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.

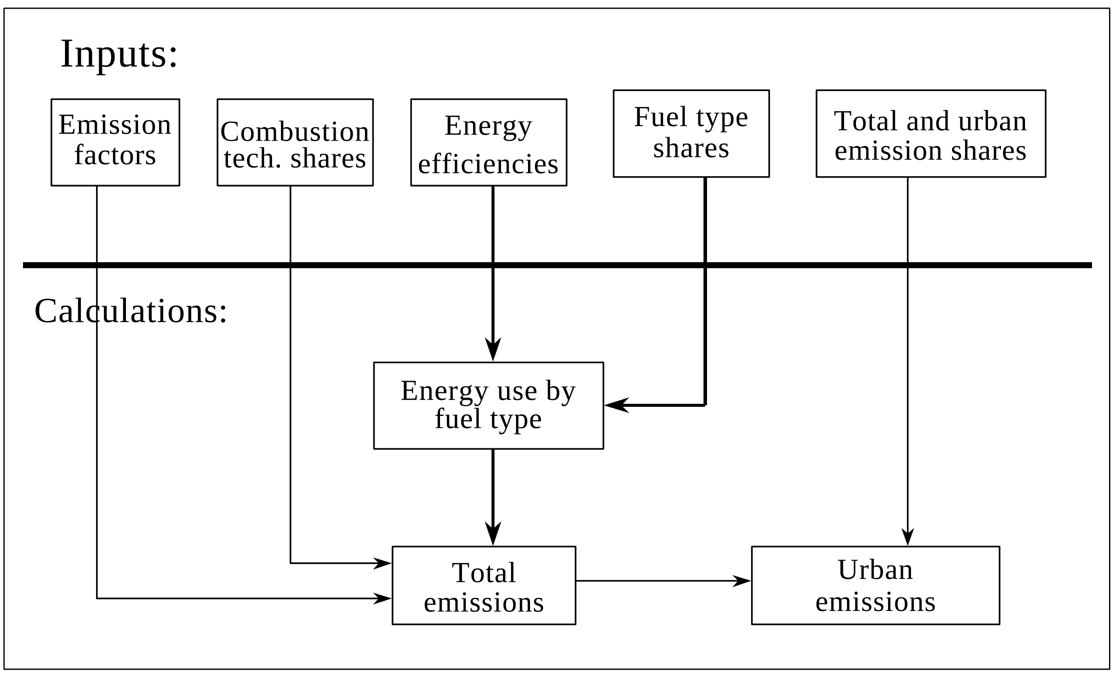

Figure 5.1 GREET's Logistics for Upstream Energy Use and Emissions Calculations

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.

Section 6
Fuel-Cycle Energy Use and Emissions Results

This section presents results of energy use and emissions associated with individual alternative fuels and advanced vehicle technologies, as calculated by GREET 1.5. To generate the results presented in this section, we used default assumptions (presented in previous sections) about upstream fuel production activities and vehicle operations. As stated throughout this report, the default assumptions used in GREET are based on our research. Readers need to pay attention to the assumptions as much as to the results. It is preferable that, for their own analyses, users collect the necessary data, make changes to critical assumptions in GREET, and produce their own results. However, the results presented in this section do represent our best judgments, made on the basis of our research.

6.1 Near- and Long-Term Alternative Fuels and Vehicle Technologies

Among the fuels and vehicle technologies included in GREET, some are already available in the marketplace and being used, while others, still in the research and development stage, must overcome technological hurdles or are not marketable because of cost and infrastructure constraints. Economics and market readiness of these long-term technologies are beyond the scope of this study.

Thus, evaluation of fuel-cycle energy and emission impacts of alternative fuels and advanced technologies is conducted separately for near-term and long-term technologies. The separation is necessary because, over time, baseline conventional technologies will be improved, and the improved baseline conventional technologies should be used to analyze the impacts of long-term technologies. For our analysis, near-term technologies are those already available in the United States, and long-term technologies could become available around the year 2010 (see Tables 4.35, 4.45, and 4.46 for near- and long-term technologies).

To evaluate near-term technologies, we assumed that they would be applied to vehicles produced around 2001 (MY 2001) and that the baseline MY 2001 GVs would meet National Low-Emission Vehicle (NLEV) emission standards. The NLEV program, adopted by EPA in the spring of 1998, is a voluntary program in which 9 northeast U.S. states and 23 automakers participate. The program requires that NLEV vehicles begin to be introduced to the northeast United States in MY 1999 and to the rest of the United States (except California) in MY 2001 (EPA 1998a). The NLEV program allows manufacturers to certify vehicles fueled by gasolines like the federal Phase 2 RFG.

Table 6.1 presents NLEV emission standards and Tier 1 standards currently in place. Tier 1 emission standards were fully in effect beginning in MY 1996. Under the NLEV program, each automaker is subject to fleet average NMOG standards. In the Northeast United States, the fleet average NMOG standards are 0.148 g/mi for MY 1999 and 0.095 g/mi for

Table 6.1 Tier 1 and NLEV Emission Standards for Light-Duty Vehicles and Trucks (in g/mi)[a]

Vehicle		THC	NMHC	NMOG	CO	NO_x	PM[b]	HCHO[c]
				5 Years/50,000 Miles Useful Life				
Cars	Tier 1	NE[d]	0.25	NE	3.4	0.4	0.08	NE
	TLEV	NE	NE	0.125	3.4	0.4	NE	0.015
	LEV	NE	NE	0.075	3.4	0.2	NE	0.015
	ULEV	NE	NE	0.040	1.7	0.2	NE	0.008
LDT1[e]	Tier 1	NE	0.25	NE	3.4	0.4	0.08	NE
	TLEV	NE	NE	0.125	3.4	0.4	NE	0.015
	LEV	NE	NE	0.075	3.4	0.2	NE	0.015
	ULEV	NE	NE	0.040	1.7	0.2	NE	0.008
LDT2[e]	Tier 1	NE	0.32	NE	4.4	0.7	0.08	NE
	TLEV	NE	NE	0.160	4.4	0.7	NE	0.018
	LEV	NE	NE	0.100	4.4	0.4	NE	0.018
	ULEV	NE	NE	0.050	2.2	0.4	NE	0.009
LDT3[f]	Tier 1	NE	0.32	NE	4.4	0.7	NE	NE
LDT4[f]	Tier 1	NE	0.39	NE	5.0	1.1	NE	NE
				10 Years/100,000 Miles Useful Life				
Cars	Tier 1	NE	0.31	NE	4.2	0.6	0.10	NE
	TLEV	NE	NE	0.156	4.2	0.6	0.08	0.018
	LEV	NE	NE	0.090	4.2	0.3	0.08	0.018
	ULEV	NE	NE	0.055	2.1	0.3	0.04	0.011
LDT1[e]	Tier 1	0.80	0.31	NE	4.2	0.6	0.10	NE
	TLEV	NE	NE	0.156	4.2	0.6	0.08	0.018
	LEV	NE	NE	0.090	4.2	0.3	0.08	0.018
	ULEV	NE	NE	0.055	2.1	0.3	0.04	0.011
LDT2[e]	Tier 1	0.80	0.40	NE	5.5	0.97	0.10	NE
	TLEV	NE	NE	0.200	5.5	0.9	0.10	0.023
	LEV	NE	NE	0.130	5.5	0.5	0.10	0.023
	ULEV	NE	NE	0.070	2.8	0.5	0.05	0.013
LDT3[f]	Tier 1	0.80	0.46	NE	6.4	0.98	0.10	NE
LDT4[f]	Tier 1	0.80	0.56	NE	7.3	1.53	0.12	NE

[a] Source: EPA Office of Mobile Sources Internet Home Page.

[b] PM emission standards are applied to diesel vehicles only.

[c] HCHO = formaldehyde.

[d] NE = not established.

[e] Definitions of LDT1 and LDT2 are different between emission regulations and emission estimations in Mobile 5b. In emission regulations, LDT1 is defined as an LDT with a loaded vehicle weight of 0–3,750 lb and with a GVW below 6,000 lb; LDT2 is defined as an LDT with a loaded vehicle weight of 3,750–5,570 lb and with a GVW below 6,000 lb. For emission estimation in Mobile 5b, LDT1 is defined as an LDT with a GVW of less than 6,000 lb; LDT2 is defined as an LDT with a GVW of 6,000–8,500 lb.

[f] LDT3 and LDT4 for emission regulations are the LDT2 defined in Mobile 5b simulations. Both LDT3 and LDT4 have a GVW of 6,001–18,500 lb. LDT3 has a loaded vehicle weight of 0–3,750 lb, and LDT4 has a GVW of greater than 3,750 lb.

MY 2000 and beyond for cars and LDT1; and 0.190 g/mi for MY 1999 and 0.124 g/mi for MY 2000 and beyond for LDT2. Nationwide, the fleet average NMOG standards are 0.075 g/mi for cars and LDT1 and 0.100 g/mi for LDT2, both beginning in MY 2001. Nationwide, NLEV vehicles will be required to account for at least 25% of total vehicle sales in MY 2001, 50% in MY 2002, and 85% in MY 2003 and beyond.

To represent the average lifetime emissions of MY 2001 vehicles, we estimate, with Mobile 5b and Part 5, per-mile emissions of the MY 2001 baseline vehicles (i.e., gasoline and diesel vehicles) in calendar year 2006, when these vehicles will accumulate about half of their lifetime VMT. Consequently, GREET 1.5 was run for calendar year 2006 for near-term technologies.

The GREET 1 series is designed to estimate fuel-cycle energy use and emissions for passenger cars, light-duty trucks 1 (LDT1s, pickups, minivans, passenger vans, and sport utility vehicles with a GVW up to 6,000 lb), and light-duty trucks 2 (LDT2s with a GVW between 6,001 and 8,500 lb). Energy use and emissions are estimated for passenger cars, LDT1s, and LDT2s separately. Tables 4.45 and 4.46 indicate that changes in fuel economy and emissions of alternative-fuel transportation technologies are assumed to be the same for passenger cars and LDT1s, while changes for LDT2s are different. Consequently, relative changes in fuel-cycle energy use and emissions for passenger cars and LDT1s are the same. On the other hand, fuel economy (affecting per-mile upstream emissions) and per-mile vehicular emissions are distinctly different for the three vehicle classes. Thus, changes in absolute amount (i.e., Btu/mi and g/mi) for energy and emissions are also different for the three.

To run GREET 1.5 for calendar year 2006, where both current and future emission factors are applied to a given combustion technology, we assumed a split of 20%/80% between current emission factors and future emission factors to calculate average emission factors for the combustion technology. Table 6.2 summarizes key assumptions about upstream activities for evaluating near- and long-term technologies.

To estimate fuel-cycle energy and emission impacts of long-term technologies, GREET was run in calendar year 2015 for MY 2010 vehicle technologies. Besides changes in vehicle operations emissions, changes were also made in the assumptions about upstream activities. For the long-term technology evaluation, future emission factors alone were used for combustion technologies; current emission factors were zeroed out. For the four NG-based fuels (methanol, DME, FTD, and H_2), energy efficiencies in production plants were increased, or steam credit was assumed (see Table 6.2). Energy intensity for manufacturing fertilizers and pesticides was reduced by 15%. Farming energy use (in Btu/bu) and use of fertilizers and pesticides (in g/bu) were reduced by 10% for both corn and soybean farming. Energy use in ethanol plants and biodiesel plants was reduced by 10%. The share of NG as the process fuel in ethanol plants was increased, while the share of coal was decreased. Ethanol yield was increased from 2.6 to 2.7 gal/bu of corn for dry milling corn ethanol plants and from 2.5 to 2.6 gal/bu for wet milling ethanol plants. The electric generation mix projected in EIA's *Annual Energy Outlook 1998* (EIA 1997d; see Table 4.34) for 2015 was used.

Table 6.2 Key Parametric Assumptions for Near- and Long-Term Technologies (in the exact forms accepted by GREET 1.5)

Item	Near-Term (2006)	Long-Term (2015)
Upstream fuel combustion: current emission factors	20%	0%
Upstream fuel combustion: future emission factors	80%	100%
Methanol plant efficiency: NG as feedstock	68%	65%[a]
Methanol plant efficiency: flared gas as feedstock	65%	65%
FTD plant efficiency: NG as feedstock	54%	53%[b]
FTD plant efficiency: flared gas as feedstock	52%	52%
DME plant efficiency: NG as feedstock	69%	68%[c]
DME plant efficiency: flared gas as feedstock	66%	66%
NG to H_2 plant efficiency: central plant	73%	67%[d]
NG to H_2 plant efficiency: refuel station production	65%	65%
Liquid H_2 liquefaction efficiency	82%	85%
Chemical manufacture energy intensity	Default values	85% of default values
Energy use intensity: corn and soybean farming	Default values	90% of default values
Chemical use intensity: corn and soybean farming	Default values	90% of default values
Energy use intensity: biodiesel production	Default values	90% of default values
Corn ethanol plants		
Ethanol yield: dry milling (gal/bu)	2.6	2.7
Ethanol yield: wet milling (gal/bu)	2.5	2.6
Dry milling production share	1/3	1/2
Wet milling production share	2/3	1/2
Ethanol plant energy use intensity	Default values	90% of default values
Share of coal as process fuel: dry milling plants	50%	20%
Share of coal as process fuel: wet milling plants	80%	50%
Electricity generation		
Electric generation mix (see Table 4.34)	2005 mix	2015 mix
NG combined cycle: % of NG capacity	30%	45%
Advanced coal technology: % of coal capacity[e]	5%	20%
Baseline GVs[f]		
Fuel economy (mpg): cars/LDT1/LDT2	22.4/16.8/14.4	24/18/15.4
Baseline Fuel	CG	FRFG2
Exhaust VOC emissions	NLEV emissions	Tier 2 emissions
Evaporative VOC emissions	NLEV emissions	Tier 2 emissions
Exhaust CO emissions	NLEV emissions	Tier 2 emissions
Exhaust NO_x emissions	NLEV emissions	Tier 2 emissions
Exhaust PM emissions	NLEV emissions	Tier 2 emissions
Baseline DVs[f]		
Exhaust VOC emissions	NLEV emissions	Tier 2 emissions
Exhaust CO emissions	NLEV emissions	Tier 2 emissions
Exhaust NO_x emissions	NLEV emissions	Tier 2 emissions
Exhaust PM emissions	NLEV emissions	Tier 2 emissions

[a] Plus 111,000 Btu of steam credit per million Btu of methanol produced.

[b] Plus 264,000 Btu of steam credit per million Btu of FTD produced.

[c] Plus 44,000 Btu of steam credit per million Btu of DME produced.

[d] Plus 269,000 Btu of steam credit per million Btu of H_2 produced.

[e] Advanced coal technologies for electric power plants include PFB/CC and IGCC, both of which have high energy conversion efficiency and low emissions.

[f] Fuel economy and emissions for baseline vehicles are for the 55/45 combined cycle. Fuel economy values are on-road-adjusted results. Emission estimates for baseline vehicles are presented in Section 6.2.

Corn ethanol is produced from both wet milling and dry milling facilities. At present, two-thirds of total U.S. ethanol is produced from wet milling plants and one-third from dry milling plants. For near-term corn ethanol, we used this split to combine the results of wet and dry milling plants. In the future, more dry milling plants will likely be built than wet milling plants, partly because capital requirements are lower for dry milling plants and because some states offer tax incentives for building small dry milling plants. Thus, for long-term corn ethanol production, we assumed 50% from wet milling plants and 50% from dry milling plants.

We assumed that long-term fuels and vehicle technologies would be applied to MY 2010 vehicles and that MY 2010 baseline GVs would meet the Tier 2 emission standards proposed by EPA (EPA 1999). Table 6.3 presents the proposed Tier 2 standards for cars, light LDTs (LLDTs), and heavy LDTs (HLDTs). In the Tier 2 proposal, EPA defined LLDTs as LDTs with a GVW of 0–6,000 lb and HLDTs as LTDs with a GVW of 6,000–8,500 lb. That is, the newly defined LLDTs are Mobile 5b-defined LDT1, and the newly defined HLDTs are Mobile 5b-defined LDT2. Note that beginning in MY 2009, all cars, LLDTs, and HLDTs will be subject to the same Tier 2 standards. For Tier 2, EPA proposed that evaporative emission standards be reduced by 50%.

6.2 Mobile 5b and Part 5 Runs

We used EPA’s Mobile 5b and Part 5 to generate per-mile emission rates for baseline GVs and DVs. For evaluation of near-term fuels and technologies, we used Mobile 5b and Part 5 to generate emissions estimates for LEVs that are six years old and have accumulated about 64,000 miles, which represents the mid-point of a vehicle’s lifetime. In accordance with EPA’s guidelines for estimating emission inventories, we estimated emissions of VOCs and NO_x for summer conditions and emissions of CO for winter conditions. PM emissions are not affected by ambient temperature, so we assumed summer conditions to generate PM emissions by using the Part 5 model.

In 1998, EPA developed an NLEV version of Mobile 5b to estimate emission impacts of the NLEV program (EPA 1998b). We used the Mobile 5 NLEV version to generate emissions of baseline GVs and DVs. Together with the NLEV program, the enhanced phase 2 on-board diagnosis system (OBDII) will be required for light-duty vehicles. In Mobile 5 NLEV runs, we included OBDII and an annual I/M program. However, our tests with Mobile 5 NLEV showed that OBDII overrode the I/M programs. That is, as long as OBDII is included, the I/M program does not offer any additional emission benefits for OBDII-equipped cars. We suspected that too many emission credits are assigned to OBDII in Mobile 5 NLEV. The new evaporative test procedure, which considers multiple diurnal tests, took effect in MY 1996. Cold CO emission standards were assumed for LEV vehicles. Beginning in 1998, an on-board refueling vapor recovery system was also assumed. We considered these requirements as well. Because of limitations of vehicle types in Mobile 5 NLEV, we had to make some adjustments outside of Mobile 5 NLEV. The footnotes in Table 6.4 describe these adjustments.

Vehicle emissions and fuel economy (especially emissions) are significantly affected by vehicle driving cycles. While emissions are regulated under the federal urban driving schedule (FUDS), corporate average fuel economy (CAFE) is regulated under the FUDS and the

Table 6.3 Proposed Tier 2 Vehicle Emissions Standards for Passenger Cars and Light-Duty Trucks[a,b]

Bin	NMOG	CO	NO_x	PM	HCHO
Tier 2 Light-Duty Vehicle Standards[c]					
7	0.125	4.2	0.20	0.02	0.018
6	0.090	4.2	0.15	0.02	0.018
5	0.090	4.2	0.07	0.01	0.018
4	0.055	2.1	0.07	0.01	0.011
3	0.070	2.1	0.04	0.01	0.011
2	0.010	2.1	0.02	0.01	0.004
1	0.000	0.0	0.00	0.00	0.000
Interim Standards for Non-Tier 2 Cars and LLDTs during Tier 2 Phase-In[d]					
5	0.156	4.2	0.60	0.06	0.018
4	0.090	4.2	0.30	0.06	0.018
3	0.055	2.1	0.30	0.04	0.011
2	0.090	4.2	0.07	0.01	0.018
1	0.000	0.0	0.00	0.00	0.000
Interim Standards for HLDTs during Tier 2 Phase-In[e]					
5	0.230	4.2	0.60	0.06	0.018
4	0.180	4.2	0.30	0.06	0.018
3	0.156	4.2	0.20	0.02	0.018
2	0.090	4.2	0.07	0.01	0.018
1	0.000	0.0	0.00	0.00	0.000

[a] Source: EPA (1999).

[b] The emission standards are in g/mi for a useful lifetime of 120,000 mi.

[c] For cars and LLDTs, the Tier 2 standards will be phased in beginning in MY 2004 and will be fully in effect in MY 2007. For HLDTs, the standards will be phased in beginning in MY 2008 and will be fully in effect in MY 2009. That is, beginning in MY 2009, cars, LLDTs, and HLDTs will be subject to the Tier 2 standards. The three vehicle groups together will be subject to a fleet average NO_x standard of 0.07 g/mi for each automaker.

For cars and LLDTs, the minimum Tier 2 vehicle sales percentages are 25% in MY 2004, 50% in MY 2005, 75% in MY 2006, and 100% in MY 2007 and beyond. For HLDTs, the minimum sales percentages are 50% in MY 2008 and 100% in MY 2009 and beyond.

[d] These standards will be applied to non-Tier 2 cars and LLDTs between MY 2004 and 2006. The non-Tier 2 vehicles together will be subject to a fleet average NO_x standard of 0.30 g/mi for each automaker. The maximum non-Tier 2 vehicle sales percentage will be 75% in MY 2004, 50% in MY 2005, 25% in MY 2006, and 0% in MY 2007 and beyond.

[e] These standards will be applied to HLDTs between MY 2004 and 2008. These vehicles together will be subject to a fleet average NO_x standard of 0.20 g/mi for each automaker. The minimum sales percentages of HLDTs subject to the interim standards are 25% in MY 2004, 50% in MY 2005, 75% in MY 2006, 100% in MY 2007, 50% (maximum) in MY 2008, and 0% in MY 2009 and beyond. The remainder of the new HLDT fleet between MY 2004 and 2007 will be subject to Tier 1 standards.

highway cycle. We ran Mobile 5b and Part 5 separately for the FUDS and the highway driving cycle, then averaged the results of the two cycles together with 55% mileage for the FUDS and 45% for the highway cycle. This “55/45 combined cycle” is used for the CAFE regulation. This cycle is more appropriate for estimating energy use and GHG emissions than for estimating criteria pollutant emissions. If the user’s main focus is on criteria pollutants, the FUDS and other urban driving cycles should be used.

Mobile 5b and Part 5 cannot be used to estimate emissions for the proposed Tier 2 vehicles, so we applied changes in emission standards from LEVs to Tier 2 to emissions of LEVs to estimate emissions of Tier 2 vehicles. As Tables 6.1 and 6.3 show, there are large reductions in emission standards between LEVs and Tier 2 vehicles. Table 6.5 lists these reductions, which are especially significant for NO_x and PM. Also note that reductions for HLDTs are much higher than those for cars and LLDTs. We used these reduction rates to estimate on-road emissions of Tier 2 vehicles from on-road emissions of LEVs. The footnotes in Table 6.4 describe our estimates.

Table 6.4 Fuel Economy and Emissions Rates of Baseline Gasoline and Diesel Vehicles[a]

Item	Gasoline Car	Gasoline LDT1[b]	Gasoline LDT2[b]	Diesel Car[c]	Diesel LDT1[c,d]	Diesel LDT2[c,d]
Near-Term Vehicles: LEVs Fueled with CG or CD[e]						
Economy (mpgeg)[f]	22.4	16.8	14.4	30.2	22.7	19.4
Emissions (g/mi)						
Exhaust VOC	0.080	0.091	0.629	0.080[g]	0.091[g]	0.540
Evaporative VOC	0.127	0.107	0.156	0.000	0.000	0.000
CO	5.517	8.247	16.846	1.070	1.139	1.208
NO_x	0.275	0.381	1.173	0.600[g]	0.600[g]	1.224
Exhaust PM_{10}	0.012	0.015	0.015	0.100	0.100	0.109
Brake and tire wear PM_{10}	0.021	0.021	0.021	0.021	0.021	0.021
CH_4[h]	0.084	0.090	0.090	0.011	0.014	0.017
N_2O[i]	0.028	0.033	0.040	0.016	0.024	0.032
Long-Term Vehicles: Tier 2 Vehicles Fueled with FRFG2 or RFD[j]						
Economy (mpgeg)[k]	24.0	18.0	15.4	36	27	23.1
Emissions (g/mi)						
Exhaust VOC	0.062	0.062	0.080	0.049	0.080	0.112
Evaporative VOC	0.063	0.063	0.078	0.000	0.000	0.000
CO	2.759	2.759	5.518	2.759	5.518	5.518
NO_x	0.036	0.036	0.135	0.063	0.135	0.180
Exhaust PM_{10}[l]	0.010	0.010	0.020	0.010	0.020	0.020
Brake and tire wear PM_{10}	0.021	0.021	0.021	0.021	0.021	0.021
CH_4[m]	0.065	0.065	0.091	0.011	0.014	0.017
N_2O[n]	0.028	0.033	0.040	0.016	0.024	0.032

[a] Fuel economy and emissions for baseline vehicles are for the 55/45 combined cycle.

[b] Mobile 5b defines light-duty gasoline truck 1 (LDGT1) as vehicles with a GVW of up to 6,000 lb and light-duty gasoline truck 2 (LDGT2) as vehicles with a GVW between 6,001 and 8,500 lb.

[c] For diesel vehicles, we assumed DI engines for both near-term and long vehicles.

[d] Mobile 5b does not estimate emissions for diesel LDT1. Instead, the model estimates emissions for LDTs, which include both LDT1 and LDT2. However, most diesel trucks are classified as LDT2. So we used Mobile 5b-estimated diesel LDT emissions as emissions for diesel LDT2. We estimated emissions of diesel LDT1 as the average emissions of diesel cars and diesel LDT2, except as noted.

[e] LEVs were assumed to be fueled with conventional gasoline or conventional diesel. PM emissions were estimated by using Part 5, and other emissions were estimated by using the NLEV version of Mobile 5b, except as noted.

[f] Fuel economies of LEVs are from EIA's 1998 Annual Energy Outlook (AEO98) projections for MY 2001 new vehicles (EIA 1997d) with supplemental data from EPA (Heavenrich and Hellman 1996). Near-term direct injection diesel vehicle fuel economy, presented in mpgeg, is estimated from GV fuel economy and the assumed 35% mpgeg improvement between GVs and DVs.

[g] The NLEV version of Mobile 5b does not estimate emissions of diesel cars and diesel LDT1 that are subject to NLEV standards. For exhaust VOC emissions, we assumed that emissions from diesel cars and LDT1 will be the same as those for GVs and LDT1, respectively. For exhaust NO_x emissions, we assumed that diesel cars and LDT1 will meet the TLEV NO_x standard (0.6 g/mi; see Table 6.1) under the NLEV program.

[h] CH_4 emissions were calculated as the difference between THC and NMHC, both of which were estimated by using Mobile 5b.

[i] N_2O emissions are from EPA (1998c).

Table 6.4 (Cont.)

[j] Emissions from Tier 2 GVs were estimated on the basis of emissions from gasoline-fueled LEVs and reductions in emission standards between gasoline-fueled LEVs and Tier 2 GVs (see Table 6.5), except as noted below.

Emissions from Tier 2 gasoline-fueled LDT1 were assumed to be the same as those for Tier 2 gasoline cars (except as noted), because both cars and LDT1 were assumed to be subject to Bin 3 of the Tier 2 proposal (see Table 6.5).

Emissions from Tier 2 gasoline-fueled LDT2 were estimated on the basis of emissions from Tier 2 gasoline cars and the difference in emission standards between Bin 3, to which Tier 2 gasoline cars are subject and Bin 6, to which LDT2 are subject (see Table 6.5), except as noted.

Emissions from Tier 2 diesel cars, diesel-fueled LDT1, and diesel-fueled LDT2 were estimated using a method similar to that used to calculate emissions from Tier 2 gasoline-fueled LDT2.

[k] We projected fuel economy of MY 2010 vehicles on the basis of MY 2000 vehicle fuel economy and mpg improvement between MY 2001 and 2010 for passenger cars, as predicted in EIA's AEO98 (7% improvement over the period) (EIA 1997d).

[l] PM emissions from Tier 2 vehicles were assumed to be at the applicable PM standard levels.

[m] CH_4 emissions from Tier 2 GVs were calculated on the basis of the differences in exhaust VOC emissions. CH_4 emissions from Tier 2 diesel vehicles were assumed to be the same as CH_4 emissions from diesel-fueled LEVs, because diesel-fueled LEVs already have low CH_4 emissions.

[n] N_2O emissions from Tier 2 vehicles were assumed to be the same as emissions from LEV vehicles, because no N_2O emission data are available for Tier 2 vehicles, and because only small improvements in N_2O emissions have been shown with further NO_x emission control (see EPA 1998c).

Table 6.5 Reductions in Emissions Standards for Tier 2 Vehicles Relative to LEVs[a]

Vehicle	Applicable Tier 2 Bin Assumed[b]	Exhaust VOC	Evaporative VOC	CO	NO_x	PM_{10}[c]
Gasoline cars	3	22%	50%	50%	87%	NA[d]
Gasoline LLDTs	3	36%	50%	57%	90%	NA
Gasoline HLDTs	6	82%	50%	39%	88%	NA
Diesel cars	4	39%	NA	50%	77%	88%
Diesel LLDTs	6	18%	NA	13%	63%	78%
Diesel HLDTs	7	75%	NA	39%	84%	82%

[a] Reductions in emission standards were calculated from standards presented in Tables 6.1 and 6.3. For LLDTs, the average of standards for LDT1 and LDT2 in Table 6.1 was used. For HLDTs, the average of standards for LDT3 and LDT4 in Table 6.1 was used.

[b] Under the Tier 2 proposal, an automaker can certify its vehicles to any of the seven bins, as long as its fleet average NO_x standard is below 0.07 g/mi. Consequently, many combinations of vehicle sales among the seven bins exist for automakers to select for meeting the average NO_x standard. The applicable Tier 2 bin that we selected for each vehicle group, one of the many possible combinations, represents our assessment of technological potentials.

[c] PM emission standards in Table 6.1 are applied to DVs only. For LEVs, PM emissions from GVs are not constrained by PM standards. Reductions for PM emission standards for GVs were therefore not calculated here.

[d] NA = not applicable.

Relative to GVs, DVs have inherently higher NO_x and PM emissions. The Tier 2 bins we have chosen for DVs are based on the assumption that automakers will certify DVs at higher emission levels for NO_x and PM. On the basis of this assumption, NO_x and PM emissions from DVs are about twice as high as those from GVs (except PM emissions from diesel cars).

Table 6.4 presents estimated fuel economy and vehicular emissions of baseline GVs and DVs for passenger cars, LDT1, and LDT2. As stated above, emissions of near-term baseline vehicles were estimated by using the Mobile 5 NLEV version and assuming that baseline passenger cars and LLDTs will meet NLEV standards and that HLDTs will meet Tier 1 standards. Because most of the United States will still use CG and because no RFD will be introduced in the near term, we assumed use of CG in baseline GVs and CD in baseline DVs.

The long-term baseline vehicles were assumed to meet the newly proposed Tier 2 standards. To help meet the standards, Tier 2 vehicles were assumed to be fueled with FRFG2 and RFD. Tier 2 vehicle emissions were estimated on the basis of LEV emissions and emission standard reductions between LEVs and Tier 2 vehicles (see Table 6.5).

In particular, for Tier 2 gasoline-fueled cars, emissions of exhaust VOCs, evaporative VOCs, CO, and NO_x were estimated from LEV emissions and emission standard reductions from NLEVs to Tier 2 vehicles (as presented in Table 6.5). Exhaust PM emissions for Tier 2 gasoline-fueled cars were assumed to be at the PM standard for Tier 2 Bin 3. Exhaust CH_4 emissions were estimated from LEV CH_4 emissions and exhaust VOC emission reductions between LEVs and Tier 2 Bin 3. There are no data on N_2O emissions from Tier 2 vehicles. Because NO_x emissions are significantly reduced for Tier 2 vehicles, we expect that N_2O emissions could increase, on the basis of nitrogen mass balance calculations. On the other hand, emission control technologies and clean gasoline and diesel will help reduce N_2O emissions. We assumed the same N_2O emissions for LEVs and Tier 2 vehicles.

We assumed that Tier 2 gasoline-fueled LDT1 (LLDTs, as defined in the Tier 2 proposal) would be subject to Tier 2 Bin 3, the same bin to which Tier 2 gasoline cars are subject. Emissions of the former were assumed to be the same as those of the latter, except for N_2O, for which emissions from Tier 2 LDT1 were assumed to be the same as those from LEV LDT1.

We estimated emissions from Tier 2 gasoline-fueled LDT2 on the basis of Tier 2 gasoline-fueled car emissions and emission standard differences between Tier 2 Bin 3 (to which gasoline-fueled cars are subject) and Bin 6 (to which gasoline-fueled LDT2 are subject), except as noted. VOC evaporative emissions from Tier 2 gasoline-fueled LDT2 are estimated on the basis of LEV gasoline LDT2 and emission standard differences between LEV LDT2 and Tier 2 LDT2.

Emissions from Tier 2 diesel-fueled cars, diesel-fueled LDT1, and diesel-fueled LDT2 were calculated using a method similar to that used to calculate emissions from Tier 2 gasoline-fueled LDT2, except as noted. Tier 2 CH_4 emissions from DVs were assumed to be the same as those for LEV diesel vehicles, because DVs in general have very low CH_4 emissions.

PM emissions for all Tier 2 vehicles were assumed to be at the applicable Tier 2 PM standard levels.

Table 6.4 shows the results of our emissions estimates for baseline GVs and DVs. For the near-term baseline vehicles, there are large increases in emissions from LDT1 to LDT2. This is because, while LDT1 will be subject to the NLEV standards, LDT2 will continue to be subject to the Tier 1 standards (see Table 6.1; the NLEV program does not cover Mobile 5-defined LDT2). From the near-term to the long-term baseline vehicles, substantial reductions in emissions result from Tier 2 standards. If Tier 2 standards are implemented, baseline vehicle emissions will be significantly reduced.

6.3 Contribution of Each Stage to Fuel-Cycle Energy Use and Emissions

The 21 figures that follow present shares of fuel-cycle energy use and emissions by fuel-cycle stage for each combination of fuels and vehicles. These figures, created automatically in GREET 1.5, are meant to help readers readily grasp the key stage for a given combination in terms of fuel-cycle results. For this purpose, fuel-cycle activities are grouped into three stages: feedstock-related, fuel-related, and vehicle operation stages. The feedstock-related stage includes feedstock recovery, transportation, and storage. The fuel-related stage includes fuel production, transportation, storage, and distribution. The vehicle operation stage includes vehicle refueling and operations.

The 21 figures described below are based on calculations for passenger cars. Among the three light-duty vehicle types (passenger cars, LDT1s, and LDT2s), stage contributions to total fuel-cycle energy use and emissions are similar.

6.3.1 Near-Term Technologies

Figure 6.1 shows stage contributions for conventional GVs. Three types of gasoline (CG, FRFG2, and CARFG2) are included in GREET, and the two RFG types can be produced with MTBE, ETBE, and ethanol. Stage contributions are similar for these options. The figure here presents the results for CG. As the figure shows, vehicle operations contribute the most to total fuel-cycle results, except for emissions of SO_x and CH_4. Petroleum refining accounts for the largest amount of SO_x emissions. Crude recovery in oil fields produces a large amount of CH_4 emissions.

Figure 6.2 shows stage contributions for DVs. Overall, the pattern for DVs is similar to that for GVs, except for PM_{10}, NO_x, and VOCs, for which DV operation accounts for most of the total emissions.

Figure 6.3 shows the results for dedicated CNG vehicles. As one might expect, vehicle operation involves no petroleum use and a very small amount of SO_x emissions. NG compression, which consumes a considerable amount of electricity and NG, produces most of the fuel-cycle SO_x emissions. NG recovery and processing produce a large amount of CH_4 emissions. For NO_x emissions, feedstock- and fuel-related activities account for more than half of the total fuel-cycle emissions. Upstream VOC emissions account for a large share of total

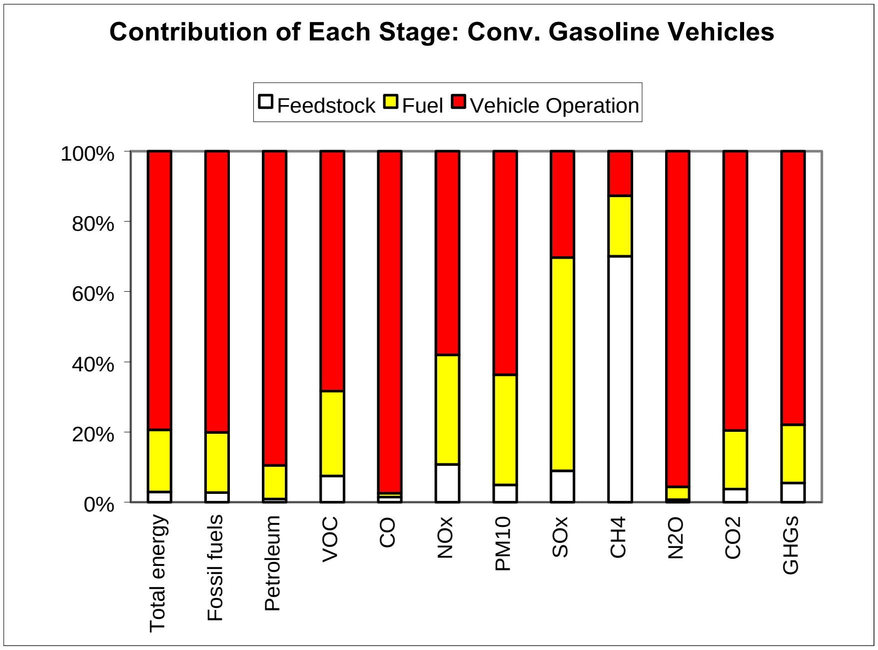

Figure 6.1 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Converted Gasoline Vehicles

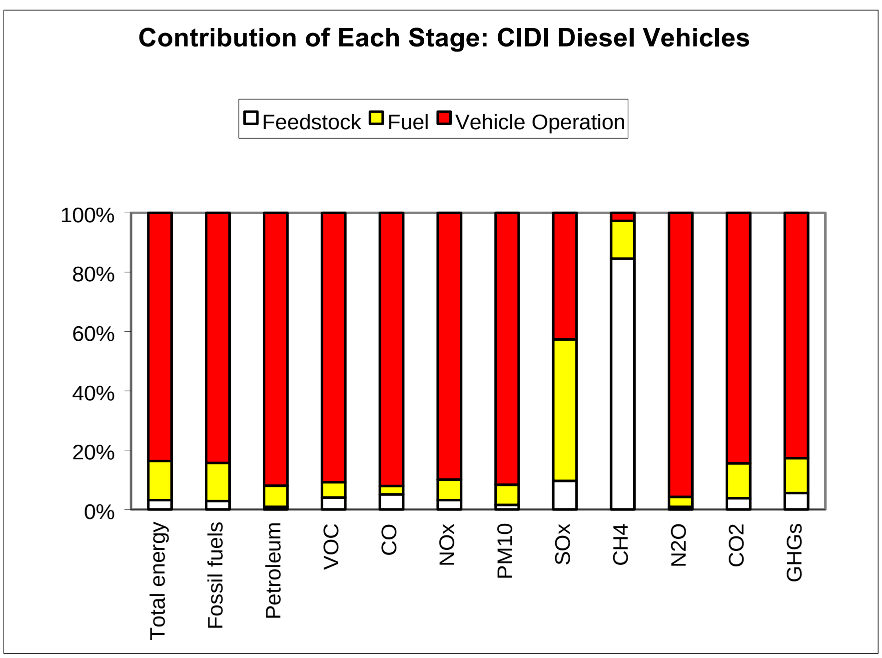

Figure 6.2 Shares of Fuel-Cycle Energy Use and Emissions by Stage: CIDI Diesel Vehicles

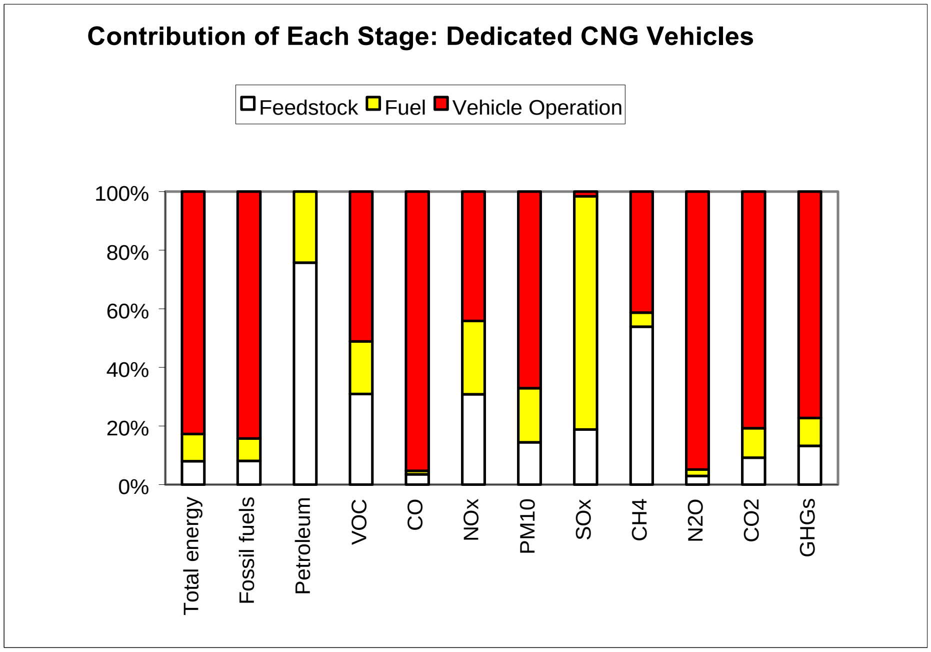

Figure 6.3 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Dedicated CNG Vehicles

VOC emissions. A similar pattern of stage contributions exists for bi-fuel CNG vehicles burning NG.

Figure 6.4 presents results from methanol FFVs fueled with M85. Upstream NG recovery and processing produce most of the total fuel-cycle CH_4 emissions. Methanol production at methanol plants accounts for the largest share of the total SO_x emissions. Methanol production accounts for a noticeable portion of the total energy use, fossil fuel use, and emissions of NO_x, PM_{10}, VOC, CO_2, and GHGs.

Figure 6.5 presents shares of stages for LPG vehicles. In GREET 1.5, production of LPG is simulated with two pathways: crude and NG to LPG. On average, the United States produces 60% of its LPG from NG and 40% from crude. The results in Figure 6.5 are for this combination of production. As the figure shows, upstream activities contribute to all the SO_x emissions. Crude recovery and NG recovery and processing contribute most to the total CH_4 emissions.

Figure 6.6 shows results for ethanol FFVs fueled with E85, where ethanol is produced from corn. Ethanol can be produced in either dry or wet milling plants. The results in this figure are for a combination of both, with two-thirds of the ethanol produced from wet milling plants and one-third from dry milling plants. Except for total energy use, petroleum use, and emissions of CO and VOC, upstream activities account for most of the total fossil energy use and

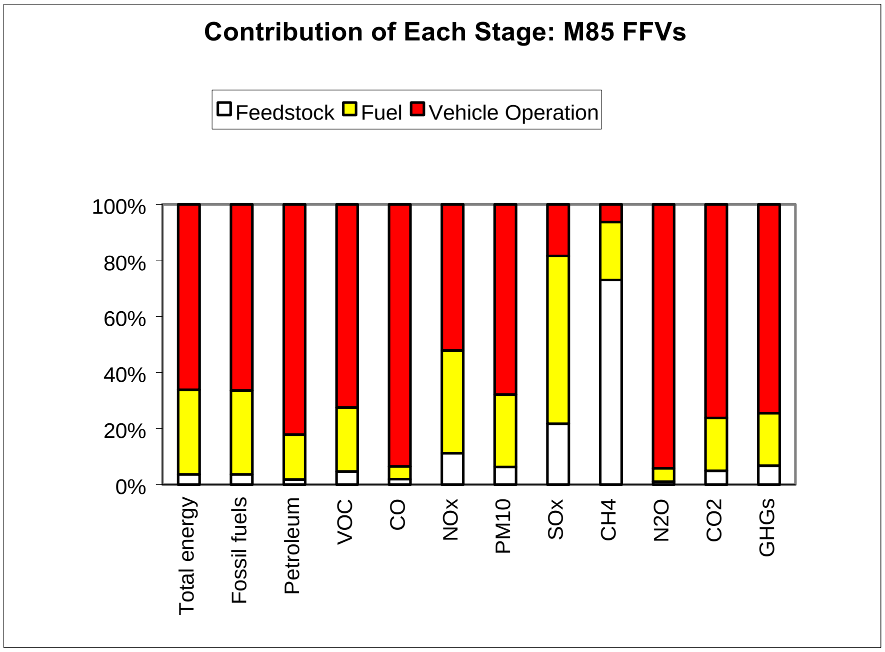

Figure 6.4 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Methanol FFVs Fueled with M85

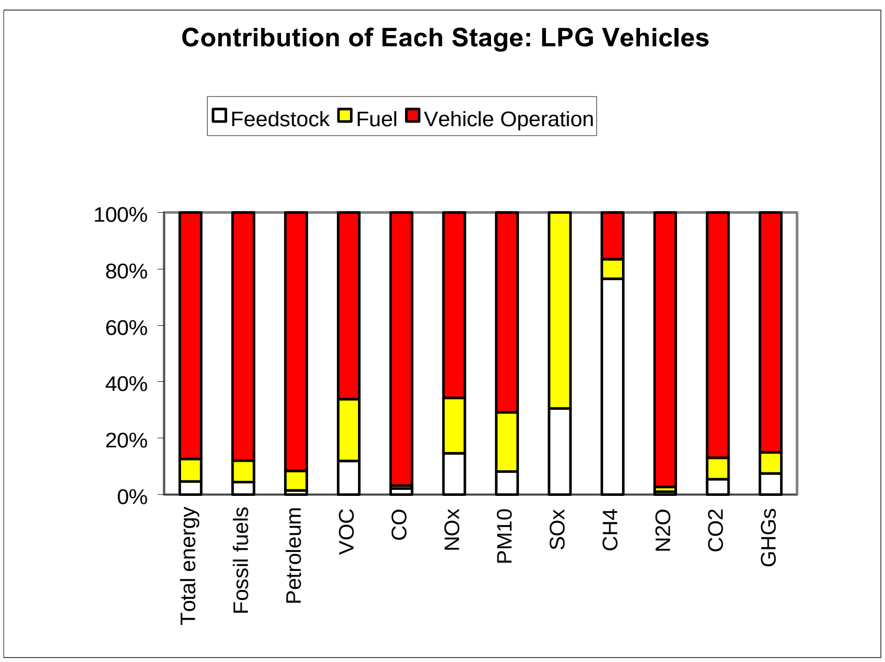

Figure 6.5 Shares of Fuel-Cycle Energy Use and Emissions by Stage: LPG Vehicles

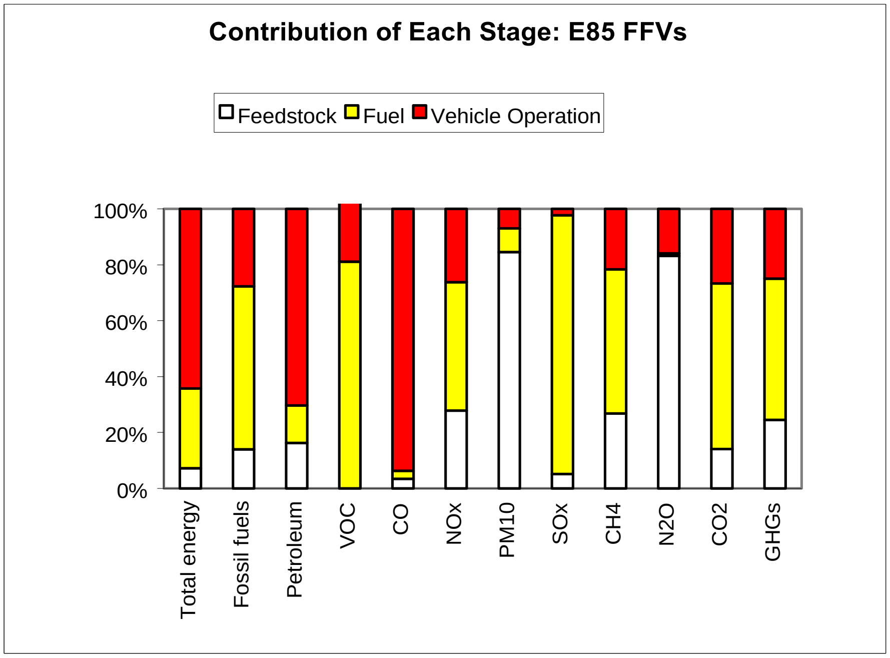

Figure 6.6 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Ethanol FFVs Fueled with E85 Produced from Corn

emissions. This indicates that assumptions about upstream activities have large effects on fuel-cycle results for ethanol FFVs. Because of nitrification and denitrification of nitrogen fertilizer, corn farming contributes the most to the total N_2O emissions. Ethanol production at corn ethanol plants consumes a large amount of fossil fuels and produces large amounts of PM_{10}, VOC, NO_x, SO_x, CH_4, CO_2, and GHG emissions. PM emissions from corn farming (mainly tillage emissions and farming tractor emissions) account for the largest share of fuel-cycle PM emissions.

Figure 6.7 shows the results for EVs. The results are for the U.S. generation mix, under which 54% of electricity is generated from coal. Energy use and emissions occur during upstream stages, except for PM_{10}, where EV brake- and tire-wear emissions are noticeable. Furthermore, among the upstream activities, energy use and emissions occur mostly during electricity generation. Methane emissions occur primarily during coal mining and NG recovery and processing. Also, a large amount of VOC and CO emissions and petroleum use occur during coal mining and NG recovery and processing.

Figure 6.8 presents the results for grid-connected HEVs, where ICEs are fueled with California RFG2. In our study, we assume that for grid-connected HEVs, grid electricity powers 30% of their VMT, with on-board ICEs providing energy for the remaining 70%. Except for petroleum use and emissions of VOC, CO and N_2O, energy use and emissions occur more during upstream stages (especially during fuel production stages) than during the vehicle operation stage.

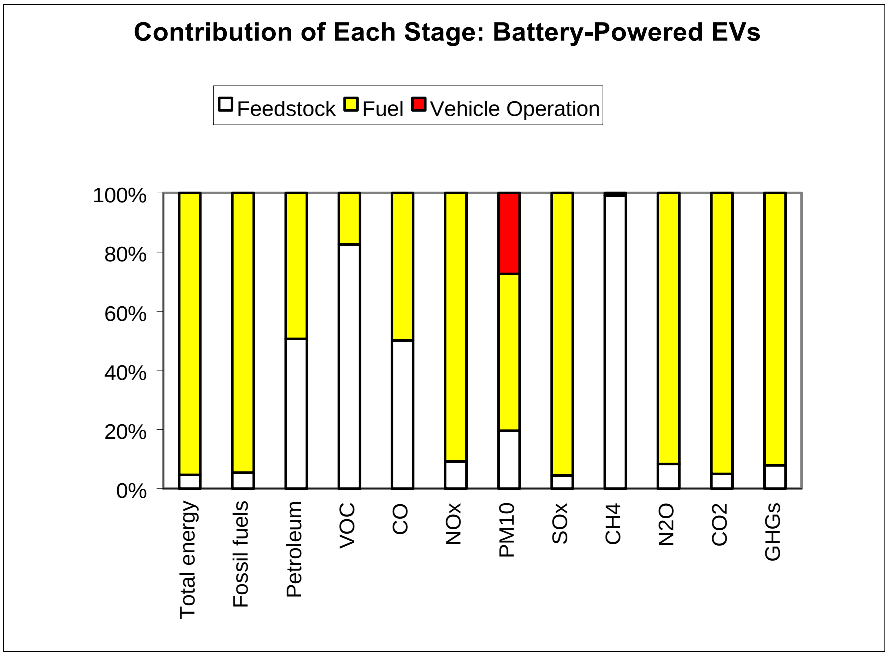

Figure 6.7 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Battery-Powered EVs

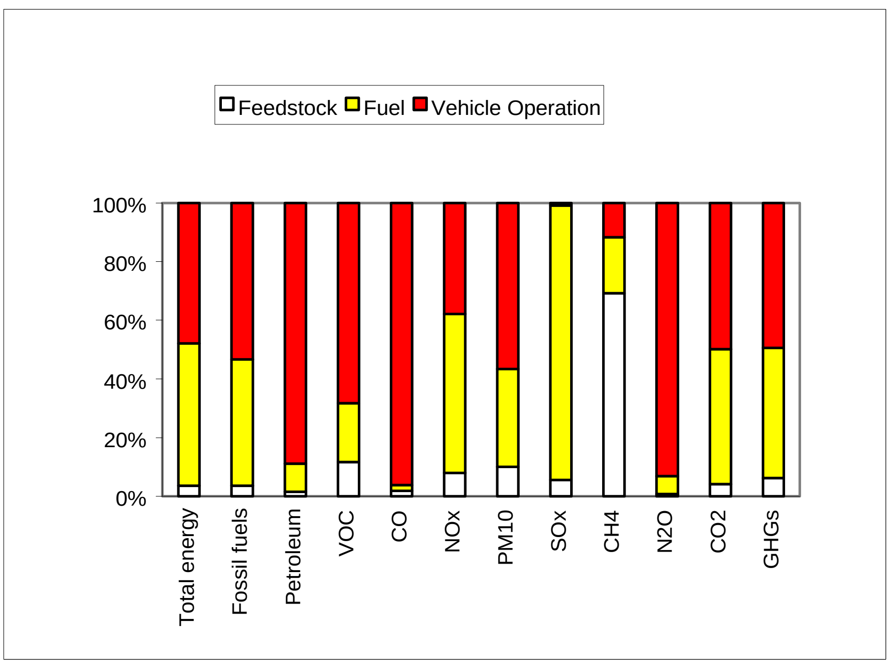

Figure 6.8 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Grid-Connected HEVs, ICEs Fueled with RFG

Figures 6.9 and 6.10 present stage contributions for grid-independent HEVs fueled with RFG and CD. Petroleum refining accounts for a large portion of the total SO_x emissions. Petroleum recovery accounts for a large portion of the total CH_4 emissions. Otherwise, vehicle operations contribute overwhelmingly to total energy use and emissions.

In the above ten figures, stage contributions for the five criteria pollutants are for total emissions. Stage contributions for urban emissions of the five pollutants are different from those for total emissions. Even though upstream contributions to total emissions are large for a given vehicle technology, the upstream contributions could be very small because most upstream activities (and upstream emissions) occur outside of an urban area.

6.3.2 Long-Term Technologies

This section presents the results for those long-term technology options that are very different from the near-term options. Technology options similar to the near-term options are presented in Section 6.3.1. In particular, stage contributions for ICE vehicles fueled with CNG and LNG are similar to those for near-term dedicated CNGVs (Figure 6.3), although as vehicle fuel economy increases among vehicle technologies, upstream contributions become smaller. Stage contributions for ICE vehicles fueled with M90 are similar to those for the near-term M85 FFVs (Figure 6.4). Stage contributions for ICE vehicles fueled with E90 are similar to those for the near-term E85 FFVs (Figure 6.6).

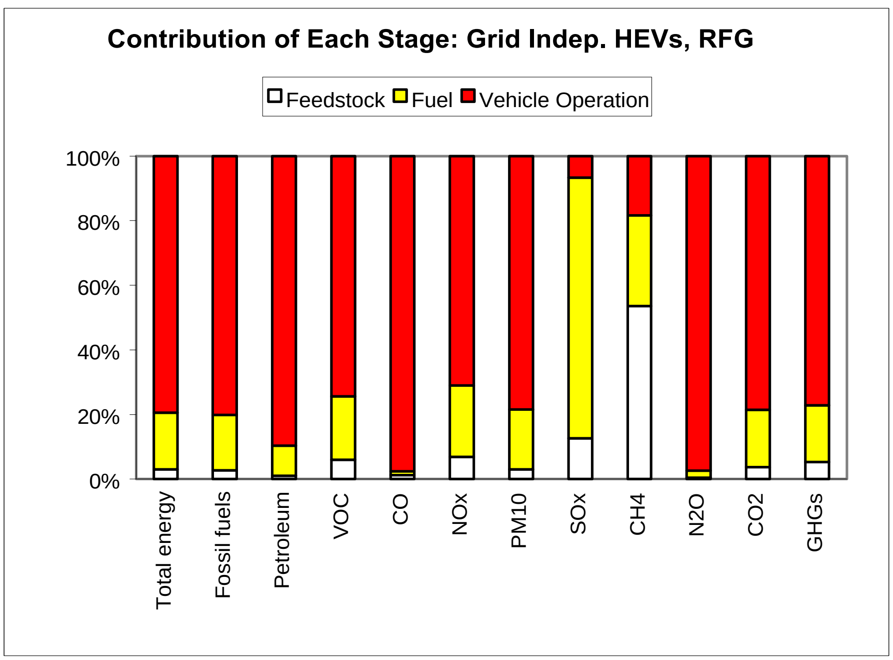

Figure 6.9 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Grid-Independent HEVs, ICEs Fueled with RFG

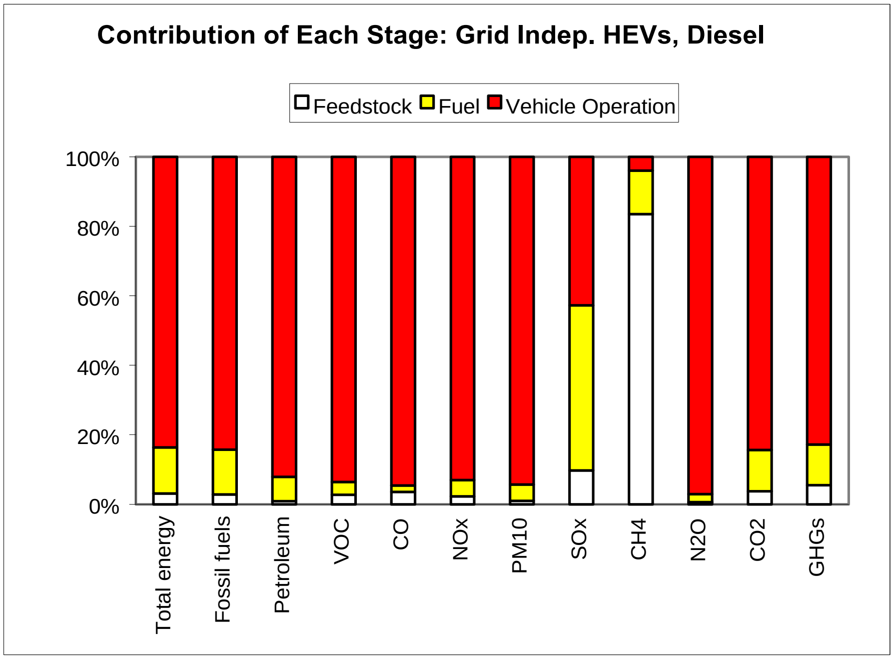

Figure 6.10 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Grid-Independent HEVs, ICEs Fueled with CD

Figures 6.11 and 6.12 show the results for CIDI vehicles fueled with FT50 and BD20. Because diesel is used in blending with both FTD (50%) and biodiesel (80%), the results for the two blends are similar. Except for emissions of SO_x, CH_4, and NO_x vehicle operations contribute mostly to the total energy use and emissions. For SO_x emissions, production of fuels (diesel, FTD, and biodiesel) contributes significantly to the total fuel-cycle emissions. Petroleum recovery and NG recovery and processing (for FTD) produce the greater portion of the total CH_4 emissions. Fuel production contributes to a large share of total NO_x emissions. With BD20, a large amount of VOC emissions are generated during biodiesel production (mainly because of n-hexane loss during soy oil extraction).

Figure 6.13 shows that for CIDI vehicles fueled with DME, upstream activities account for all the petroleum use and SO_x emissions as well as a greater portion of total CH_4 emissions. Furthermore, petroleum use emissions are primarily from DME production; CH_4 emissions are primarily from NG recovery and processing, and SO_x emissions are from both NG recovery and DME production. For other energy use and emissions, vehicle operations account for a large portion. Note that upstream activities contribute a significant portion to total energy use, fossil energy use, and emissions of NO_x, VOC, CO_2, and GHGs.

Figure 6.14 shows the results for grid-connected HEVs, where on-board ICEs are fueled with CNG. Except for CO emissions, energy use and emissions occur primarily during upstream stages. Furthermore, feedstock production accounts for the greater part of upstream

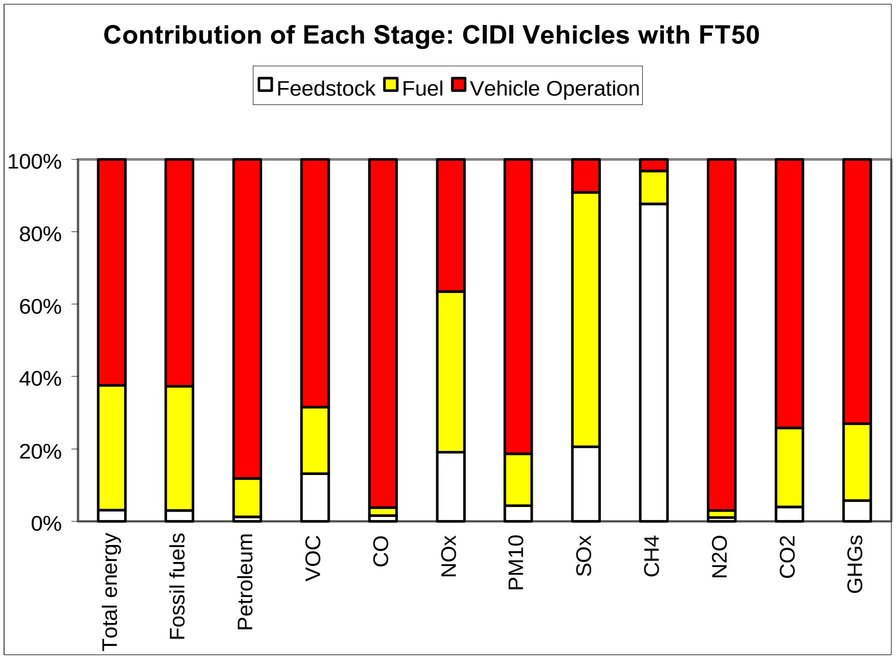

Figure 6.11 Shares of Fuel-Cycle Energy Use and Emissions by Stage: CIDI Vehicles Fueled with FT50

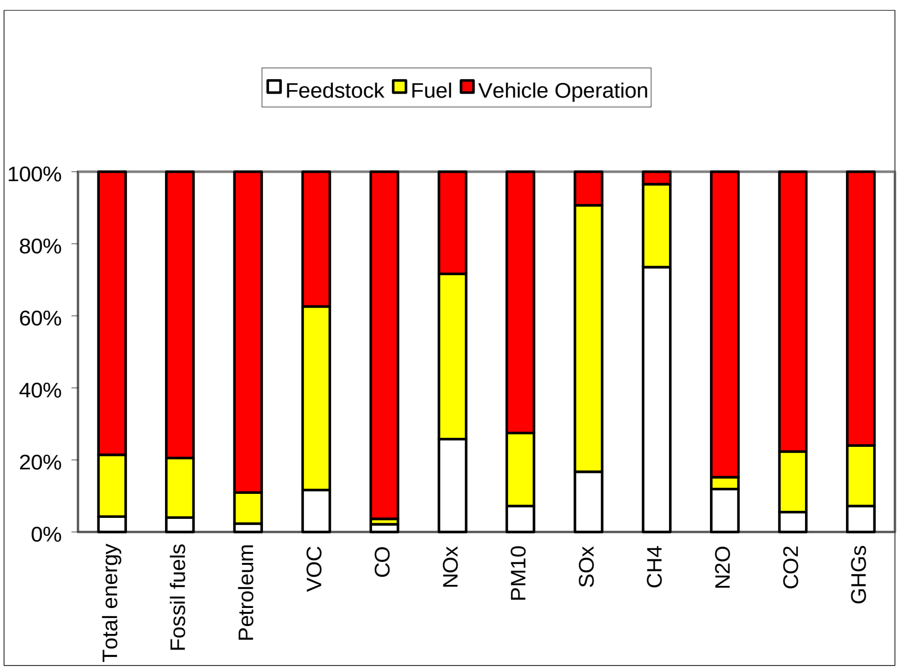

Figure 6.12 Shares of Fuel-Cycle Energy Use and Emissions by Stage: CIDI Vehicles Fueled with BD20

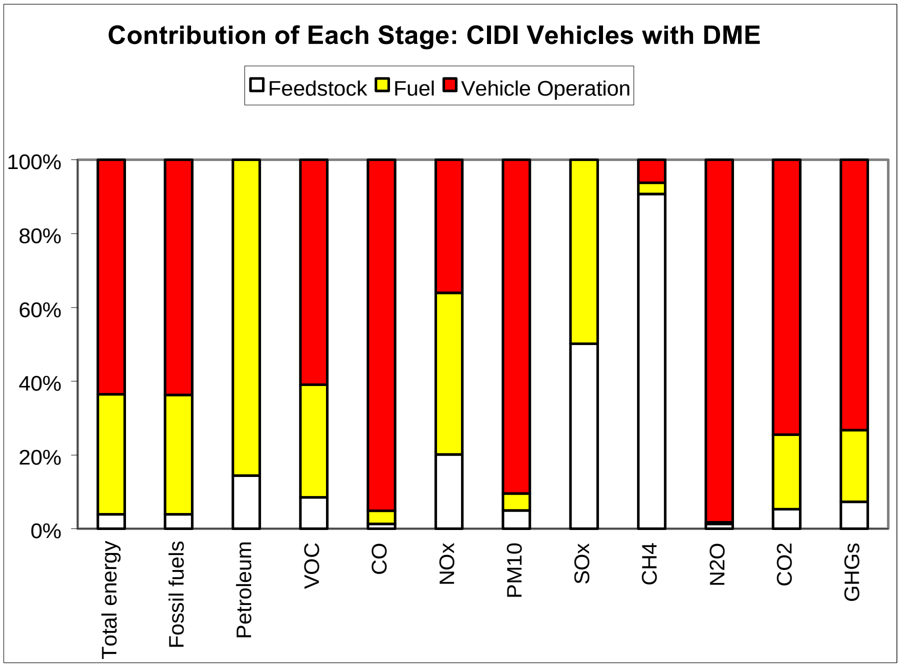

Figure 6.13 Shares of Fuel-Cycle Energy Use and Emissions by Stage: CIDI Vehicles Fueled with DME

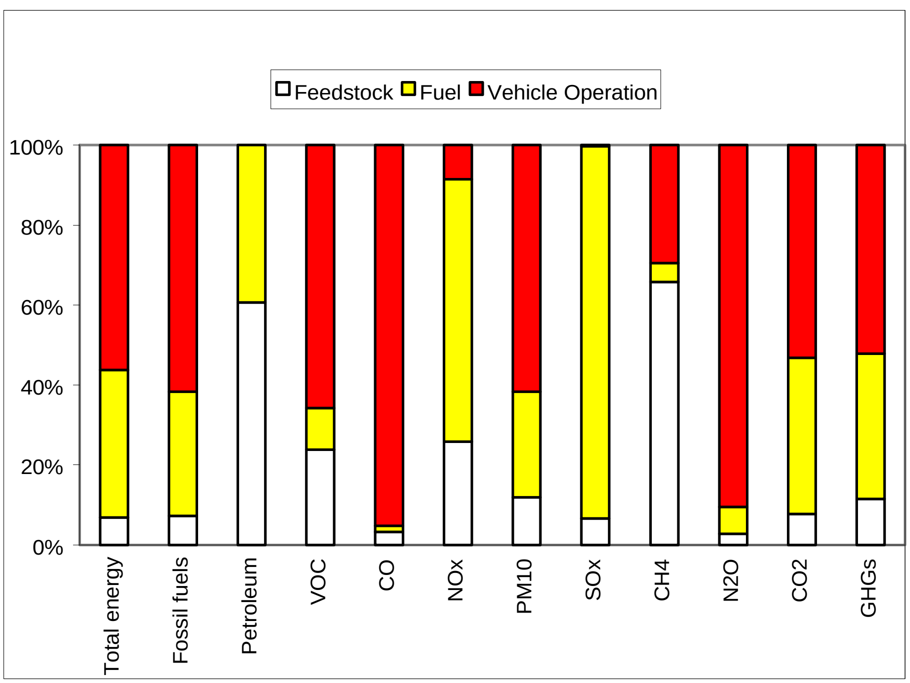

Figure 6.14 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Grid-Connected HEVs, ICEs Fueled with CNG

petroleum use and CH_4 emissions. For other energy use and emissions, fuel production (i.e., electricity generation and NG compression) contributes the most.

Figure 6.15 presents stage contributions for grid-independent HEVs fueled with NG. The general pattern for the HEVs is similar to that for the grid-connected HEV with ICE operation fueled with NG. With the former, however, the contribution from vehicle operations is increased.

Figure 6.16 presents the results for FCVs fueled with gaseous H_2 produced from NG. Except for total energy, fossil energy, and PM_{10} emissions, energy use and emissions occur during upstream stages. Vehicular PM_{10} emissions are from tire and brake wear. Most upstream petroleum use and emissions occur during H_2 production. The exception is CH_4 and petroleum use, where NG recovery and processing account for a large portion of the total CH_4 emissions and petroleum use.

As for FCVs fueled with H_2 produced from solar energy, Figure 6.17 shows that energy use and emissions are from transportation and compression of gaseous hydrogen, except for total energy use and PM_{10} emissions, where vehicle operations also contribute. As Figures 6.16 and 6.17 show, FCVs fueled by H_2, like EVs (Figure 6.7), generate no tailpipe emissions.

Figure 6.18 presents the results for FCVs fueled with NG-based methanol. NG recovery and processing accounts for the greater portion of the total CH_4 emissions. Methanol production at methanol plants consumes a large amount of petroleum and produces a large amount of NO_x and SO_x emissions. Vehicle operations contribute significantly to the total energy use, fossil energy use, and emissions of VOCs, CO, PM_{10} (from brake and tire wear), N_2O, CO_2, and GHGs.

Figure 6.19 shows that for FCVs fueled with RFG, crude recovery accounts for the greater portion of the total CH_4 emissions. Petroleum refining accounts for a large amount of the total emissions for NO_x and SO_x. Vehicle operations contribute most to the total energy use, fossil energy use, petroleum use, and emissions of VOCs, CO, PM_{10}, N_2O, CO_2, and GHGs.

Figure 6.20 shows stage contributions for FCVs fueled with ethanol produced from corn. Except for total energy use and CO emissions, upstream stages contribute most of the energy use and emissions. Between corn farming and ethanol production, ethanol production contributes mainly to fossil energy use and emissions of VOCs, NO_x, SO_x, CH_4, CO_2, and GHGs. Corn farming contributes mainly to petroleum use and emissions of PM_{10} and N_2O.

Figure 6.21 presents the results for CNG-fueled FCVs. NG recovery, processing, and transmission contribute significantly to petroleum use and emissions of NO_x and CH_4. NG compression produces a large amount of emissions of NO_x and SO_x. Vehicle operations consume the greater portion of the total energy and fossil energy and produce most of the CO, N_2O, PM_{10}, CO_2, and GHG emissions.

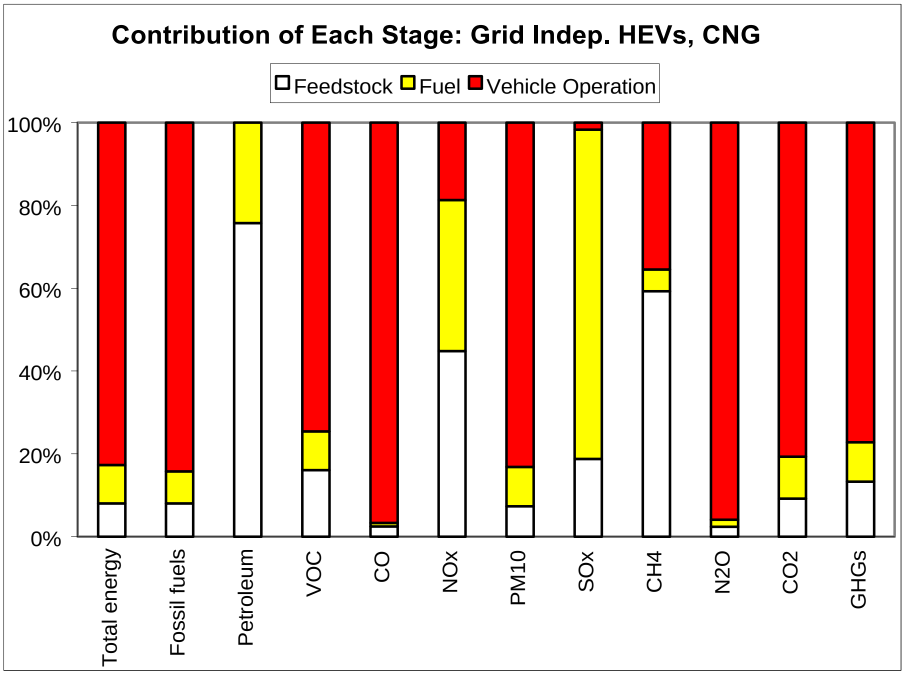

Figure 6.15 Shares of Fuel-Cycle Energy Use and Emissions by Stage: Grid-Independent HEVs, ICEs Fueled with NG

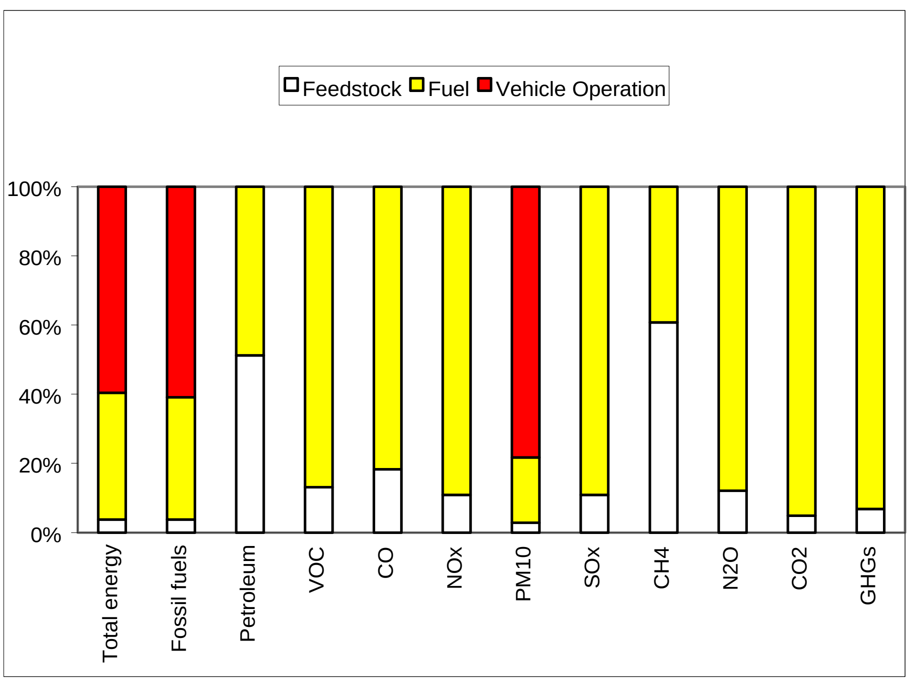

Figure 6.16 Shares of Fuel-Cycle Energy Use and Emissions by Stage: FCVs Fueled with H_2 Produced from NG

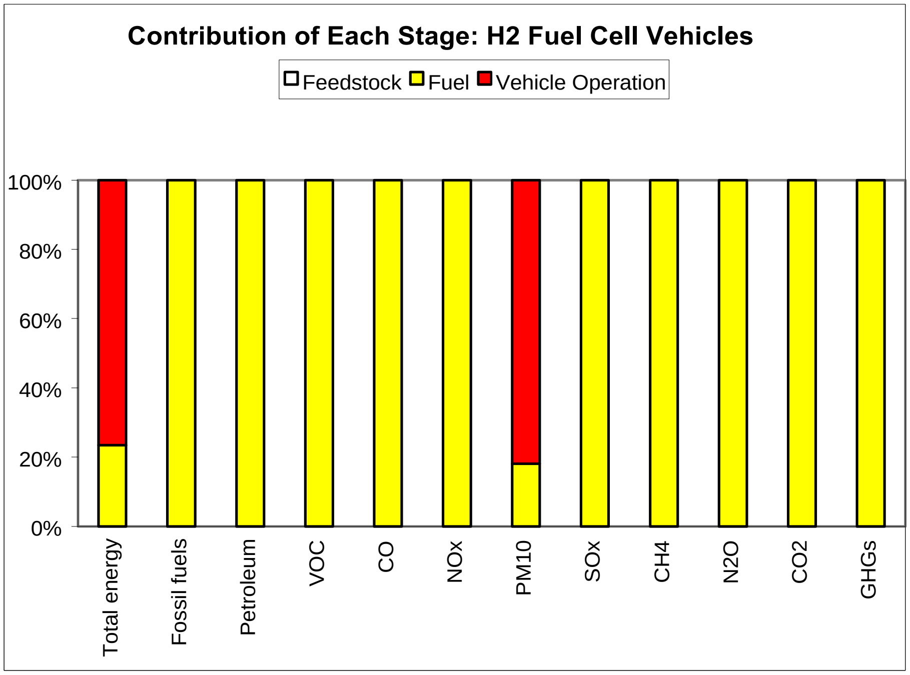

Figure 6.17 Shares of Fuel-Cycle Energy Use and Emissions by Stage: FCVs Fueled with H_2 from Solar Energy

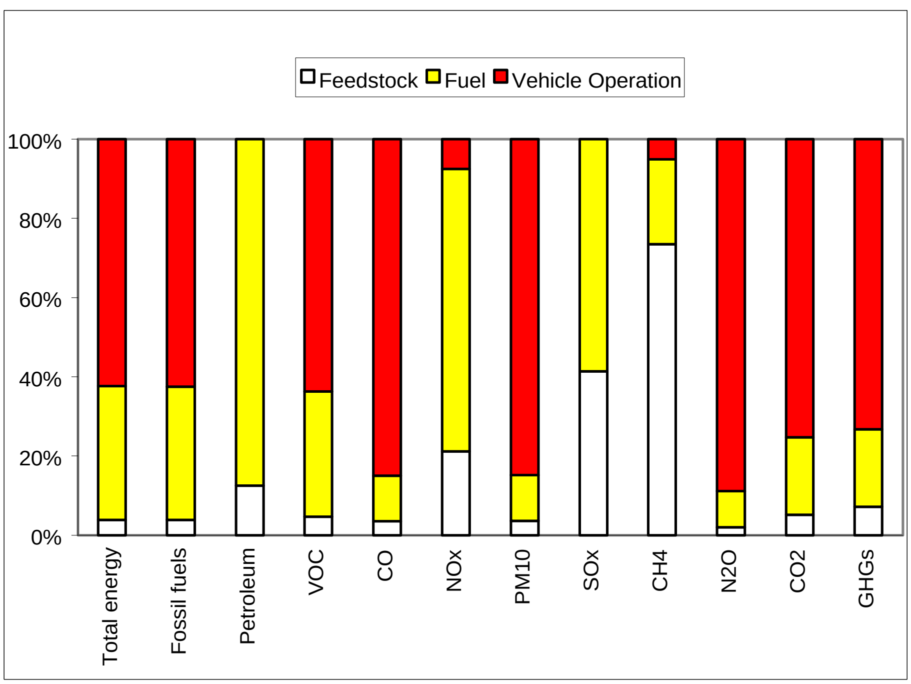

Figure 6.18 Shares of Fuel-Cycle Energy Use and Emissions by Stage: FCVs Fueled with Methanol

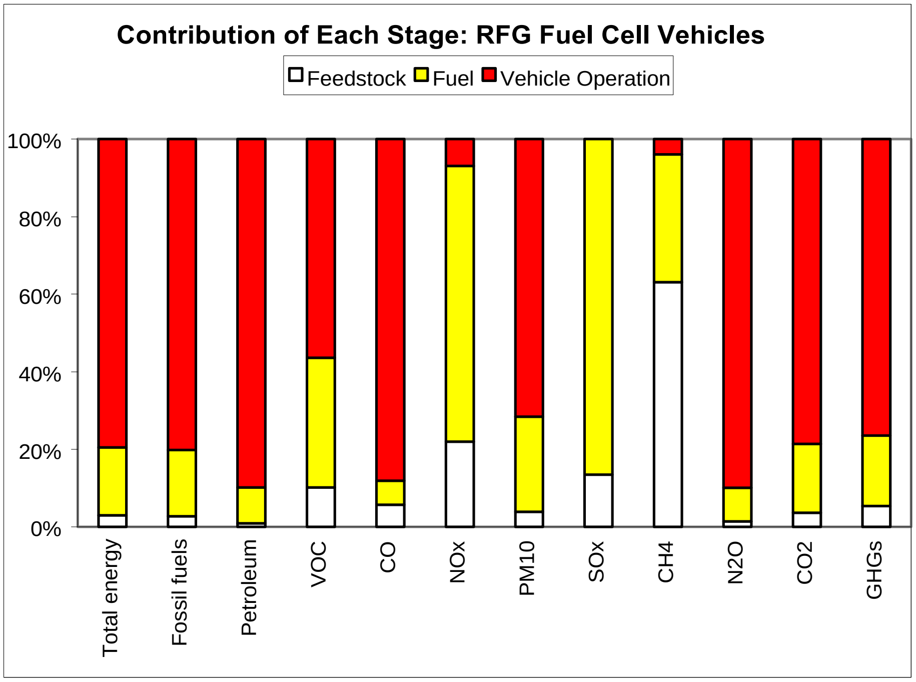

Figure 6.19 Shares of Fuel-Cycle Energy Use and Emissions by Stage: FCVs Fueled with RFG

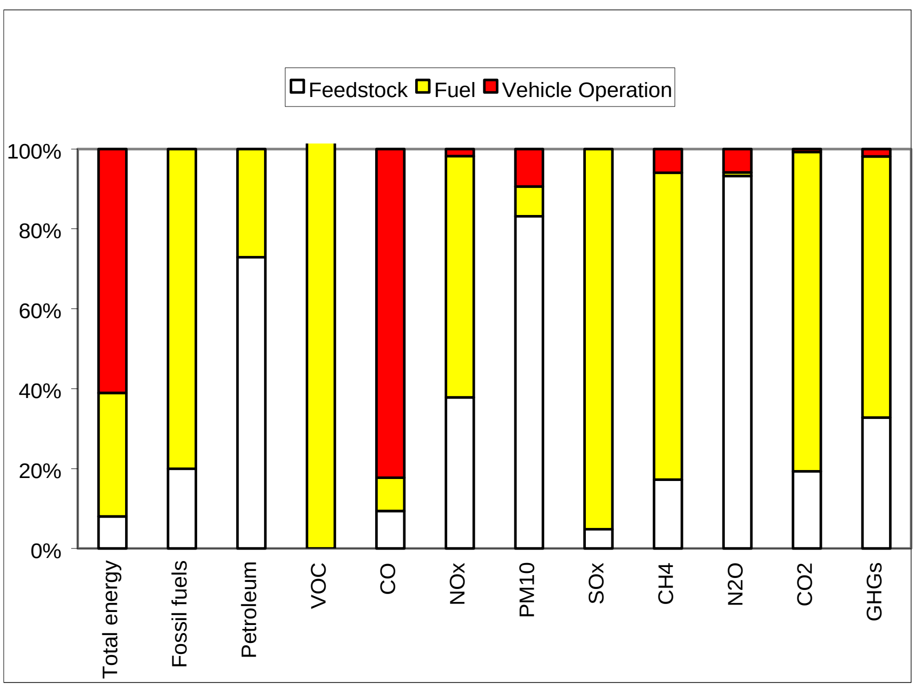

Figure 6.20 Shares of Fuel-Cycle Energy Use and Emissions by Stage: FCVs Fueled with Ethanol