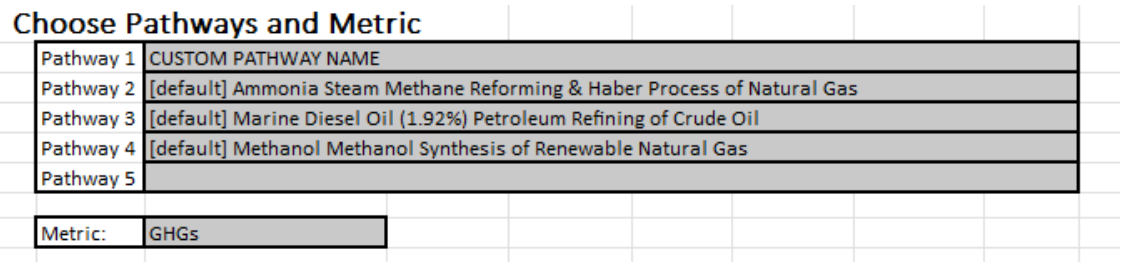
Clicking the "Save Results" button will open a dialogue box asking for a unique name with which to label the results. By default, a unique name based on the fuel, feedstock, and conversion process is provided; however, this can be overwritten with any other preferred name:





Clicking "OK" stores the life cycle results by stage for the current dashboard pathway, including the results of any user defined parameter values. After saving, these results can be reviewed on the *Saved Results* tab, along with the default results of all available marine pathways. Clicking the "Reset" button on this tab will remove all non-default saved results. Results are always saved in the form of default units: MJ for energy use, L for water consumption, and g for emissions, all on a per MJ marine fuel basis.

Once saved, results will also appear on the *Compare Fuels* tab as selections within the drop-down pathway menus:



These menus allow users to choose up to 5 pathways to compare simultaneously. All default pathways from GREET are immediately available in addition to any results that have been saved by the user. The "Metric" drop-down menu also allows users to choose different GREET metrics to display. Pathway selections can be overwritten by choosing a different pathway or removed by selecting the empty option (at the top of the drop-down menu).

Trip Calculation Dashboard

The Trip Calculation dashboard allows for the calculation of life cycle results for specific marine transportation options. Different fuel types can be selected for specific legs of the journey using the available dropdowns. Results for selected fuels will reflect the GREET default parameter values with the exception that results for the fuel pathway currently active in the Dashboard tab will reflect the currently active calculated results based on the user defined parameter values. Users can choose from an existing combination of trip parameters or select "User Defined" and enter specific parameters in the "User Defined" section of the dashboard. As on the main dashboard, any of the available GREET metrics can be selected in the "Metric" selection menu and rendered in the figure pane. Units for display can be altered via drop-down menus for energy, water, and emissions, as well as the functional unit of the trip (per trip or per million tonne-km). Changing any selection will update the figure accordingly.

1) Fuel Selections

	Leg:	Selected fuels:
	Cruise (Global waters)	Heavy Fuel Oil (2.7%) - Petroleum Refining of Crude Oil
	Cruise (CA waters)	Heavy Fuel Oil (2.7%) - Petroleum Refining of Crude Oil
*	RSZ (1)	FT-Diesel - Gasification & Fischer Tropsch Synthesis of Biomass
*	RSZ (2)	FT-Diesel - Gasification & Fischer Tropsch Synthesis of Biomass
	Hotel (1)	Renewable Diesel - Hydrotreating of Yellow Grease
	Hotel (2)	Renewable Diesel - Hydrotreating of Yellow Grease

2) Trip Selections

Selected trip: Bulk-Foreign, Pacific (Domestic-International)

Pre- or User-defined:	Predefined (Regional characteristics)
Vessels:	Bulk
Travel:	Foreign
Region:	Pacific

<-- Select "User-defined" to enter custom values below

	Selected: Predefined (Regional characteristics)				User-defined			
	Distance (nm)	Speed (knots)	Leg Time (hours)	Load Factors	Distance (nm)	Speed (knots)	Leg Time (hours)	Load Factors
Cruise (Global waters)	4421	14	309	0.8	584	14	41	0.8
Cruise (CA waters)	0	14	0	0.8	0	15	0	0.8
RSZ (1)	81	14	6	0.8	69	14	5	0.8
RSZ (2)	25	14	2	0.8	85	14	6	0.8
Hotel (1)			117	0.1			117	0.1
Hotel (2)			117	0.1			117	0.1
Payload (wet ton)	57541				57541			
million tonne-km	438				71			

Acknowledgments

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