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User Manual and Technical Issues of GREET for MOVES Integration

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User Manual and Technical Issues of GREET for MOVES Integration

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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NOTICE

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NOTATION

ACRONYMS AND ABBREVIATIONS

BD	biodiesel
BD20	mixture of 20% biodiesel and 80% diesel by volume
CARFG	California reformulated gasoline
CD	Conventional diesel
CG	Conventional gasoline
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DDGS	distillers' dried grains and solubles
DME	dimethyl ether
DMP	dry milling plant
DOE	U.S. Department of Energy
EF	emission factor
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
ETBE	ethyl tertiary butyl ether
EtOH	ethanol
EV	electric vehicle
E85	mixture of 85% ethanol and 15% gasoline by volume
E90	mixture of 90% ethanol and 10% gasoline by volume
FCV	fuel cell vehicle
FG	flared gas
FTD	Fischer-Tropsch diesel
FTN	Fischer-Tropsch naphtha
GHGs	greenhouse gases
GREET	**G**reenhouse Gases, **R**egulated **E**missions, and **E**nergy Use in **T**ransportation
GUI	**G**raphic **U**ser **I**nterface
HEV	hybrid electric vehicle
HTGR	high-temperature gas-cooled reactor
IGCC	integrated gasification combined cycle
IPCC	Intergovernment Panel on Climate Change
LG	landfill gas
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LSD	low-sulfur diesel
LT	long-term
LWR	light water reactor
MeOH	methanol
MOVES	**MO**tor **V**ehicle **E**mission **S**imulator
MTBE	methyl tertiary butyl ether
M85	fuel mixture of 85% methanol and 15% gasoline by volume
M90	fuel mixture of 90% methanol and 10% gasoline by volume
N_2O	nitrous oxide

NO_X	nitrogen oxides
NA	North American
NE U.S.	North-Eastern United States
NG	natural gas
NGCC	natural gas combined cycle
NNA	non-North American
O_2	oxygen
PTW	pump-to-wheel
PM_{10}	particulate matter with diameters of 10 micrometers or less
RFG	reformulated gasoline
SMR	steam methane reforming
SO_2	sulfur dioxide
SO_X	sulfur oxides
SWU	separative work units
T&D	transportation and distribution
TAME	tertiary amyl methyl ether
TCWC	thermo-chemical water cracking
TS	time series
VOC	volatile organic compound
WMP	wet milling plant
WTP	well-to-pump
WTW	well-to-wheel

1. GREETGUI User Guide

1.1 INTRODUCTION

This version of GREETGUI is designed to interact with MOVES, receive input from the user and conduct simulation studies on energy use and greenhouse gas emissions during the well-to-pump production and distribution phases of different transportation fuels. GREETGUI receives from MOVES the fuel types and years to be simulated, and produces the energy efficiencies and emissions for different pollutants of interest to MOVES. A flowchart explaining the flow of information between GREETGUI and MOVES is shown in Figure 1.1 below.

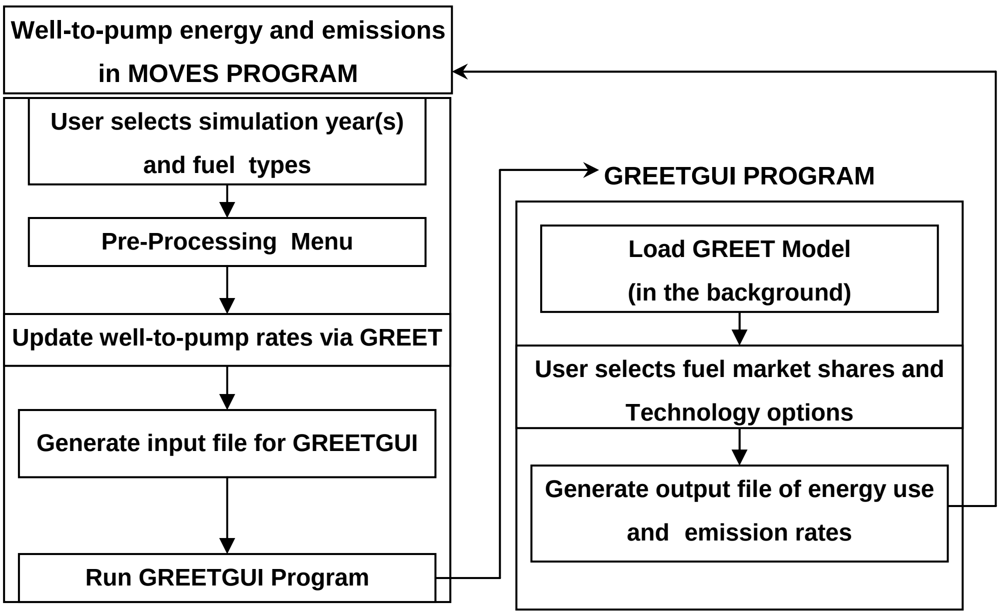


Figure 1.1 Information Flow between GREETGUI and MOVES

GREETGUI is a graphical user interface (GUI) developed using Microsoft Visual Basic 6.0. It takes input from the user using option buttons, check boxes and text boxes, and communicates the user input (in the background) into corresponding input cells of a hidden Excel program, GREET1_6.xls, known as the GREET model. Finally, GREETGUI invokes the GREET spreadsheet model (running in the background) to generate the output results in ASCII format, which are later imported by MOVES to update the Well-to-Pump (WTP) energy and emission rates.

This document describes the system requirements to install and run the simulation program GREETGUI as well as the instructions for using the program. Throughout this document, the user should note the distinction between GREET, which is the hidden spreadsheet model running in the background and GREETGUI, which is the graphical user interface (GUI) between the user and the hidden GREET model. The setup program installs the GREETGUI program as well as the underlying GREET spreadsheet model in a common folder. The GREET model is an Excel spreadsheet file marked with the Hidden and Read-Only properties.

1.2 SYSTEM REQUIREMENTS FOR GREETGUI

GREETGUI works on IBM compatible PCs running Microsoft's Windows 95, Windows 98, Windows 2000, Windows Millennium Edition (ME), Windows NT, or Windows XP. This application program will not run on the Windows 3.1 operating system. GREETGUI requires Microsoft Excel 2000 or higher versions to be installed on the user machine before running GREETGUI. Microsoft Excel 97 and earlier versions will not work with the GREETGUI program.

Minimum hardware requirements include: Pentium processor at 166 MHz or higher; at least 64 MB RAM; and at least 30 MB of free space on the hard drive.

Recommended hardware profile: Pentium processor at 400 MHz or higher, 128MB or more of RAM, 100MB of free hard disk space or more.

1.3 INSTALLING GREETGUI

GREETGUI installation is part of the MOVES setup program. It is recommended that the user close all other applications before proceeding with the GREETGUI installation. The user may specify the installation drive letter and the folder name or accept the default drive and folder name assigned by the installation program. If prompted, please restart your computer to complete the installation process. The installation program will create shortcut to GREETGUI on the desktop displaying the program icon (the green Argonne National Laboratory triangle) and its name.

1.4 RUNNING GREETGUI

Running GREETGUI is initiated from the MOVES program by clicking the “Update Well-to-Pump” option under the “Pre-Processing” menu, as shown in the flow chart in the above introduction. In such case, MOVES generates an XML file, which includes the user selection of simulation years and the fuel pathways to be simulated. This XML file is ported to GREETGUI. Then GREETGUI loads the GREET spreadsheet model in the background and displays the default assumptions of GREET parameters for the imported fuel pathways.

GREETGUI runs in three distinct interactive phases with the user: (1) specify Market Shares of selected fuels for different years of simulation, (2) select/specify Technology Options for production of selected fuels, and (3) review/change Parametric Assumptions associated with production and distribution of different fuels. Finally, GREETGUI runs the main GREET spreadsheet program in the background and exports the output results to an ASCII, tab delimited file. The GREETGUI output file, which is transparent to the user, contains the following fields:

a. Year ID (an Integer identifying the year to which the calculations were made)
b. Pollutant ID (an Integer from a set of values used in MOVES)
c. Fuel Subtype ID (an Integer from a set of values used in MOVES)
d. Energy use or emission rate (a floating point number, expressed in Joules of energy use per Joules of fuel's heating value or grams of pollutant per Joules of fuel's heating value, as appropriate for each pollutant)

In particular, for this phase of GREET/MOVES integration, energy use is reported for total energy, fossil energy, and petroleum energy and emissions are reported for CO_2, CH_4, and N_2O (the latter two are presented in CO_2-equivalent emissions). Furthermore, CO_2-equivalent GHG emissions are calculated with global warming potentials of 1, 23, and 296 for CO_2, CH_4, and N_2O, respectively, the values for the 100-year time horizon developed by IPCC. MOVES then imports the GREETGUI output file to update its database of energy use and emissions. The following are the main steps involved in running the GREETGUI program interactively with MOVES:

1. GREETGUI session is initiated when it receives a call from the MOVES program.

2. If MOVES is calling GREETGUI for the first time, a message box will advise the user to open and read a Readme.doc file before using GREETGUI for the first time. Microsoft Word should be installed on the user's machine to view this document.

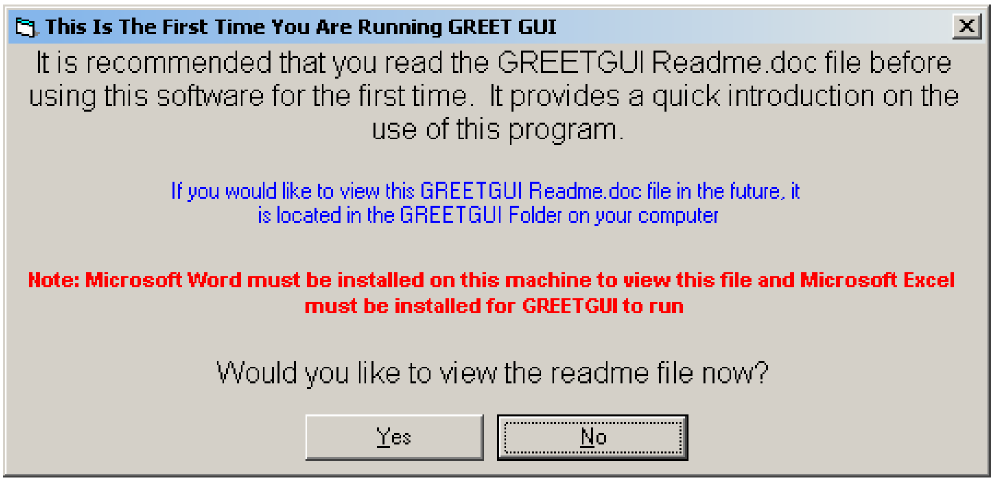


Figure 1.2 First Time Screen

The GREETGUI program will also advise the user of the location of the Readme.doc file for future access.

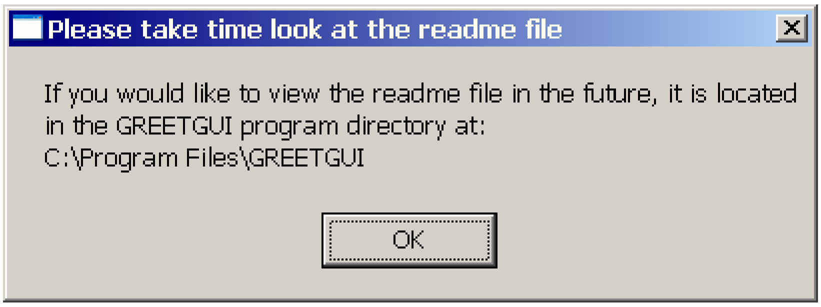


Figure 1.3 Location of Readme File

3. A warning window will next display asking the user to close all open excel files before proceeding with the GREETGUI session. The user must close any open Excel files before clicking the OK button to continue with the current session; otherwise all open Excel files will be closed by GREETGUI without saving. This is required for GREETGUI to run properly since GREETGUI manipulates many of the Excel features in the background, which may affect or be affected by the execution of other open Excel sessions. All Excel files will be closed without saving if the user responds to the warning message by clicking “OK”. Alternatively, the user can click the “Cancel” button to quit the GREETGUI Program and keep all open Excel files running.

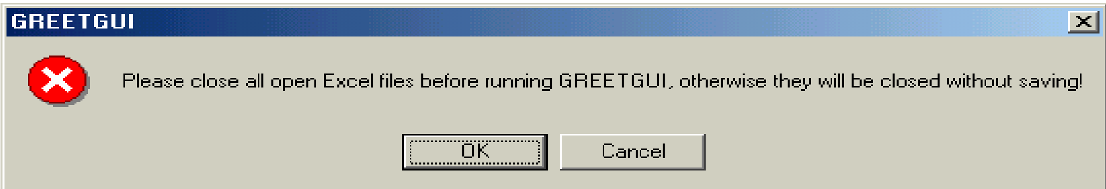


Figure 1.4 Warning Message to Close All Open EXCEL Sessions

4. If the user clicks “OK” in the warning window, GREETGUI will start loading the XML input file, created by MOVES, and loads the GREET spreadsheet model in the background.

5. Next the user will see a window with animated graphics, as GREETGUI is being initialized.

Figure 1.5 Typical Background Activity Screen

6. Next, the first interactive phase begins with specifying market shares of selected fuel types. A new window named "User Options" will open as shown in Figure 1.6. This window includes selected fuel types passed to GREETGUI by MOVES. The user may choose the GREET default option, the linear interpolation option, or the user select option.

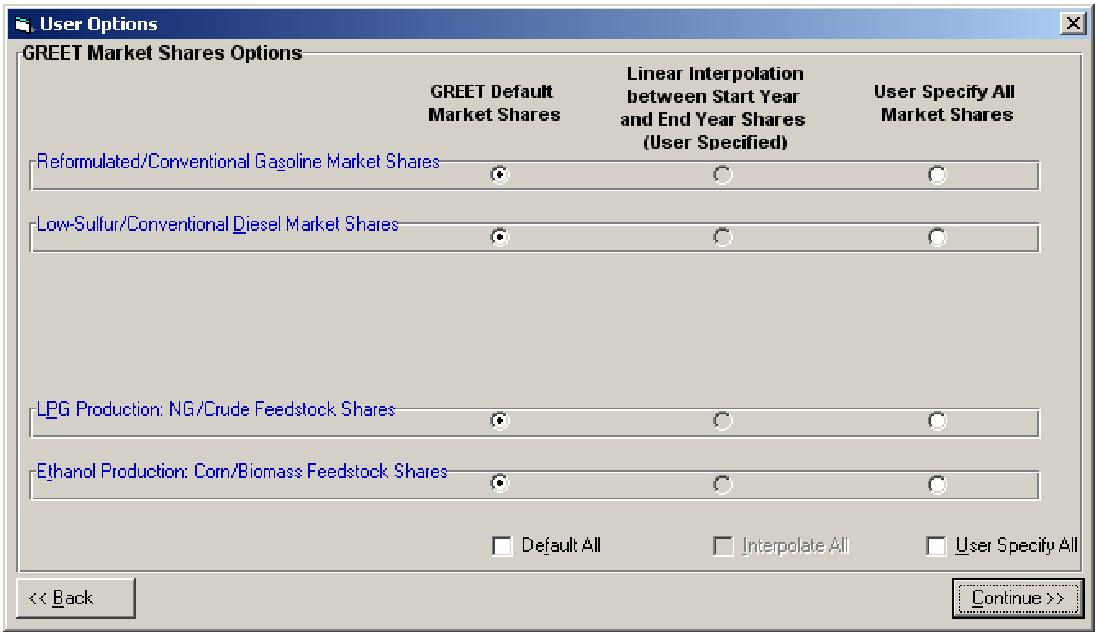


Figure 1.6 User Options for Market Shares Specifications

It should be noted that the GREET spreadsheet model, running in the background, is currently designed to simulate different fuel production pathways scenarios based on estimates in lookup tables for the range of years from 1990 to 2020, arranged in a five years interval, e.g., 1990, 1995, 2000, etc. (see Figure 1.7). Estimates for simulation years that are not divisible by 5 are calculated from simple interpolation between the estimates immediately surrounding them in the GREET lookup tables.

All simulation years beyond 2020 are assumed to have the same estimates for those of 2020 in the lookup tables.

5-year period	Market Share of RFG Gasoline
1990	0%
1995	15%
2000	30%
2005	35%
2010	**50%**
2015	65%
2020	100%

Figure 1.7 Typical Marketshare Lookup Table in GREET

Selecting the GREET Default option allows the user to view the default fuel market share values in the subsequent windows, but without modifying or changing them. The Linear Interpolation option allows the user to specify fuel market shares for the first and last year selected for simulation, and performs simple linear interpolation for all simulation years in between. Therefore, the Linear Interpolation option is available only if the number of years selected for simulation is three or more. The User Select option allows the user to modify and change the fuel market shares for any of the simulation years as desired. The user is expected to select market share specification options for the shown fuel types, and then click the "Continue" button to view the fuel market shares for the selected simulation years.

Note that throughout the GREETGUI session, tips are provided to assist the user with understanding the options and abbreviations displayed in each window. The user can move the mouse cursor over any button or selection in the displayed window to view the tip associated with that button or selection.

7. Next, depending on how many fuel types are passed by MOVES to GREETGUI, one or more window will appear successively to view and/or modify the market shares of the selected fuel types for different simulation years. The first and last simulation years' market shares are specified on the top of each window, while the rest of the years are specified in a separate table, see Figure 1.8. The user can modify each year's market share individually, or click the "Interpolate" button to interpolate between the first and last years' market share values. The user can edit only cells with dark yellow background. All white cells are calculated automatically as the balance of the market shares for all simulation years.

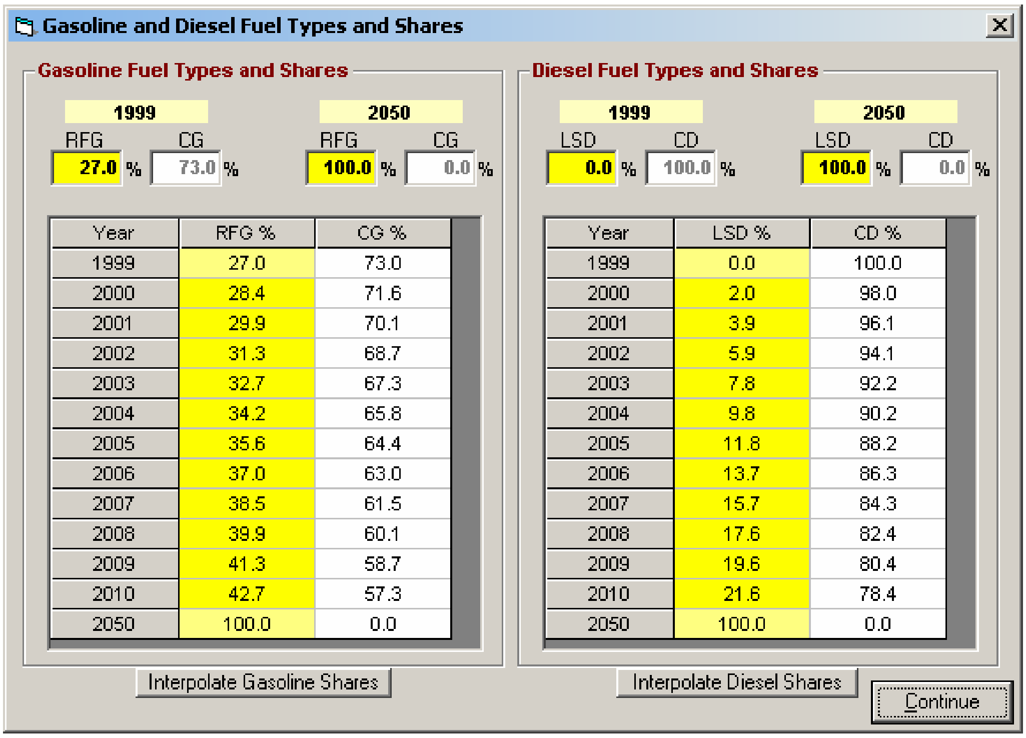


Figure 1.8 Typical Market Shares Screen

The user should click “Continue” to set the market share values for all fuels.

8. Next, the second phase starts with selecting/specifying technology options associated with the production of the selected fuels. In this phase, GREETGUI presents the user with the estimates of the simulation year closest to 2010, since the GREET model has its best estimates for the year 2010. All other years’ estimates are made relative to the estimate of 2010. The following is detailed description of the logic of “base year” selection in GREET and the consequent adjustment of estimates for subsequent years:

   i. The user starts by selecting one or more simulation years in MOVES.
   ii. If the user selects more than one simulation year in MOVES, GREET picks one of the simulation years as its “base year” for presenting characteristics of technology options.
   iii. Specifically, GREET will pick the user-specified simulation year closest to 2010 as its “base” year, and then display the technology characteristics assumed in GREET for this “base year”.
   iv. If the user modifies technologies in the presented base year (which is also one of the user-specified simulation years – the one closest to 2010), then GREET makes proportionate modifications to the technology characteristics for all other simulation years. For example, if the user changes the share of corn-ethanol production from 50% to 60% for the year 2010, then all estimates for all simulation years subsequent to 2010 would increase by the same percentage, which is 20% in this case.

It should be noted that GREETGUI does not adjust technology options and estimates for simulation years before 2010 because of their historical significance.

A window will then open, showing blue tabs for the selected fuel pathways. The Electricity tab will always appear, regardless of the fuel pathway selections made by the user. This is because all other fuel pathways use electricity in their production. There are two types of electricity generation mix, the marginal mix and the average mix. The marginal mix is that used for modeling electric vehicles (EVs) and grid-connected hybrid electric vehicles (HEVs). The average mix is that used for the well-to-pump stage of the fuel cycle. Each blue tab will display the input fields and options for its corresponding pathway group. It should be noted that, throughout the GREETGUI program, all the yellow fields are input fields that can be edited/changed by the user. The user can click or double-click inside the yellow field to modify the default value, provided by GREET, in that field. It should be noted here that the estimates shown in the yellow fields are extracted from the GREET lookup tables for a specific year, which is the base year of simulation as mentioned above.

Although GREET lookup tables are not viewed by the user, any change made by the user to the base year's default estimate will automatically adjust all of the subsequent years' default estimates in the lookup tables by the same percentage change made to the base year's estimate. Holding the mouse cursor above any of the input fields will display a tool-tip box describing the significance of that field. Figure 1.9 below shows a typical pathway simulation options screen in GRETGUI.

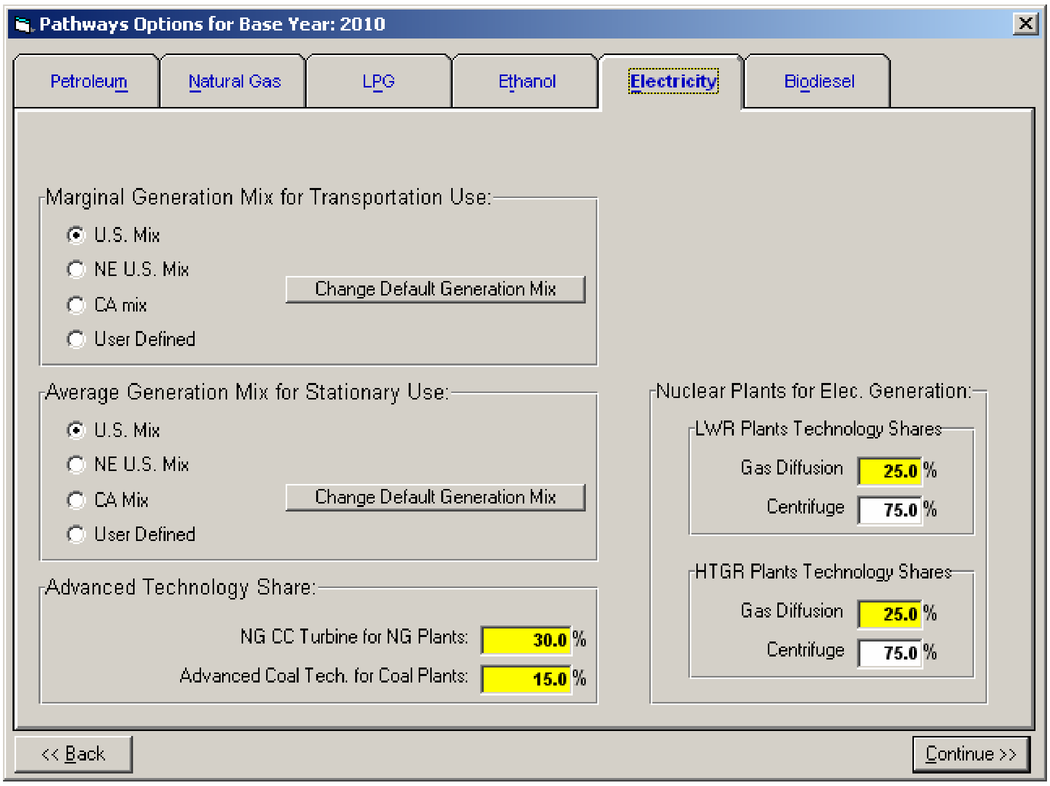


Figure 1.9 Typical Pathway Simulation Options Screen in GRETGUI

9. The Petroleum and Natural Gas tabs have several subgroups of pathways, divided into convenient sub-tabs, which are displayed in Red, see Figure 1.10. The user must review all the displayed blue and red tabs before continuing to the next window, otherwise GREETGUI will remind the user to do so. The user may click the “Continue” button to proceed, or click the “Back” button to review the earlier phase of market shares selections. As mentioned earlier, the user can move the mouse cursor over any button or selection in the displayed window to view the tip associated with that button or selection.

10. Next, a window named “Simulation Options for Alternative Fuel Blends” will appear. It allows the user to select the shares of the alternative fuels to blend with gasoline and diesel fuels. The user may adjust the default values for blend shares shown in the yellow fields. It should be noted that MOVES does not pass to GREETGUI the shares of alternative fuels for blending in conventional fuels. Therefore, the alternative fuel shares which the user can specify in GREETGUI, is disconnected from what is used in MOVES. The MOVES user should be aware of this disconnection and is advised to specify alternative fuel shares for blending with gasoline and diesel in GREETGUI that are consistent with those which are used by MOVES. The user may click the “Continue” button to proceed, or click the “Back” button to review the technology options of the previous window.

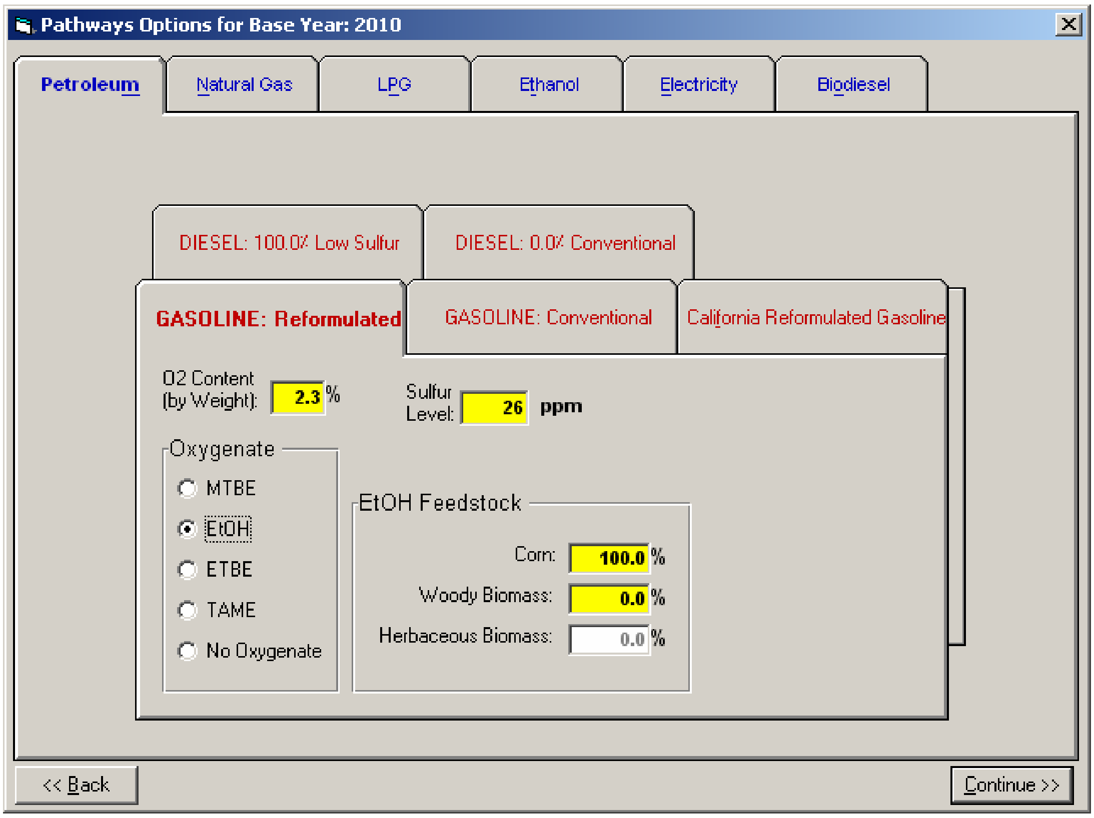


Figure 1.10 Petroleum Pathways Simulation Options in GRETGUI

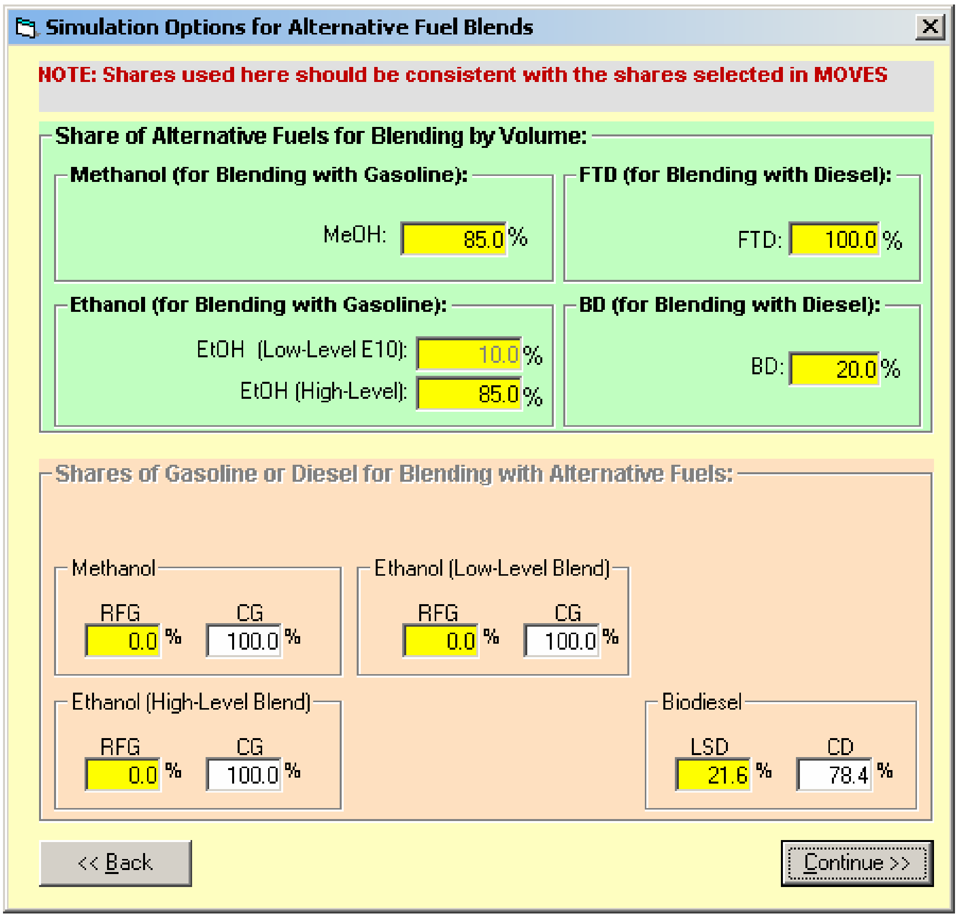


Figure 1.11 Alternative Fuel Blends Simulation Options Screen

11. After the second phase of technology selecting/specifying is completed, a window, Figure 1.12, will pop-up offering two options:

    -**Continue**: This takes the user to the third and last phase of GREETGUI, which is the reviewing/changing of parametric assumptions associated with production and distribution of the selected fuel types. If clicked, GREETGUI will proceed to view and/or change the parametric assumptions of the base year. The base year is the year closest to 2010, for which GREET model has its estimates with the least uncertainty.

    -**Review selected scenario options**: This allows the user to return to the beginning of the previous technology selection/specification window, where changes can be made to previous selections by clicking on the appropriate pathway tabs and making new selections as desired.

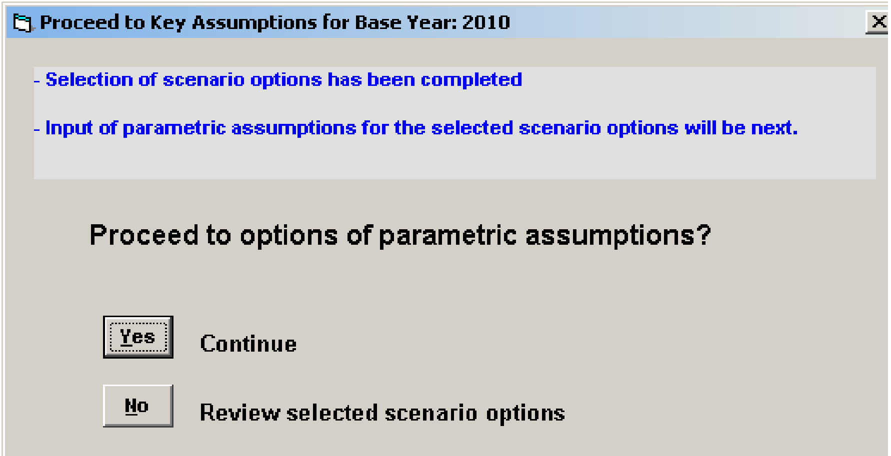


Figure 1.12 End of Pathways Simulation Options Screen

12. When the user clicks on the "Continue" button, the program proceeds to the third phase of key assumptions for the selected fuel pathways and scenarios. A window displaying the simulation options for the base year's parametric assumptions will show, see Figure 1.13.

    The user is reminded that the GREET spreadsheet model, running in the background, has estimates of key assumptions in lookup tables for the range of years from 1990 to 2020, arranged in a five years interval. Only the base year's estimates of the key assumptions will be presented to the user for changing or modification. The assumptions for all other years in the lookup tables will be adjusted by the same percentage changes made by the user to the base year's estimates.

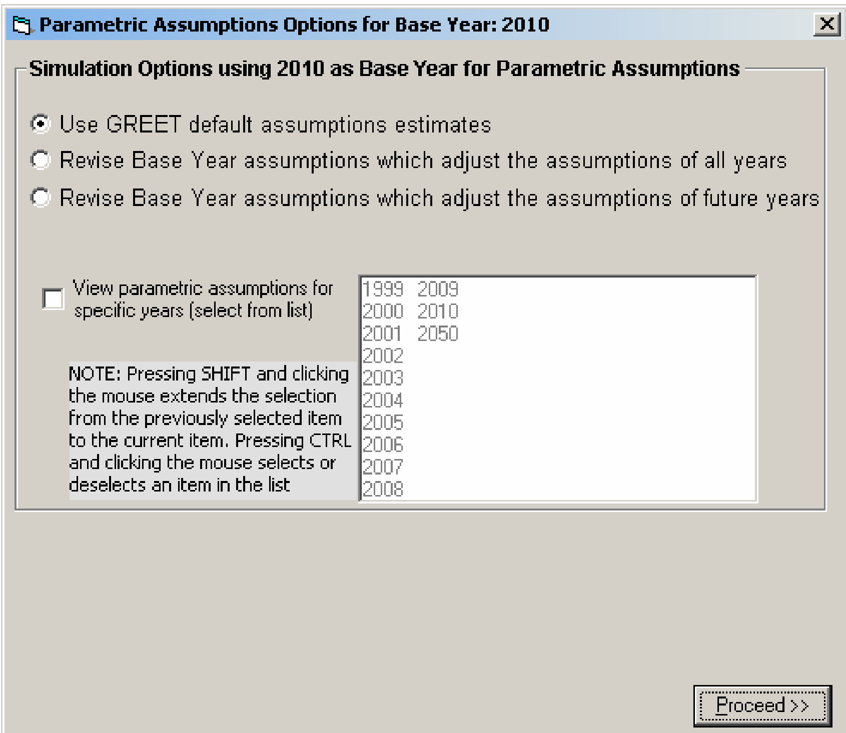


Figure 1.13 Parametric Assumptions Simulation Options

The user may select one of three options: (1) Use GREET default assumptions estimates; (2) Revise Base Year assumptions which automatically adjust the assumptions of all years by the same percentage change made to the base year's estimates; or (3) Revise Base Year assumptions which automatically adjust the assumptions of future years by the same percentage change made to the base year's estimates.

Selecting the first option in the above window allows the user to view the GREET default assumption estimates in the subsequent windows, but without modifying or changing them. The second option allows the user to revise the base year's estimates and automatically adjusts all other years' estimates in the GREET lookup tables by the same percentage change made to the base year's estimate. This case is typical when the user wants to revise the default estimates in the entire lookup table upward or downward simply by changing the default estimate of the base year. The third option allows the user to revise the base year's estimates and automatically adjusts only the future years' estimates in the GREET lookup tables by the same percentage change made to the base year's estimate. This case is typical when the user wants to revise the default estimates only for the base year's estimates and the estimates of all subsequent years up to 2020, but wants to hold the estimates of the earlier years (previous to the base year) unchanged at their original default values because of their historical significance.

Although the user cannot view the GREET lookup tables for the key assumptions, he/she may check a box to view the parametric assumptions, used by GREET, for any of the simulation years by selecting those years from the displayed list. The user should click "Proceed" to continue. More details about GREETGUI handling of the assumptions for different simulation years are given at the end of this document under a section entitled "Technical Issues with Running GREETGUI".

13. The key assumptions, listed in table format, will appear in a following window. It should be noted that GREETGUI displays only the <u>key</u> assumptions for viewing or modification by the user. Other assumptions used by the GREET model are not displayed in the tables and cannot be viewed or changed by the user through GREETGUI. However, the user can always go to the GREET model in Excel to change any of the parametric assumptions.

14. The key assumptions are displayed in two successive windows, "Fuel Production Assumptions" and "Feedstock and Fuel Transportation Assumptions." The first window, "Fuel Production Assumptions", includes a blue tab for each of the fuel pathways selected is shown in Figure 1.14. The yellow cells in the table may be edited, by a single-click in the cell, to modify any of the key assumptions of the base year as desired. After reviewing the fuel production assumptions, the user should click

the "Continue" button to proceed to the "Feedstock and Fuel Transportation Assumptions" window.

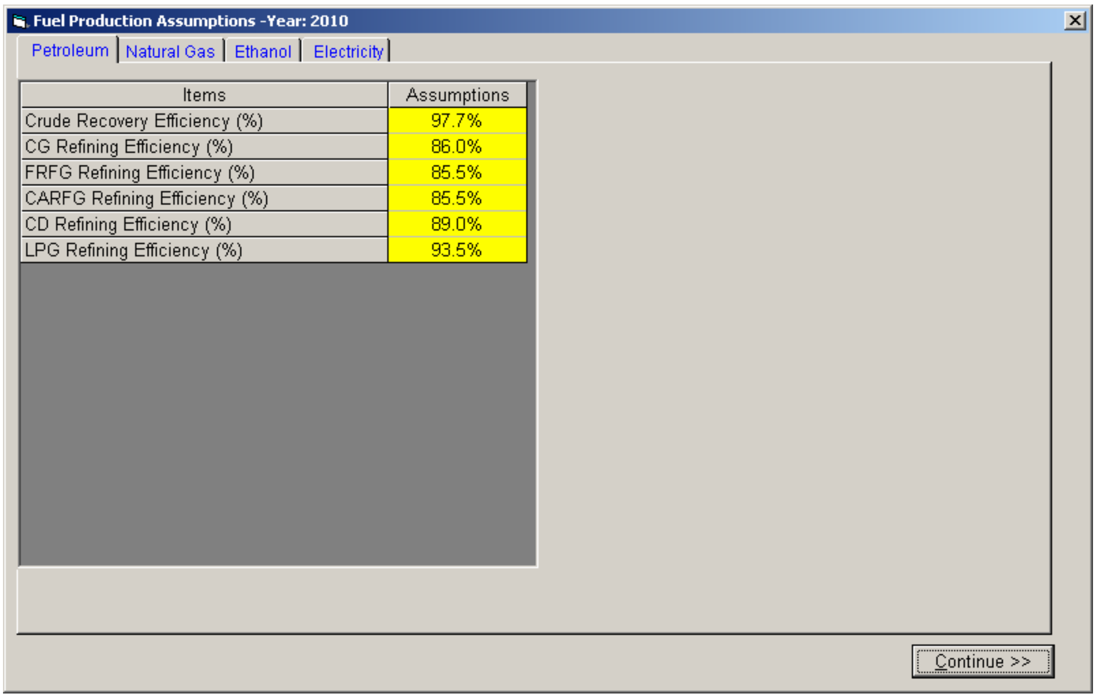
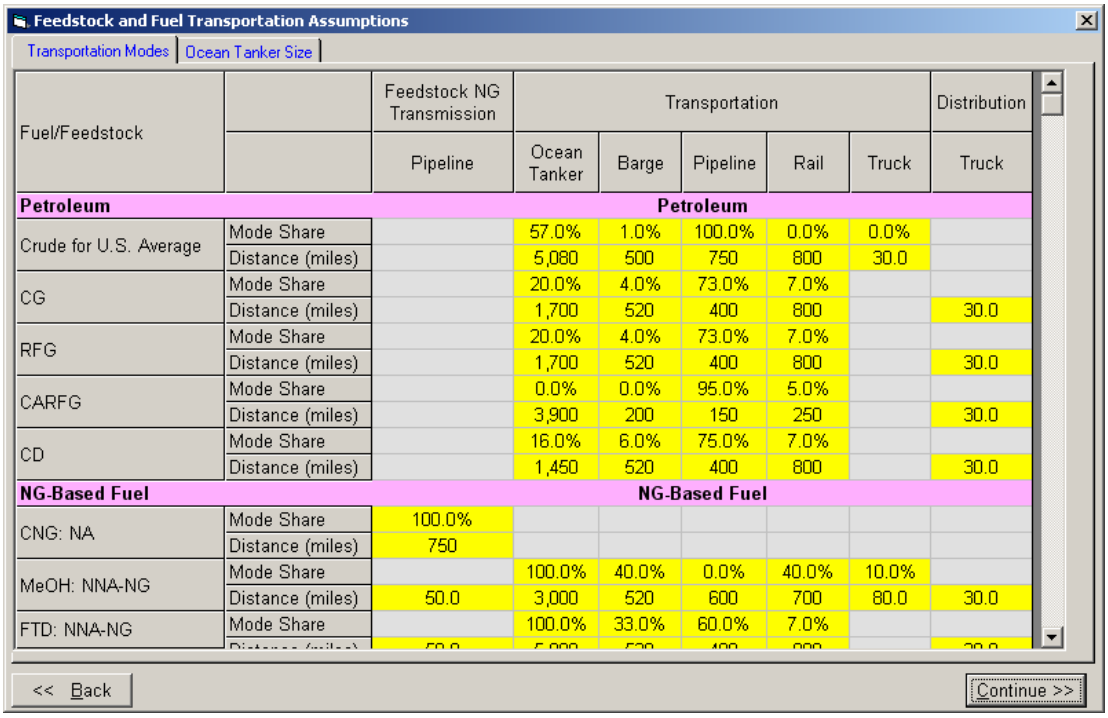


Figure 1.14 Typical Fuel Production Assumptions Screen

15. The second key assumptions window, "Feedstock and Fuel Transportation Assumptions", includes one or more blue tabs, depending on the selected fuel types for that session. The first tab includes the key assumptions for the fuel transportation modes of the feedstock for the selected fuel types. The second tab includes the key assumptions for the boiloff of LNG during transportation. The third tab includes the key assumptions for the ocean tanker size for those fuels and feedstock imported from overseas. All yellow cells in the displayed table can be edited, by a single-click in the cell, to modify the key assumptions as desired. It should be noted that this form appears only once throughout the entire running session, since its values do not depend on the simulation year. After reviewing/editing the "Feedstock and Fuel Transportation Assumptions", the user may click the "Continue" button to continue to the final dialogue box or click the "Back" button to review the previous window of "Fuel Production Assumptions".



Fuel/Feedstock		Feedstock NG Transmission	Transportation					Distribution
		Pipeline	Ocean Tanker	Barge	Pipeline	Rail	Truck	Truck
Petroleum			**Petroleum**					
Crude for U.S. Average	Mode Share		57.0%	1.0%	100.0%	0.0%	0.0%	
	Distance (miles)		5,080	500	750	800	30.0	
CG	Mode Share		20.0%	4.0%	73.0%	7.0%		
	Distance (miles)		1,700	520	400	800		30.0
RFG	Mode Share		20.0%	4.0%	73.0%	7.0%		
	Distance (miles)		1,700	520	400	800		30.0
CARFG	Mode Share		0.0%	0.0%	95.0%	5.0%		
	Distance (miles)		3,900	200	150	250		30.0
CD	Mode Share		16.0%	6.0%	75.0%	7.0%		
	Distance (miles)		1,450	520	400	800		30.0
NG-Based Fuel			**NG-Based Fuel**					
CNG: NA	Mode Share	100.0%						
	Distance (miles)	750						
MeOH: NNA-NG	Mode Share		100.0%	40.0%	0.0%	40.0%	10.0%	
	Distance (miles)	50.0	3,000	520	600	700	80.0	30.0
FTD: NNA-NG	Mode Share		100.0%	33.0%	60.0%	7.0%		

Figure 1.15 Typical Transportation Assumptions Screen

16. After all key assumptions have been reviewed or modified; another window, Figure 1.16, will present two options:

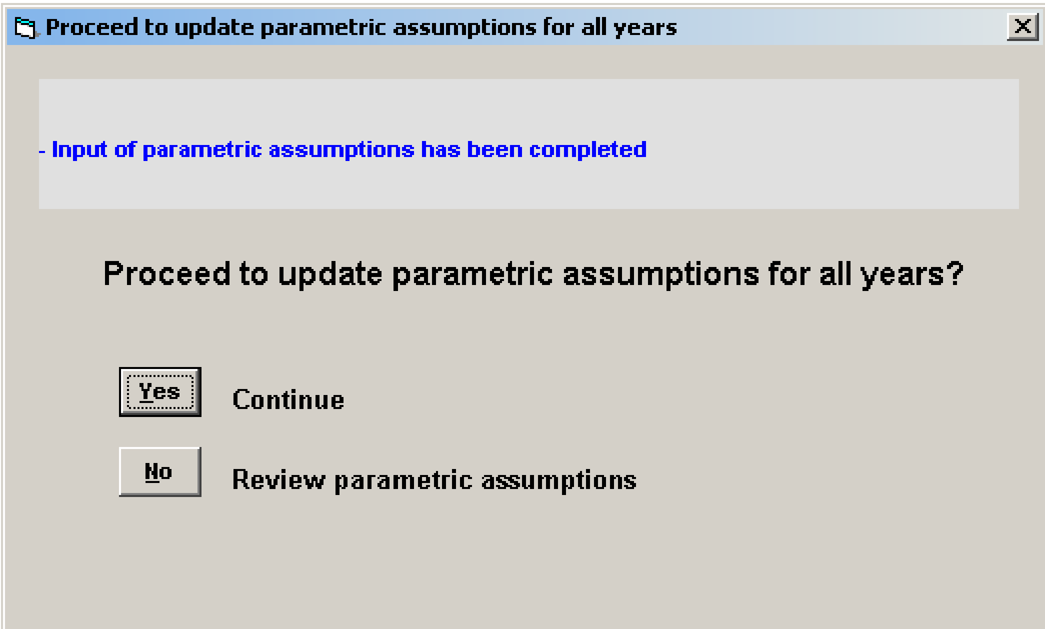


Figure 1.16 End of Parametric Assumptions Screen

- **Continue:** This option allows the user to proceed to the completion of the GREET simulation. GREETGUI will take the user's selected scenario options, together with the parametric assumptions, run the main Excel program in the background for all simulation years, and export the output results in the form of ASCII, tab delimited file.

- **Review parametric assumptions:** This option allows the user to return to the parametric assumptions windows and review the selections and/or changes earlier made in these windows.

17. After GREETGUI completes its run, it generates an output file, Figure 1.17, and the control goes back to the calling program, MOVES. MOVES then imports the output file generated by GREETGUI to update its database of energy and emission rates. The GREETGUI output file, which is transparent to the user, contains the following fields:

    a. The first column includes a Year ID (an Integer identifying the year to which the calculations were made)
    b. The second column includes a Pollutant ID (an Integer from a set of values used in MOVES)
    c. The third column includes a Fuel Subtype ID (an Integer from a set of values used in MOVES).
    d. The fourth column includes the Energy use or emission rate (a floating point number, expressed in Joules of energy use per Joules of fuel's heating value or grams of pollutant per Joules of fuel's heating value, as appropriate for each pollutant).

The pollutants in the GREETGUI output file include: total energy use, fossil energy use, petroleum energy use, CO_2 emission rate, CH_4 emission rate and N_2O emission rate.

WTPOutput.DAT - Notepad

File Edit Format Help

1999	91	10	0.364495509962188
1999	93	10	0.354146916809408
1999	92	10	0.127380450706959
1999	90	10	2.52363018229882E-02
1999	5	10	1.00902914061806E-04
1999	6	10	4.27126672737714E-07
1999	91	11	0.401530689803679
1999	93	11	0.391075029805986
1999	92	11	0.125272694368376
1999	90	11	2.63437998582448E-02
1999	5	11	1.15650334836014E-04
1999	6	11	4.46827172697549E-07
1999	91	13	0.387751803160415
1999	93	13	0.377460875267538
1999	92	13	0.119530403438115
1999	90	13	2.55363079901355E-02
1999	5	13	1.12636777901456E-04
1999	6	13	4.28316677819598E-07
1999	91	20	0.330792262970042
1999	93	20	0.320939194205072
1999	92	20	0.111320299180079
1999	90	20	2.30444401036186E-02
1999	5	20	9.84493411262209E-05
1999	6	20	3.93722720001473E-07
1999	91	30	0.150233644249111
1999	93	30	0.139429725364451
1999	92	30	5.68545629758768E-03
1999	90	30	1.09512066625066E-02
1999	5	30	2.34599840828899E-04
1999	6	30	1.60185437525274E-07
1999	91	40	0.158856447274593
1999	93	40	0.1552538325371
1999	92	40	3.43064322645258E-02
1999	90	40	1.11244649575561E-02
1999	5	40	1.09930464460292E-04
1999	6	40	1.95120304350474E-07

Figure 1.17 GREETGUI Output File to MOVES

1.5 TECHNICAL ISSUES WITH RUNNING GREETGUI

1.5.1 System Related Issues:

System Speed Considerations

GREETGUI is a calculation-intensive program. If during a GREETGUI session it appears that the program execution has frozen up after hitting a "Continue" button, the program should be allowed sufficient time to complete its calculations before clicking the "Continue" button again.

1.5.2 Calculation Logistic of Lookup (Time-Series) Tables:

Lookup tables are tables built in the GREET (Excel) model which include values for fuel market shares, fuel production pathways options, and fuel production and transportation assumptions between 1990 and 2020, estimated at five-year intervals. For any simulation year between those years listed in the lookup table, GREETGUI simply uses a linear interpolation algorithm to calculate the estimate for that particular year. Below are examples of lookup table for reformulated gasoline (RFG) market shares and production assumptions of conventional gasoline (CG) refining efficiency.

24.0%

5-year period	Share of RFG	Relative Efficiency (to yr 2010)
1990	0%	
1995	15%	
2000	30%	
2005	35%	
2010	**50%**	
2015	65%	
2020	100%	

86.0%

5-year period	CG Refining Efficiency	Relative Efficiency (to yr 2010)
1990	86.5%	100.6%
1995	86.5%	100.6%
2000	86.0%	100.0%
2005	86.0%	100.0%
2010	**86.0%**	**100.0%**
2015	86.0%	100.0%
2020	85.5%	99.4%

Figure 1.18 Typical Lookup Tables in GREET

It should be noted that the lookup tables in the GREET model has estimates with the least uncertainty for the year 2010. All other years' estimates are made relative to the estimate of 2010. GREETGUI uses three different methods to handle the entries of the lookup tables depending on whether a table represents fuel market shares, fuel production pathway (technology) options, or fuel production and transportation (parametric) assumptions. Those three different methods are described below.

(a) For fuel market share estimates, GREETGUI provides the user with three options. These options are: GREET default estimates, linear interpolation between first and last year estimates, or user select market shares for some or all of the simulation years. If the user selects GREET default, then GREETGUI will show market shares based on the lookup tables built in the GREET model, but the user won't be able to change any of the GREET default estimates. Alternatively, the user may select to calculate the market share estimates based on a linear interpolation between the first and last year estimates. In such case, the user will be able to change the first and last year estimates, and GREETGUI will automatically calculate the estimates for all years in between using a linear interpolation algorithm. If the user selects the option to specify the market shares, then market share estimates for all years will be amenable to change by the user.

(b) For fuel production pathway (technology) options, GREETGUI presents the user with the estimates of the simulation year closest to 2010, since GREET has its best estimates for the year 2010 as noted above. Therefore, the simulation year closest to 2010 is chosen by GREETGUI as the base year, for which the user may change the technology options and estimates. It should be noted that any changes made by the user to the base year estimates would automatically adjust estimates to all subsequent simulation years (subsequent to the base year) with the same amount of change made to the base year's estimate. For example, if the user changes the share of LPG production from natural gas from 50% to 60% for the year 2010, then all estimates for all simulation years subsequent to 2010 would increase by the same percentage, which is 20% in this case. GREETGUI does not adjust technology options and estimates for simulation years before 2010 because of their historical significance.

(c) For fuel production and transportation (parametric) assumptions, GREETGUI presents the user with three options: use GREET default estimates, revise the assumptions for base year (closest to 2010), which would automatically adjust assumptions for all simulation years in GREET lookup tables with the same percentage change made to the base year's estimate, or revise the assumptions for base year, which would automatically adjust assumptions for future simulation years (subsequent to the base year) in GREET lookup tables with the same percentage change made to the base year's estimate.

For more information on the GREET model and GREETGUI developments, please visit the Argonne National Laboratory GREET web site: http://greet.anl.gov/. The user may also download a standalone version of GREETGUI to evaluate energy and emission impacts of advanced vehicle technologies and new transportation fuels for the entire well-to-wheel (WTW) fuel cycle, which includes the well-to-pump (WTP) cycle as well as the pump-to-wheel (PTW) cycle.

2. GREET Simulation Options

Information on key parametric assumptions and pathway simulation options used in various fuel-cycle simulations are listed in the following subsections. The GREET methodology for fuel-cycle simulations is not discussed in this manual. Publications that address GREET methodology are posted and available for download at the Argonne's National Laboratory GREET model web site http://www.transportation.anl.gov/publications/index.html. The following is a list of the key publications relevant to the GREET fuel-cycle model:

1) Wang, M., 2001, *Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies*, ANL/ESD-TM163, Argonne National Laboratory, Argonne, Ill., Jun.
2) Wang, M., 1999a, *GREET 1.5 — Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use, and Results*, ANL/ESD-39, Vol.1, Argonne National Laboratory, Argonne, Ill., Aug.
3) General Motors Corporation, Argonne National Laboratory, BP, ExxonMobil, and Shell, 2001, *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – a North American Analysis,* Jun.

2.1 Market shares of fuel options for given transportation fuels

In GREETGUI, market shares of transportation fuels are presented in tabular form for different years of simulation selected by the user. This includes: 1) gasoline fuels market shares, which specify the split between reformulated gasoline (RFG) and conventional gasoline (CG) market shares; 2) diesel fuels market shares, which specify the split between low-sulfur diesel (LSD) and conventional diesel (CD) market shares; 3) LPG feedstock market shares, which specify the split between natural gas (NG) and crude feedstock market shares; and 4) ethanol feedstock market shares, which specify the split between corn, woody biomass and herbaceous biomass feedstock market shares, see Figure 2.1.

Market shares in GREETGUI are linked to lookup (time-series) tables which are built in the underlying GREET spreadsheet model for the above mentioned transportation fuels. The time-series tables are developed to account for the expected changes in the fuel market shares over time. Table 2.1 lists the default market shares for the above mentioned six transportation fuels in GREET. The following paragraphs explains the rationale behind the GREET shares shown in Table 2.1.

The market shares of reformulated gasoline and conventional gasoline, shown in Table 2.1, are based on the expected trend that RFG market share will continue to increase over time in the U.S., and could eventually displace conventional gasoline in the future.

The market shares for low-sulfur diesel, shown in Table 2.1, are based on the requirement that all diesel fuels to be sold in the U.S. for on-road motor vehicles will have low sulfur content below 15 ppm by weight beginning 2006.

The market share of NG-based LPG is expected to increase over time at the expense of crude-based LPG in the U.S., primarily due to the expected increase of LPG imports from other countries to the U.S.

At present, the ethanol fuel is entirely produced from corn. The GREET model assumes corn to be the only feedstock for ethanol production until 2020 in the U.S.; since cellulosic biomass-based ethanol is still in the R&D stage.

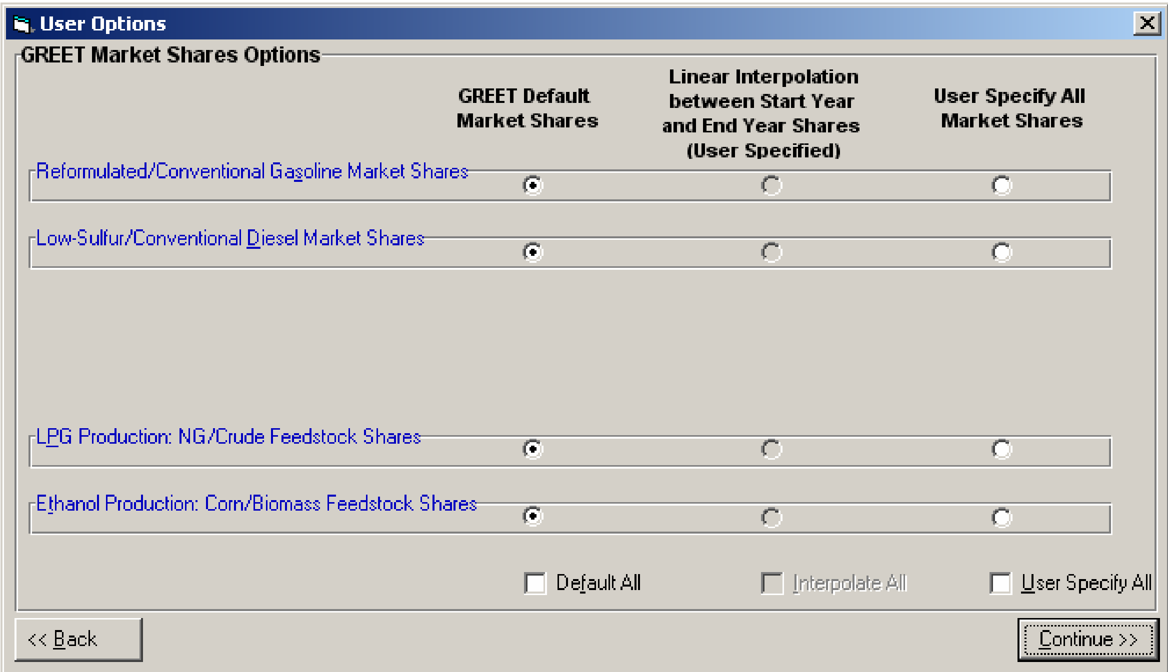


Figure 2.1. Transportation fuels market share options

Table 2.1. Default market shares for selected transportation fuels

Year	Gasoline		Diesel	
	RFG	CG	LSD	CD
1990	0%	100%	0%	100%
1995	15%	85%	0%	100%
2000	30%	70%	0%	100%
2005	35%	65%	0%	100%
2010	50%	50%	100%	0%
2015	65%	35%	100%	0%
2020	100%	0%	100%	0%

Year	LPG		Ethanol		
	Crude Feedstock	NG Feedstock	Corn Feedstock	Woody Biomass Feedstock	Herbaceous Biomass Feedstock
1990	50%	50%	100%	0%	0%
1995	45%	55%	100%	0%	0%
2000	40%	60%	100%	0%	0%
2005	40%	60%	100%	0%	0%
2010	40%	60%	100%	0%	0%
2015	35%	65%	100%	0%	0%
2020	30%	70%	100%	0%	0%

2.2 Key simulation options for petroleum-based fuel production pathways

2.2.1 Gasoline fuels

For reformulated gasoline, conventional gasoline, and California reformulated gasoline, the user can select the type of oxygenate for blending into gasoline, and specify their O_2 content by weight, as shown in Figures 2.2, 2.3 and 2.4, respectively. The types of oxygenate that can be selected in GREET are: 1) MTBE, 2) EtOH, 3) ETBE or 4) TAME. However, if the user selects the "no oxygenate" option, the O_2 content will be automatically set to zero.

The default sulfur contents in reformulated gasoline and California reformulated gasoline are 26 ppm and 11 ppm, respectively. Since sulfur content in conventional gasoline is expected to change over time, time-series tables have been created for the default sulfur content in conventional gasoline as shown in Table 2.2. It should be noted that MOVES does not pass to GREETGUI the fuel's sulfur content. Therefore, the sulfur content which the user can specify in GREETGUI, for any of the fuels listed in Table 2.2, is disconnected from what is used in MOVES. The MOVES user should be aware of this disconnection and is advised to specify sulfur content in GREETGUI that is consistent with that which is used by MOVES.

In addition to the differences in their refining efficiencies, the California gasoline and the US gasoline have different transportation modes and distances of crude oil from oil fields to refineries. For the California reformulated gasoline pathway, the transportation mode and distance of crude oil to the California refineries will be used in the simulation.

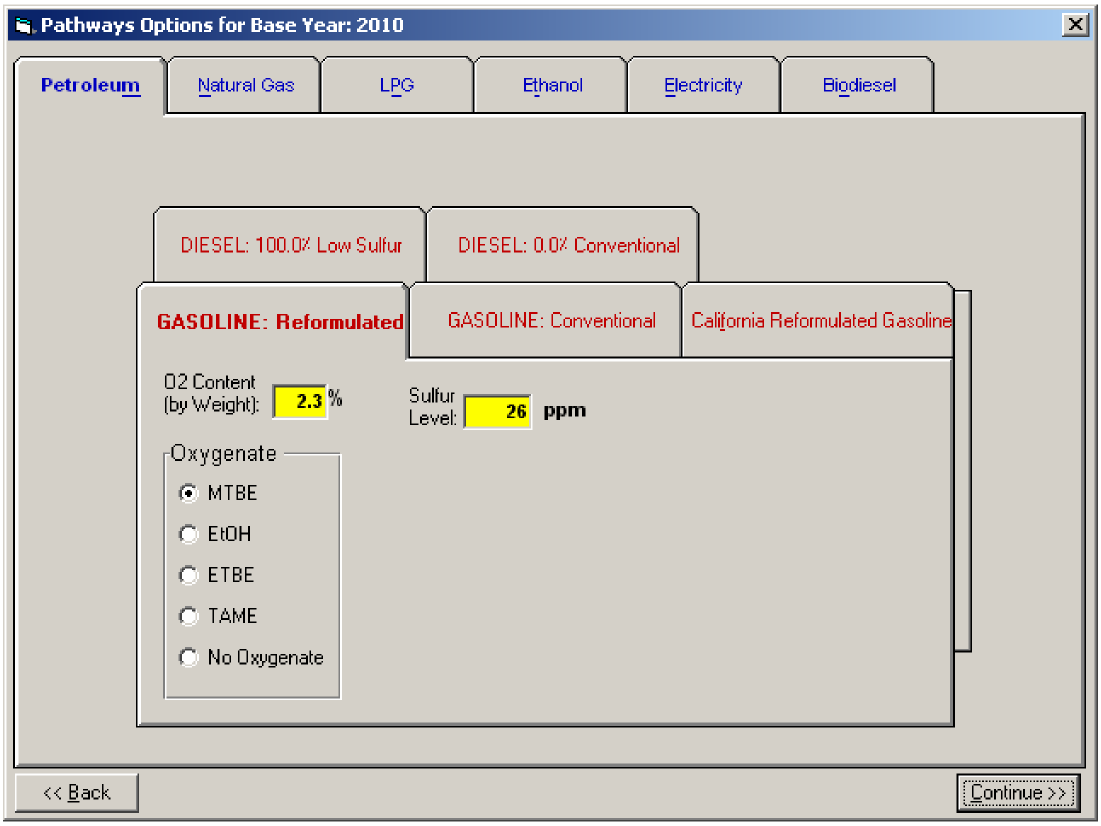


Figure 2.2. Reformulated gasoline production pathway options

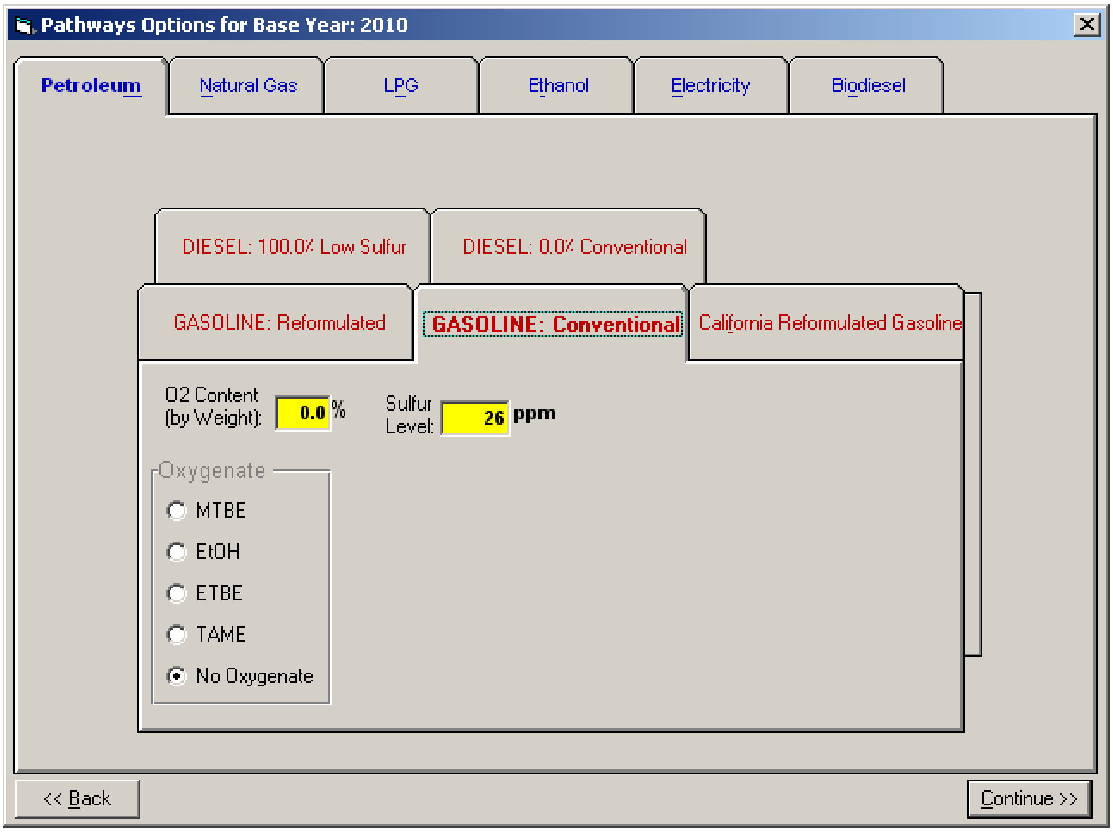


Figure 2.3. Conventional gasoline production pathway options

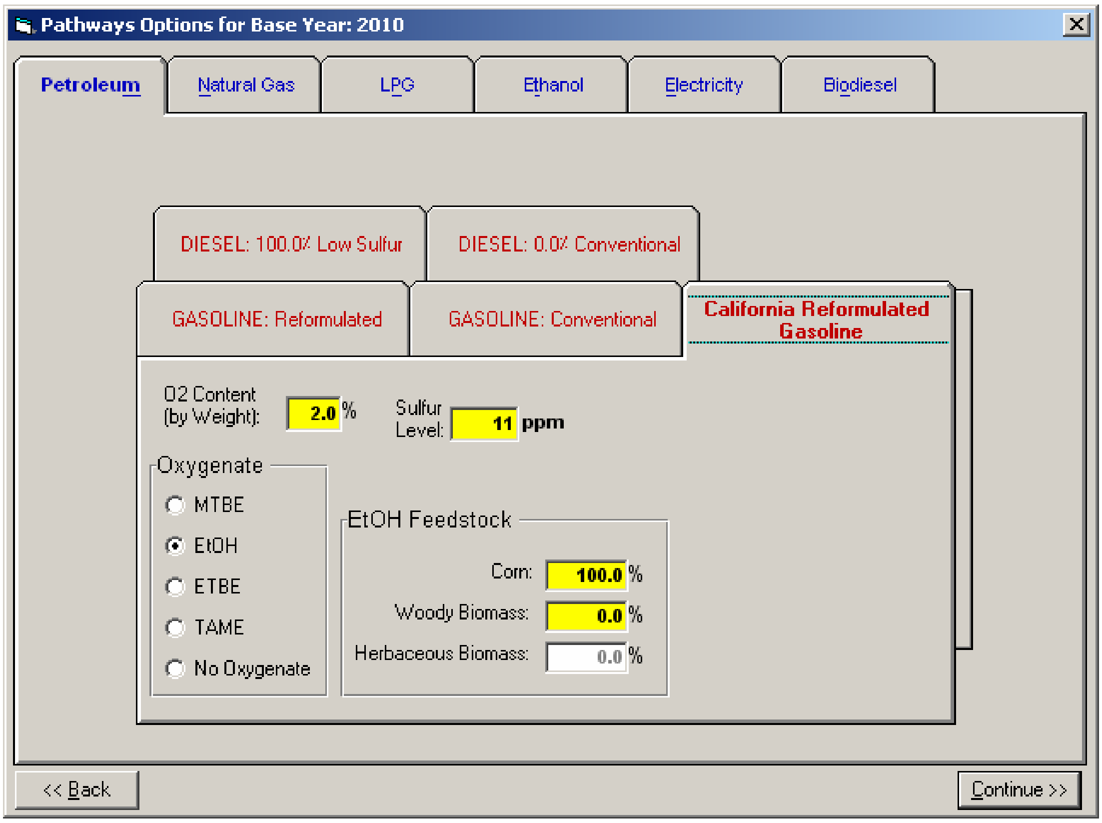


Figure 2.4. California reformulated gasoline production pathway options

Table 2.2. Default sulfur content of selected transportation fuels

Year	CG	CD	California CD	Low-Sulfur Diesel	Non-Road Diesel
1990	500	600	350	NA	2,283
1995	340	350	200	NA	2,283
2000	200	200	120	NA	2,283
2005	26	200	120	NA	2,283
2010	26	NA	120	11	163
2015	26	NA	120	11	11
2020	26	NA	120	11	11

NA – not applicable.

2.2.2 Diesel Fuels

For low sulfur diesel and conventional diesel, the user can select the location for use as U.S. or California, as shown in Figures 2.5 and 2.6, respectively. The default location for use is the entire U.S. If the California location is selected, the transportation mode and distance of crude oil to the California refineries will be used in the simulation.

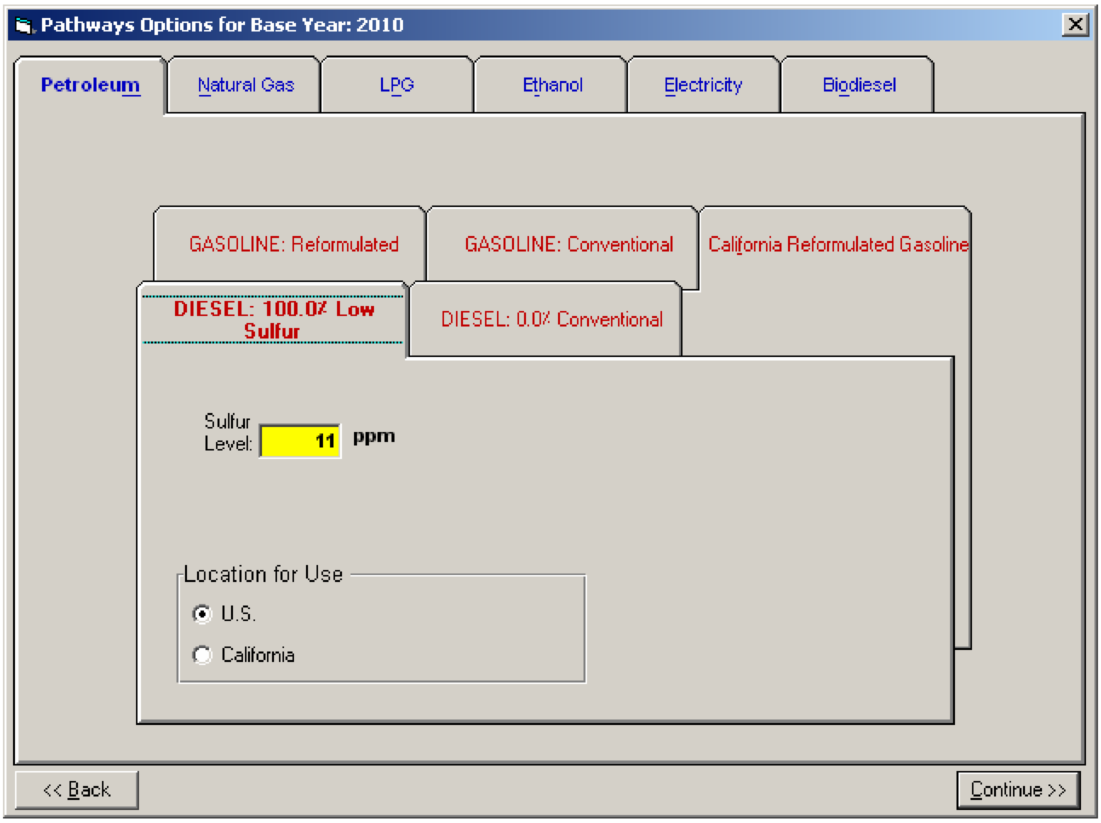


Figure 2.5. Low sulfur diesel production pathway options

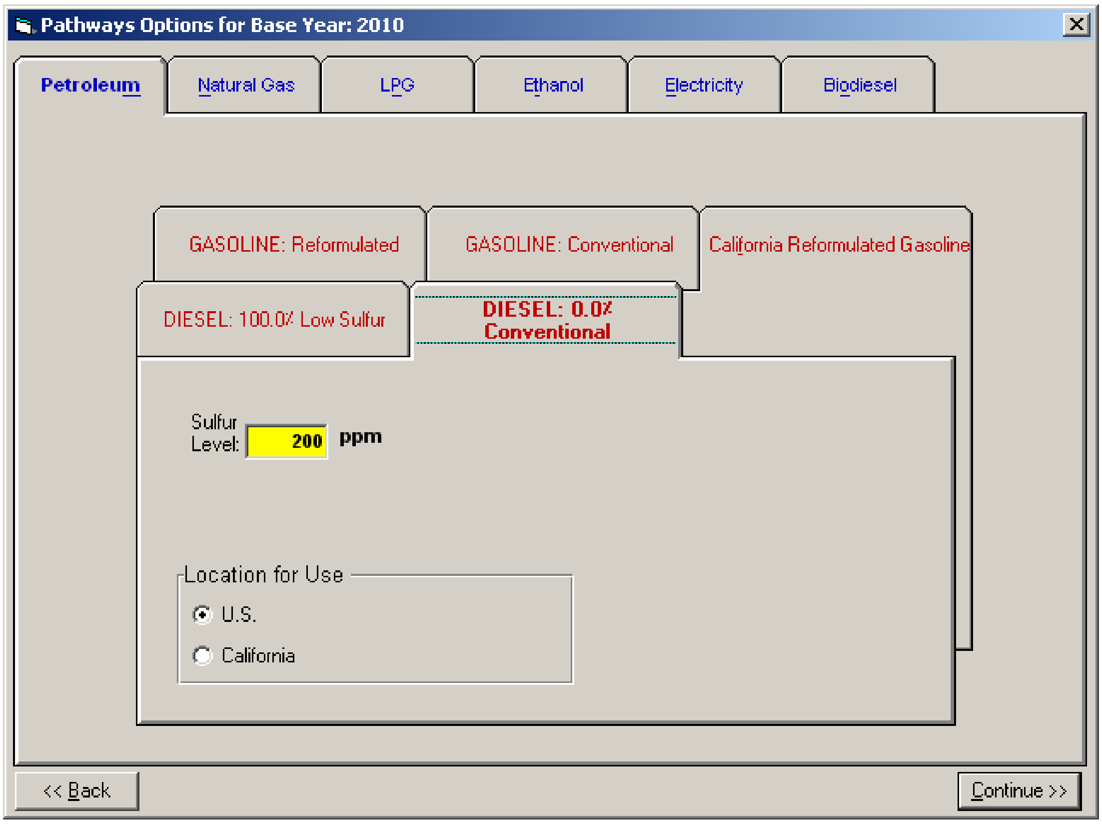


Figure 2.6. Conventional diesel production pathway options

The default sulfur content in GREET for low sulfur diesel is 11 ppm, regardless of its location for use. The sulfur content in conventional diesel is expected to change over time, and therefore, time-series tables have been developed in GREET for the default sulfur content in conventional diesel, both for U.S. and California locations, as shown in Table 2.2 above. Note that the sulfur content for conventional diesel is specified in Table 2.2 only from 1990 to 2005, beyond which the sulfur content of conventional diesel does not affect the calculations since its market share is set to zero, see Table 2.1.

It should be noted that MOVES does not pass to GREETGUI the fuel's sulfur content. Therefore, the sulfur content which the user can specify in GREETGUI, for any of the fuels listed in Table 2.2, is disconnected from what is used in MOVES. The MOVES user should be aware of this disconnection and is advised to specify sulfur content in GREETGUI that is consistent with that which is used by MOVES.

2.3 Key simulation options for NG-based pathways

The natural gas (NG) based fuels simulated in GREETGUI are compressed natural gas (CNG), Fitsch-Tropsch Diesel (FTD) and methanol (MeOH). For the CNG and FTD fuels, GREETGUI presents the user with three options for the feedstock source: 1) North American natural gas (NA NG), 2) non-North American natural gas (NNA NG), or 3) non-North American flared gas (FG), as shown in Figures 2.7 and 2.8, respectively. For methanol, in addition to the above three feedstock sources, the user is presented with landfill gas as a fourth feedstock option (Figure 2.9). For the non-North America sources to CNG, the feedstock gas is converted into liquefied natural gas (LNG) for transportation to North America, where it is gasified. The production plant design types for FTD and methanol in GREET include three design options: 1) without steam or electricity export, 2) with steam export, or 3) with electricity export. For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET.

2.3.1 CNG

The GREET default simulation option for CNG feedstock source is North America natural gas as shown in Figure 2.7.

2.3.2 FTD

All announced FTD plants so far are outside of North America, mainly due to the high price of NG in North America. Therefore, the default options for feedstock source and plant design type in GREET are non-North American NG and without steam or electricity export, as shown in Figure 2.8.

2.3.3 Methanol

Due to the high NG price in North America, most methanol plants are located outside of North America. Therefore, the default feedstock source for methanol production in GREET is non-North American, and the default plant design type is without steam or electricity export, as shown in Figure 2.9.

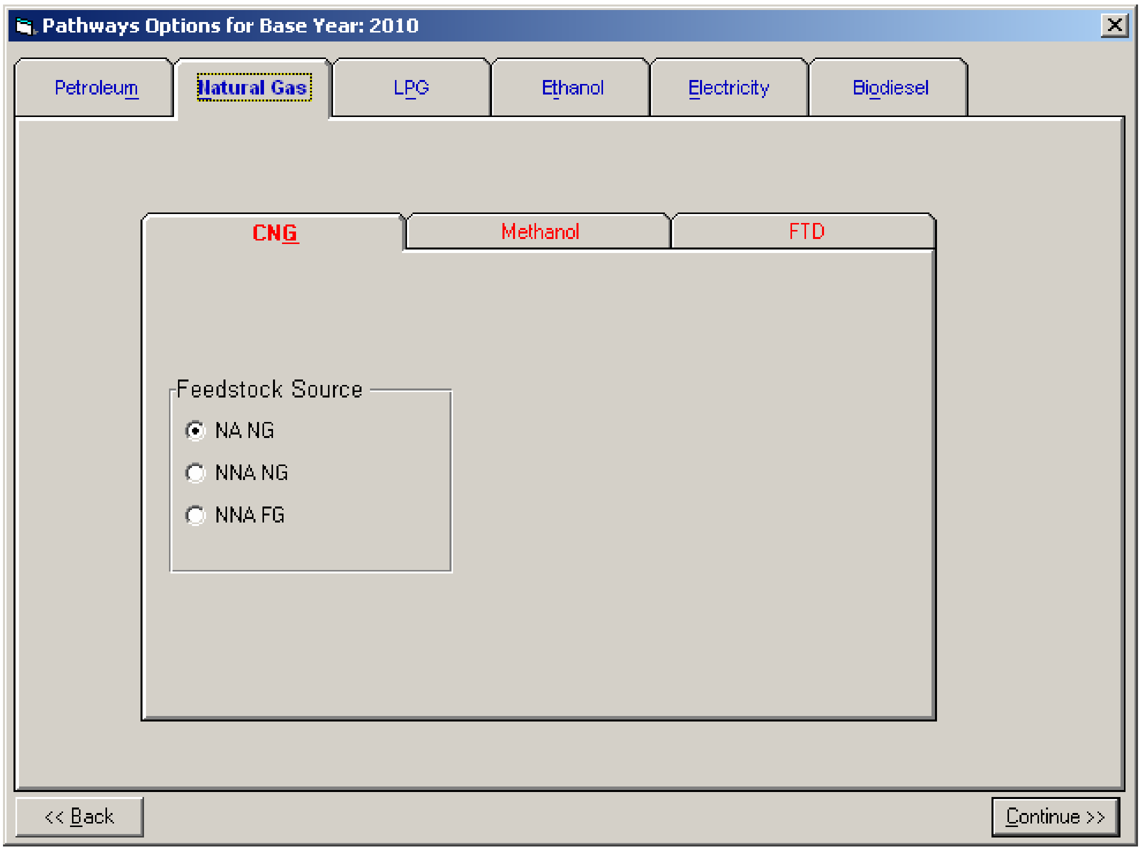


Figure 2.7. CNG production pathway options

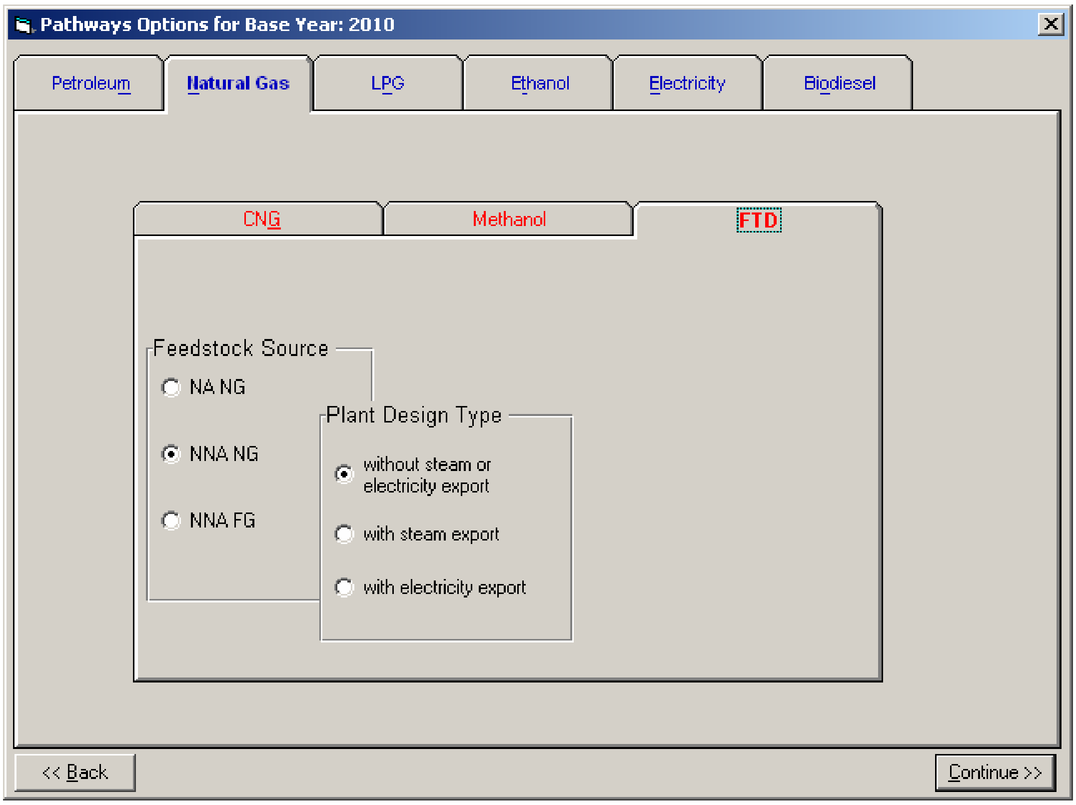


Figure 2.8. FTD production pathway options

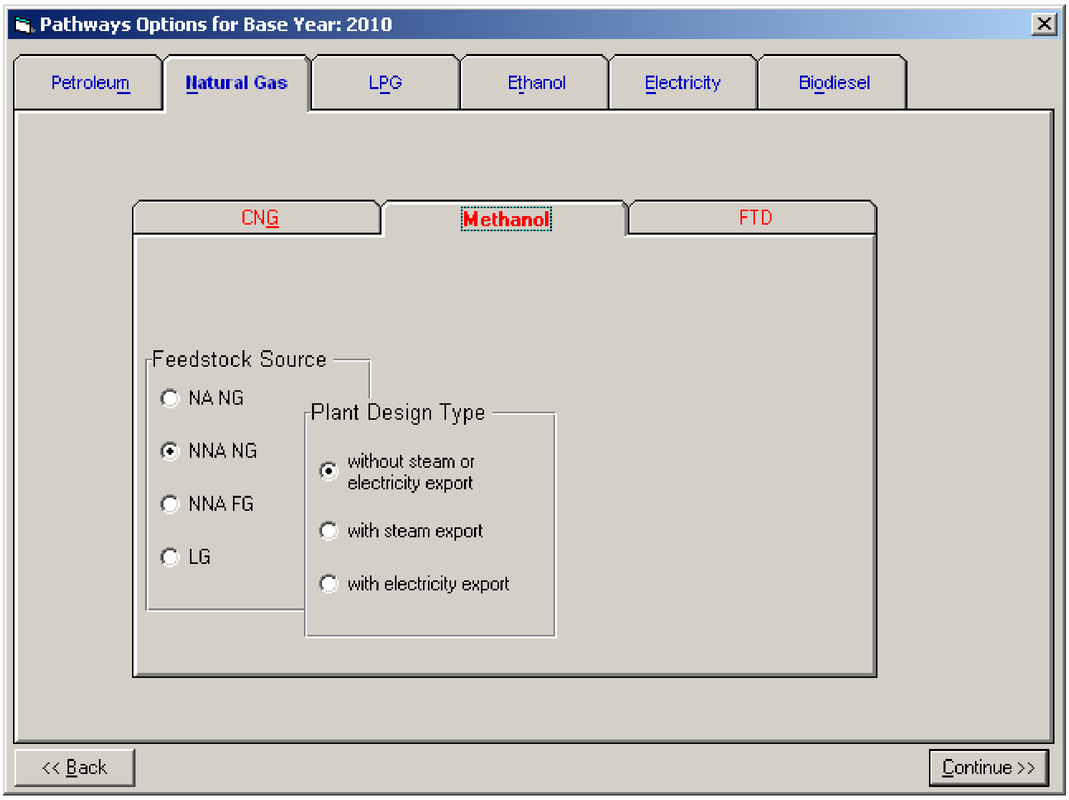


Figure 2.9. Methanol production pathway options

2.4 Key simulation options for LPG production pathway

LPG can be produced from petroleum refineries and/or NG processing plants. The GREET model allows the user to select the market share of each LPG feedstock source (see subsection 2.1 above). For NG-based LPG production pathway, the user can select the feedstock source for LPG production as 1) North American NG, or 2) non-North American NG. The default simulation option in GREET is North American NG as the feedstock, see Figure 2.10.

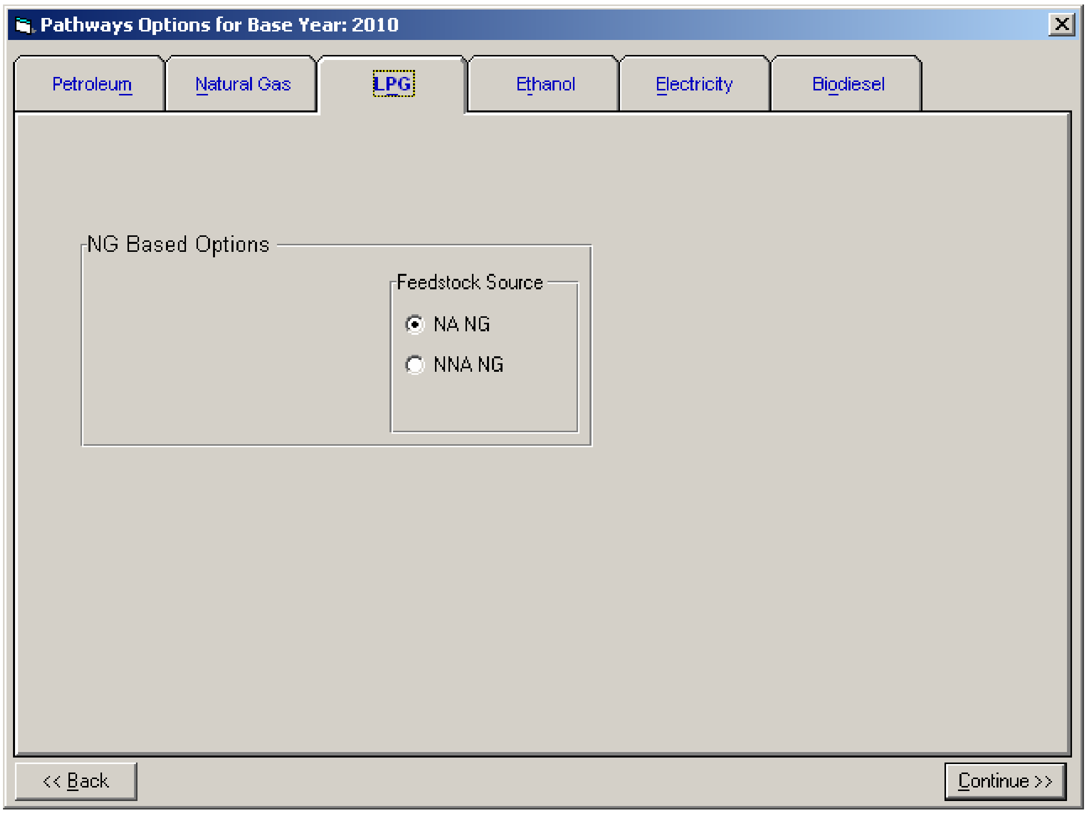


Figure 2.10. LPG production pathway options

2.5 Key simulation options for ethanol production pathway

Ethanol (EtOH) could be produced from 1) corn, 2) woody biomass, and/or 3) herbaceous biomass. The GREET model allows the user to select the market share of each ethanol feedstock source (see subsection 2.1 above).

For corn producing ethanol pathway, GREET includes the following plant design options to produce fuel ethanol: 1) dry milling plants (DMP), and/or 2) wet milling plants (WMP), see Figure 2.11. Wet milling plants produce ethanol from corn starch. Other co-products in wet milling plants include high-fructose corn syrup, glucose, gluten feed, and gluten meal. Dry milling plants, which are smaller than wet milling plants, are designed exclusively for ethanol production. In dry milling plants, ethanol is produced from corn starch, while other constituents of the corn kernel are used to produce distillers' dried grains and solubles (DDGS). The shares of ethanol production in dry milling and wet milling plants may change over time. Therefore, time-series tables for plant shares (dry milling vs. wet milling) contributing to the production of corn-based ethanol were developed in GREET, see Table 2.3.

Process fuels used for dry milling plants and wet milling plants are typically NG and coal. The share of process fuels for each plant type may also change over time. Time-series tables for the default shares of process fuels for each plant type were developed in GREET, as shown in Table 2.3.

In addition to ethanol production, corn-based ethanol plants produce a variety of co-products as mentioned above. While dry milling plants co-produce DDGS, wet milling plants co-produce corn gluten feed, corn gluten meal, and corn oil. GREET allocates emissions and energy use charge between ethanol and its co-products by using either a product displacement method or a market value-based method. The default method in GREET is the product displacement method.

Table 2.3. Default shares of plant types and process fuels for corn-ethanol

Year	Share of corn-ethanol plant type		Share of process fuels for DMP		Share of process fuels for WMP	
	DMP	WMP	Coal	NG	Coal	NG
1990	30%	70%	40%	60%	50%	50%
1995	33%	67%	35%	65%	50%	50%
2000	67%	33%	30%	70%	40%	60%
2005	68%	32%	20%	80%	40%	60%
2010	70%	30%	20%	80%	40%	60%
2015	70%	30%	20%	80%	40%	60%
2020	70%	30%	20%	80%	40%	60%

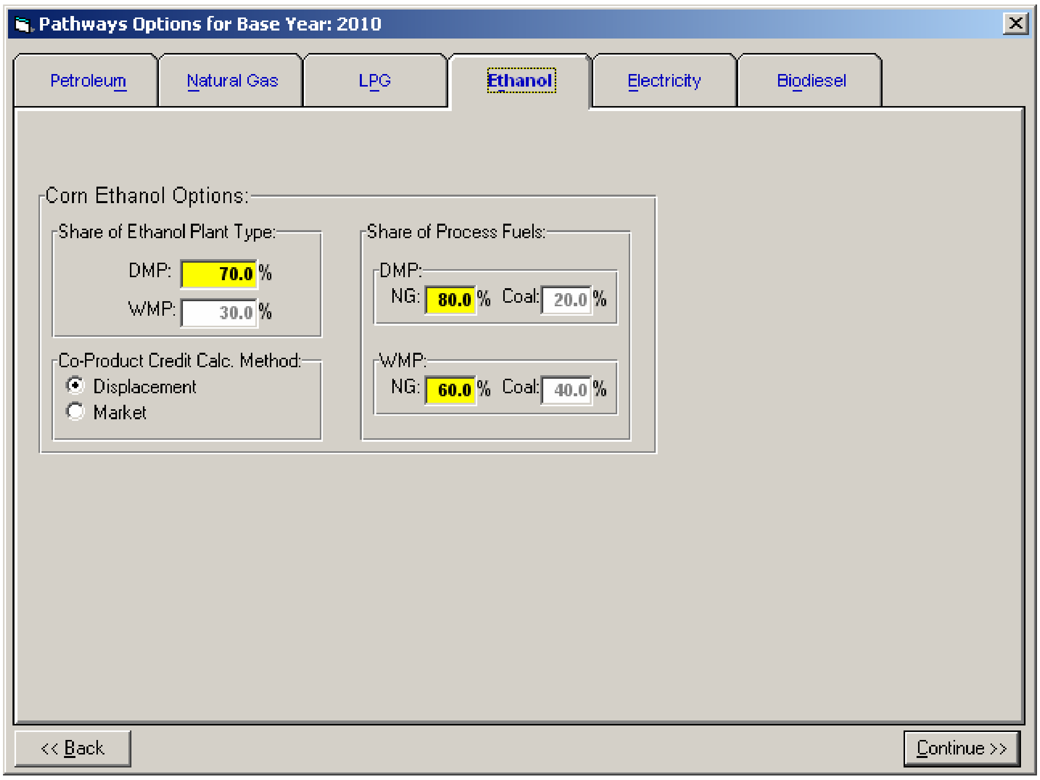


Figure 2.11. Ethanol production pathway options

2.6 Key simulation options for electricity generation

Energy use and emissions of electricity generation are needed in GREET for two purposes: 1) electricity usage in well-to-pump (WTP) activities, and 2) electricity use in electric vehicles (EVs) and grid-connected hybrid electric vehicles (HEVs). The GREET model calculates emissions associated with electricity generation from residual oil, NG, coal, and uranium. Of the various power plants, those fueled by residual oil, NG, and coal produce emissions at the plant site. Nuclear power plants do not produce air emissions at the plant site. However, other emissions and energy use associated with the upstream production of uranium and its preparation stages are accounted for in GREET. Electricity generated from hydropower, solar, wind, and geothermal sources are treated as zero emission plants in GREET; and are categorized together in one group named “Others”.

GREET has two sets of electricity generation mix: 1) marginal generation mix for transportation use, which is used for EVs and grid-connected HEVs; and 2) average generation mix for use in all WTP activities. The user can select a set of electricity generation mix from one of the following options: 1) U.S. average electricity mix, 2) North-Eastern U.S. average electricity mix, 3) California electricity mix, or 4) user defined mix. Table 2.4 lists the default electricity generation mix over time in GREET. Future trends (2005-2020) for U.S. average electricity mix, North-Eastern U.S. average electricity, and California electricity mix are based on projections from Energy Information Administration (EIA), DOE.

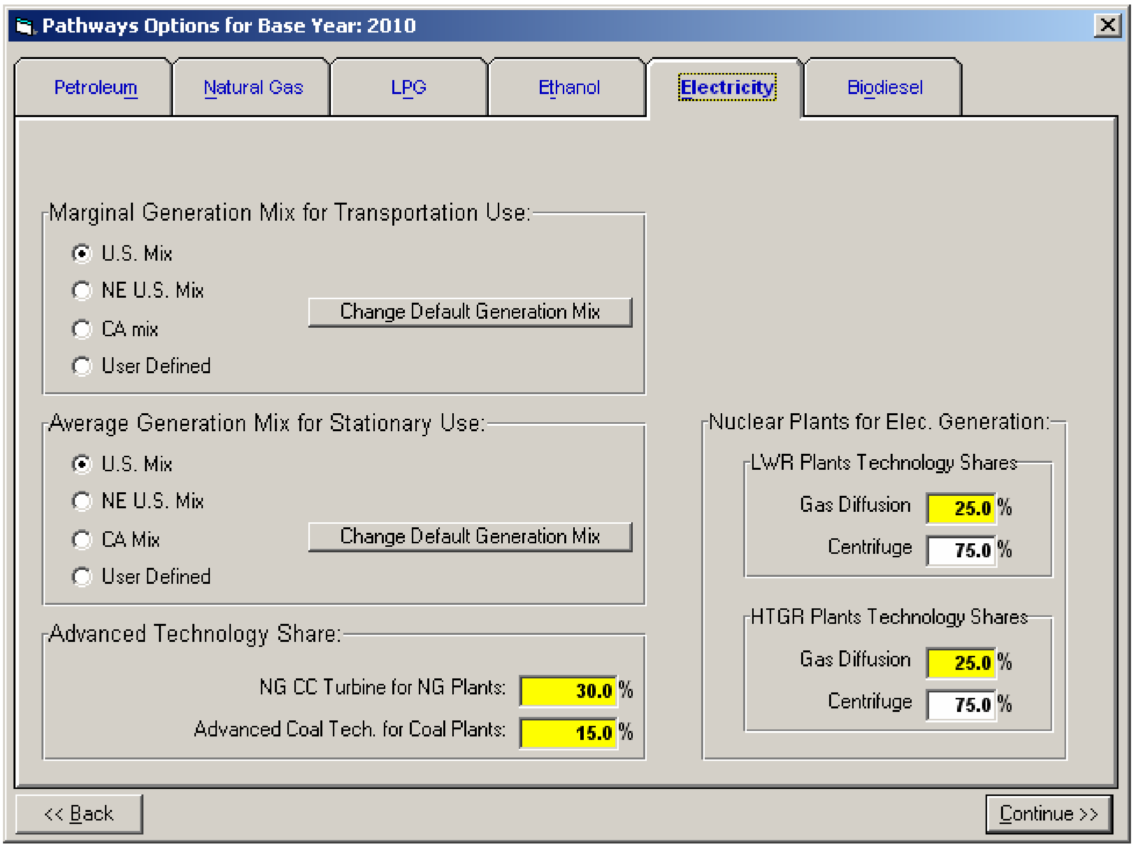


Figure 2.12. Electricity generation options

The GREET model include two types of nuclear reactor technologies for electricity generation, the light water reactor [LWR] and the high-temperature gas-cooled reactor [HTGR]. The user can select the technology shares of uranium enrichment for each type of the nuclear reactors. The technologies used for uranium enrichment include gaseous diffusion and centrifuge. The market share of these two technologies may change over time. Table 2.5 shows the time-series tables for the GREET default shares of gaseous diffusion and centrifuge technologies used for uranium enrichment. It should be noted that electricity consumption for uranium enrichment in gaseous diffusion plants is 50 times as high as that in centrifuge plants (see subsection 2.16.3 below).

Some advanced technologies for electricity generation, such as NG combined-cycle (NGCC) gas turbine for NG power plants and integrated gasification combined-cycle (IGCC) for coal power plants, could increase their shares of electricity generation over time. The time-series tables for the default shares of these advanced technologies used for NG power plants and coal power plants in GREET are shown in Table 2.6.

Table 2.4. Default electricity generation mix

U.S. mix: Average

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	4.2%	12.3%	52.5%	19.0%	12.1%
1995	2.2%	14.8%	51.0%	20.1%	11.9%
2000	2.9%	15.8%	51.7%	19.8%	9.7%
2005	1.7%	18.4%	50.3%	19.4%	10.2%
2010	1.7%	20.6%	50.2%	17.7%	9.9%
2015	2.5%	22.7%	48.6%	16.6%	9.6%
2020	1.9%	24.2%	49.2%	15.4%	9.3%

U.S. mix: Marginal

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	4.2%	12.3%	52.5%	19.0%	12.1%
1995	2.2%	14.8%	51.0%	20.1%	11.9%
2000	2.9%	15.8%	51.7%	19.8%	9.7%
2005	1.7%	18.4%	50.3%	19.4%	10.2%
2010	1.7%	20.6%	50.2%	17.7%	9.9%
2015	2.5%	22.7%	48.6%	16.6%	9.6%
2020	1.9%	24.2%	49.2%	15.4%	9.3%

NE U.S. mix: Average

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	15.1%	8.6%	37.2%	28.7%	10.4%
1995	5.6%	18.9%	35.6%	30.2%	9.7%
2000	7.4%	15.2%	35.9%	32.0%	9.5%
2005	5.8%	19.5%	31.0%	31.9%	11.8%
2010	5.7%	22.6%	31.1%	29.2%	11.3%
2015	7.7%	24.7%	29.3%	27.2%	11.1%
2020	6.2%	27.9%	29.2%	25.8%	10.9%

NE U.S. mix: Marginal

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	15.1%	8.6%	37.2%	28.7%	10.4%
1995	5.6%	18.9%	35.6%	30.2%	9.7%
2000	7.4%	15.2%	35.9%	32.0%	9.5%
2005	5.8%	19.5%	31.0%	31.9%	11.8%
2010	5.7%	22.6%	31.1%	29.2%	11.3%
2015	7.7%	24.7%	29.3%	27.2%	11.1%
2020	6.2%	27.9%	29.2%	25.8%	10.9%

Table 2.4. Default electricity generation mix (Cont'd)

California mix: Average

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	2.3%	40.0%	11.2%	19.2%	27.3%
1995	0.2%	37.5%	8.6%	17.3%	36.3%
2000	0.2%	42.1%	14.5%	17.1%	26.0%
2005	0.8%	40.7%	14.7%	18.1%	25.8%
2010	0.5%	38.4%	19.1%	16.2%	25.7%
2015	0.6%	34.5%	24.9%	14.7%	25.4%
2020	0.4%	32.1%	27.5%	13.4%	26.7%

California mix: Marginal

Year	Power Plant types				
	Residual Oil	NG	Coal	Nuclear	Others
1990	2.3%	40.0%	11.2%	19.2%	27.3%
1995	0.2%	37.5%	8.6%	17.3%	36.3%
2000	0.2%	42.1%	14.5%	17.1%	26.0%
2005	0.8%	40.7%	14.7%	18.1%	25.8%
2010	0.5%	38.4%	19.1%	16.2%	25.7%
2015	0.6%	34.5%	24.9%	14.7%	25.4%
2020	0.4%	32.1%	27.5%	13.4%	26.7%

Table 2.5. GREET default shares of gaseous diffusion and centrifuge technologies for uranium enrichment

Year	LWR: electric generation		HTGR: electric generation	
	Gaseous diffusion	Centrifuge	Gaseous diffusion	Centrifuge
1990	93%	7%	93%	7%
1995	87%	13%	87%	13%
2000	57%	43%	57%	43%
2005	30%	70%	30%	70%
2010	25%	75%	25%	75%
2015	15%	85%	15%	85%
2020	10%	90%	10%	90%

Table 2.6. Default shares of advanced power plant technologies

Year	NGCC share of total NG power plant capacity	Advanced coal technology share of total coal power plant capacity
1990	10.0%	0.0%
1995	15.0%	5.0%
2000	20.0%	5.0%
2005	25.0%	10.0%
2010	30.0%	15.0%
2015	35.0%	15.0%
2020	35.0%	15.0%

2.7 Key simulation options for biodiesel production pathway

Methyl or ethyl esters, produced from vegetable oils or animal fats, are commonly called biodiesel. In the United States, biodiesel is mainly produced from soybeans. The GREET model includes the soybean-to-biodiesel fuel cycle.

In addition to the biodiesel fuel, Soybean-to-biodiesel fuel cycle produces co-products such as soy meal and glycerine. GREET allocates emissions and energy use charge for each process between the biodiesel and its co-products. The default energy and emission allocations for biodiesel in the soybean farming, soy oil extraction, and soy oil transesterification processes are 33.6%, 33.6% and 70.1%, respectively, based on market value-based method as shown in Figure 2.13.

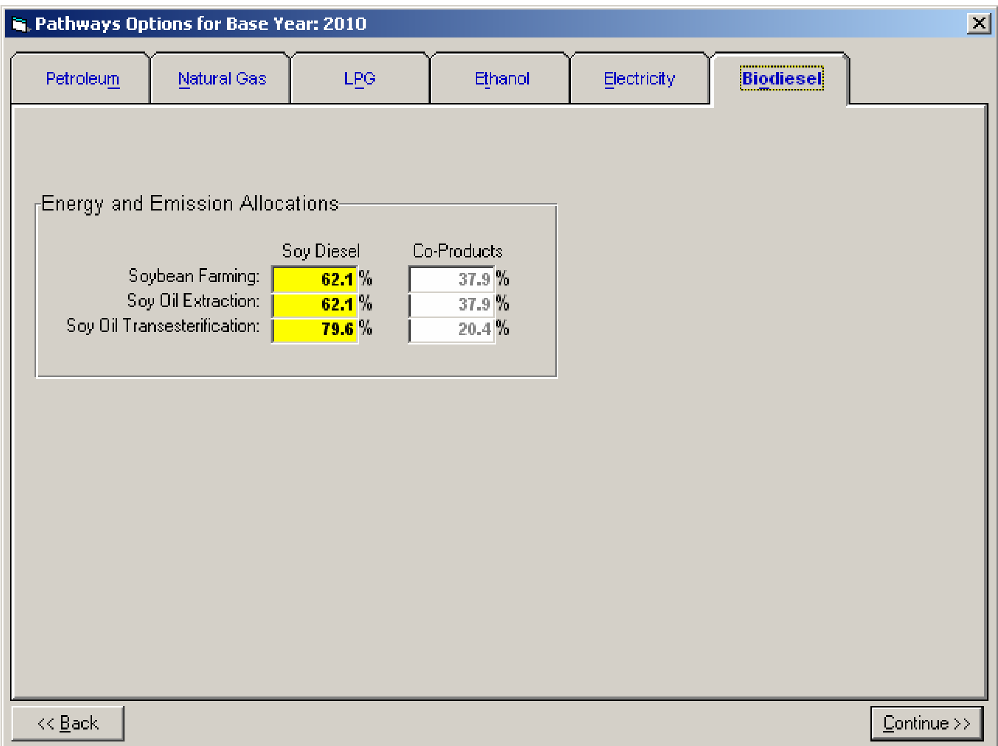


Figure 2.13. Biodiesel production pathway options

2.8 Key simulation options for alternative fuel blends

In GREETGUI, the user can specify the volumetric shares of alternative fuels for blending with gasoline or diesel (see Figure 2.14). The default blending levels of alternative fuels with gasoline or diesel are listed in Table 2.7. The user can change the blending levels of methanol, ethanol (high-level blending), Fischer-Tropsch diesel or biodiesel in GREETGUI. Since the default blending levels are passed to GREETGUI from MOVES, the user is cautioned to make any changes in GREETGUI to be consistent with that in MOVES.

Ethanol-gasoline blends have two blending levels in GREET: low-level blend with ethanol volumetric content of 5% - 15% (the default value set in MOVES is 10%) and high-level blend with ethanol volumetric content of 15% - 90% (the default value set in GREET is 85%). If user specifies a different blend level (e.g., 40%) for the high-level blend, the user should revise the vehicle fuel economy and emission factors in MOVES to reflect the new blend level.

The GREET user can select either conventional gasoline, reformulated gasoline, or a combination of these two fuels, with specific market share of each, for blending with methanol and ethanol. GREET assumes that ethanol is blended with CG for low-level blends (similar to wintertime oxygenated fuel) and with market share-weighted combination of CG and RFG for high-level blends. Note that ethanol used as RFG oxygenate is simulated separately under the RFG simulation options, not as ethanol blend simulation option. Similar to ethanol high-level blends, GREET assumes that methanol is blended with market share-weighted combination of CG and RFG.

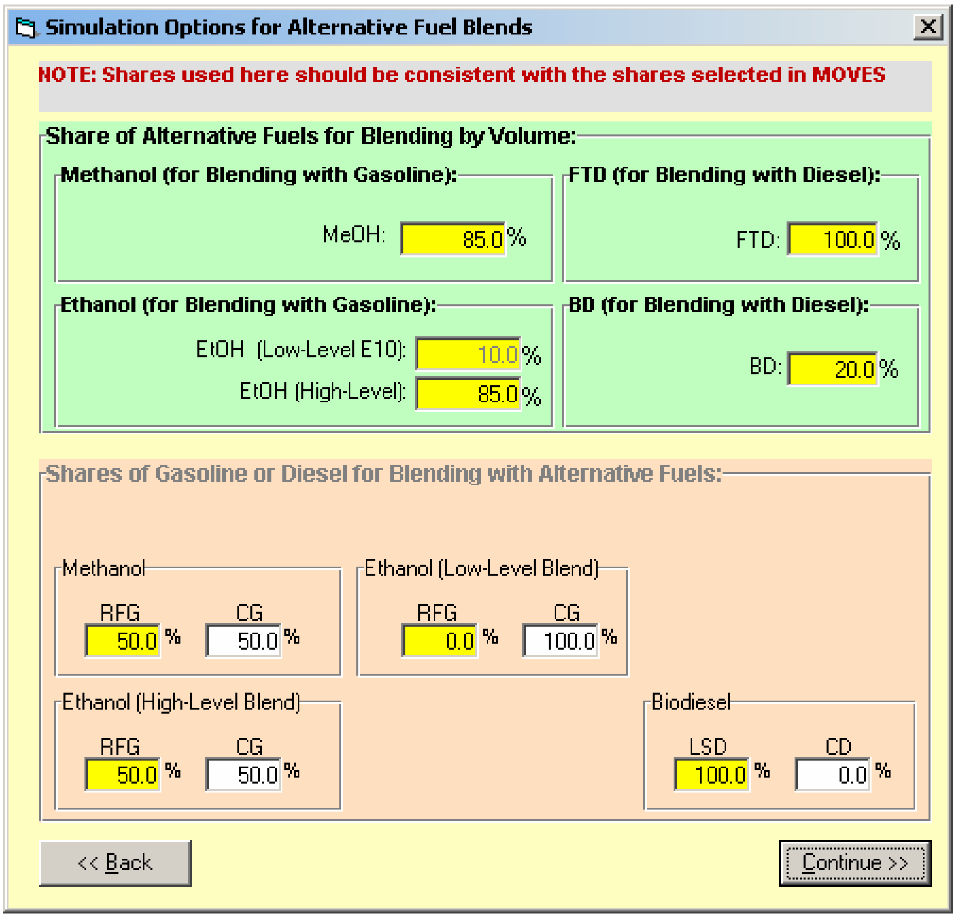


Figure 2.14. Simulation options for alternative fuel blends

The GREET user can select either conventional diesel, low-sulfur diesel, or a combination of these two fuels, with specific market share of each, for blending with Fischer-Tropsch diesel and biodiesel. GREETGUI currently assumes that FT diesel and biodiesel to be blended with market share-weighted combination of conventional diesel and low-sulfur diesel.

Table 2.7. Default shares of alternative fuels for blending with gasoline or diesel

Alternative fuels	Blending share (vol, %)
Methanol	85%
Ethanol (low-level, E10)	10%
Ethanol (high-level)	85%
Fischer-Tropsch diesel	100%
Biodiesel	20%

3. Key Parametric Assumptions

3.1 Key parametric assumptions for the production of petroleum-based fuels

Energy efficiencies of crude oil recovery and refining process to produce various fuels are considered key parameters, which the user can specify in GREETGUI, see Figure 3.1. Since these parameters may change over time, time-series tables were developed in GREET for energy efficiencies of petroleum-related processes, Table 3.1.

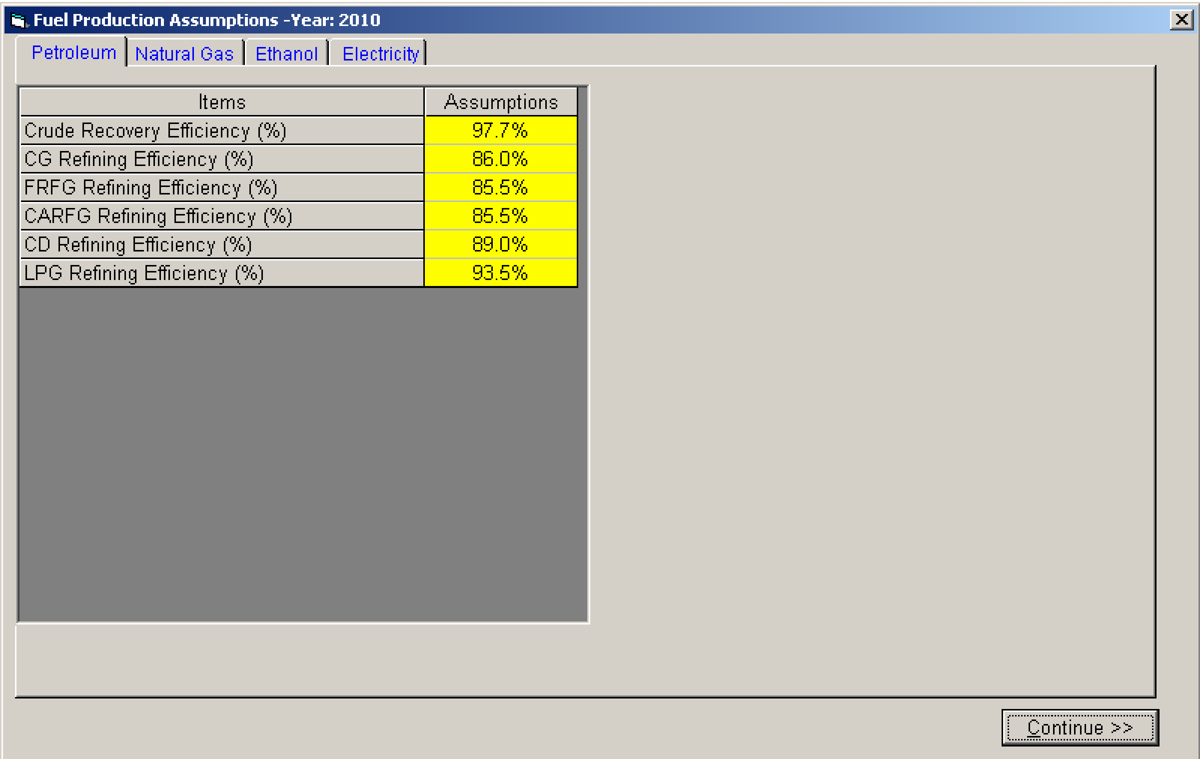


Figure 3.1. Key parametric assumptions for production of petroleum-based fuels

Table 3.1. Default energy efficiencies for petroleum-related processes

Year	Energy efficiency, %						
	Crude Recovery	CG Refining	RFG Refining	CARFG Refining	CD Refining	LSD Refining	LPG Refining
1990	97.7	86.5	86.0	86.0	89.5	87.0	93.5
1995	97.7	86.5	86.0	86.0	89.5	87.0	93.5
2000	97.7	86.0	85.5	85.5	89.5	87.0	93.5
2005	97.7	86.0	85.5	85.5	89.5	87.0	93.5
2010	97.7	86.0	85.5	85.5	89.0	87.0	93.5
2015	97.7	86.0	85.5	85.5	89.0	87.0	93.5
2020	97.7	85.5	85.0	85.0	89.0	87.0	93.5

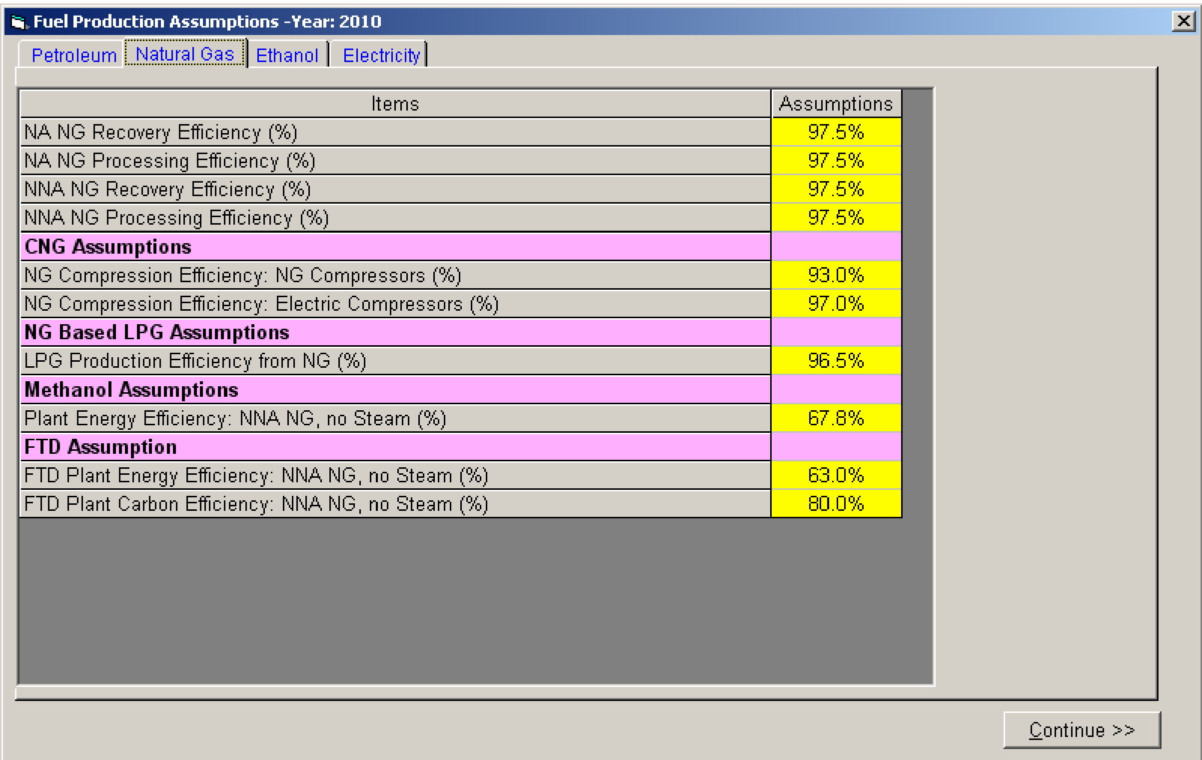
3.2 Key parametric assumptions for the production of NG-based fuels

Energy efficiencies associated with NG recovery and processing, NG-based fuels production, and steam credit are key parameters, which the user can specify in GREETGUI, Figure 3.2. Since some of these parameters may change over time, time-series tables were developed in GREET for energy efficiencies and steam credits of NG-related processes, which are discussed below in details.

3.2.1 Key fuel combustion technologies

Energy efficiency of steam boilers is a key parameter for steam co-generation in many fuel production facilities. This parameter is used to calculate the steam export credit. The default value in GREET is 80%.

The efficiency of electricity generated from low-quality steam is a key parameter for electricity co-generation in some fuel production facilities. This parameter is used to calculate the electricity export credit in those facilities. The GREET default efficiency for electricity cogeneration is 30%. The low efficiency is due to the low-quality steam used for electricity generation.



Items	Assumptions
NA NG Recovery Efficiency (%)	97.5%
NA NG Processing Efficiency (%)	97.5%
NNA NG Recovery Efficiency (%)	97.5%
NNA NG Processing Efficiency (%)	97.5%
CNG Assumptions	
NG Compression Efficiency: NG Compressors (%)	93.0%
NG Compression Efficiency: Electric Compressors (%)	97.0%
NG Based LPG Assumptions	
LPG Production Efficiency from NG (%)	96.5%
Methanol Assumptions	
Plant Energy Efficiency: NNA NG, no Steam (%)	67.8%
FTD Assumption	
FTD Plant Energy Efficiency: NNA NG, no Steam (%)	63.0%
FTD Plant Carbon Efficiency: NNA NG, no Steam (%)	80.0%

Figure 3.2. Key parametric assumptions for production of NG-based fuels

3.2.2 NG recovery and processing

The default energy efficiencies for NG recovery and processing in GREET are shown in Table 3.2.

3.2.3 NG compression and liquefaction

The default energy efficiencies for NG compression and liquefaction in GREET are shown in Table 3.3. When NNA NG or NNA FG is selected as the feed stock source for CNG production, liquefied natural gas (LNG) is assumed to be an intermediate fuel to bring NNA NG or FG to North America, which is accounted for in the simulation of these specific pathways.

Table 3.2. Default energy efficiencies for NG recovery and processing

Year	Feedstock: NA NG		Feedstock: NNA NG		Feedstock: NNA FG	
	Recovery	Processing	Recovery	Processing	Recovery	Processing
1990	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
1995	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
2000	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
2005	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
2010	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
2015	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%
2020	97.5%	97.5%	97.5%	97.5%	97.0%	97.0%

Table 3.3. Default energy efficiencies for NG compression and liquefaction

Year	Compression		Liquefaction		
	NG compressor	Electric compressor	NA NG	NNA NG	NNA FG
1990	93.0%	97.0%	88.5%	88.5%	88.5%
1995	93.0%	97.0%	89.0%	89.0%	89.0%
2000	93.0%	97.0%	90.0%	90.0%	90.0%
2005	93.0%	97.0%	90.0%	90.0%	90.0%
2010	93.0%	97.0%	90.3%	90.3%	90.3%
2015	93.0%	97.0%	91.0%	91.0%	91.0%
2020	93.0%	97.0%	91.5%	91.5%	91.5%

3.2.4 NG-based LPG production

The default energy efficiencies for LPG production from NG are shown in Table 3.4.

Table 3.4. Default energy efficiencies for NG-based LPG production

Year	LPG production: NG as feedstock
1990	96.5%
1995	96.5%
2000	96.5%
2005	96.5%
2010	96.5%
2015	96.5%
2020	96.5%

3.2.5 Methanol production

The default energy efficiencies and steam credit for methanol production in GREET are shown in Tables 3.5 and 3.6, respectively. Electricity export credit is calculated from the amount of steam credit in Table 3.6 and the electricity cogeneration efficiency (GREET default value is 30%).

Table 3.5. Default energy efficiencies for methanol production

Year	Feedstock: NA NG		Feedstock: NNA NG		Feedstock: NNA FG	
	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export
1990	65.0%	62.0%	65.0%	62.0%	64.5%	61.5%
1995	66.0%	62.5%	66.0%	62.5%	65.5%	62.0%
2000	67.0%	63.0%	67.0%	63.0%	66.5%	62.5%
2005	67.5%	63.5%	67.5%	63.5%	67.0%	63.0%
2010	67.8%	64.0%	67.8%	64.0%	67.5%	63.5%
2015	70.0%	67.0%	70.0%	67.0%	69.5%	66.5%
2020	71.0%	69.0%	71.0%	69.0%	70.5%	68.5%

Table 3.6. Default steam credit (Btu/mmBtu of fuel produced) for methanol

Year	Feedstock: NA NG	Feedstock: NNA NG	Feedstock: NNA FG
1990	77853	77853	77853
1995	77853	77853	77853
2000	77853	77853	77853
2005	77853	77853	77853
2010	77853	77853	77853
2015	77853	77853	77853
2020	77853	77853	77853

3.2.6 FTD production

The default energy efficiencies, steam credit and carbon efficiencies for FTD production in GREET are shown in Tables 3.7, 3.8 and 3.9, respectively. Electricity export credit is calculated from the amount of steam credit in Table 3.8, and the electricity cogeneration efficiency (GREET default value is 30%).

3.3 Key parametric assumptions for ethanol production

Energy use in corn/biomass farming and ethanol production, and CO_2 emissions due to land use change by corn/biomass farming are key parameters, which the user can specify in GREET, see Figure 3.3. Depending on the selection of different market shares of ethanol feedstock sources and/or different plant design types, the default parametric assumptions shown in Figure 3.3 could change. Since these parameters may change over time, time-series tables were developed in GREET for the default assumptions in each ethanol-related process as shown in Tables 3.10, 3.11 and 3.12, respectively.

Table 3.7. Default energy efficiencies for FTD production

Year	Feedstock: NA NG		Feedstock: NNA NG		Feedstock: NNA FG	
	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export
1990	61.0%	51.0%	61.0%	51.0%	60.5%	50.5%
1995	61.5%	52.0%	61.5%	52.0%	61.0%	51.5%
2000	62.0%	53.0%	62.0%	53.0%	61.5%	52.5%
2005	62.5%	54.0%	62.5%	54.0%	62.0%	53.5%
2010	63.0%	55.0%	63.0%	55.0%	62.5%	54.5%
2015	64.0%	57.0%	64.0%	57.0%	63.5%	56.5%
2020	65.0%	58.0%	65.0%	58.0%	64.5%	57.5%

Table 3.8. Default steam credit (Btu/mmBtu of fuel produced) for FTD production

Year	Feedstock: NA NG	Feedstock: NNA NG	Feedstock: NNA FG
1990	202000	202000	202000
1995	202000	202000	202000
2000	202000	202000	202000
2005	202000	202000	202000
2010	202000	202000	202000
2015	202000	202000	202000
2020	202000	202000	202000

Table 3.9. Default carbon efficiencies for FTD production

Year	Feedstock: NA NG		Feedstock: NNA NG		Feedstock: NNA FG	
	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export	no steam or kWh export	with steam or kWh export
1990	78.0%	78.0%	78.0%	78.0%	78.0%	78.0%
1995	78.0%	78.0%	78.0%	78.0%	78.0%	78.0%
2000	78.0%	78.0%	78.0%	78.0%	78.0%	78.0%
2005	79.0%	79.0%	79.0%	79.0%	79.0%	79.0%
2010	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
2015	80.5%	80.5%	80.5%	80.5%	80.5%	80.5%
2020	81.0%	81.0%	81.0%	81.0%	81.0%	81.0%

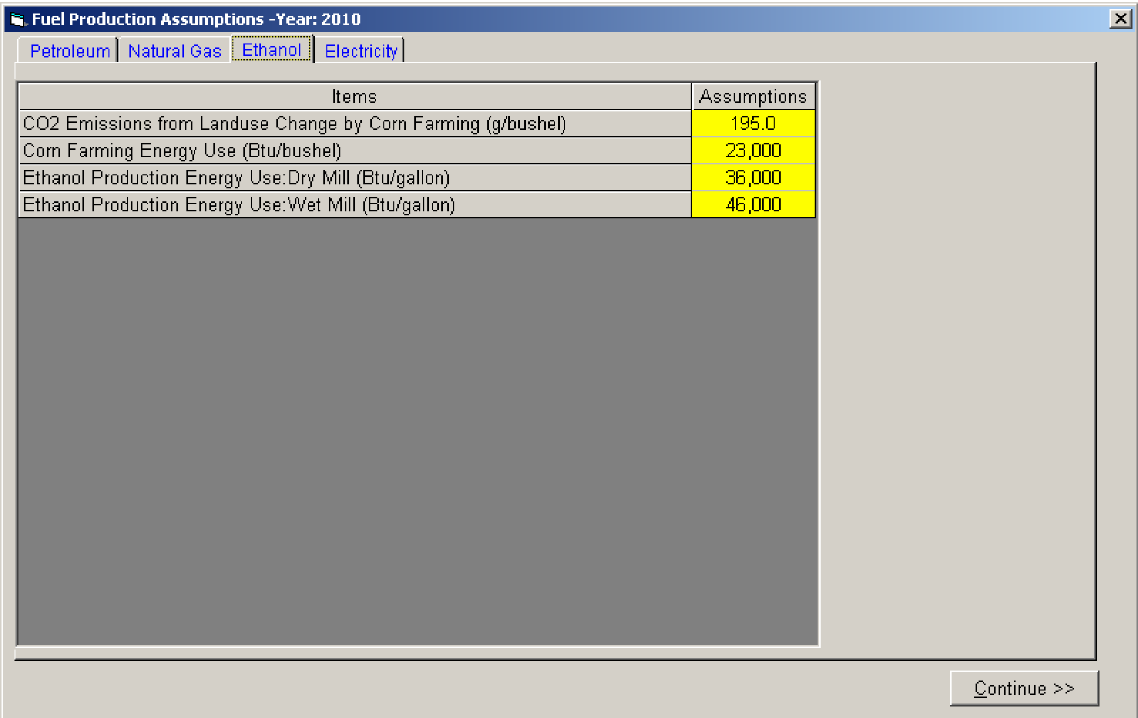


Figure 3.3. Key parametric assumptions for production of ethanol fuel

Table 3.10. Default corn/biomass farming energy use

Year	Corn farming, Btu/bushel	Woody biomass farming, Btu/dry ton	Herbaceous biomass farming, Btu/dry ton
1990	23600	234770	217230
1995	23500	234770	217230
2000	23288	234770	217230
2005	23000	234770	217230
2010	22500	234770	217230
2015	22500	234770	217230
2020	22500	234770	217230

Table 3.11. Default energy use, yield or kWh co-production for ethanol production

Year	Energy use of corn-ethanol production, Btu/gal		Woody biomass-ethanol production		Herbaceous biomass-ethanol production	
	Dry milling	Wet milling	Yield: gal/dry ton	Electricity co-production: kWh/gal	Yield: gal/dry ton	Electricity co-production: kWh/gal
1990	40000	55000	82.0	-1.150	85.0	-0.600
1995	39000	50000	83.0	-1.150	87.0	-0.600
2000	37000	46200	84.0	-1.150	89.0	-0.600
2005	36500	46000	85.0	-1.150	90.0	-0.600
2010	36000	45950	87.0	-1.145	91.5	-0.572
2015	36000	45950	87.0	-1.145	91.5	-0.572
2020	36000	45950	87.0	-1.145	91.5	-0.572

Note: negative values imply credit.

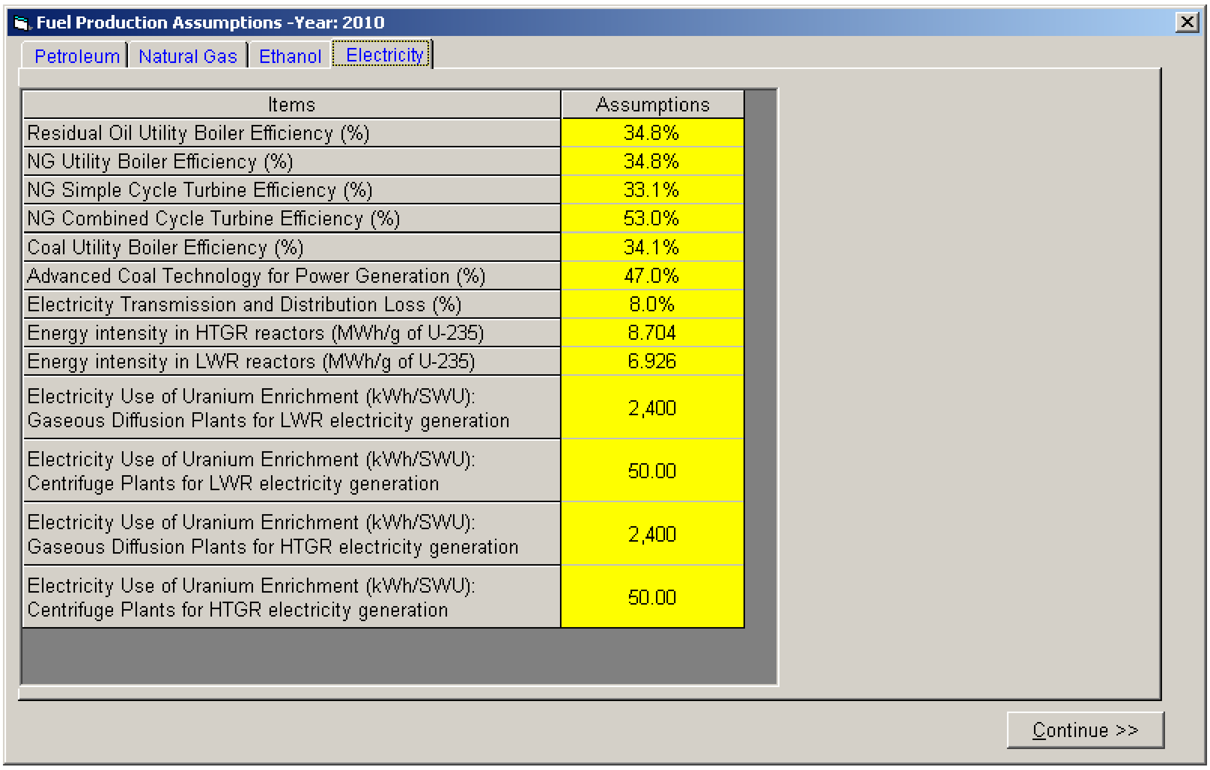
Table 3.12. Default CO_2 emissions due to land use change by corn/biomass farming

Year	Corn farming, g/bushel	Woody biomass farming, g/dry ton	Herbaceous biomass farming, g/dry ton
1990	195.0	-112,500	-48,500
1995	195.0	-112,500	-48,500
2000	195.0	-112,500	-48,500
2005	195.0	-112,500	-48,500
2010	195.0	-112,500	-48,500
2015	195.0	-112,500	-48,500
2020	195.0	-112,500	-48,500

Note: positive values imply emissions, and negative values imply sequestration.

3.4 Key parametric assumptions for electricity generation

Efficiency of electricity generation at various types of power plant, and electricity transmission and distribution losses are key parameters, which the user can specify in the GREET model (see Figure 3.4). The user can also specify other key parameters for nuclear-based electricity generation processes. Since these parameters may change over time, time-series tables were built in GREET for each electricity generation process, which are discussed in the following sections.



Fuel Production Assumptions -Year: 2010

Petroleum | Natural Gas | Ethanol | Electricity

Items	Assumptions
Residual Oil Utility Boiler Efficiency (%)	34.8%
NG Utility Boiler Efficiency (%)	34.8%
NG Simple Cycle Turbine Efficiency (%)	33.1%
NG Combined Cycle Turbine Efficiency (%)	53.0%
Coal Utility Boiler Efficiency (%)	34.1%
Advanced Coal Technology for Power Generation (%)	47.0%
Electricity Transmission and Distribution Loss (%)	8.0%
Energy intensity in HTGR reactors (MWh/g of U-235)	8.704
Energy intensity in LWR reactors (MWh/g of U-235)	6.926
Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for LWR electricity generation	2,400
Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for LWR electricity generation	50.00
Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for HTGR electricity generation	2,400
Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for HTGR electricity generation	50.00

Continue >>

Figure 3.4. Key parametric assumptions for production of electricity

3.4.1 Electricity generation efficiencies

The default electricity generation efficiencies in GREET for different types of power plant are shown in the Table 3.13.

Table 3.13. Default electricity generation efficiencies of various types of power plant

Year	Residual oil	NG			Coal	
	Utility boiler	Utility boiler	Simple cycle turbine	Combined cycle turbine	Utility boiler	Advanced coal combined cycle turbine
1990	31.0%	31.0%	31.0%	45.0%	32.0%	40.0%
1995	32.0%	32.0%	32.0%	45.0%	33.0%	40.0%
2000	33.0%	33.0%	33.0%	45.0%	33.5%	43.0%
2005	34.0%	34.0%	33.0%	47.0%	34.0%	45.0%
2010	34.8%	34.8%	33.1%	53.0%	34.1%	47.0%
2015	34.8%	34.8%	33.1%	53.0%	34.1%	47.0%
2020	34.8%	34.8%	33.5%	55.0%	34.4%	50.0%

3.4.2 Electricity transmission and distribution loss

The default electricity transmission and distribution loss in GREET is 8%.

3.4.3 Key parameters of nuclear-related electricity generation processes

The GREET defaults for electricity generation intensity of nuclear reactors and electricity use in uranium enrichment process are shown in Table 3.14.

Table 3.14. Default parameters of nuclear-related electricity generation processes

Year	Electricity generation intensity: MWh/g of ^{235}U		Electricity use of uranium enrichment: kWh/SWU[a]			
			Gaseous diffusion plant		Centrifuge plant	
	LWR	HTGR	LWR	HTGR	LWR	HTGR
1990	6.926	8.704	2400	2400	50	50
1995	6.926	8.704	2400	2400	50	50
2000	6.926	8.704	2400	2400	50	50
2005	6.926	8.704	2400	2400	50	50
2010	6.926	8.704	2400	2400	50	50
2015	6.926	8.704	2400	2400	50	50
2020	6.926	8.704	2400	2400	50	50

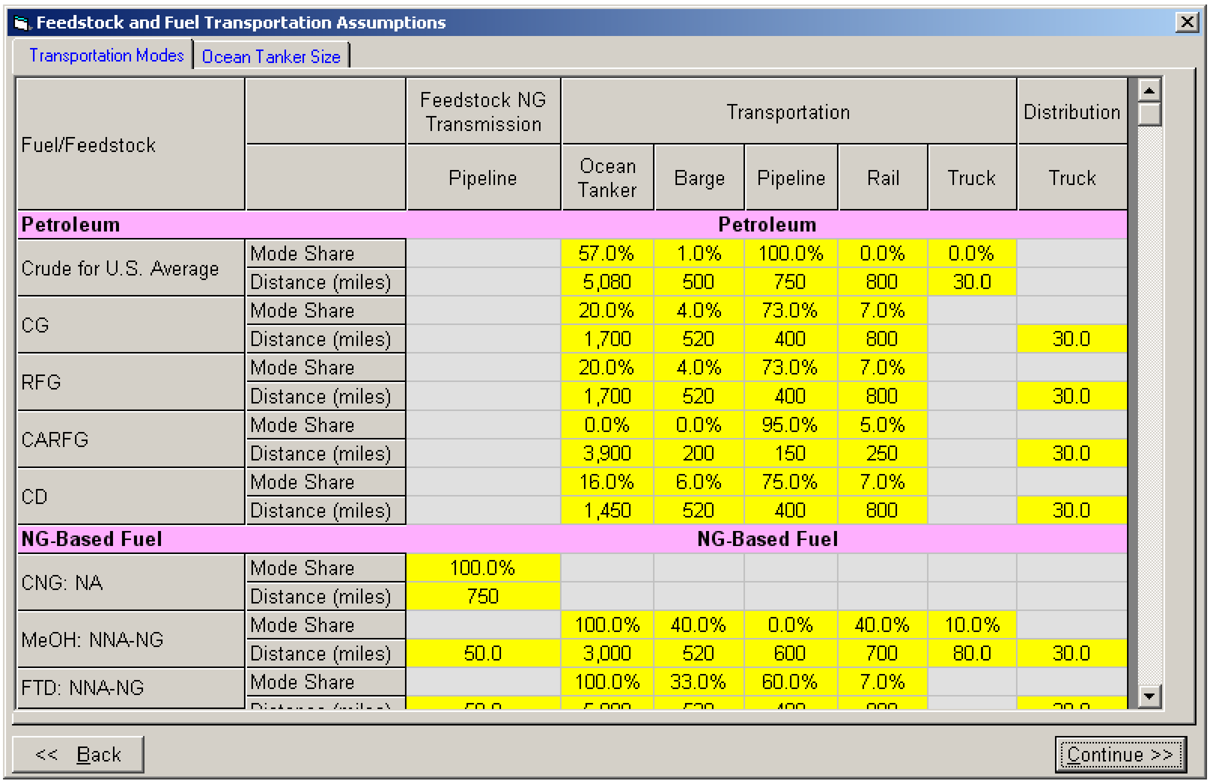
[a]: SWU: separative work units.

3.5 Key parameters for fuel transportation, distribution and storage

In GREET, transportation-related activities are simulated by using input parameters such as transportation modes, transportation distances and energy use intensities (in Btu/ton-mi) for various modes of transportation. These parameters, which can be specified by the user as shown in Figure 3.5, are discussed in the following subsections.

3.5.1 Transportation mode and distance

Transportation modes for transportation fuels in GREET include the following: 1) ocean tankers for crude oil, gasoline, diesel, LPG, LNG, methanol and FTD; 2) barges for crude oil, gasoline, diesel, LPG, LNG, methanol, FTD, ethanol, and biodiesel; 3) pipelines for crude oil, gasoline, diesel, LPG, FTD, biodiesel, and NG; 4) rails for gasoline, diesel, LPG, LNG, methanol, ethanol, FTD, and biodiesel; and 5) trucks for delivering liquid fuels from bulk terminals to refueling stations. The user can specify shares of transportation mode, and transportation distance for each mode as shown in Figure 3.5. The default estimates of these parameters in GREET are shown in Tables 3.15 through 3.17. Note that the total percentage of all transportation modes may exceed 100% for some fuels because more than one mode may be involved for transporting the fuel.



Fuel/Feedstock		Feedstock NG Transmission	Transportation					Distribution
		Pipeline	Ocean Tanker	Barge	Pipeline	Rail	Truck	Truck
Petroleum				**Petroleum**				
Crude for U.S. Average	Mode Share		57.0%	1.0%	100.0%	0.0%	0.0%	
	Distance (miles)		5,080	500	750	800	30.0	
CG	Mode Share		20.0%	4.0%	73.0%	7.0%		
	Distance (miles)		1,700	520	400	800		30.0
RFG	Mode Share		20.0%	4.0%	73.0%	7.0%		
	Distance (miles)		1,700	520	400	800		30.0
CARFG	Mode Share		0.0%	0.0%	95.0%	5.0%		
	Distance (miles)		3,900	200	150	250		30.0
CD	Mode Share		16.0%	6.0%	75.0%	7.0%		
	Distance (miles)		1,450	520	400	800		30.0
NG-Based Fuel				**NG-Based Fuel**				
CNG: NA	Mode Share	100.0%						
	Distance (miles)	750						
MeOH: NNA-NG	Mode Share		100.0%	40.0%	0.0%	40.0%	10.0%	
	Distance (miles)	50.0	3,000	520	600	700	80.0	30.0
FTD: NNA-NG	Mode Share		100.0%	33.0%	60.0%	7.0%		

Figure 3.5. Feedstock and fuels transportation modes and distances

Table 3.15. Default Transportation Modes and Distance for Fuels from Production Sites to Bulk Terminals

		Ocean tanker	Barge	Pipeline	Rail	Truck
Crude oil: U.S. use	Mode share	57%	1%	100%	0%	0%
	Distance, mile	5080	500	750	800	30
Crude oil: CA use	Mode share	58%	0%	42%	0%	
	Distance, mile	3900	200	150	200	
CG	Mode share	20%	4%	73%	7%	
	Distance, mile	1700	520	400	800	
RFG	Mode share	20%	4%	73%	7%	
	Distance, mile	1700	520	400	800	
CARFG	Mode share	0%	0%	95%	5%	
	Distance, mile	3900	200	150	250	
CD	Mode share	16%	6%	75%	7%	
	Distance, mile	1450	520	400	800	
CA CD	Mode share	16%	6%	75%	7%	
	Distance, mile	3900	200	150	300	
LSD	Mode share	16%	6%	75%	7%	
	Distance, mile	1450	520	400	800	
CA LSD	Mode share	16%	6%	75%	7%	
	Distance, mile	3900	200	150	300	

		Ocean tanker	Barge	Pipeline	Rail	Truck
LPG: NA NG	Mode share	0%	6%	64%	34%	
	Distance, mile	5200	520	400	800	
LPG: NNA NG	Mode share	100%	6%	60%	34%	
	Distance, mile	5200	520	400	800	
LNG: NNA NG	Mode share	100%	0%		0%	
	Distance, mile	5000	520		800	
LNG: NNA FG	Mode share	100%	0%		0%	
	Distance, mile	5900	520		800	
MeOH: NA NG	Mode share	0%	40%	0%	40%	10%
	Distance, mile	0	520	600	700	80
MeOH: NNA NG	Mode share	100%	40%	0%	40%	10%
	Distance, mile	3000	520	600	700	80
MeOH: NNA FG	Mode share	100%	40%	0%	40%	10%
	Distance, mile	5900	520	600	700	80
MeOH: LG	Mode share	0%	40%	0%	40%	10%
	Distance, mile	0	0	0	0	0
FTD: NA NG	Mode share	0%	33%	60%	7%	
	Distance, mile	0	520	400	800	
FTD: NNA NG	Mode share	100%	33%	60%	7%	
	Distance, mile	5000	520	400	800	
FTD: NNA FG	Mode share	100%	33%	60%	7%	
	Distance, mile	5900	520	400	800	
Biodiesel	Mode share		8%	63%	29%	
	Distance, mile		520	400	800	
EtOH	Mode share		40%	0%	40%	20%
	Distance, mile		520	600	800	80

Table 3.16. Default distance from NG fields to NG-based production plants

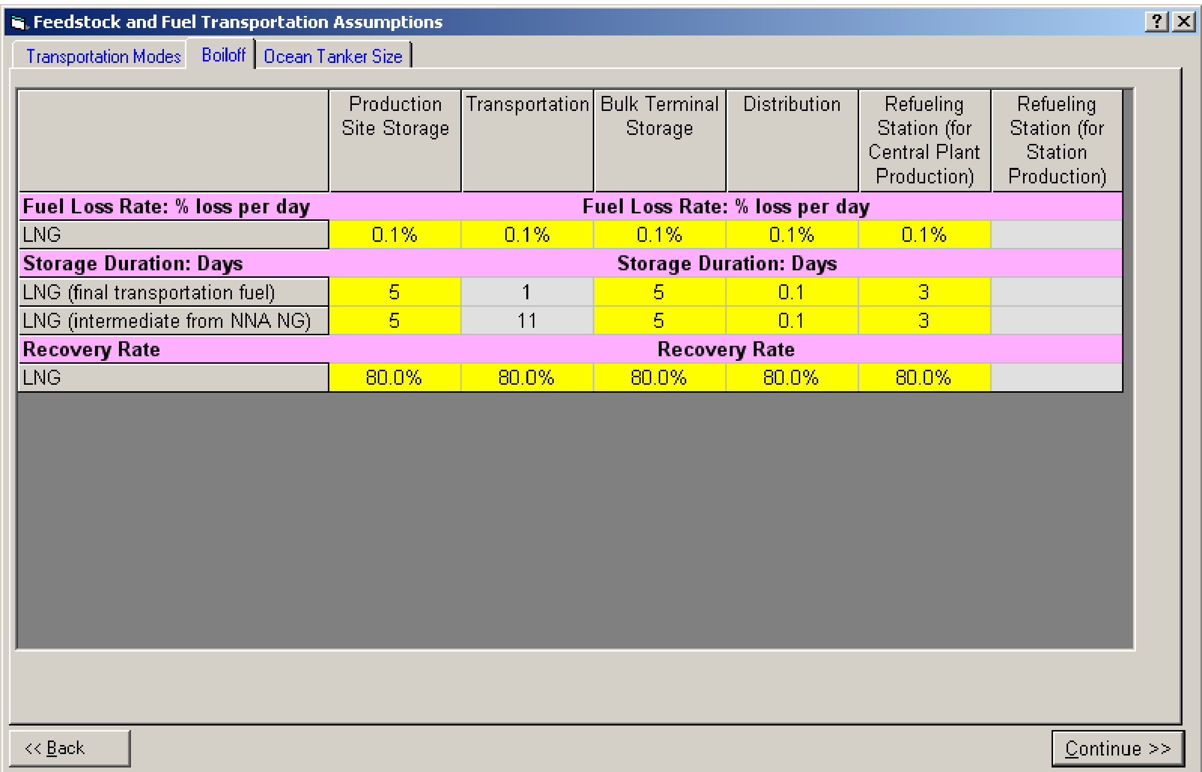
NG usage	Distance (mile)
LNG Plant	50
LPG plant	50
Methanol plant	50
FTD Plant	50

Table 3.17. Default distance for fuel distribution from bulk terminals to refueling stations

	Distance (mile)
Crude oil: CA use	30
CG	30
RFG	30
CARFG	30
CD	30
CA CD	30
LSD	30
CA LSD	30
LPG	30
LNG	30
MeOH	30
FTD	30
Biodiesel	30
EtOH	30

3.5.2 LNG boil-off

The GREET user can specify the boiler-off rate, duration of storage and recovery rate of boil-off gas for LNG fuel as shown in Figure 3.6. The default values of these parameters in GREET are listed in Table 3.18.



	Production Site Storage	Transportation	Bulk Terminal Storage	Distribution	Refueling Station (for Central Plant Production)	Refueling Station (for Station Production)
Fuel Loss Rate: % loss per day	**Fuel Loss Rate: % loss per day**					
LNG	0.1%	0.1%	0.1%	0.1%	0.1%	
Storage Duration: Days	**Storage Duration: Days**					
LNG (final transportation fuel)	5	1	5	0.1	3	
LNG (intermediate from NNA NG)	5	11	5	0.1	3	
Recovery Rate	**Recovery Rate**					
LNG	80.0%	80.0%	80.0%	80.0%	80.0%	

Figure 3.6. LNG boil-off data

Table 3.18. Default parameters for LNG boil-off process

	Storage at production plant	Plant to bulk terminal	Bulk terminal storage	Bulk terminal to stations	Station storage for central plant pathway	Station storage for refueling station pathway
	Boil-off rate: % loss per day					
LNG	0.1%	0.1%	0.1%	0.1%	0.1%	
	Duration of storage or transit: days					
LNG: NNA NG	5	11[a]	5	0.1	3	
LNG: NNA FG	5	13[a]	5	0.1	3	
	Recovery rate for boil-off gas[b]					
LNG	80%	80%	80%	80%	80%	

[a] Calculated based on transportation mode share and distance specified for LNG in GREET and cannot be changed by the user

[b] The boil-off gas from bulk terminals and refueling stations can be recovered

3.5.3 Cargo payload of ocean tanker

The user can specify cargo payload of ocean tanker for some transportation fuels as shown in Figure 3.9. The default values for cargo payload of ocean tankers are listed in Table 3.39.

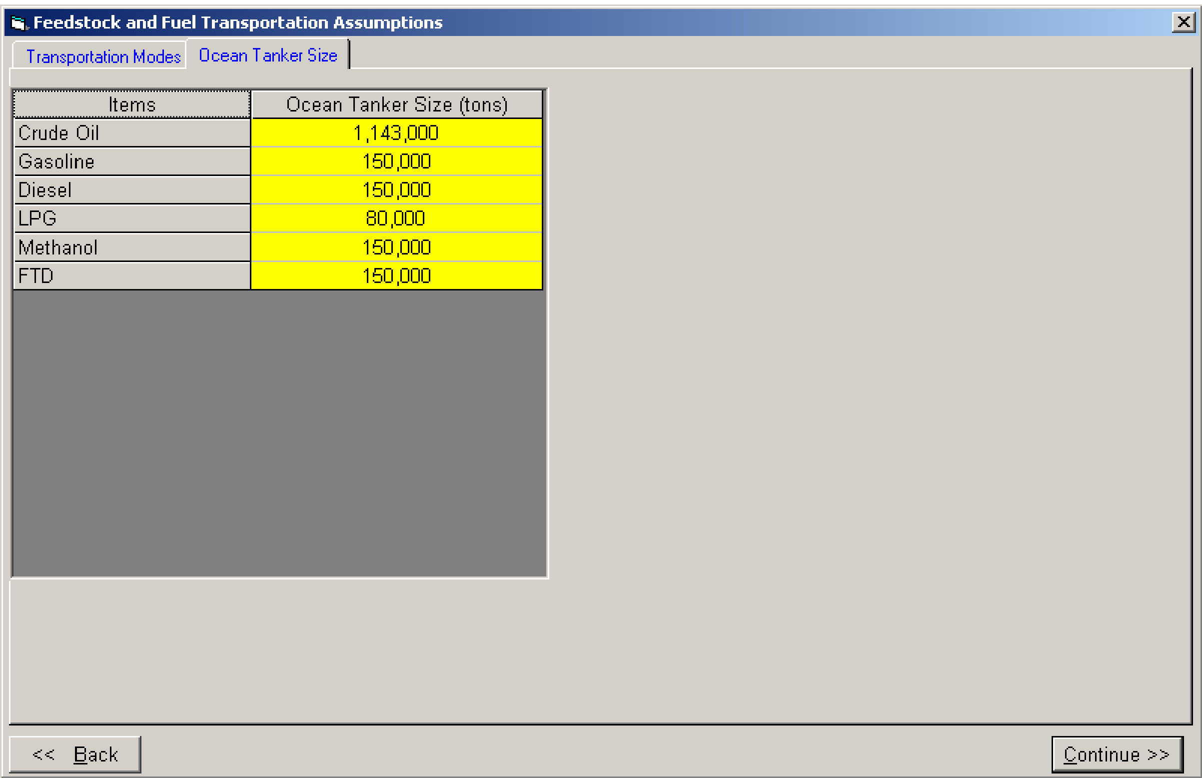


Figure 3.7. Ocean tanker size

Table 3.19. Default cargo payload of ocean tanker for fuels

Fuel	Payload (tons)
Crude oil	1,143,000
Gasoline	150,000
Diesel	150,000
LPG	80,000
LNG	58,000
Methanol	150,000
FTD	150,000

4. GREET Model Structure

The current version of the GREET spreadsheet model (version 1.6) consists of 23 Excel sheets; each of which is briefly described below.

4.1 Overview

This sheet contains the GREET copyright statement. It presents a brief summary of each of the worksheets in GREET and is intended to briefly introduce the functions of each sheet. It is highly recommended that first-time GREET user reads this sheet before proceeding with any GREET calculations.

4.2 Inputs

In this sheet, key control variables are presented for various scenarios to be simulated in GREET and key parametric assumptions are specified for the simulation. GREETGUI mainly interacts with this sheet to set the parameters of the fuel pathways to be simulated in GREET.

The cells colored in yellow and green are input cells and represent the key options and parameters for simulation of different fuel cycles in GREET. The user can edit the yellow and green cells to change the default simulation options or assumptions in these cells. The green cells have probability distribution functions built into them for use with Crystal Ball, commercial software developed by Decisioneering, Inc. The user can load the GREET model into the Crystal Ball program to generate stochastic results rather than a point estimate of energy use and emissions.

The cells without background color have formulas linked with other cells or with the time-series (TS) tables in the following worksheets *Fuel_TS*, *Cars_LDT1_TS*, *LDT2_TS* and *Fuel_Specs*. Detailed discussion of these sheets can be found in sections 4.4, 4.6, 4.7 and 4.8, respectively. The user is strongly cautioned against any change to these cells, which could result in broking formula links and failed or inaccurate simulation. To change any of the key parameters associated with time-series (lookup) tables, e.g., conventional crude recovery efficiency, the user may go to the appropriate time-series worksheet (e.g., *Fuel_TS* in this case) to change the entry of the corresponding yellow cell immediately above the time-series table.

4.3 EF

In this sheet, emission factors (EFs) are presented for individual combustion technologies that burn various fuels. These emission factors are used by other sheets of GREET to calculate emissions associated with fuel combustion in various WTP stages.

The first section of this sheet lists emission factors for combustion technologies applied to stationary sources. Here all the cells have formula link with other cells or time-series tables in *ET_TS* sheet (see detailed introduction of the *EF_TS* sheet in section 4.5). CO_2 emission factors for all combustion fuels are calculated by using a carbon balance approach. SO_X emission factors for combustion technologies of all fuels except coal, biomass, crude and residual oil are calculated by assuming that all sulfur contained in these process fuels is converted into SO_2. The user is strongly cautioned against any change to these cells, which could result in broking formula links and failed or inaccurate simulation. All other emission factors are linked to time-series tables in the *ET_TS* sheet. For those emission factors linked with time-series tables, e.g., VOC, CO, and CH_4, the user may go to the *EF_TS* sheet to make any desired changes to the emission factors.

The second section in this sheet includes three tables. The first table lists emission changes of alternative fuels relative to a baseline fuel for power units applied to transportation facilities (such as ocean tankers, barges, locomotives, trucks, pipelines, etc.). The second table lists the emission rates for different transportation modes and different fuels used for the trips from the product origin to its destination. The third table lists the emission rates for different transportation modes and different fuels used for the trips from product destinations back to its origin (back-haul trips).

4.4 Fuels_TS

This sheet presents all of the key parametric assumptions for various fuel production pathways. Since these parameters may change over time, lookup (time-series) tables were developed for each parameter over a period from 1990 to 2020, in five-year intervals. These parameters are separated into seven groups: 1) petroleum-related fuel production processes (e.g., crude recovery efficiency, CG refining efficiency, etc.); 2) NG-related fuel production processes (e.g., North American NG recovery efficiency, North American NG processing efficiency, etc.); 3) ethanol production processes (e.g., corn farming energy use, ethanol yield of woody biomass plant, etc.); 4) biodiesel production processes (e.g., soy bean farming energy use, soy oil extraction energy use, etc.); 5) electricity generation processes (e.g., residual oil power plant energy conversion efficiency, NG combined-cycle turbine power plant energy conversion efficiency, etc.); and 6) nuclear fuel production processes (e.g., electricity use of uranium enrichment using gaseous diffusion technology or centrifuge technology, etc.). For any simulation year between those years listed in the tables, GREET simply uses a linear interpolation algorithm to calculate the estimate for that particular year.

The cell immediately above the time-series table, which is colored in yellow, has been interpolated from the time-series table and represents the value of the parameter corresponding to the target year of simulation. The yellow cell above the time-series table serves also as a user input cell. If the user adjusts of the yellow cell value, the entire time-series table may be automatically adjusted by the same percentage, depending on the time-series simulation option selected by the user in section 2.3 of the *Inputs* sheet. Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *Inputs* sheet.

4.5 EF_TS

This sheet presents time-series tables for emission factors from combustion technologies applied to stationary sources. VOC, CO, NO_X, PM_{10}, CH_4, and N_2O emissions from various combustor types fueled with NG, residual oil, diesel, gasoline, crude oil, LPG, coal and biomass may change over time, as well as SO_X emissions from various combustor types fueled with coal, biomass, crude and residual oil. Time-series tables for emission factors associated with different WTP activities are created in this sheet have the same format and functionality as those created in the FUELS_TS sheet, which are discussed above in section 4.4. Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *EF* sheet for emission calculations by GREET.

4.6 Car_LDT1_TS

In this sheet, time-series tables of fuel economy and emission rates/changes associated with vehicle operations are presented for passenger cars and light duty truck 1 (LDT1). This sheet is constructed in two sections. The first section contains time-series tables of fuel economy and emission rates for baseline vehicles fueled with gasoline or diesel. The emission factors of exhausted VOC, evaporative VOC, CO, NO_X, exhausted PM_{10}, tire and brake wearing PM_{10}, CH_4 and N_2O are included in each time-series table in this sheet. The second section contains time-series tables for the changes of fuel economy and emissions of alternative-fueled vehicles and advanced technology vehicles relative to the baseline gasoline or diesel vehicles. The time-series tables in this sheet have the same format and functionality as those created in the FUELS_TS sheet, which are discussed above in section 4.4. Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *Inputs* sheet for calculations of energy use and emissions due to vehicle operations. It should be noted that the fuel economy in GREET does not affect the well-to-pump calculations, and therefore is not passed from GREET to MOVES in any way. It remains, however, a feature in GREET life cycle analysis of transportation fuels, which could be used separately in an independent GREET run.

4.7 LDT2_TS

This worksheet is similar to the *CAR_LDT1_TS* worksheet in format and functionality. However, the time-series tables of fuel economy and emission rates/changes associated with vehicle operations are presented here for the light duty truck 2 (LDT2). Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *Inputs* sheet for calculations of energy use and emissions due to vehicle operations. It should be noted that the fuel economy in GREET does not affect the well-to-pump calculations, and therefore is not passed from GREET to MOVES in any way. It remains, however, a feature in GREET life cycle analysis of transportation fuels, which could be used separately in an independent GREET run.

4.8 Fuel_Specs

This sheet includes specifications for individual fuels. Fuel specifications of interest to GREET are lower and higher heating values, fuel density, carbon weight ratio, and sulfur weight ratio. Probability distribution functions are built for most of the fuel specifications. These cells are colored in green. The parametric values for these fuel specifications are used to estimate the energy consumption and emissions, as well as conversions among mass, volume, and energy contents.

This sheet also contains other conversion parameters such as the global warming potentials (GWPs) for individual greenhouse gases (GHGs). These are used in GREET to convert emissions of GHGs into CO_2-equivalent emissions. The *Fuel_Specs* sheet also contains the carbon content in VOCs, CO, CH_4, and CO_2, and the sulfur content in SO_2. These are used for carbon emission and SO_x emission calculations throughout the GREET model.

Since sulfur contents in conventional gasoline, conventional diesel, and conventional California diesel are expected to change over time, time-series tables are developed at the bottom of this sheet for the sulfur content of these three fuels.

4.9 T&D

This sheet is developed for calculations of energy use and emissions for transportation and distribution (T&D) of feedstock's and fuels. The results of this sheet — energy use (in Btu) and emissions (in g/mmBtu) — are used in other sheets for calculations associated with different fuel cycles.

4.10 Urban_Shares

In this sheet, a default splits between urban and non-urban areas for a given facility type are provided to calculate the urban emissions of five criteria air pollutants (VOC, CO, NO_X, SO_X, and PM_{10}) for each WTP stage and vehicle operation within various fuel-vehicle systems in the GREET model.

4.11 Petroleum

This sheet is used to calculate well-to-pump (WTP) energy use and emissions of petroleum-based fuels. Eight petroleum-based fuels are included in GREET: conventional gasoline (CG), reformulated gasoline (RFG), California reformulated gasoline (CARFG), conventional diesel (CD), low-sulfur diesel (LSD), liquefied petroleum gas (LPG), crude naphtha, and residual oil. Although residual oil is not a vehicle fuel, it is included here to calculate the energy use and emissions associated with producing different transportation fuels and electricity.

This sheet also presents calculations for MTBE, ethyl tertiary butyl ether (ETBE), and tertiary amyl methyl ether (TAME), which together with ethanol, can be used as oxygenates in RFG and CARFG. Energy use and emissions for ethanol are calculated in a separate sheet designed specifically for ethanol (*EtOH* sheet, section 4.15 below). Based on the oxygenate types and O_2 content specified in the *Inputs* sheet for RFG and CARFG, this portion of the *Petroleum* sheet calculates the appropriate amount of the selected oxygenate. Energy use and emissions associated with producing the selected oxygenate are carefully taken into account for RFG and CARFG energy and emission calculations in GREET.

4.12 NG

This sheet presents calculations of energy use and emissions for natural gas (NG)-based fuels: compressed natural gas (CNG), liquefied natural gas (LNG), LPG, methanol (MeOH), dimethyl ether (DME), Fischer-Tropsch diesel (FTD), and Fischer-Tropsch naphtha (FTN). GREET can simulate production of these fuels from North American natural gas, non-North American natural gas, and non-North American flared gas. For the non-North America sources, GREET assumes that non-North American natural gas and flared gas are converted into LNG for transportation to North America, where the fuel is produced.

4.13 Ag_Inputs

This sheet presents calculations for agricultural chemicals (or agricultural inputs, *Ag_Inputs*), including synthetic fertilizers and pesticides, which are used for the farming of corn, biomass, and soybeans. Corn is a feedstock for ethanol, biomass is a feedstock for ethanol, and soybeans are a feedstock for biodiesel. Three fertilizers are included: nitrogen, phosphate, and potash. Pesticides include herbicides and insecticides. This sheet includes calculations for the manufacturing of the chemicals as well as the transportation of the chemicals from manufacturing plants to farms.

4.14 EtOH

This sheet calculates energy use and emissions for fuel cycles that involve producing ethanol (EtOH) from corn, woody biomass, and herbaceous biomass. The following stages are included in this sheet: corn/biomass farming and transportation, corn/biomass ethanol production, as well as the transportation, distribution and storage of the ethanol fuel. For corn-based ethanol, the sheet includes both wet and dry milling plants. For each plant type, energy and emission credits for ethanol co-products can be estimated by using the displacement or the market value methods. For ethanol production from woody and herbaceous biomass, the energy and emission credits for the co-generated electricity in cellulosic ethanol plants are estimated by using the displacement method.

4.15 E-D Additives

This sheet presents energy use and emission calculations for additives in ethanol-diesel fuel (E-diesel or E-D). The following stages are included in this sheet: additives manufacture, additives transportation and storage.

4.16 BD

This sheet calculates energy use and emissions associated with producing biodiesel (BD) from soybeans. The sheet includes soybean farming and transportation, soyoil extraction, and soyoil transesterification to biodiesel. Energy use and emissions are allocated between biodiesel and by-products according to the market value method.

4.17 Coal

This sheet is to calculate energy use and emissions for coal mining, cleaning, and transportation. The results are used in other fuel cycles in which coal is used as a process fuel or as a feedstock. For example, in calculating the energy use and emissions associated with electricity generation in coal-fired power plants, GREET takes into account energy use and emissions in coal mining, cleaning, and transportation, all of which are calculated in this sheet.

4.18 Uranium

This sheet is used to calculate energy use and emissions for uranium ore mining and milling, uranium ore transportation, uranium fuel enrichment, uranium conversion, fabrication and waste storage, and uranium fuel transportation. The results of this sheet are used in the *Electric* sheet for calculating the energy use and emissions of nuclear electric power plants using LWR or HTGR. Even though nuclear power plants have zero operational energy use and emissions, the upstream processing and the transportation of uranium consume energy and generate emissions.

4.19 LF_Gas

This sheet presents energy use and emission calculations for the fuel cycle that consists of producing methanol from landfill gases (LF_Gas). GREET assumes that without methanol production, landfill gases would otherwise be flared. Flaring the gases generates a significant amount of emissions. The emissions offset by producing methanol are taken into account as emission credits for methanol production. Emissions from methanol combustion are taken into account during vehicle operation.

4.20 Electric

This sheet is used to calculate energy use and emissions associated with the generation of electricity, which is used for the production of transportation fuels and for the operation of electric vehicles and grid-connected HEVs. In this sheet, GREET can calculate emission factors of electric power plants according to combustion emission factors incorporated in the model or take emission factors directly from the user. Energy use and emissions during processing and transportation of power plant fuels, as well as during power plant electricity generation, are all accounted for in the GREET model. The results in this sheet are in Btu or g/mmBtu of electricity available at the user's site. That is, electricity loss during transmission and distribution of electricity from power plants to the user's site is account for in GREET. In this sheet, a total of ten types of electricity for energy use and emission calculations needed by other worksheets are simulated. These types include the electricity generated from oil power plants, NG power plants, coal power plants, nuclear power plants (LWR or HTGR), hydro power plants, NG combined-cycle turbine power plants, U.S average generation mix, North-eastern U.S generation mix, California generation mix, or user defined generation mix.

4.21 Vehicles

The *Vehicles* sheet is designed to calculate energy use and emissions associated with vehicle operations. This sheet is constructed in three sections. The first (*Scenario Control*) section, includes methanol and ethanol flexible-fuel vehicles, vehicles with low-level ethanol blended in gasoline, and dedicated methanol and ethanol vehicles. The user can specify the content of methanol or ethanol in the fuel blends. For Fischer-Tropsch diesel and biodiesel blended with diesel, the user can specify the content of Fischer-Tropsch diesel or biodiesel in the fuel blends. For ethanol blended with diesel, the user can specify the content of ethanol and additives in the fuel blends. Furthermore, the user can specify the market share of RFG out of RFG and CG or the market share of LSD out of LSD and CD for these alternative fuel blends. The split for vehicle miles traveled by vehicles powered with grid electricity and onboard internal combustion engines (for grid-connected HEVs) is also presented in this section.

The second section of the *Vehicles* sheet (*Vehicle Fuel Economy and Emission Changes*) presents fuel economy and emission changes associated with alternative-fueled vehicles and advanced technology vehicles relative to the baseline gasoline or diesel vehicles. All these data on fuel economy and emission changes may change over time, and are linked with time-series tables constructed in the *Cars_LDT1_TS* and *LDT2_TS* sheets.

The third section (*Per-Mile Fuel Consumption and Emissions*) in the *Vehicles* sheet calculates energy use and emissions associated with vehicle operations for individual vehicle types. The fuel economy and emissions of baseline gasoline and diesel vehicles are established in this section.

4.22 Results

This sheet presents results for the complete fuel cycle. The sheet is constructed in three sections. In the first section (*Well-to-Pump Energy Use and Emissions*), energy and emission results from wells to refueling station pumps (in Btu or g/mmBtu of fuel available at fuel pumps) are presented for each transportation fuel.

In the second section (*Well-to-Wheels Energy Use and Emissions*), fuel-cycle (well-to-wheels) energy use and emissions for each vehicle type are calculated. For each vehicle type, energy use and emissions are presented separately for three stages: feedstock (including recovery, transportation, and storage), fuel (including production, transportation, storage, and distribution), and vehicle operation. Shares of energy use and emissions for each of the three stages are also presented in this section. Both urban emissions (emissions occurring in urban areas) and total emissions (emissions occurring everywhere) for the five criteria pollutants are calculated in this section.

In the third section (*Well-to-Wheels Energy and Emission Changes*) of this sheet, changes in fuel-cycle energy use and emissions by individual alternative-fueled vehicle type/advanced vehicle technology type are calculated. The changes by fuel/vehicle technologies are calculated against gasoline vehicles fueled with CG and/or RFG.

Users can generate the results with probability distributions of WTP, WTW, and WTW changes for the cells colored in blue. This can be achieved using the Crystal Ball software to conduct stochastic simulations within the GREET model. Without Crystal Ball, users can conduct only point estimates of energy use and emissions.

4.23 Graphs

This sheet graphically presents bar charts for the energy use and emissions shares of feedstock, fuel, and vehicle operations, for each simulated fuel/vehicle type. Furthermore, it shows energy use and emissions changes by individual vehicle technologies relative to the baseline gasoline vehicles powered by conventional gasoline and/or reformulated gasoline.