Section 5
Model Layout

GREET 1.5, developed as a multidimensional spreadsheet model in Microsoft Excel 97, consists of 15 sheets; these sheets are briefly described below. If the GREET model is available to the reader, it is helpful to browse through it in Excel while reading this section.

Overview. This sheet presents a brief summary of each of the sheets in GREET to introduce their functions. It also presents some key notes for running GREET and our disclaimers. First-time users need to read this sheet before proceeding with GREET simulations.

EF. Here, "EF" represents emission factors. In this sheet, emission factors (in $g/10^6$ Btu of fuel burned) are presented for individual combustion technologies that burn NG, residual oil, diesel, gasoline, crude oil, LPG, coal, and biomass. These emission factors are used in other sheets of the GREET 1 series model (and in the GREET 2 and 3 series models) to calculate emissions associated with fuel combustion in various upstream stages. For each combustion technology, emission factors are presented (in $g/10^6$ Btu) for VOCs, CO, NO_x, PM_{10}, SO_x, CH_4, N_2O, and CO_2. As stated in Section 3, GREET's emission factors for VOCs, CO, NO_x, PM_{10}, CH_4, and NO_2 are derived primarily from the EPA's AP-42 document. Emission factors for CO_2 are calculated in the GREET model from carbon contained in a given fuel minus carbon contained in VOCs, CO, and CH_4 emitted during combustion of the fuel.

For the sake of calculating CO_2 emissions, the carbon ratios of VOCs, CO, and CH_4 are listed in this sheet. The carbon ratios for CO and CH_4 are precisely calculated from their molecular compositions, but the ratio for VOCs is estimated on the basis of an assumption about the aggregate composition of individual hydrocarbon species in exhaust gases. SO_x emission factors for the combustion of NG, gasoline, diesel, crude, and LPG are calculated by assuming that all the sulfur contained in these fuels is converted to SO_2. The calculations of CO_2 and SO_x emissions of fuel combustion are built into appropriate cells in this sheet.

This sheet encompasses 43 combustion technologies. For many of the combustion technologies, emission factors are presented in terms of so-called "current" and "future" factors. For a given combustion technology, current emission factors applied to the technology reflect requirements of the 1990 Clean Air Act Amendments. These requirements were usually in place by the mid-1990s. Future emission factors apply to a future technology with some further emission controls as appropriate. To determine future emission factors, we first assessed the need for controlling emissions of certain pollutants for a given combustion technology. We then studied the EPA's AP-42 document and other documents to determine the appropriate emission control measures applicable to the given technology.

To estimate emissions for a given fuel-cycle stage over time, a GREET user can gradually increase the share of the future technologies for a given combustion technology to reflect

implementation of further emission control technologies in the future. That is, when the users simulate a more remote future year, they can assume a larger share of future emission factors. When running GREET to generate results in this report, we assumed 20% of the current emission factors and 80% of the future emission factors for a given combustion technology (say, NG-fired industrial boiler) for the evaluation of near-term transportation fuels and technologies in calendar year 2005. For the evaluation of long-term fuels and technologies in calendar year 2015, we increased the share of future emission factors to 100%. That is, we phased out current emission factors by 2015.

Fuel_Specs. This sheet presents specifications for individual fuels. Lower and higher heating values (in Btu/gal, Btu/scf, or Btu/ton for liquid, gaseous, or solid fuels, respectively), fuel density (in g/gal, g/scf, or g/ton for liquid, gaseous, or solid fuels, respectively), carbon weight ratio, and sulfur weight ratio are specified for each fuel. Sulfur content for each fuel is presented in ppm and actual ratio by weight. Users can put sulfur content (in ppm) into GREET, and the actual ratio is changed in GREET accordingly.

The parametric values for these fuel specifications are needed to estimate energy consumption and emissions, as well as for conversions among mass, volume, and energy content. Fuel specifications are presented for crude oil, CG, RFG (both California and federal phase 2 RFG), CD, RFD, residual oil, methanol, ethanol, LPG, LNG, DME, dimethoxy methane (DMM) (the current version of GREET does not calculate energy use and emissions for DMM — these may be included in a future version), biodiesel, FTD, liquid hydrogen, MTBE, ETBE, TAME, butane, isobutane, isobutylene, propane, NG liquids, still gas, NG, gaseous hydrogen, coal, coking coal, woody biomass, and herbaceous biomass. The information in this sheet is called on by all the other sheets in GREET.

GREET uses the LHVs of fuels for its calculations. Some studies have used HHVs. Both LHVs and HHVs are presented in GREET. If HHVs are required for the user's own calculations, those values can be copied to the calculation cells designed in this sheet, and GREET will then take HHVs into account automatically. However, changes from LHVs to HHVs requires changing emission factors (in $g/10^6$ Btu) from LHVs to HHVs too.

GWPs for individual GHGs also are presented in this sheet. The GWPs are used in GREET to combine emissions of GHGs together to calculate CO_2-equivalent emissions. As stated in Section 3, GREET uses the IPCC-adopted GWPs. That is, GWP is 1 for CO_2, 21 for CH_4, and 310 for N_2O. At present, GREET assigns GWPs of zero to VOCs, CO, and NO_x, although cells are designated in this sheet for assigning GWPs to these three gases. If users decide to test other GWP values for the six pollutants, they can simply change the default GWP values in this sheet.

Petroleum. This sheet is used to calculate upstream energy use and emissions of petroleum-based fuels. Six petroleum-based fuels are included in GREET: CG, RFG, CD, RFD, LPG, and residual oil. Residual oil itself is not a motor vehicle fuel; it is included here for calculating upstream energy use and emissions associated with producing transportation fuels and electricity.

The petroleum sheet, together with the other eight upstream calculation sheets (*NG, Ag_Inputs, EtOH, BD, Coal, Uranium, LF_Gas,* and *Electric*), follows the calculation logistics described in Section 3 and presented in Figure 5.1. For each upstream stage, the model uses assumptions about shares of fuel combustion technologies, energy efficiencies, total and urban emission shares, and shares of process fuels. Energy consumption (by process fuel) is calculated on the basis of energy efficiencies and process fuel shares. For each stage, energy use is calculated for total energy (all process fuels and energy in feedstocks), fossil energy (petroleum, NG, and coal), and petroleum. Emissions are calculated from the amount of a given process fuel used, combustion technology shares for the given fuel, and emission factors for each combustion technology. In addition, such noncombustion emissions as those from fuel leakage and evaporation, gaseous fuel venting, and chemical reactions are estimated, as applicable. Energy use and emissions are then summarized for two aggregate groups: feedstock- and fuel-related stages. Urban emissions of the five criteria pollutants are calculated by considering the split between urban facilities and nonurban facilities for a given upstream activity.

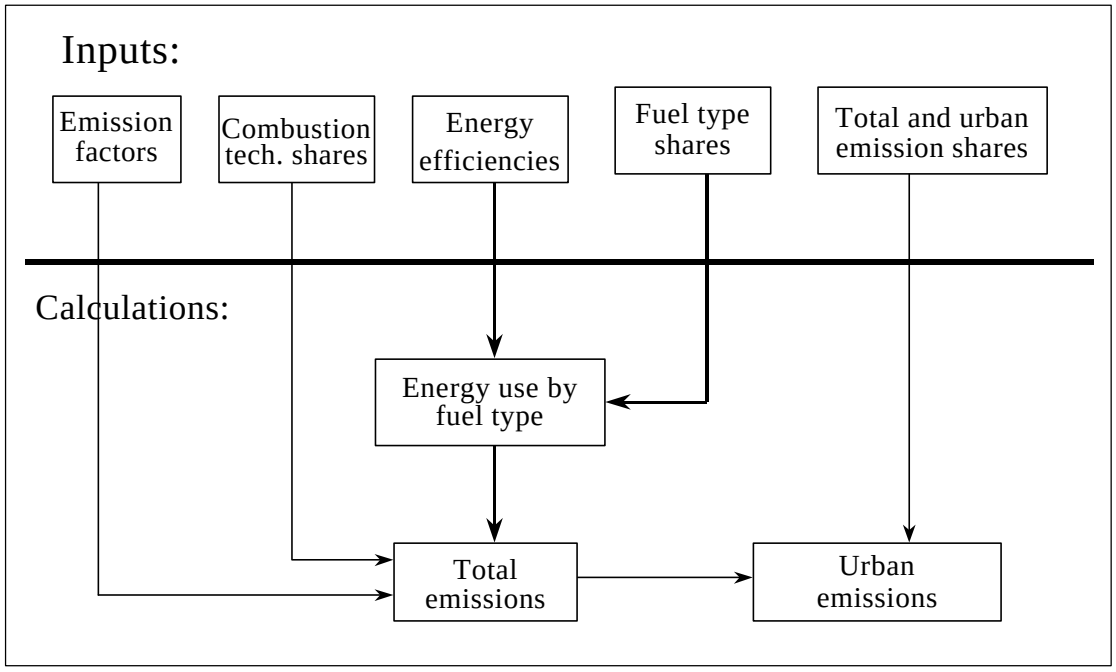

Figure 5.1 GREET's Logistics for Upstream Energy Use and Emissions Calculations

The nine upstream sheets are constructed in similar ways. Most sheets are divided into four sections. The first section (the so-called scenario control and key input parameters section) presents key assumptions about a fuel cycle and the control parameters for multipathway fuels to select which pathway is to be simulated; some of the nine sheets (*Ag_Inputs, Coal, Uranium, and LF_Gas*) lack this section. The second section presents shares of combustion technologies for a given fuel burned during a given upstream stage. Depending on specific cases to be simulated, one can change combustion technology shares in this section. The third section

presents, for each upstream stage, assumptions about energy efficiencies, urban emission shares, a loss factor (which is used to combine energy and emission results from different stages together), and shares of process fuels. With these input parameters, GREET calculates energy use and emissions for each stage in this section. Also, if applicable, assumptions about the so-called "noncombustion emissions" for some stages are presented in this section. The fourth section presents a summary of the energy use and emissions as calculated in the third section, divided into two groups: feedstock- and fuel-related stages for individual fuel cycles. The summarized results in this section are called on by other parts of the GREET model.

For the petroleum sheet, the scenario control section presents the assumptions of MTBE content of CG and the oxygen requirements of RFG. Currently, MTBE is added to CG to maintain an adequate level of octane, even though there is no oxygen requirement for CG. On average, CG contains 2% MTBE by volume. This percentage has been input into the petroleum sheet as a default value. Note that the recent discovery in California of water contamination associated with MTBE may eliminate the use of MBTE in CG in the future. The oxygen requirements of California and federal RFG are also based on regulations that could change in the future.

GREET allows use of MTBE, ETBE, TAME, or ethanol in RFG to meet oxygen requirements. As the scenario control section of the petroleum sheet shows, users can simply select one of the four ethers for use in their GREET simulations.

NG. This sheet presents calculations of energy use and emissions for NG-based fuels, namely CNG, LNG, LPG, methanol, DME, FTD, and H_2. Fuel cycles from shared gas to methanol, DME, and FTD are also presented. For convenience, the fuel cycle that consists of producing renewable H_2 from solar energy via water electrolysis is presented in this section, too. For H_2 fuel cycles, H_2 can be produced in either gaseous or liquid form; either form may be selected for simulation. If it is assumed that gaseous H_2 produced in central plants is used, the produced gaseous H_2 is transported via pipelines to service stations and is compressed and used to fuel vehicles. If liquid H_2 is assumed, gaseous H_2 is first liquefied at H_2 plants, and the liquid H_2 is stored and transported cryogenically.

In the scenario control section, users can choose to simulate a specific pathway for a fuel that can be produced from multiple pathways. For example, users can choose whether liquid H_2 is produced from NG or solar energy; whether gaseous H_2 is produced from NG in centralized plants, from NG in refueling stations, or from solar energy in centralized plants; and whether liquid or gaseous H_2 is used in motor vehicles. Users can also choose whether methanol is produced from NG, flared gas, or landfill gas; whether LPG is produced from NG, crude, or any combination of both; and whether FTD and DME are produced from NG or flared gas. Because CO_2 sequestration in NG-H_2 plants is a key factor in determining GHG emission impacts of NG-to-H_2 pathways, the assumption of CO_2 sequestration is presented in this section, too. LPG, methanol, and gaseous H_2 could be used for stationary applications as well as for vehicle applications. In order that stationary applications of these fuels are not affected by their production pathways for vehicle applications, stationary application pathways are presented for these fuels separately from pathway assumptions for vehicle applications.

Ag_Inputs. This sheet presents calculations for agricultural chemicals, including synthetic fertilizers and pesticides. Three fertilizers are included: nitrogen, P_2O_5, and K_2O. Pesticides include herbicides and insecticides. Furthermore, herbicides include atrazine, metolachlor, acetochlor, and cyanazine, four major herbicides for which energy intensity data are available. Many other herbicides are used for farming, but no energy intensity data are available for them. A generic insecticide is assumed in GREET, because there are no specific energy intensity data for individual insecticides. The fertilizers and pesticides are used in growing corn, soybeans, woody biomass, and herbaceous biomass. Calculated energy use and emissions for these chemicals are used to calculate energy use and emissions of ethanol (produced from corn, woody biomass, and herbaceous biomass) and biodiesel (produced from soybeans). Average energy use and emissions of herbicides are presented in this sheet for corn, soybeans, woody biomass, and herbaceous biomass, with assumed shares of individual herbicide types for each crop.

This sheet also includes calculations of energy use and emissions associated with transportation of chemicals from manufacturing plants to farms. Transportation of chemicals is separated into three steps: manufacturing plants to bulk distribution terminals, to mixers, and then to farms. Calculations of energy use and emissions are separated for each step, each chemical, and each crop. In this way, the user's own data can be readily inputted for application of an individual chemical to an individual crop type.

EtOH. This sheet calculates energy use and emissions for fuel cycles that involve producing ethanol from corn, woody biomass, and herbaceous biomass. In the first section (the scenario control and key input parameters section), users can elect to:

1. Simulate ethanol production from corn [(a) dry milling plants, (b) wet milling plants, or (c) a combination of both];

2. Simulate ethanol production from corn and biomass [(a) ethanol from corn, (b) ethanol from woody biomass, (c) ethanol from herbaceous biomass, or (d) a combination of the three];

3. Include changes in CO_2 emissions from land-use changes due to corn and biomass farming; and

4. Use the market-value-based approach or the displacement approach to estimate energy and emission credits of coproducts from corn ethanol plants.

This section also presents parametric assumptions regarding ethanol yield in corn ethanol plants (in gal/bu of corn), the shares of NG and coal as process fuels in corn ethanol plants, electricity credits from cellulosic ethanol plants (in kWh/gal of ethanol produced), and ethanol yield in cellulosic ethanol plants (in gal/dry ton of biomass). For the market-value-based approach and the displacement approach of dealing with coproducts of corn ethanol, this section presents key assumptions to be used to estimate coproduct credits for each approach.

In the calculation section, energy and emissions are calculated for corn farming in Btu/bu and g/bu of corn produced and for biomass farming in Btu/dry ton and g/dry ton of biomass produced. Energy use and emissions of ethanol production are calculated in Btu/gal and g/gal of ethanol produced. Energy use and emissions from different stages are converted into Btu/10^6 Btu and g/10^6 Btu of ethanol produced in the summary section, on the basis of ethanol yield of plants (gal/bu of corn or gal/dry ton of biomass) and the ethanol's energy content.

BD. This sheet calculates energy use and emissions associated with producing BD from soybeans. Allocation of energy use and emissions between BD and its coproducts is needed for this fuel cycle. The allocation assumptions for soybean farming, soy oil extraction, and soy oil transesterification are presented in the scenario control section. In GREET 1.5, the market-value-based approach is used to allocate energy use and emissions between BD and its coproducts. Also, assumptions about soybeans required per pound of soy oil produced and soy oil required per pound of BD produced are presented in this section.

Energy use and emissions are calculated for soybean farming in Btu/bu and g/bu of soybeans produced and for soy oil extraction or transesterification in Btu/lb and g/lb of soy oil or biodiesel produced. In the summary section, energy use and emissions for each stage are converted into Btu/10^6 Btu and g/10^6 Btu of biodiesel produced by using yield data for each stage and the energy content of biodiesel.

Coal. This sheet is used to calculate energy use and emissions for coal mining and transportation. The results are used in other upstream calculation sheets.

Uranium. This sheet is used to calculate energy use and emissions for uranium mining, transportation, and enrichment. The results are used in the electricity sheet for calculating upstream energy use and emissions of nuclear electric power plants.

LF_Gas. This sheet presents energy and emission calculations for the fuel cycle that consists of producing methanol from landfill gases. It is assumed in GREET that without methanol production, landfill gases would otherwise be flared. Flaring the gases produces significant amounts of emissions. The emissions offset by methanol production are taken into account as emission credits for methanol production. On the other hand, emissions from methanol combustion are taken into account during vehicle operation.

Electric. This sheet is used to calculate energy use and emissions associated with electricity generation for production of transportation fuels (where electricity is used) and for operation of EVs and grid-connected HEVs. The layout of this sheet is different from other upstream sheets. In the scenario control section, there is a control variable for selection of either GREET-calculated electric power generation emission factors or user-provided emission factors. In calculating electric power generation emission factors, GREET takes into account the type of fuel used, the type of generation technologies used, and emission controls employed. For a specific electric utility system, if a user has measured emission factors for electricity generation by the system, the user can input the system-specific, measured emission factors in section 4 of this sheet to override the GREET-calculated emission factors.

The next section presents information about average and marginal electric generation mixes, combustion technology shares for a given fuel, power-plant conversion efficiencies, and urban and total emission splits. The average electric generation mix is used to calculate emission factors of electric generation for determining energy use and emissions associated with producing transportation fuels (i.e., the upstream activities). The marginal electric generation mix is used to calculate emission factors for EVs and the grid electric operations of grid-connected HEVs. In other words, the average generation mix is used for electricity use in stationary sources; the marginal mix, for electricity use by motor vehicles.

The third section of the electric sheet presents electricity loss during electricity transmission and distribution. Section 4 presents the method for calculating g/kWh emission rates for oil-, NG-, and coal-fired power plants by GREET or user-input power plant emission rates. Section 5 presents power plant emission rates in g/kWh for a utility system with a given generation mix. Section 6 presents power plant energy use and emissions per million Btu of electricity generated from an electric utility system. Section 7 presents energy use and emissions of both electric power plants and activities prior to electric power plants.

Vehicles. This sheet is used to calculate energy use and emissions associated with vehicle operations. The sheet is constructed in three sections. In the first (scenario control) section, for methanol and ethanol FFVs and dedicated methanol and ethanol vehicles, users can specify the content of methanol or ethanol in fuel blends. For FTD and biodiesel blended with diesel, users can specify the content of FTD or biodiesel in fuel blends. The VMT split between grid electricity operation and ICE operation for grid-connected HEVs also is presented in the scenario control section.

Methanol and ethanol blends can be CG- or RFG-based. As RFG use becomes widespread in the future, methanol and ethanol will likely be blended with RFG. An option provided in this section allows users to decide whether CG or RFG will be blended with methanol and ethanol. Another option allows users to decide whether CD or RFD will be blended with FTD and BD.

In the second section, fuel economy and emission changes associated with AFVs and advanced vehicle technologies relative to baseline gasoline or diesel vehicles are presented. Since fuel economy and emissions of baseline vehicles are different for near- and long-term technology options, fuel economy and emission changes for near- and long-term technologies are presented separately in this section.

The third section calculates energy use and emissions associated with vehicle operations for individual vehicle types. The fuel economy of baseline GVs is input in this section. Emissions of baseline gasoline and diesel vehicles are calculated with EPA's MOBILE 5b and PART 5 and input here. Energy use of other vehicle types (including diesel vehicles) is calculated on the basis of baseline GV fuel economy and relative change in fuel economy between GVs and AFVs. Emissions of AFVs are calculated from emissions of GVs or DVs and relative emission changes of AFVs. For alternative fuels applicable to spark ignition engines, the emissions are calculated from baseline GV emissions. For alternative fuels applicable to CI engines (DME, FTD, and biodiesel), the emissions are calculated from baseline DV emissions. Again, energy use and emissions are presented for near- and long-term technologies separately.

For the two biofuels (ethanol and biodiesel), combustion CO_2 emissions are treated as being zero in this section, because the CO_2 emitted to the atmosphere is simply the CO_2 obtained from the atmosphere by corn and soybean plants during photosynthesis. Alternatively, CO_2 emissions from combustion of ethanol or biodiesel can be calculated here, and a CO_2 emission credit can be assigned to farming of corn or soybeans.

Results. Fuel-cycle energy use and emissions for each individual vehicle type are calculated in this sheet. For each vehicle type, energy use and emissions are calculated 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 by each of the three stages are also calculated in this section. For the five criteria pollutants, both urban emissions and total emissions (emissions occurring everywhere) are calculated in this section.

The first section presents per-mile energy use and emissions for all near-term technology options. The second section presents those for all long-term technology options. In the third and fourth sections of this sheet, changes in fuel-cycle energy use and emissions by individual AFV types are calculated. The changes for near-term options are calculated against conventional GVs fueled with CG; the changes for long-term options are against conventional GVs fueled with RFG.

Graphs. In this sheet, Section 1 graphically presents shares of energy use and emissions by feedstock, fuel, and vehicle operations for each vehicle type. Again, charts are presented for near- and long-term technologies separately. In this section, each chart represents a vehicle or fuel technology.

Section 2 of this sheet presents changes in energy use and emissions by vehicle type. Vehicle and fuel technologies are separated into four groups: near-term technologies, long-term SI and SIDI vehicles, long-term CIDI vehicles and CIDI hybrid electric vehicles, and long-term electric vehicles and fuel-cell vehicles. Each chart in this section represents a particular energy or emission item.

Within the GREET model, some cells present default assumptions used for fuel-cycle energy and emission calculations, while others are logic calculations. Users have the option to change any of the default assumptions. The cells that contain critical assumptions are colored yellow so that users can easily distinguish these assumptions from logic calculations and can change key assumptions as necessary.