Assessing the Total Fuel Cycle Energy and Environmental Impacts of Alternative Transportation Fuels

Development and Use of NY-GREET

Final Report 07-09
September 2007

New York State
Energy Research and
Development Authority

NYSERDA

NYSERDA

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Final Report

Prepared for the

New York State Energy Research and Development Authority

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ABSTRACT

This report presents the *New York Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation* (NY-GREET) model. *NY-GREET* can be used to assess the total fuel-cycle (i.e., "well-to-wheels") emissions and energy use characteristics for alternative fuel vehicles (AFVs) operating in New York State. Alternative fuel types evaluated in *NY-GREET* include hydrogen, ethanol, biodiesel, natural gas, and electricity, among others. In this report we introduce the model and demonstrate its use through the presentation of 12 scenarios that together provide a comprehensive picture of the energy and environmental attributes of AFVs operating in New York.

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

This report presents the *New York Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation* (NY-GREET) model. *NY-GREET* is based on the national GREET model used by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and others to assess the total fuel-cycle emissions and energy use for alternative fuel vehicles (AFVs), including hydrogen fuel cell vehicles and hybrid electric vehicles. Such analyses are also called "well-to-wheels" (W2W) analyses.

NY-GREET is a user-friendly model that will provide New York decision makers with a tool to assess the full energy and environmental impacts of various alternative fuel pathways for passenger vehicles. *NY-GREET*, which runs on a MS Excel platform, is able to quantify total fuel cycle energy use (petroleum and fossil fuel) and emissions (greenhouse gas and criteria pollutants) for a number of alternative fuels. *NY-GREET* operates much like the national GREET model, but uses data specific to New York to simulate AFV operation in New York State.

The uses of this model are many and varied. First, *NY-GREET* provides New York with its first W2W analysis tool for hydrogen, natural gas, propane, ethanol, methanol, hybrid electric, and pure electric vehicles. Second, the national GREET model has recently been integrated into the EPA Motor Vehicle Emissions Simulator (MOVES) model. MOVES is the successor of the MOBILE model used by states for regulatory compliance modeling. Therefore, *NY-GREET* provides a significant benefit for New York as the state begins to use MOVES for its regulatory modeling work. Finally, *NY-GREET* is a valuable tool as the Regional Greenhouse Gas Initiative (RGGI) program moves forward. *NY-GREET* allows for a comprehensive analysis of GHG emissions from mobile sources, including emissions emanating from the upstream processes used to make and deliver alternative fuels.

In this report we introduce the model and demonstrate its use through the presentation of 12 scenarios that together provide a comprehensive picture of the energy and environmental attributes of AFVs operating in New York.

1. INTRODUCTION

1.1. DESCRIPTION OF PROJECT

This project developed the *New York Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation* (NY-GREET) model. *NY-GREET* is based on the national GREET model used by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and others to assess total fuel-cycle emissions and energy use for alternative fuel vehicles, including hydrogen fuel cell vehicles and hybrid electric vehicles. Total fuel cycle analyses consider not just the energy use and emissions at the tailpipe, but also energy use and emissions along the entire fuel pathway—from feedstock extraction --> transportation --> fuel processing --> distribution --> end use. Such analyses are also called "well-to-wheels" (W2W) analyses.[1]

The main deliverable for this project is a user-friendly model that provides New York decision makers with a tool to assess the full energy and environmental impacts of various alternative fuel pathways for transportation. *NY-GREET*, which runs on a Microsoft Excel platform, is able to quantify total fuel-cycle energy use (petroleum, fossil fuel) and emissions (greenhouse gas and criteria pollutants) for various alternative fuels. *NY-GREET* operates much like the national GREET model, but uses data specific to New York so that we can evaluate the energy and environmental attributes of AFVs operating in the state. Like the national GREET model, *NY-GREET* is currently focused on light duty vehicles (LDVs). These include passenger cars and light-duty trucks (LDT). Future versions of *NY-GREET* may include assessments of heavy-duty vehicles.

There are numerous ancillary benefits of this project. First, *NY-GREET* allows for assessments and comparisons of various alternative fuels and fuel production pathways, such as natural gas (CNG), hydrogen, propane (LPG), ethanol (EtOH), methanol (MeOH), pure electric vehicles (EV) and hybrid electric vehicles (HEV). Second, the national GREET model has recently been integrated into the EPA Motor Vehicle Emissions Simulator (MOVES) model. MOVES is the successor of the MOBILE model used by states for regulatory compliance modeling.[2] Therefore, *NY-GREET* is a significant benefit for New York as it begins to use MOVES for its regulatory modeling work. Finally, *NY-GREET* is a valuable tool as the Regional Greenhouse Gas Initiative (RGGI) program moves forward.[3] *NY-GREET* allows for a comprehensive and accurate analysis of GHG emissions from mobile sources, including emissions emanating from the upstream processes used to make and deliver alternative fuels.

1.2. JUSTIFICATION FOR NY-GREET

The *New York State Hydrogen Roadmap* (the Roadmap) identified some key research activities that need to occur in Phase I of hydrogen expansion in New York (NYSERDA 2005). Some of these activities explicitly include studies of hydrogen fueling pathways for transportation technologies. For example, the Roadmap suggested that New York "explore

[1] Note that a total fuel cycle analysis is focused only on the "fuel cycle" component of a vehicle's life cycle. Therefore, NY-GREET does not account for energy and emissions that occur in *vehicle production or disposal*. Other life-cycle models are aimed at quantifying these impacts, and NY-GREET may be used to complement such models for a complete energy and emissions picture of vehicle use in the state.
[2] See http://www.epa.gov/otaq/ngm.htm for more information on EPA MOVES.
[3] See http://www.rggi.org for more information on RGGI.

fueling options" and "evaluate fueling options and strategies." The Roadmap goes on to say that New York needs to "conduct strategic analyses of energy supply pathways, competitive technologies, and infrastructure needs." (p.21) The Roadmap also calls for a vision of significant refueling infrastructure to be in place by 2020. (p.28) A similar call to understand the energy and environmental impacts of different hydrogen pathways has also been stressed by the National Academies of Science in their recent report on hydrogen fuel (National Academies of Science 2004).

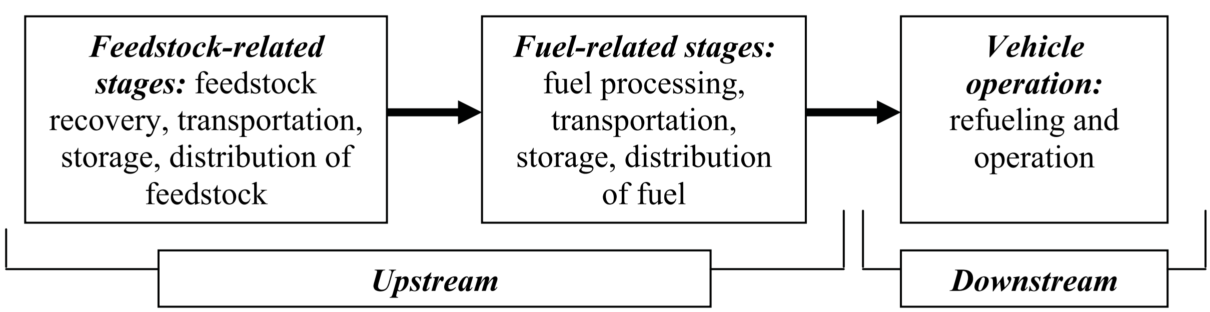
Prior to the development of *NY-GREET* there were limited tools available to conduct such assessments. As previously mentioned, at the national level the GREET model used by DOE and EPA can conduct *national* hydrogen W2W analyses. For example, GREET has been used to explore energy and emissions use for various hydrogen delivery pathways for hydrogen-fueled vehicles (Brinkman et al. 2005). However, GREET employs national averages for its analysis and therefore distorts the true picture that may exist in a particular state.[4] For instance, the assumptions used for electricity generation in GREET are based on national fuel profiles, and not New York's generating technologies. Another example includes the use of national assumptions about technologies used for fuel distribution and the size of the distribution network. These examples are obvious—but there are numerous other areas where GREET must be modified so that the fuel pathways for each alternative fuel's production, storage, and distribution are defined in the model as uniquely "New York."

The *NY-GREET* model uses GREET as its methodological foundation, but fortifies GREET with New York-specific data and a custom user-interface designed specifically for New York users. Doing so allows *NY-GREET* to capture unique aspects of New York's potential hydrogen and other fuel pathway options. For these reasons, we believe *NY-GREET* will provide a useful and lasting benefit to analysts concerned about the energy and emissions characteristics of AFVs.

1.3. A METHODOLOGICAL PRIMER ON W2W ANALYSES

Understanding the true energy and emissions impacts from AFVs requires a W2W analysis. W2W analyses involve consideration of energy use and emissions from the extraction of raw fuel (e.g., oil from the well), the processing of that fuel (e.g., turning crude into gasoline), and ultimately the distribution and use of the processed fuel in the vehicle itself. Figure 1 identifies the components of a total fuel-cycle, partitioned in "upstream" and "downstream" categories.

Figure 1. Components of a total fuel-cycle.



[4] The GREET model does allow hydrogen pathway analysis for California, but California is the only state for which analyses can be conducted in GREET.

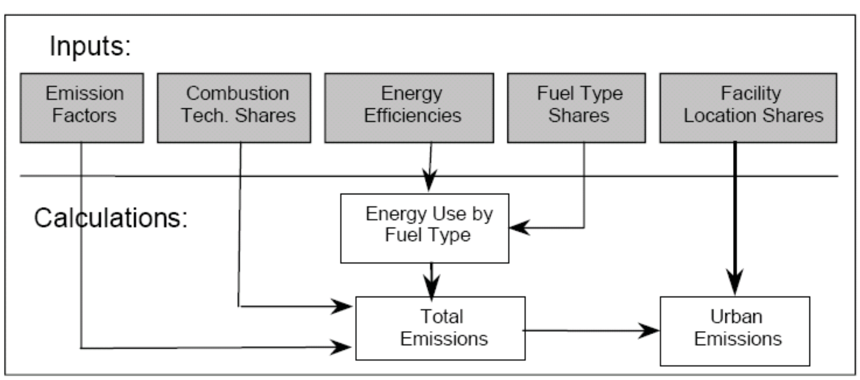
Each stage in the fuel-cycle in Figure 1 includes activities that produce GHG and criteria pollutant emissions. These emissions are typically caused by fuel combustion during a particular stage, although some non-combustion emissions occur (e.g., natural gas emissions from pipeline leaks, evaporative losses in refueling). *The goal of a W2W analysis is to account for each of the emissions events along the entire fuel-cycle chain.*

These analyses are not simple. Process fuel consumed at each upstream stage (for example, in the energy-intensive activity of petroleum refining) also has its own fuel-cycle chain that must be considered. These processes are called "up-upstream" processes. Likewise, fuel used to produce the process fuel has an upstream chain associated with it ("up-up-upstream" processes). These upstream chains go on *ad infinitum*, in what we call the "up^n-stream process" (Winebrake, Wang, and He 2001). The previously mentioned GREET algorithm, developed at Argonne National Lab and the "gold-standard" for total fuel-cycle analysis, can be used to calculate emissions from up^n-stream and downstream fuel-cycle stages for land-side transportation modes.

It is worthwhile to briefly review GREET's approach; more detailed discussion has been elaborated in previous work (Wang 1996; Wang, Wu, and Elgowainy 2005; Wang 1999). GREET calculates energy use (in Btu per mile [Btu/mi]) and emissions (in grams per mile [g/mi]) for different AFVs by taking into account energy use and emissions of combustion and non-combustion events in the upstream and downstream stages of the total fuel-cycle. The model calculates total energy use (all energy sources), fossil energy use (petroleum, natural gas, and coal), and petroleum use. GREET calculates emissions of three major GHGs (CO_2, CH_4, and N_2O) and five criteria pollutants (VOC, CO, NO_x, PM_{10}, and SO_x).

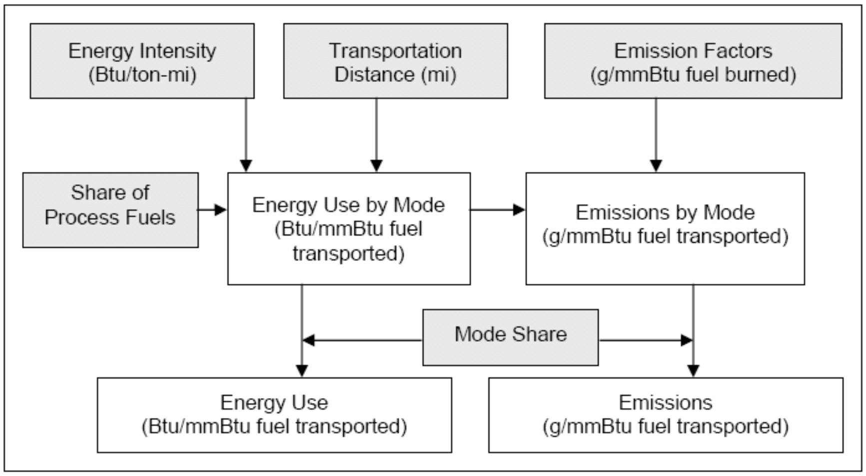
Upstream emissions of these pollutants are first calculated in grams per million Btu (g/mmBtu) of fuel throughput from each upstream stage. Emissions occurring during a stage include those resulting from the combustion of process fuels and from non-combustion processes such as chemical reactions, fuel leakage, and evaporation. The types of inputs needed for such W2W analyses are shown in Figure 2. In Figure 3, we show how other factors are used to ultimately calculate energy use and emissions. Note that each of the inputs identified in Figures 2 and 3 have *state-specific* elements to them. For example, emissions factors, combustion technologies, and fuel use are determined by the types of combustion technologies operating in the state.

Figure 2. Inputs and Outputs for NY-GREET



Source: (Brinkman et al. 2005)

Figure 3. Graphical Representation of Inputs and Outputs for GREET.



Source: (Brinkman et al. 2005)

Emissions from the combustion of process fuels for a particular upstream stage are calculated by using the following formula:

$$EM_{cm,i} = \left(\sum_{j} \sum_{k} EF_{i,j,k} \times EC_{j,k}\right) \div 1{,}000{,}000$$

where $EM_{cm,I}$ is the combustion emissions of pollutant *i* in g/mmBtu of fuel throughput; $EF_{i,j,k}$ is the emission factor of pollutant *i* for process fuel *j* with combustion technology *k* (g/mmBtu of fuel burned); and $EC_{j,k}$ is the consumption of process fuel *j* with combustion technology *k* (Btu/mmBtu of fuel throughput).

$EC_{j,k}$ for a given stage is, in turn, calculated by using the following formula:

$$EC_{j,k} = EC \times Share_{fuelj} \times Share_{techk,j}$$

where, EC is the total energy consumption for the given stage (in Btu/mmBtu of fuel throughput); $Share_{fuelj}$ is the share of process fuel *j* out of all process fuels consumed during the stage ($\sum_j Share_{fuelj} = 1$); and $Share_{techk,j}$ is the share of combustion technology *k* out of all combustion technologies for fuel *j* ($\sum_k Share_{techk,j} = 1$). Combustion technology shares ($Share_{techk,j}$) for a given process fuel are further influenced by technology performance, technology costs, and emissions for stationary sources. All of these variables are state-specific and need to reflect conditions in New York in order to appropriately apply the GREET model to analyses in New York State.

It is important to note that *NY-GREET* models a vehicle operating in New York State, but energy consumption and emissions in the total fuel-cycle process may occur outside state borders. For example, emissions related to the extraction of petroleum from the ground might occur in the Middle East, while emissions due to refining petroleum into crude could occur in Pennsylvania.

For GHGs (a global pollutant), the geographic location of the emissions source is not important; however, for local pollutants such as VOC, CO, PM, and NOx, geographic location is critical. Future work with *NY-GREET* may include the spatial attribution of local pollutants and exploration of the health impacts of these pollutants on exposed populations.

Output generated by *NY-GREET* comes in various forms. Graphs are automatically generated, in *NY-GREET,* that identify how total energy use and emissions are distributed along the upstream and downstream parts of the fuel-cycle for each vehicle type. Graphs are also generated that compare total fuel-cycle results for AFVs with conventional gasoline internal combustion engines (ICE). Tabular results are also readily available in *NY-GREET*. We present a more complete discussion of output options later in this report.

1.4. POTENTIAL USES OF NY-GREET

Without a total fuel-cycle analysis, emissions assessments from transportation are not accurate. For this reason, much effort has been placed on understanding the total fuel-cycle impacts of new technologies. Prior to the development of *NY-GREET*, only California had a version of GREET that was state-specific. Now New York has its own total fuel-cycle model for its own, state-specific analyses. Some potential uses of *NY-GREET* include:

- Assessing the full energy and environmental impacts of various AFV fuel pathways for New York;
- Evaluating the tradeoffs among pollutants and alternative fuel options for New York;
- Providing supporting information to activities related to emissions inventories for GHGs from transportation; this may be a critical element to the RGGI work that will be conducted in the coming years in the state; and
- Allocating emissions from transportation along various parts of the total fuel cycle, including an identification of where, geographically, those emissions occur.

2. MODEL STRUCTURE

NY-GREET is a Microsoft (MS) Excel-based model. To access the model, the user should open the most recent version of the "NY-GREET_V1.X.xls" file. The user will immediately see the NY-GREET tab that lists the project creators, the funding agency, and contact information. To begin a NY-GREET simulation, the user should navigate to the *Inputs* sheet at the bottom of the Excel window.

The *Inputs* sheet contains most of the required inputs for a NY-GREET simulation. As indicated in the Cell Color Key, required inputs are highlighted yellow, optional inputs are highlighted green, calculated inputs are highlighted tan, and placeholder calculations are highlighted grey. First-time users will likely make alterations only to required inputs (yellow), but more advanced users may find it necessary to alter the optional inputs (green).

After altering the desired inputs on the *Inputs* sheet, the user should navigate to each of the other sheets in the workbook. The user should note that a large number of inputs is located on the *Fuel_Prod_TS* sheet. Updating the inputs on that sheet will automatically update many uncolored cells on the *Inputs* sheet.

Once the user is confident that he/she has entered all desired inputs, the user can navigate to one of the four *Results* sheets. By default, NY-GREET utilizes *Automatic Calculations*. This means that any changes to input values are automatically and instantaneously reflected in the scenario results. Thus, no action is needed by the user to "run" the simulation. However, if the user has deactivated Automatic Calculations and has since altered input values, the user must press F9 to manually calculate the new results.

Results are presented in four different output styles. These are shown below with a short description of each result type:

1. Results – KEY VEHICLES. These results show W2W results for 12 of the most popular types of alternative fuel vehicles in operation. Results are provided for total energy consumption, petroleum consumption, and total GHG emissions. Results are provided both in tabular and graphical format, and energy use and emissions from each stage of the W2W life-cycle are provided.
2. Results (Tables) – All Vehicles. These results show W2W results for all vehicles considered in the NY-GREET model (total of 66 vehicle and fuel combinations). Results are in tabular form and provide readily available, comprehensive numeric output for all simulated vehicles. Results include not only energy and GHG emissions, but also all criteria pollutants considered in NY-GREET.
3. Results (Graphs) – All Vehicles. These results show W2W results for 36 vehicle types in graphical form for Total Energy, Petroleum Consumption, and GHG emissions.
4. Results – Relative Changes. These results show W2W results broken down by percentage of attribution of emissions and energy use by fuel-cycle stage for 61 vehicle and fuel combinations. This sheet also shows comparative graphs across 66 vehicle and fuel combinations for each energy and emissions constituent.

3. GREET / NY-GREET COMPARISONS

3.1 BASE ALTERATIONS OF GREET DATA

As explained in the introduction of this report, at the national level the GREET model used by DOE and EPA can conduct *national* hydrogen and alternative fuel W2W analyses. However, GREET employs national averages for its analysis and therefore distorts the true picture that may exist in a particular state. To reflect the situation in New York State, numerous data inputs were updated for the purpose of fortifying the baseline scenario (see the following *NY-Specific Scenarios* section of this report). Table 1 indicates the base alterations made from GREET assumptions to NY-GREET assumptions. The assumptions in the NY-GREET column serve as the base inputs for the scenarios to be explained in the next section (these inputs are further altered in some scenarios as identified in Table 4: Scenario Input Summary). GREET values not altered were researched and confirmed to reflect the current New York State situation.

Table 1: Base Alterations of GREET Data

Variable	GREET v1.7 Value	NY-GREET v1.1 Value
Fuel Pathways		
Pathways	All	All Except CARFG[5]
RFG %	50%	30%[6]
Diesel Fuel Types	100% LSD	100% LSD
G.H2 Production Shares	100% Station Production	100% Central Production
L.H2 Production Shares	100% Station Production	100% Central Production
G.H2 Feedstock Shares	100% NG	100% NG
L.H2 Feedstock Shares	100% NG	100% NG
LPG Feedstock Shares	60% NG; 40% Crude	60% NG; 40% Crude
Ethanol Feedstock Shares	100% Corn	100% Corn
Reformulated Gasoline		
Oxygenate	Ethanol	Ethanol
O2 Content	0.0%	0.0%
CARFG	On	Off
Sulfur Level	25.5ppm	25.5ppm
Conventional Gasoline		
Sulfur Level	25.5ppm	25.5ppm
Low-Sulfur Diesel		
Sulfur Level	11.0ppm	11.0ppm
CNG		
Feedstock Source	North American NG	North American NG
LNG		
Feedstock Source	North American NG	North American NG
Methanol		
Feedstock Source	Non-North American NG	North American NG[7]
Plant Design	Without Export	Without Export

[5] CARFG is not used in New York State.
[6] EPA (1999).
[7] EIA Natural Gas Navigator. NY State receives NG from CT, MA, NJ, PA, and Canada. http://tonto.eia.doe.gov/dnav/ng/ng_move_ist_a2dcu_SNY_a.htm

Table 1 Continued

Variable	GREET v1.7 Value	NY-GREET v1.1 Value
FTD		
Feedstock Source	Non-North American NG	North American NG
Plant Design	Without Export	Without Export
DME		
Feedstock Source	Non-North American NG	North American NG
Plant Design	Without Export	Without Export
Naphtha		
Share of FT vs Crude Naphtha	100% FT; 0% Crude	100% FT; 0% Crude
Feedstock Source	Non-North American NG	North American NG
Plant Design	Without Export	Without Export
LPG		
Feedstock Source	North American NG	North American NG
Ethanol		
Share of Plant Type	70% DMP; 30% WMP	70% DMP; 30% WMP
Share of Process Fuels: DMP	80% NG; 20% Coal	80% NG; 20% Coal
Share of Process Fuels: WMP	60% NG; 40% Coal	60% NG; 40% Coal
Electricity		
Generation Mix	U.S. Mix	NYS Baseline Mix (implies RPS)[8]
Adv. Power Plant Tech. Share	44% NG Turbine CC; 36% NG Turbine SC	44% NG Turbine CC; 36% NG Turbine SC
Nuclear Plants; LWR Plants	25% Gas Diff.; 75% Centrifuge	25% Gas Diff.; 75% Centrifuge
Nuclear Plants; HTGR Plants	25% Gas Diff.; 75% Centrifuge	25% Gas Diff.; 75% Centrifuge
Biomass Plant Feedstock	100% Woody Biomass	100% Woody Biomass
Biodiesel		
Energy/Emissions Allocations	Co-Prod.: Farming 37.9%; Extraction 37.9%; Transest. 20.4%	Co-Prod.: Farming 37.9%; Extraction 37.9%; Transest. 20.4%
G.H2 Central		
NG Feedstock Source	North American NG	North American NG
Plant Design	Without Export	Without Export
CO2 Sequestration	No	No
L.H2 Central		
NG Feedstock Source	North American NG	North American NG
Plant Design	Without Export	Without Export
CO2 Sequestration	No	No
Energy for Liquefaction	NGCC	NGCC
Share of Alternative Fuels for Blending		
Methanol (Blend with Gas)	Dedi. and HEV 90%; FFV 85%	Dedi. and HEV 90%; FFV 85%
FTD (Blend with Diesel)	FTD 100%	FTD 100%
Ethanol (Blend with Gas)	Low-Level 10%; High-Level 85%; Dedi. and HEV 90%	Low-Level 10%; High-Level 85%; Dedi. and HEV 90%
Ethanol (Blend with Diesel)	Low-Level 10%	Low-Level 10%
BD (Blend with Diesel)	BD20	BD20
Share of VMT for GC HEVs by Power Source		
Power Source	33% Grid Electricity; 67% On-Board ICE	33% Grid Electricity; 67% On-Board ICE
Feedstock and Fuel Transportation Assumptions		
Feedstock and Fuel Distances	Stock	New York State Specific[9]

[8] See Table 5 for details.
[9] Includes the alteration of 40 transportation pathways to reflect NY-specific transportation distances. EIA Petroleum Supply Annual 2005; EIA Natural Gas Annual 2004; mapcrow.info.

3.2 GREET / NY-GREET SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to demonstrate the importance of state-specific data when conducting state-level analysis. For the analysis NY-GREET 1.1 baseline results were compared to GREET 1.7 default results and a percent change was calculated between the resulting data. Table 9 and Table 10 located in Appendix B contain the results data from NY-GREET and GREET, respectively, used for the comparison. **Table 2** below identifies the analysis results. Instances where NY-GREET results differ from GREET results by 10% or greater have been highlighted.

Table 2: Percent Change from GREET to NY-GREET Results

	(highlighted if 10% or greater change)		
	Total Energy	**Petroleum**	**GHGs**
Gasoline Vehicle: CG and RFG	-1.9%	-0.1%	-2.3%
CIDI Vehicle: Conventional and LS Diesel	-10.0%	-9.5%	-10.5%
Grid-Connected SI HEV: CG and RFG	-10.0%	-1.5%	-22.1%
Grid-Independent SI HEV: CG and RFG	-1.9%	-0.1%	-2.3%
Electric Vehicle	-24.4%	-52.0%	-54.8%
CIDI Vehicle: BD	-10.3%	-9.5%	-11.6%
EtOH FFV: E85	-2.6%	-1.3%	-7.2%
Low-Level EtOH Blend with Gasoline	-1.5%	-0.8%	-2.6%
FCV: G.H2	-4.2%	10.9%	-12.5%
G.H2 ICE Vehicle	-4.2%	10.9%	-12.4%
Dedicated CNGV	-10.1%	-30.9%	-13.2%
LPGV: Dedicated	-5.7%	-5.5%	-6.1%

As is evident in the table, the most extreme differences were realized with the electric vehicle due to NY-GREET's use of a New York-specific electricity mix. The use of a New York-specific electricity mix also impacts the grid-connected hybrid-electric vehicle and has a minor impact on other pathways due to the fact that any New York-based electricity-consuming facility involved in the fuel cycle will use the New York mix.

Other differences were observed with diesel, grid-independent hybrid-electric, biodiesel, fuel cell, hydrogen, and compressed natural gas vehicles due to NY-GREET's use of New York-specific feedstock and fuel transportation distances. Whereas GREET uses transportation distances based on national averages, NY-GREET uses distances based on imports to PADD1 (Eastern US, including New York) obtained from the EIA Petroleum Supply Annual (2005) and EIA Natural Gas Annual (2004). For example, for natural gas pathways GREET uses *non*-North American transportation distances (often in excess of 5000 miles). NY-GREET on the other hand uses North American natural gas distances based on the fact that PADD1 receives most of its natural gas by pipeline from Canada. Furthermore, the distances from the natural gas fields to the natural gas production facilities were truncated due to New York's proximity to Canada compared to the rest of the US.

The changes in the hydrogen pathways were due to the fact that the NY-GREET baseline assumes 100% centralized hydrogen production, whereas GREET assumes 100% decentralized hydrogen production at refueling stations. Lastly, whereas GREET assumes a 2010 target year for simulation, the NY-GREET baseline assumes a 2015 target year. The selection of a 2015 target year impacts all fuel cycles in that the analysis is reliant on cleaner emission factors and more efficient extraction, transportation, refining, and production processes.

4 NEW YORK-SPECIFIC SCENARIOS

4.1 SCENARIO INTRODUCTION

We conducted 12 New York-specific scenarios to help exercise the NY-GREET model and to demonstrate W2W results for a variety of interesting technology, market, and policy futures. Each scenario file has been saved and is available as part of the NY-GREET package. These scenarios may provide shortcuts to users who do not want to conduct a separate NY-GREET analysis, but do want to explore results related to a particular scenario. In addition, the results of these scenarios provide valuable insights into comparative energy and environmental impacts of AFVs operating in New York.

Upon opening an individual scenario file, the user will be immediately presented with the scenario results. The *Key Vehicle Results* for each scenario have been copied and are included in the Appendix of this report.

The scenarios are divided into three main groups: (1) Baseline Scenarios; (2) Hydrogen Scenarios; and (3) Biofuel Scenarios. All scenarios were set at a 2015 target simulation date. Table 3 presents each scenario name along with a brief explanation of the scenario. Table 4 presents the input values for each scenario; the cells highlighted in green indicate a differentiation between *Scenario 1: New York Baseline* and the scenario at hand. Each scenario and reasoning behind selected values is described in further detail in the following sections of this report.

Table 3: Scenario Overview

Scenario Heading	Scenario Name	Brief Explanation
Baseline Scenarios	Baseline Scenario	Baseline scenario representative of business-as-usual conditions in New York State, including a mandatory RPS.
	Aggressive Renewable Energy	Representative of aggressive growth in renewable energy (more aggressive than the baseline RPS).
	Full Renewable Energy	Representative of solely renewable electricity in New York State with centralized hydrogen produced from renewable sources only.
	In-State Energy Only	Representative of business-as-usual conditions, but domestic in-state energy sources only; no overseas transport.
Hydrogen Scenarios	Centralized; Biomass Feedstock	Representative of centralized hydrogen production with biomass as feedstock.
	Station-produced; Electrolysis; Business-as-usual Electricity Mix at Stations	Representative of decentralized hydrogen production via electrolysis utilizing a business-as-usual electricity mix.
	Station-produced; Electrolysis; Aggressive Renewable Electricity Mix at Stations	Representative of decentralized hydrogen production via electrolysis utilizing an aggressive renewable energy mix.
	Station-produced; Electrolysis; Only Renewable Electricity at Stations	Representative of decentralized hydrogen production via electrolysis utilizing only renewable electricity.
Biofuel Scenarios	Ethanol from Woody & Herbaceous Biomass (No Corn)	Representative of ethanol production using woody and herbaceous biomass as feedstock.
	BD5	Representative of production and supply of BD5 biodiesel fuel mix only.
	BD10	Representative of production and supply of BD10 biodiesel fuel mix only.
	Farming Efficiency	Representative of a situation in which there is a 20 percent reduction in farming energy use, biofuel production energy use, fertilizer, herbicide, pesticide and insecticide use. Also, farming chemicals from in-state producers only.

Table 4: Scenario Input Summary

Scenario Name	**Baseline Scenario**	**Aggressive Renewable Energy**	**Full Renewable Energy**	**In-State Energy Only**	**Hydrogen: Centralized H2 with Biomass Feedstock**	**Hydrogen: Station-produced Electrolysis BAU Electric**	**Hydrogen: Station-produced Electrolysis Aggres. Renew. Electric**
Scenario Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Target Year	2015	2015	2015	2015	2015	2015	2015
Percent Reformulated Gasoline	30%[10]	30%	30%	30%	30%	30%	30%
Hydrogen Central vs Station Production	100%	100%	100%	100%	100%	0%	0%
Hydrogen Central Feedstock	NG: 100%	NG: 100%	Solar: 70% Bio: 30%	NG: 100%	Bio: 100%	n/a	n/a
Hydrogen Decentralized Feedstock	n/a	n/a	n/a	n/a	n/a	Electrolysis	Electrolysis
Ethanol Feedstock	Corn: 100%	Corn: 100%	Corn: 100%	Corn: 100%	Corn: 100%	Corn: 100%	Corn: 100%
Farming Energy Use	Stock	Stock	Stock	Stock	Stock	Stock	Stock
Farming Fertilizer, Herbicide, Pesticide, and Insecticide Use	Stock	Stock	Stock	Stock	Stock	Stock	Stock
Soy Oil Extraction Energy Use (for Biodiesel)	Stock	Stock	Stock	Stock	Stock	Stock	Stock
Ethanol Production Energy Use	Stock	Stock	Stock	Stock	Stock	Stock	Stock
New York Electric Generation Mix RO = Residual Oil NG = Natural Gas Co = Coal Nu = Nuclear Bio = Biomass Other = Hydro, Wind and Solar	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**Aggres. Renew.** RO: 0.3% NG: 20% Co: 5% Nu: 26.7% Bio: 8% Other: 40%	**Full Renew.** RO: 0% NG: 0% Co: 0% Nu: 0% Bio: 30% Other: 70%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**Aggres. Renew.** RO: 0.3% NG: 20% Co: 5% Nu: 26.7% Bio: 8% Other: 40%
Electric Mix for Transportation	NY 2015 BAU	Aggres. Renew.	Full Renewable	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU	Aggres. Renew.
Electric Mix for Stationary Use	NY 2015 BAU	Aggres. Renew.	Full Renewable	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU	Aggres. Renew.
Electric for Decentralized H2 Production	n/a	n/a	n/a	n/a	n/a	NY 2015 BAU	Aggres. Renew.
Transportation & Distribution Distances	NY-Specific	NY-Specific	NY-Specific	In-State Transit Only	NY-Specific	NY-Specific	NY-Specific
Biodiesel Fuel Blend	BD20	BD20	BD20	BD20	BD20	BD20	BD20
Ethanol-Gasoline Fuel Blend (Low-Level)	E10	E10	E10	E10	E10	E10	E10
Ethanol-Gasoline Fuel Blend (High-Level; Flex Fuel)	E85	E85	E85	E85	E85	E85	E85
Ethanol-Gasoline Fuel Blend (Dedicated E Vehicle)	E90	E90	E90	E90	E90	E90	E90
Ethanol-Diesel Fuel Blend	ED10	ED10	ED10	ED10	ED10	ED10	ED10
RFG in Low-Level Ethanol	0%	0%	0%	0%	0%	0%	0%
Methanol-Gasoline Fuel Blend (Flex-Fuel)	M85	M85	M85	M85	M85	M85	M85
Methanol-Gasoline Fuel Blend (Dedicated M Vehicle)	M90	M90	M90	M90	M90	M90	M90
Share of HEV VMT Powered by Grid	33%	33%	33%	33%	33%	33%	33%

[10] EPA (2007).

Table 4 Continued

Scenario Name	*Baseline Scenario (Repeated for reference)*	**Hydrogen: Station-produced Electrolysis Full Renew. Electric**	**Ethanol from Woody & Herbaceous Biomass**	**Biodiesel: BD5**	**Biodiesel: BD10**	**Farming Efficiency**
Scenario Number	***1***	**8**	**9**	**10**	**11**	**12**
Target Year	*2015*	2015	2015	2015	2015	2015
Percent Reformulated Gasoline	*30%*	30%	30%	30%	30%	30%
Hydrogen Central vs Station Production	*100%*	0%	100%	100%	100%	100%
Hydrogen Central Feedstock	*NG: 100%*	n/a	NG: 100%	NG: 100%	NG: 100%	NG: 100%
Hydrogen Decentralized Feedstock	*n/a*	Electrolysis	n/a	n/a	n/a	n/a
Ethanol Feedstock	*Corn: 100%*	Corn: 100%	W. Bio: 50% Herb: 50%	Corn: 100%	Corn: 100%	Corn: 100%
Farming Energy Use	*Stock*	Stock	Stock	Stock	Stock	20% Reduction
Farming Fertilizer, Herbicide, Pesticide, and Insecticide Use	*Stock*	Stock	Stock	Stock	Stock	20% Reduction
Soy Oil Extraction Energy Use (for Biodiesel)	*Stock*	Stock	Stock	Stock	Stock	20% Reduction
Ethanol Production Energy Use	*Stock*	Stock	Stock	Stock	Stock	20% Reduction
New York Electric Generation Mix RO = Residual Oil NG = Natural Gas Co = Coal Nu = Nuclear Bio = Biomass Other = Hydro, Wind and Solar	***NY 2015 BAU*** *RO: 1.3%* *NG: 30.6%* *Co: 12.3%* *Nu: 26.7%* *Bio: 3.4%* *Other: 25.7%*	**Full Renew.** RO: 0% NG: 0% Co: 0% Nu: 0% Bio: 30% Other: 70%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%	**NY 2015 BAU** RO: 1.3% NG: 30.6% Co: 12.3% Nu: 26.7% Bio: 3.4% Other: 25.7%
Electric Mix for Transportation	*NY 2015 BAU*	Full Renewable	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU
Electric Mix for Stationary Use	*NY 2015 BAU*	Full Renewable	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU	NY 2015 BAU
Electric for Decentralized H2 Production	*n/a*	Hydroelectric	n/a	n/a	n/a	n/a
Transportation & Distribution Distances	*NY-Specific*	NY-Specific	NY-Specific	NY-Specific	NY-Specific	In-State Farming Materials
Biodiesel Fuel Blend	*BD20*	BD20	BD20	BD5	BD10	BD20
Ethanol-Gasoline Fuel Blend (Low-Level)	*E10*	E10	E10	E10	E10	E10
Ethanol-Gasoline Fuel Blend (High-Level; Flex Fuel)	*E85*	E85	E85	E85	E85	E85
Ethanol-Gasoline Fuel Blend (Dedicated E Vehicle)	*E90*	E90	E90	E90	E90	E90
Ethanol-Diesel Fuel Blend	*ED10*	ED10	ED10	ED10	ED10	ED10
RFG in Low-Level Ethanol	*0%*	0%	0%	0%	0%	0%
Methanol-Gasoline Fuel Blend (Flex-Fuel)	*M85*	M85	M85	M85	M85	M85
Methanol-Gasoline Fuel Blend (Dedicated M Vehicle)	*M90*	M90	M90	M90	M90	M90
Share of HEV VMT Powered by Grid	*33%*	33%	33%	33%	33%	33%

4.2 SCENARIO 1: NEW YORK STATE (NYS) BASELINE

This scenario assumes New York State baseline input variable values as indicated in Table 4. Specifically, thirty percent of gasoline used in the state is reformulated gasoline (EPA 1999). Hydrogen is produced at natural gas-fired central plants only. The marginal and average electricity mix is based on based on multiple sources and original projections (EIA 2007; NYPSC 2004; Wang, Wu, and Elgowainy 2005) and summarized in Table 5. Transportation and distribution distances represent distances to NYS using a weighted average from country of origin per each fuel/feedstock (EIA 2006, 2006; Mapcrow 2006). There is no carbon sequestration undertaken in the state. Biomass, methanol, di-methyl ether (DME), and Fischer-Tropsch Diesel (FTD) are from herbaceous sources only. Ethanol is from corn only. Biofuel farming and production statistics are based on national averages. Fuel mixes are as follows: biodiesel (BD) is made up of 20% biofuel and 80% diesel (BD20); low level ethanol is 10% ethanol and 90% gasoline (E10); flex-fuel ethanol is 85% ethanol and 15% gasoline (E85); dedicated ethanol is 90% ethanol and 10% gasoline (E90); flex-fuel methanol is 85% methanol and 15% gasoline (M85); and dedicated methanol is 90% methanol and 10% gasoline (M90). Thirty three percent (33%) of plug-in hybrid-electric vehicle miles traveled (VMT) are powered by grid electricity from marginal sources defined above (67% by on board engines). Vehicle characteristics (fuel consumption and emissions) for key vehicles are summarized in Appendix A.

Table 5: NYS Baseline Electricity Mix, 2015

All Electricity Sources Required for NY-GREET Input	Percent of Total Electricity Generation
Residual Oil	1.3%
Natural Gas	30.6%
Coal	12.3%
Nuclear	26.7%
Biomass and Waste	3.4%
Other (Hydro and Wind)	25.7%
Baseline Total	100%

Estimates based on multiple sources and original projections (EIA 2007; NYPSC 2004; Wang, Wu, and Elgowainy 2005).

Tabular results for *Scenario 1 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 1* Excel file.

4.3 SCENARIO 2: AGGRESSIVE RENEWABLE ENERGY

Scenario 2 assumes all inputs equal to those in *Scenario 1* except for electric generation mixes. Electric mixes affect any vehicle that receives all or some of its power from the electric grid, such as grid-connected HEVs (otherwise known as “plug-in HEVs”, or PHEVs), or pure grid-connected electric vehicles (EVs).

In this scenario the electric generation mixes are based on a future where renewable energy grows at a faster rate than the mandated RPS, as shown in Table 6.

Table 6: NYS Aggressive Renewable Electricity Mix for NY-GREET Input, 2015

All Electricity Sources Required for NY-GREET Input	Percent of Total Electricity Generation
Residual Oil	0.3%
Natural Gas	20%
Coal	5%
Nuclear	26.7%
Biomass and Waste	8%
Other (Hydro and Wind)	40%
RPS Total	100%

Estimates based on multiple sources and original projections (EIA 2007; NYPSC 2004; Wang, Wu, and Elgowainy 2005).

Tabular results for *Scenario 2 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 2* Excel file.

4.4 SCENARIO 3: FULL RENEWABLE ENERGY

Scenario 3 simulates a fully renewable NYS electricity mix. To simulate this, the electric generation mixes have been changed to 30% biomass and 70% other renewables. Table 7 identifies the NYS full-renewable electricity mix.

Table 7: NYS Full Renewable Electricity Mix for NY-GREET Input, 2015

All Electricity Sources Required for NY-GREET Input	Percent of Total Electricity Generation
Residual Oil	0%
Natural Gas	0%
Coal	0%
Nuclear	0%
Biomass and Waste	30%
Other (Hydro, Solar & Wind)	70%
Full Renewable Total	100%

Tabular results for *Scenario 3 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 3* Excel file.

4.5 SCENARIO 4: IN-STATE ENERGY ONLY

Scenario 4 maintains all inputs from *Scenario 1* except for transportation and distribution distances, which have been truncated to represent in-state transit only. This scenario mimics a case where all energy sources come from in-state. Specifically, distance traveled by ocean tanker has been reduced to 0 miles, barge reduced to no greater than 200 miles, pipeline no greater than 250 miles, rail no greater than 250 miles, and truck transport no greater than 80 miles. These alterations affect the transport of all goods, including energy feedstocks and fuels, and farming materials. It is recognized that fueling New York's energy needs with in-state sources only is likely an impossible endeavor. Thus, this scenario is not intended to imply that such a transition is desired, or even possible – but is instead intended to explore boundary conditions for a completely independent, state-wide energy system.

Tabular results for *Scenario 4 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 4* Excel file.

4.6 SCENARIO 5: CENTRALIZED HYDROGEN WITH BIOMASS FEEDSTOCK

As shown in Table 4, *Scenario 1* assumes centralized, natural gas-based hydrogen production. Here, a separate scenario is constructed to explore centralized, *biomass-based* hydrogen production. This scenario assumes 100 percent biomass feedstock for central hydrogen production, use of the New York RPS electricity mix, and carbon sequestration options for central hydrogen plants. Tabular results for *Scenario 5 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 5* Excel file.

4.7 SCENARIO 6: DECENTRALIZED HYDROGEN WITH BAU ELECTRICITY MIX

Scenario 6 explores decentralized hydrogen production using electrolysis with a business-as-usual electricity mix. The BAU electricity mix was previously explained and summarized in Table 5. Tabular results for *Scenario 6 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 6* Excel file.

4.8 SCENARIO 7: DECENTRALIZED HYDROGEN WITH RPS ELECTRICITY MIX

Scenario 7 explores decentralized hydrogen production using electrolysis with a RPS electricity mix. The RPS electricity mix was previously explained and summarized in Table 6. Tabular results for *Scenario 7* Key Vehicles are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 7* Excel file.

4.9 SCENARIO 8: DECENTRALIZED HYDROGEN WITH RENEWABLE ELECTROLYSIS

Scenario 8 examines decentralized hydrogen production using electrolysis with a full renewable electricity mix. The full renewable electricity mix was previously explained and summarized in Table 7. Tabular results for *Scenario 8 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 8* Excel file.

4.10 SCENARIO 9: ETHANOL FROM WOODY & HERBACEOUS BIOMASS

As shown in Table 4, *Scenario 1: Baseline* assumes ethanol production from corn only. Here, a separate scenario is constructed to view results of ethanol production from woody and herbaceous biomass. The feedstock is split 50/50 with half coming from woody biomass and half coming from herbaceous biomass. All other inputs are equal to *Scenario 1*. Tabular results for *Scenario 9 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 9* Excel file.

4.11 SCENARIO 10: BD5

As shown in Table 4, *Scenario 1: Baseline* assumes a biodiesel fuel mix of 80 percent diesel and 20 percent soy oil (a mix commonly known as BD20). Here, a separate scenario is constructed to view results of a biodiesel fuel mix of 95 percent diesel and 5 percent soy oil (BD5). Tabular results for *Scenario 10 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 10* Excel file.

4.12 SCENARIO 11: BD10

As shown in Table 4, *Scenario 1* assumes a biodiesel fuel mix of 80 percent diesel and 20 percent soy oil (a mix commonly known as BD20). Here, a separate scenario is constructed to view results of a biodiesel fuel mix of 90 percent diesel and 10 percent soy oil (BD10). Tabular results for *Scenario 11 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 11* Excel file.

4.13 SCENARIO 12: FARMING EFFICIENCY

The farming efficiency scenario assumes a 20 percent reduction in farming usage of energy, fertilizer, herbicides, pesticides, and insecticides. The energy reduction applies to energy use during farming of agricultural products, extraction of soy oil for use in biodiesel, and production of ethanol. Furthermore, this scenario assumes in-state supply of farming material, chemicals, and end products using the methodology discussed in *Scenario 4*. Tabular results for *Scenario 12 Key Vehicles* are presented in Appendix C. Graphical results for *Key Vehicles* are presented in Appendix D. Full results may be accessed via the *Scenario 12* Excel file.

5. CONCLUSIONS AND NEXT STEPS

This report presents the *New York Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation* (NY-GREET) model. *NY-GREET* can be used to assess the total fuel-cycle (i.e., "well-to-wheels") emissions and energy use characteristics for alternative fuel vehicles (AFVs) operating in New York State. Alternative fuel types evaluated in *NY-GREET* include hydrogen, ethanol, biodiesel, natural gas, and electricity, among others. In this report we introduce the model and demonstrate its use through the presentation of 12 scenarios that together provide a comprehensive picture of the energy and environmental attributes of AFVs operating in New York.

With this tool, NYS is now prepared to conduct comprehensive W2W analyses of alternative fuel vehicle operations within the state. This tool will no doubt be an important evaluation instrument to help consider economic, policy, and technology activities of the state. In particular, we see the varied uses of NY-GREET to include:

1. Conventional vehicle v. AFV analysis. NYSERDA can now make conventional and alternative fuel vehicle comparisons that allow a "fair" comparison of fuels based on a W2W analysis.
2. Proposal evaluation. NYSERDA can use NY-GREET to evaluate emissions and energy impacts associated with proposed alternative fuel projects within the state.
3. New technology assessments. NYSERDA can use NY-GREET to evaluate the potential W2W benefits of new technologies employed in the upstream stages of various fuel cycles.
4. Parametric/sensitivity analysis. NYSERDA can use NY-GREET to conduct parametric studies or sensitivity analyses that will identify key, high-leverage variables associated with high emissions values; such information may help NYSERDA direct resources towards certain technology development.
5. Regulatory compliance. NY-GREET may potentially be used as a regulatory compliance tool where upstream emissions calculations are an important part of the regulatory mandate (e.g., low-carbon fuel standard regulations).
6. Information database. Although designed as a W2W model, NY-GREET is also an extensive database; we believe NYSERDA will find great value in simply referring to NY-GREET worksheets to extract data relevant to other NYSERDA studies.

Although we feel the tool is technically sound, we also identify the following caveats for users:

- Users must recognize that the analyses conducted with NY-GREET represent state-wide averages. Although this means that NY-GREET results are more state-specific than national GREET analyses, one still has to be careful in applying these results to a particular region of the state or urban area. Modified NY-GREET analyses are probably required to conduct evaluations in areas within the state; for example, grid-connected EV operations in Buffalo may be quite different than those in NYC, and so such differences need to be evaluated in separate studies.
- The technologies associated with alternative fuels production, particular in the biofuels area, are advancing rapidly. Users should be aware of this, and we recommend that

annual updates be made to NY-GREET to include the most recent state-of-knowledge for various fuel production and use technologies. For example, future biorefineries may demonstrate efficiencies that are higher than those assumed in this first version of NY-GREET.

- NY-GREET is not an economic analysis tool. Thus, local or regional economic benefits associated with movement towards alternative fuels (e.g., increased economic output in the agricultural sector via a movement to biofuels) are not captured.

As a final thought, the NY-GREET model is designed to address LDV operations. However, there is growing interest in studying W2W emissions from heavy-duty vehicles (HDVs) as well. Although not directly modeled with NY-GREET, data contained within NY-GREET may be used to generate HDV W2W estimates. For example, one could look at the "upstream" emissions associated with diesel production and distribution for diesel LDVs (in g/mile) and divide by the efficiency (miles per gallon) estimate for diesel LDVs to convert these values to grams/gallon. Then, one could apply HDV efficiency factors (miles per gallon) to this value to obtain HDV upstream grams/mile emissions estimates. Those upstream estimates could then be added to vehicle-based emissions and energy use to calculate total HDV W2W impacts.

Because of the many different types of HDVs, we believe that a separate NY-GREET/HDV model should be developed to conduct these types of analyses more formally. We also believe that off-road equipment could also be included in such an analytical tool. We reserve these types of tool development for future work. With such a tool, NYS would have a HDV model to complement this LDV work.

More information about NY-GREET can be obtained by contacting NYSERDA or EERA directly at info@energyandenvironmental.com.

APPENDIX A: KEY VEHICLE CHARACTERISTICS: FUEL & EMISSIONS

Table 8: Key Vehicles Characteristics

	Baseline Gasoline Vehicle: CG and RFG	CIDI Vehicle: Conventional and LS Diesel	Grid-Connected SI HEV: CG and RFG, Grid Mode	Grid-Independent SI HEV: CG and RFG	Electric Vehicle	CIDI Vehicle: BD	EtOH Flexible-Fuel Vehicle	SIDI Vehicle: Low-Level EtOH Blend with Gasoline	G.H2 Fuel-Cell Vehicle	G.H2 ICE Vehicle	Dedicated CNGV	Dedicated LPGV
Urban Emission Shares	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%	62.2%
MPG (per gasoline equivalent gallon)	25.1	37.4	75.3	40.2	87.9	37.4	26.4	28.9	58.2	30.1	25.9	26.4
Total fuel use (Btu/mile)	4,595	3,084	1,532	2,872	1,313	3,084	4,377	3,996	1,981	3,829	4,462	4,377
Fossil fuel use (Btu/mile)	4,538	3,084	1,006	2,836	862	2,506	1,159	3,738	1,981	3,829	4,462	4,377
Coal use (Btu/mile)	0	0	301	0	258	0	0	0	0	0	0	0
Natural gas use (Btu/mile)	0	0	663	0	568	0	0	0	1,981	3,829	4,462	2,626
Petroleum use (Btu/mile)	4,538	3,084	43	2,836	36	2,506	1,159	3,738	0	0	0	1,751
Emissions: grams/mile												
VOC: exhaust	0.095	0.060	0.000	0.051	0.000	0.060	0.095	0.095	0.000	0.019	0.095	0.095
VOC: evaporation	0.057	0.000	0.000	0.057	0.000	0.000	0.048	0.057	0.000	0.000	0.029	0.046
CO	3.492	0.539	0.000	3.492	0.000	0.539	3.492	3.492	0.000	0.698	3.492	3.492
NOx	0.069	0.141	0.000	0.058	0.000	0.141	0.069	0.069	0.000	0.069	0.069	0.069
PM10: exhaust	0.008	0.009	0.000	0.008	0.000	0.009	0.008	0.008	0.000	0.001	0.008	0.008
PM10: brake and tire wear	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
PM2.5: exhaust	0.007	0.008	0.000	0.007	0.000	0.008	0.007	0.007	0.000	0.001	0.007	0.007
PM2.5: brake and tire wear	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
SOx	0.006	0.002	0.000	0.004	0.000	0.001	0.002	0.005	0.000	0.000	0.001	0.000
CH4	0.011	0.003	0.000	0.005	0.000	0.003	0.011	0.011	0.000	0.001	0.106	0.011
N2O	0.012	0.012	0.000	0.012	0.000	0.012	0.012	0.012	0.000	0.012	0.012	0.012
CO2	353	244	0	221	0	244	330	307	0	0	265	298

APPENDIX B: DATA FOR SENSITIVITY ANALYSIS

Table 9: NY-GREET Baseline Results for Sensitivity Analysis

	Total Energy				Petroleum				GHGs			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Gasoline Vehicle: CG and RFG	163	885	4595	5644	55	437	4538	5030	21	66	357	444
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	3712	37	266	3084	3386	17	38	247	302
Grid-Connected SI HEV: CG and RFG	107	840	2430	3377	31	189	1914	2134	13	76	150	239
Grid-Independent SI HEV: CG and RFG	102	553	2872	3528	34	273	2836	3143	13	41	224	279
Electric Vehicle	101	1219	1313	2633	20	17	36	73	11	125	0	136
CIDI Vehicle: BD	202	662	3084	3948	108	230	2506	2843	-23	44	248	269
EtOH FFV: E85	600	2116	4377	7092	220	178	1159	1558	-142	157	334	349
Low-Level EtOH Blend with Gasoline	178	837	3996	5010	61	357	3738	4156	8	62	310	380
FCV: G.H2	129	1214	1981	3323	8	27	0	35	16	191	0	207
G.H2 ICE Vehicle	249	2346	3829	6424	16	52	0	68	31	369	4	403
Dedicated CNGV	336	277	4462	5075	19	8	0	27	48	14	271	333
LPGV: Dedicated	228	270	4377	4875	32	97	1751	1879	29	19	302	350

Table 10: GREET Default Results for Sensitivity Analysis

	Total Energy				Petroleum				GHGs			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Gasoline Vehicle: CG and RFG	177	946	4631	5755	56	445	4535	5036	20	74	359	454
CIDI Vehicle: Conventional and LS Diesel	130	587	3405	4122	41	295	3405	3741	20	45	273	338
Grid-Connected SI HEV: CG and RFG	120	1183	2449	3751	39	207	1921	2168	15	140	151	307
Grid-Independent SI HEV: CG and RFG	111	591	2894	3597	35	278	2834	3148	13	46	226	285
Electric Vehicle	118	2042	1323	3483	41	54	58	153	18	283	0	301
CIDI Vehicle: BD	236	759	3405	4399	120	256	2767	3143	-23	54	273	304
EtOH FFV: E85	645	2222	4410	7278	226	187	1164	1578	-136	175	336	376
Low-Level EtOH Blend with Gasoline	192	867	4027	5086	63	362	3767	4192	11	67	313	390
FCV: G.H2	152	1321	1996	3470	9	23	0	32	22	214	0	236
G.H2 ICE Vehicle	295	2554	3859	6708	17	44	0	61	42	414	4	460
Dedicated CNGV	372	397	4875	5644	21	17	0	38	53	34	296	384
LPGV: Dedicated	249	292	4631	5171	34	103	1852	1989	32	21	319	373

APPENDIX C: TABULAR RESULTS FOR KEY VEHICLES

Table 11: Scenario 1 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	202	662	3084	108	230	2506	-23	44	248
EtOH FFV: E85	600	2116	4377	220	178	1159	-142	157	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	178	837	3996	61	357	3738	8	62	310
FCV: G.H2	129	1214	1981	8	27	0	16	191	0
G.H2 ICE Vehicle	249	2346	3829	16	52	0	31	369	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 12: Scenario 2 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	158	876	4595	54	435	4538	20	65	357
CIDI Vehicle: Conventional and LS Diesel	106	513	3084	36	265	3084	16	37	247
Grid-Connected SI HEV: CG and RFG	94	718	2430	30	180	1907	10	53	150
Grid-Independent SI HEV: CG and RFG	99	548	2872	34	272	2836	12	40	224
Electric Vehicle	73	912	1313	18	-5	17	5	67	0
CIDI Vehicle: BD	198	653	3084	107	228	2506	-24	42	248
EtOH FFV: E85	583	2085	4377	218	174	1159	-145	151	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	172	828	3996	60	356	3738	7	60	310
FCV: G.H2	128	1167	1981	8	21	0	16	182	0
G.H2 ICE Vehicle	247	2257	3829	16	40	0	31	352	4
Dedicated CNGV	335	242	4462	19	3	0	48	8	271
LPGV: Dedicated	225	268	4377	31	96	1751	29	19	302

Table 13: Scenario 3 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	160	879	4595	54	436	4538	19	63	357
CIDI Vehicle: Conventional and LS Diesel	107	514	3084	36	265	3084	15	36	247
Grid-Connected SI HEV: CG and RFG	85	759	2430	38	174	1909	6	28	150
Grid-Independent SI HEV: CG and RFG	100	549	2872	34	272	2836	12	39	224
Electric Vehicle	48	1016	1313	40	-22	22	-5	5	0
CIDI Vehicle: BD	199	655	3084	107	229	2506	-25	40	248
EtOH FFV: E85	587	2092	4377	219	175	1159	-149	145	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	174	830	3996	61	356	3738	6	58	310
FCV: G.H2	576	847	1981	16	31	0	-95	102	0
G.H2 ICE Vehicle	1113	1637	3829	31	60	0	-183	197	4
Dedicated CNGV	335	250	4462	19	4	0	47	0	271
LPGV: Dedicated	226	268	4377	31	96	1751	28	18	302

Table 14: Scenario 4 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	128	871	4595	27	425	4538	18	66	357
CIDI Vehicle: Conventional and LS Diesel	86	509	3084	18	258	3084	15	38	247
Grid-Connected SI HEV: CG and RFG	91	834	2430	18	185	1914	12	76	150
Grid-Independent SI HEV: CG and RFG	80	544	2872	17	265	2836	11	41	224
Electric Vehicle	98	1219	1313	17	18	35	11	125	0
CIDI Vehicle: BD	180	652	3084	90	221	2506	-25	43	248
EtOH FFV: E85	580	2083	4377	204	148	1159	-144	155	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	148	823	3996	38	346	3738	6	61	310
FCV: G.H2	128	1166	1981	8	17	0	16	188	0
G.H2 ICE Vehicle	248	2255	3829	16	32	0	31	363	4
Dedicated CNGV	336	276	4462	19	7	0	48	14	271
LPGV: Dedicated	215	255	4377	21	84	1751	28	18	302

Table 15: Scenario 5 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	202	662	3084	108	230	2506	-23	44	248
EtOH FFV: E85	600	2116	4377	220	178	1159	-142	157	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	178	837	3996	61	357	3738	8	62	310
FCV: G.H2	123	2039	1981	53	66	0	-315	362	0
G.H2 ICE Vehicle	238	3943	3829	102	127	0	-609	700	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 16: Scenario 6 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	202	662	3084	108	230	2506	-23	44	248
EtOH FFV: E85	600	2116	4377	220	178	1159	-142	157	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	178	837	3996	61	357	3738	8	62	310
FCV: G.H2	3789	0	1981	105	0	55	298	0	0
G.H2 ICE Vehicle	7325	0	3829	204	0	106	577	0	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 17: Scenario 7 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	158	876	4595	54	435	4538	20	65	357
CIDI Vehicle: Conventional and LS Diesel	106	513	3084	36	265	3084	16	37	247
Grid-Connected SI HEV: CG and RFG	94	718	2430	30	180	1907	10	53	150
Grid-Independent SI HEV: CG and RFG	99	548	2872	34	272	2836	12	40	224
Electric Vehicle	73	912	1313	18	-5	17	5	67	0
CIDI Vehicle: BD	198	653	3084	107	228	2506	-24	42	248
EtOH FFV: E85	583	2085	4377	218	174	1159	-145	151	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	172	828	3996	60	356	3738	7	60	310
FCV: G.H2	3055	0	1981	41	0	26	159	0	0
G.H2 ICE Vehicle	5907	0	3829	78	0	51	307	0	4
Dedicated CNGV	335	242	4462	19	3	0	48	8	271
LPGV: Dedicated	225	268	4377	31	96	1751	29	19	302

Table 18: Scenario 8 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	160	879	4595	54	436	4538	19	63	357
CIDI Vehicle: Conventional and LS Diesel	107	514	3084	36	265	3084	15	36	247
Grid-Connected SI HEV: CG and RFG	85	759	2430	38	174	1909	6	28	150
Grid-Independent SI HEV: CG and RFG	100	549	2872	34	272	2836	12	39	224
Electric Vehicle	48	1016	1313	40	-22	22	-5	5	0
CIDI Vehicle: BD	199	655	3084	107	229	2506	-25	40	248
EtOH FFV: E85	587	2092	4377	219	175	1159	-149	145	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	174	830	3996	61	356	3738	6	58	310
FCV: G.H2	1147	0	1981	0	0	0	0	0	0
G.H2 ICE Vehicle	2217	0	3829	0	0	0	0	0	4
Dedicated CNGV	335	250	4462	19	4	0	47	0	271
LPGV: Dedicated	226	268	4377	31	96	1751	28	18	302

Table 19: Scenario 9 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	202	662	3084	108	230	2506	-23	44	248
EtOH FFV: E85	389	4067	4377	221	167	1159	-231	21	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	161	993	3996	61	356	3738	1	51	310
FCV: G.H2	129	1214	1981	8	27	0	16	191	0
G.H2 ICE Vehicle	249	2346	3829	16	52	0	31	369	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 20: Scenario 10 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	132	554	3084	54	257	2941	7	40	248
EtOH FFV: E85	600	2116	4377	220	178	1159	-142	157	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	178	837	3996	61	357	3738	8	62	310
FCV: G.H2	129	1214	1981	8	27	0	16	191	0
G.H2 ICE Vehicle	249	2346	3829	16	52	0	31	369	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 21: Scenario 11 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	885	4595	55	437	4538	21	66	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	840	2430	31	189	1914	13	76	150
Grid-Independent SI HEV: CG and RFG	102	553	2872	34	273	2836	13	41	224
Electric Vehicle	101	1219	1313	20	17	36	11	125	0
CIDI Vehicle: BD	156	590	3084	72	248	2797	-3	41	248
EtOH FFV: E85	600	2116	4377	220	178	1159	-142	157	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	178	837	3996	61	357	3738	8	62	310
FCV: G.H2	129	1214	1981	8	27	0	16	191	0
G.H2 ICE Vehicle	249	2346	3829	16	52	0	31	369	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

Table 22: Scenario 12 Key Vehicle Results

	Total Energy			Petroleum			GHGs		
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation
Gasoline Vehicle: CG and RFG	163	877	4595	55	436	4538	21	65	357
CIDI Vehicle: Conventional and LS Diesel	110	518	3084	37	266	3084	17	38	247
Grid-Connected SI HEV: CG and RFG	107	837	2430	30	189	1914	13	75	150
Grid-Independent SI HEV: CG and RFG	102	548	2872	34	272	2836	13	41	224
Electric Vehicle	100	1219	1313	19	17	36	11	125	0
CIDI Vehicle: BD	180	639	3084	92	229	2506	-25	42	248
EtOH FFV: E85	500	1746	4377	185	175	1159	-159	130	334
SIDI Vehicle: Low-Level EtOH Blend with Gasoline	170	807	3996	58	357	3738	7	60	310
FCV: G.H2	129	1214	1981	8	27	0	16	191	0
G.H2 ICE Vehicle	249	2346	3829	16	52	0	31	369	4
Dedicated CNGV	336	277	4462	19	8	0	48	14	271
LPGV: Dedicated	228	270	4377	32	97	1751	29	19	302

APPENDIX D: GRAPHICAL RESULTS FOR KEY VEHICLES

Figure 4: Scenario 1 Total Energy Consumption for Key Vehicles

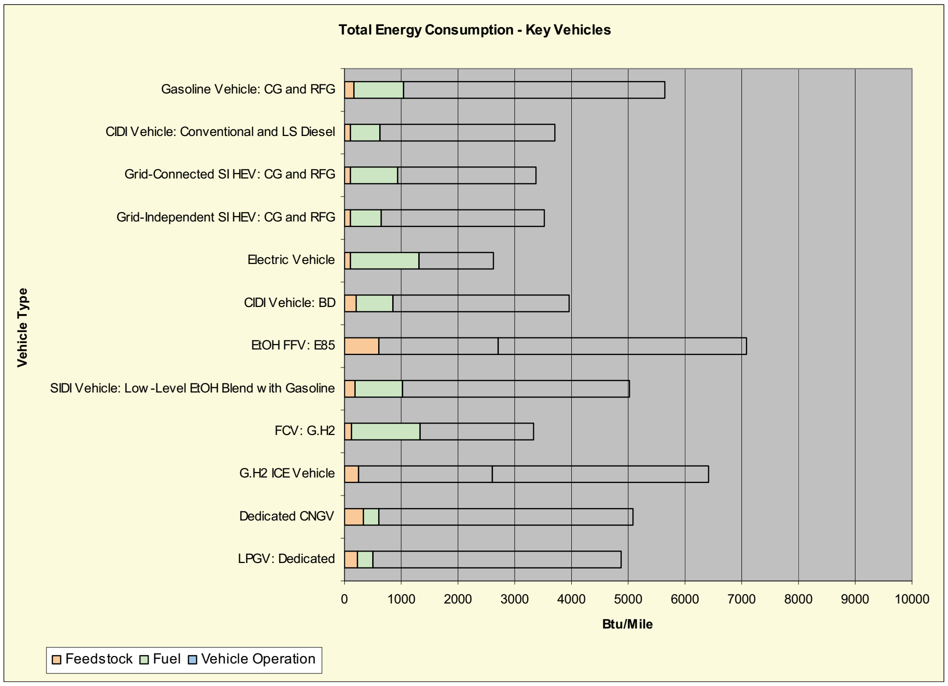


Figure 5: Scenario 1 Petroleum Consumption for Key Vehicles

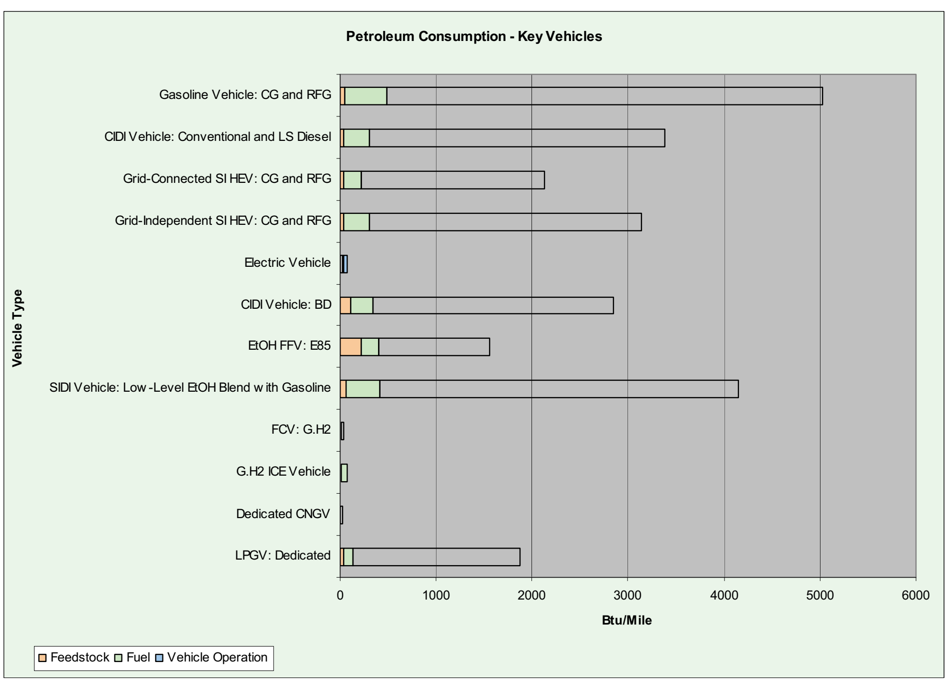


Figure 6: Scenario 1 Greenhouse Gas Emissions for Key Vehicles

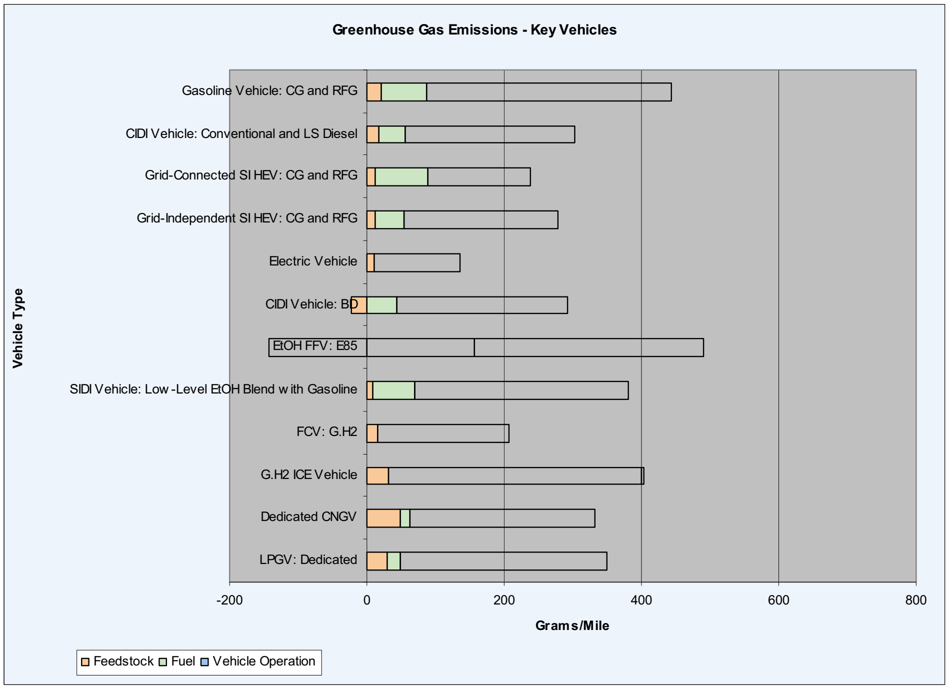


Figure 7: Scenario 2 Total Energy Consumption for Key Vehicles

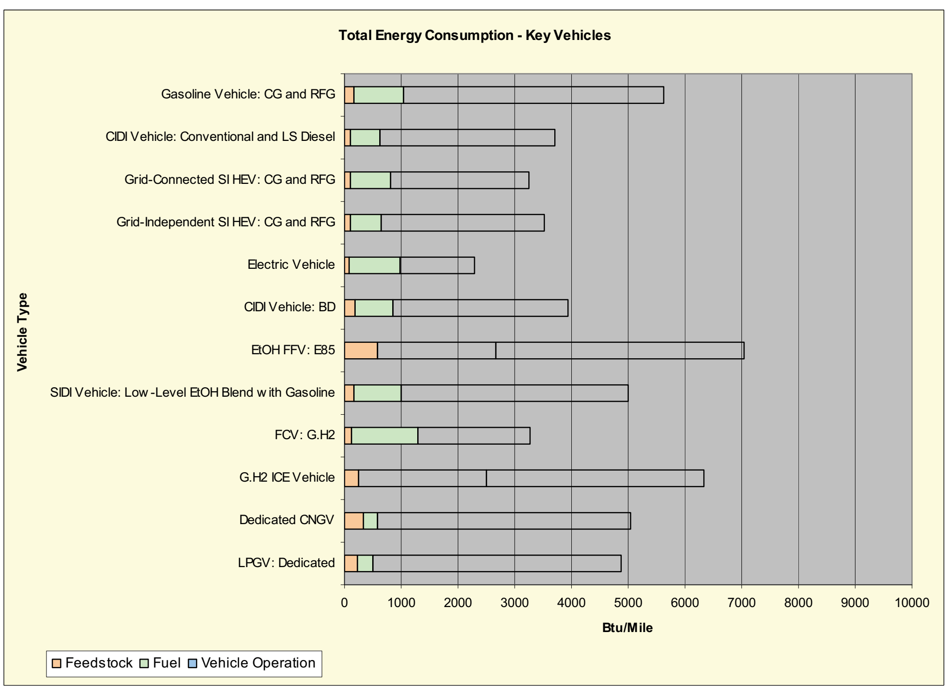


Figure 8: Scenario 2 Petroleum Consumption for Key Vehicles

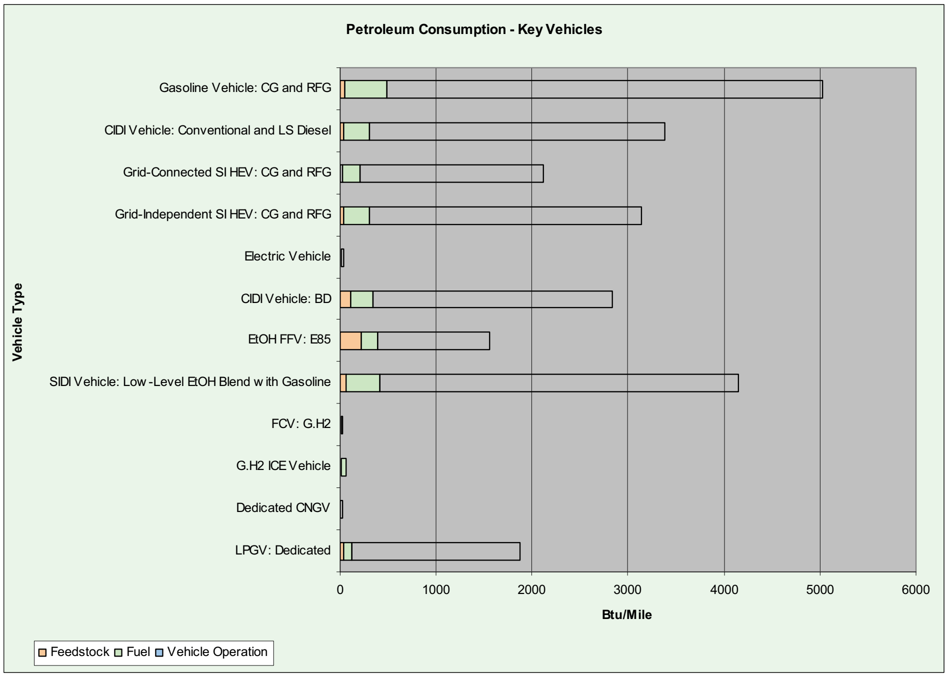


Figure 9: Scenario 2 Greenhouse Gas Emissions for Key Vehicles

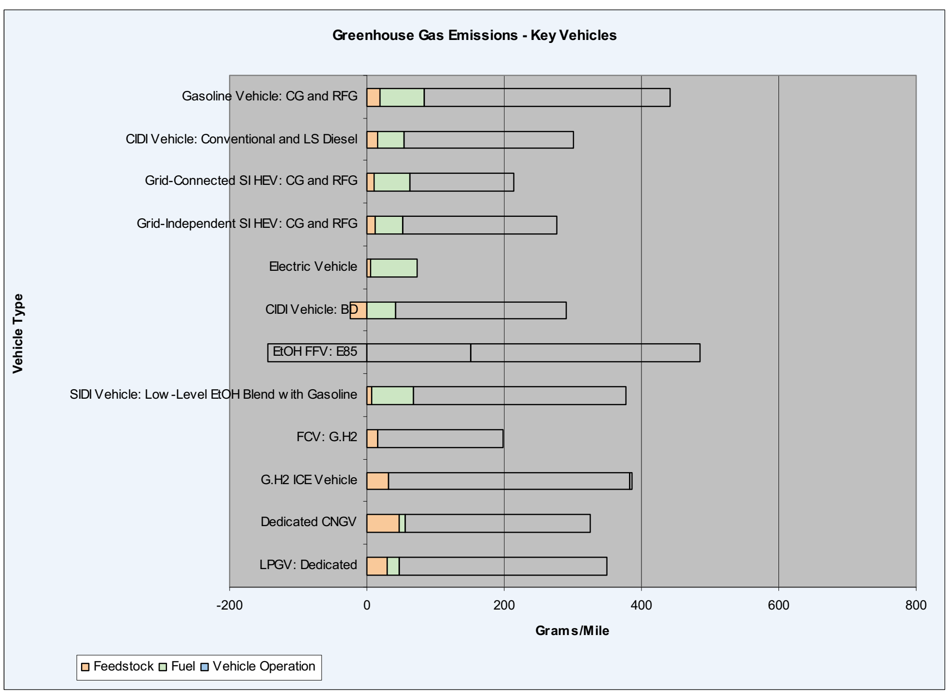


Figure 10: Scenario 3 Total Energy Consumption for Key Vehicles

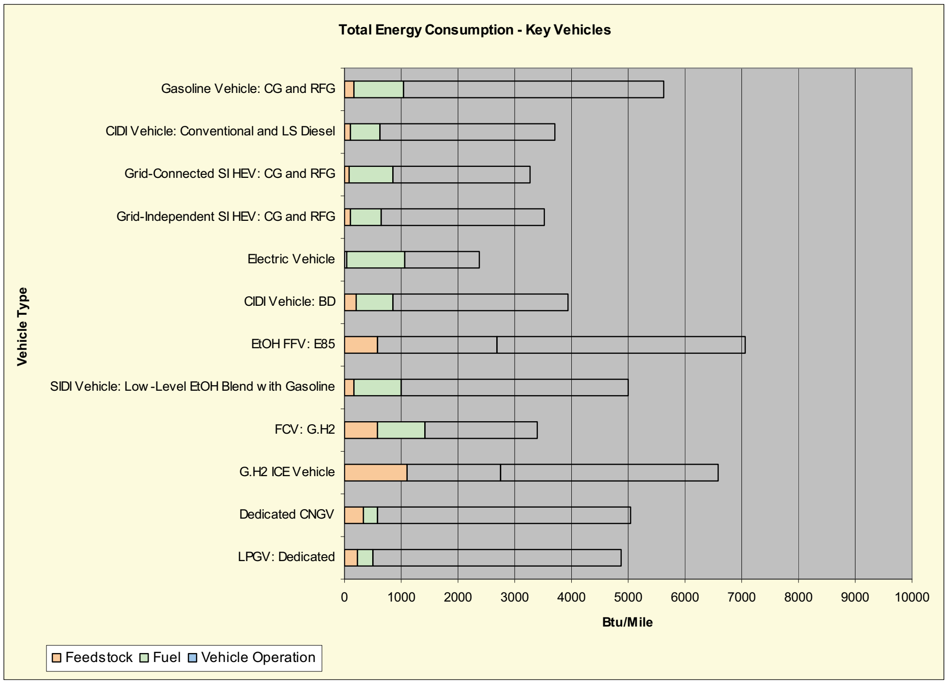


Figure 11: Scenario 3 Petroleum Consumption for Key Vehicles

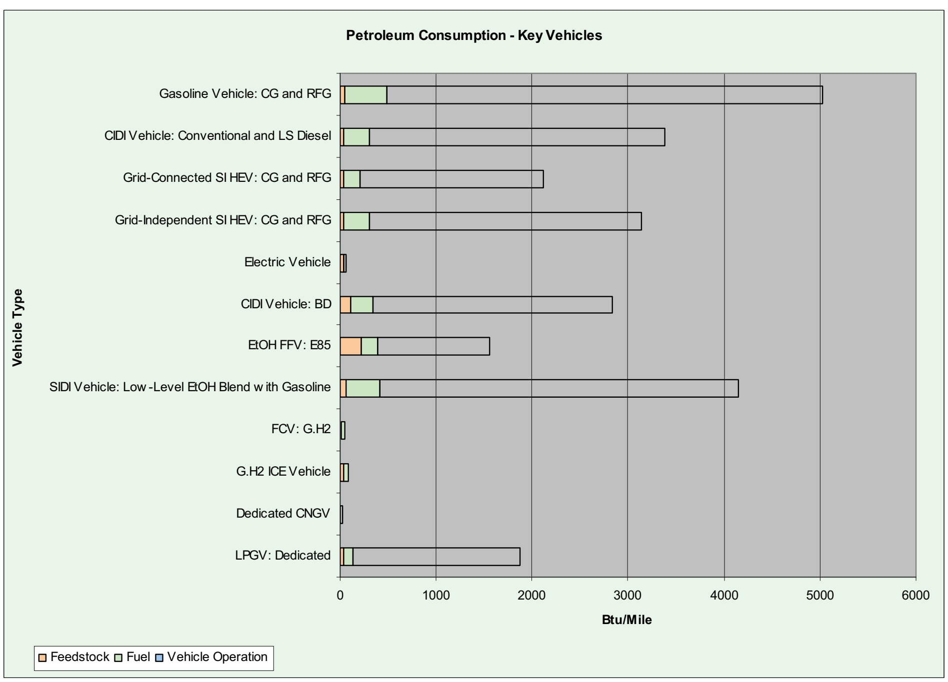


Figure 12: Scenario 3 Greenhouse Gas Emissions for Key Vehicles

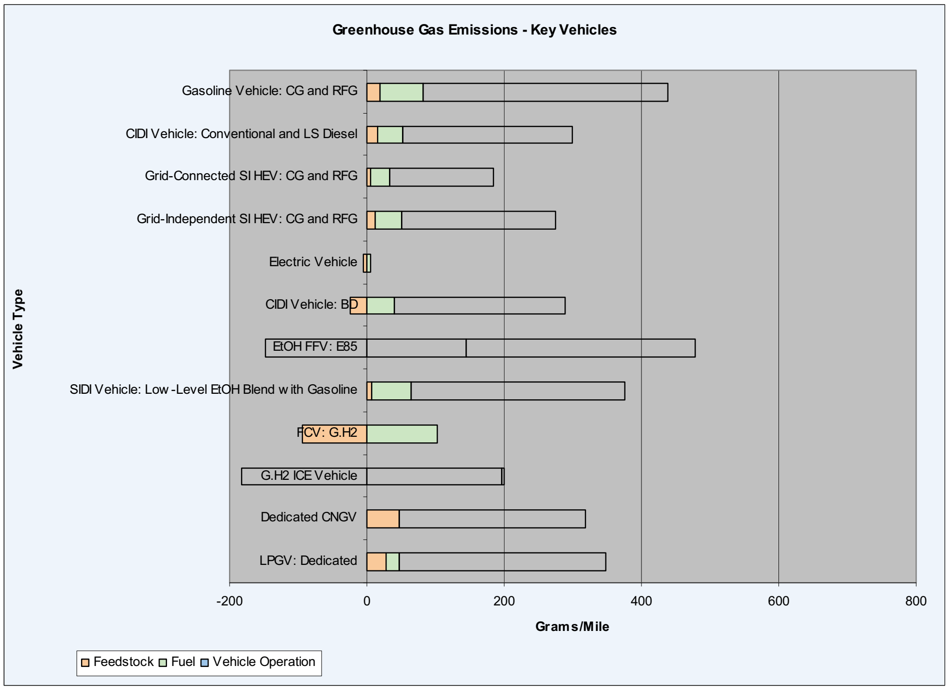


Figure 13: Scenario 4 Total Energy Consumption for Key Vehicles

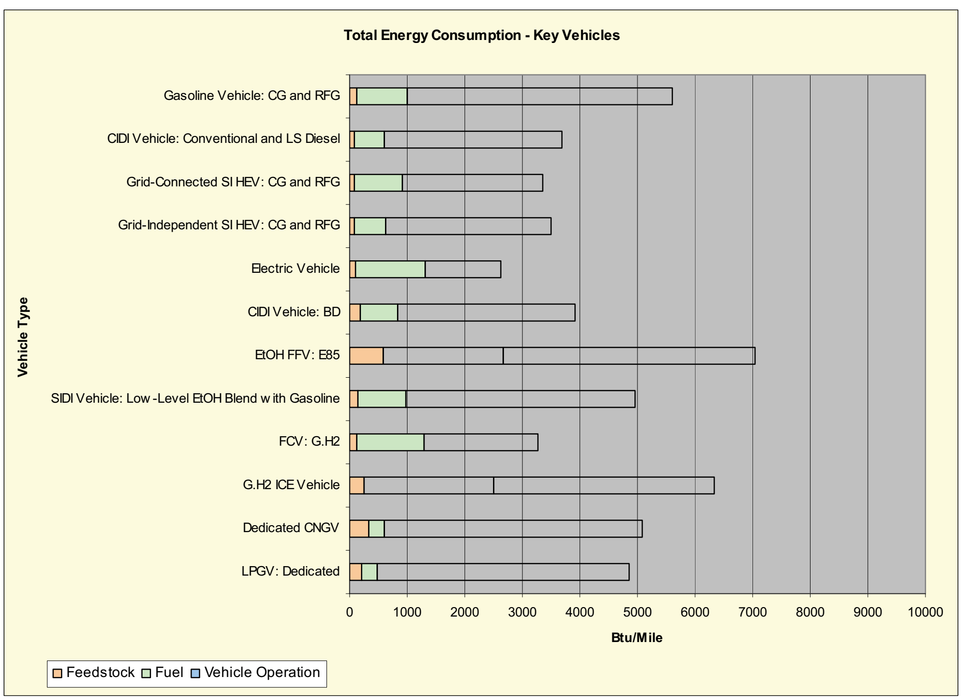


Figure 14: Scenario 4 Petroleum Consumption for Key Vehicles

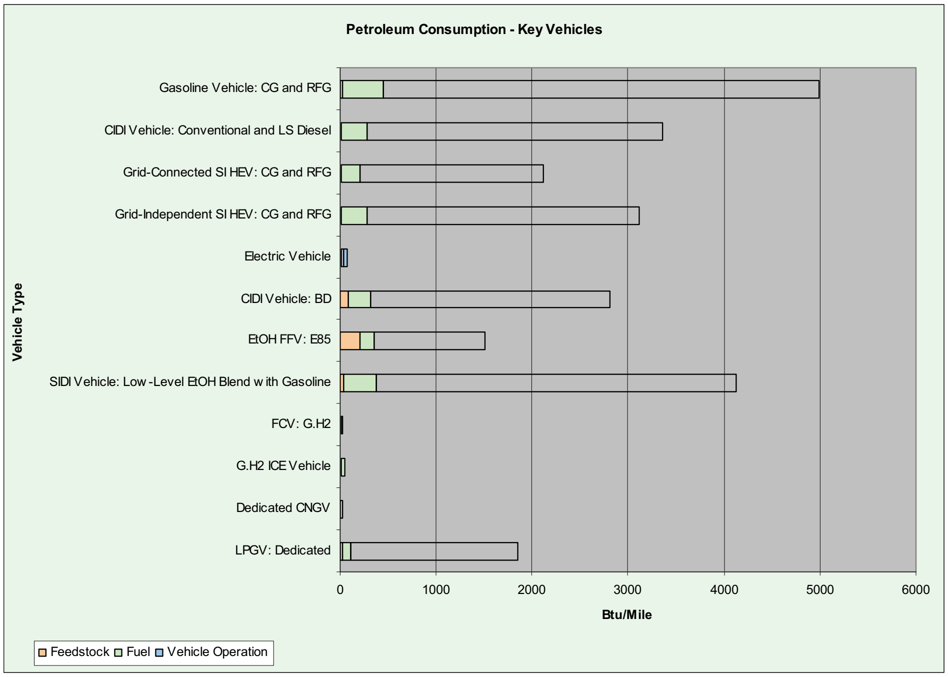


Figure 15: Scenario 4 Greenhouse Gas Emissions for Key Vehicles

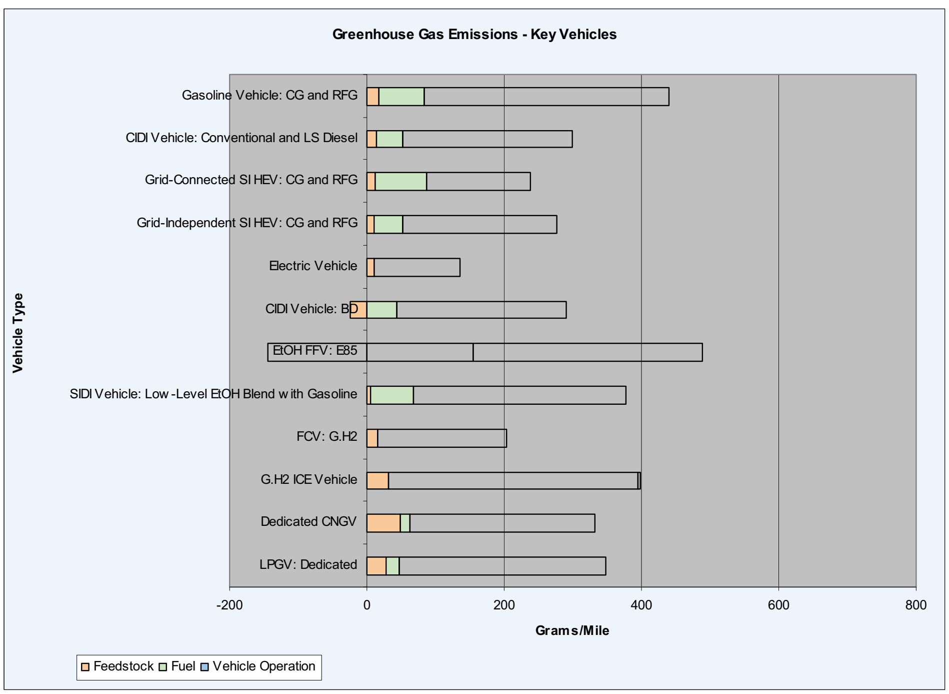


Figure 16: Scenario 5 Total Energy Consumption for Key Vehicles

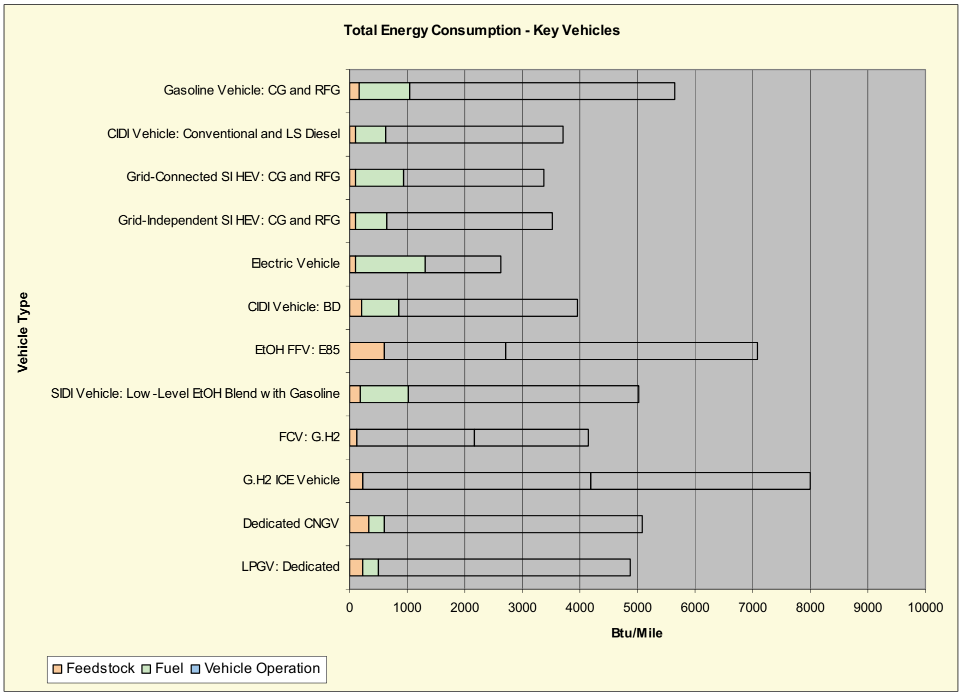


Figure 17: Scenario 5 Petroleum Consumption for Key Vehicles

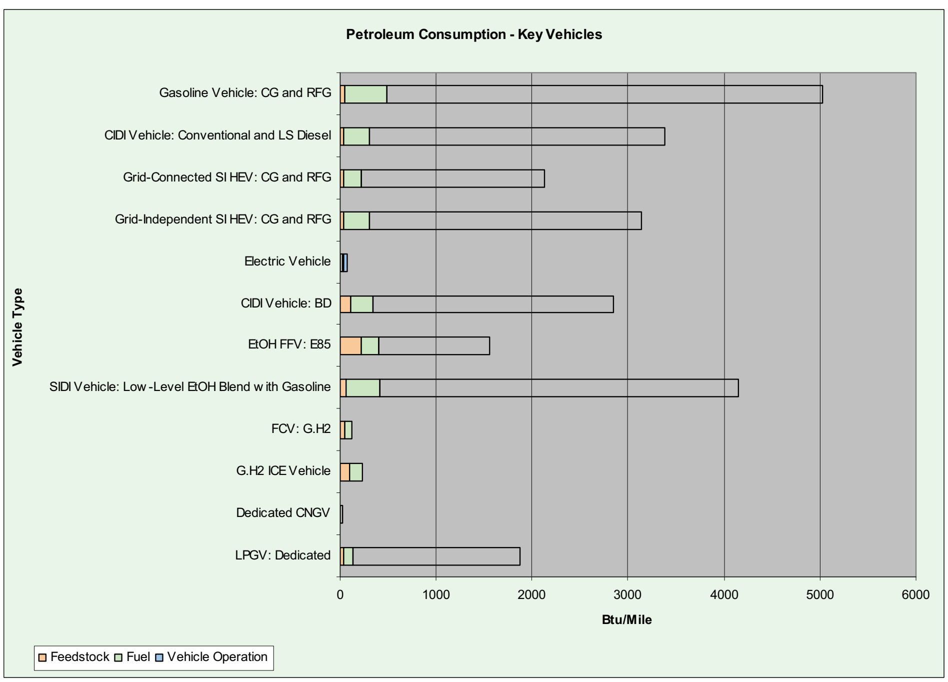


Figure 18: Scenario 5 Greenhouse Gas Emissions for Key Vehicles

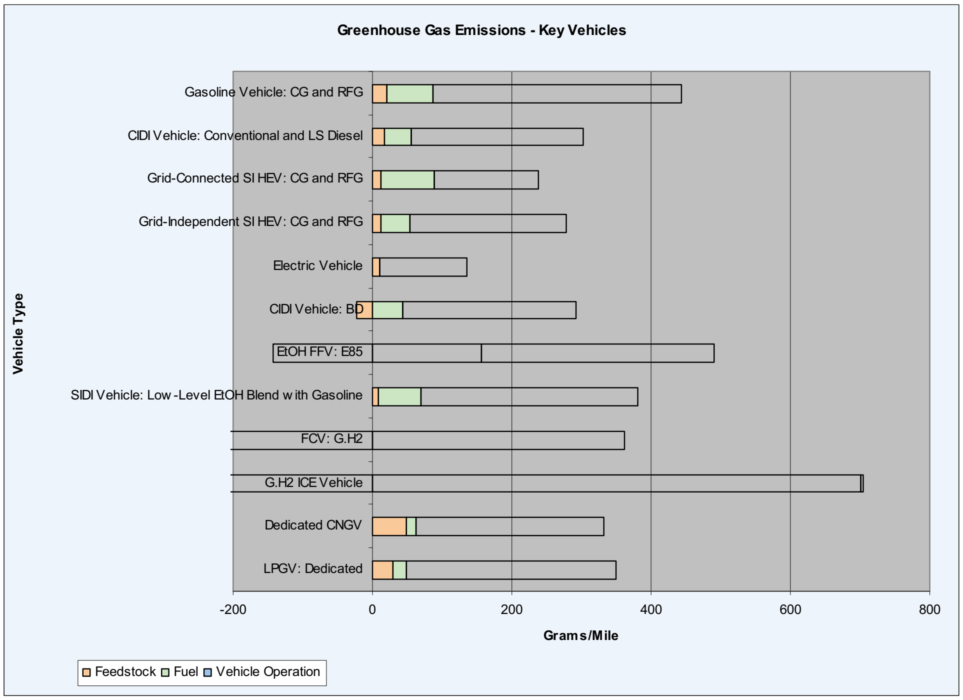


Figure 19: Scenario 6 Total Energy Consumption for Key Vehicles

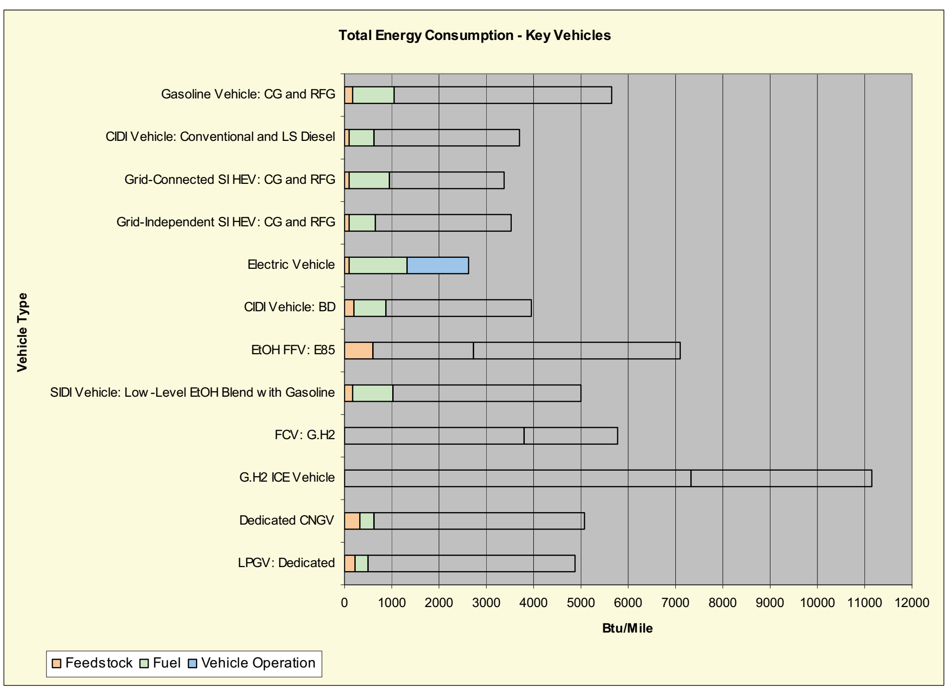


Figure 20: Scenario 6 Petroleum Consumption for Key Vehicles

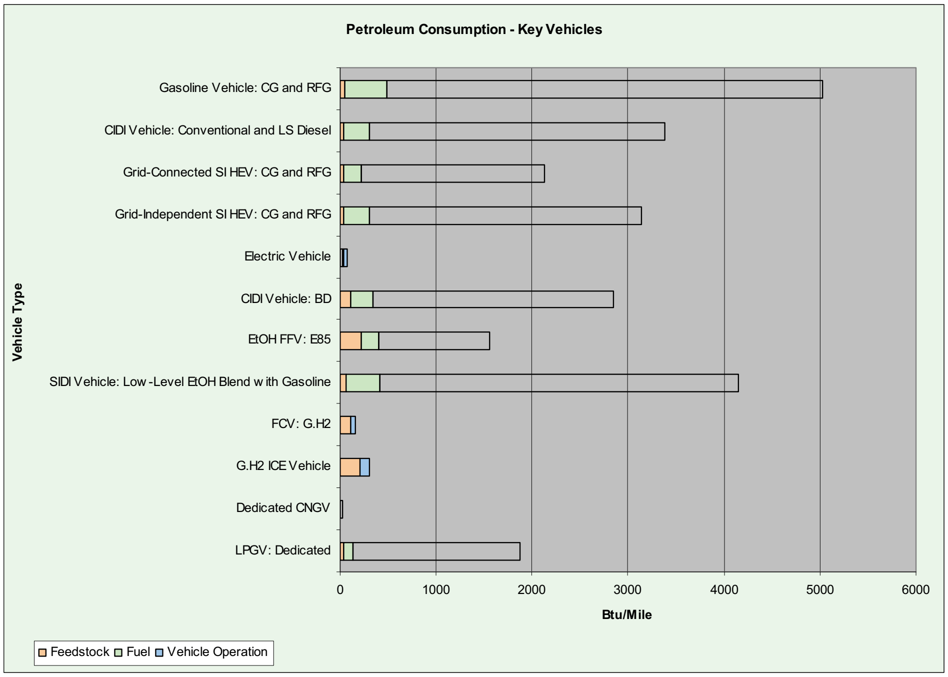


Figure 21: Scenario 6 Greenhouse Gas Emissions for Key Vehicles

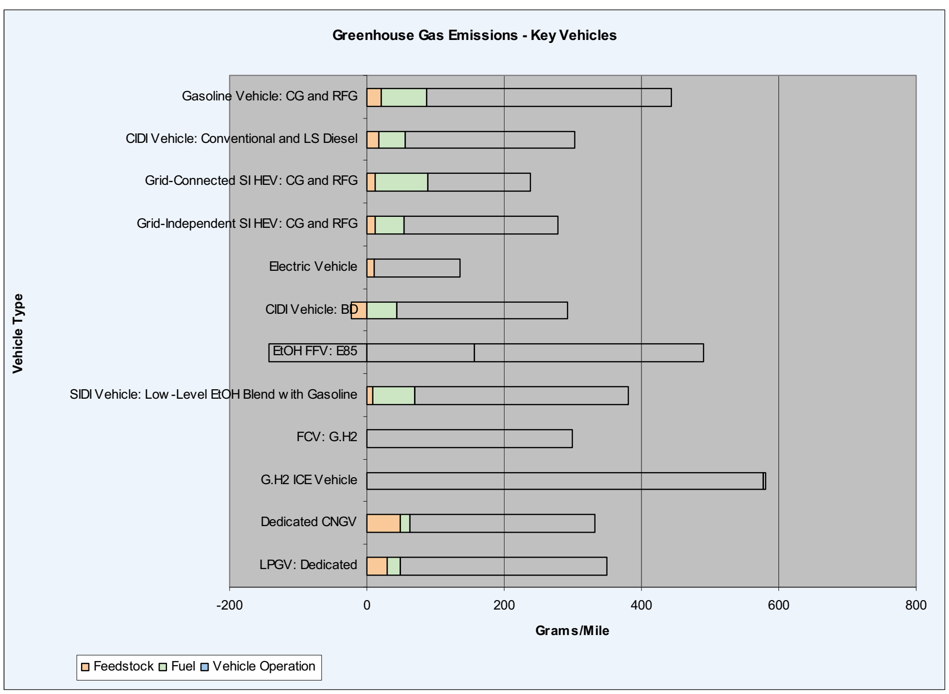


Figure 22: Scenario 7 Total Energy Consumption for Key Vehicles

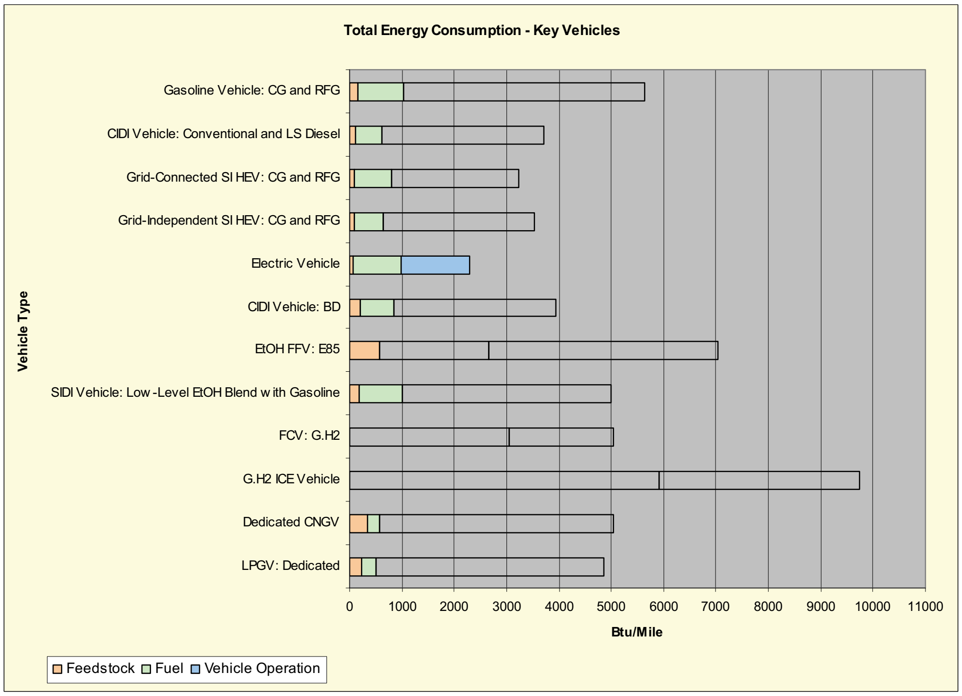


Figure 23: Scenario 7 Petroleum Consumption for Key Vehicles

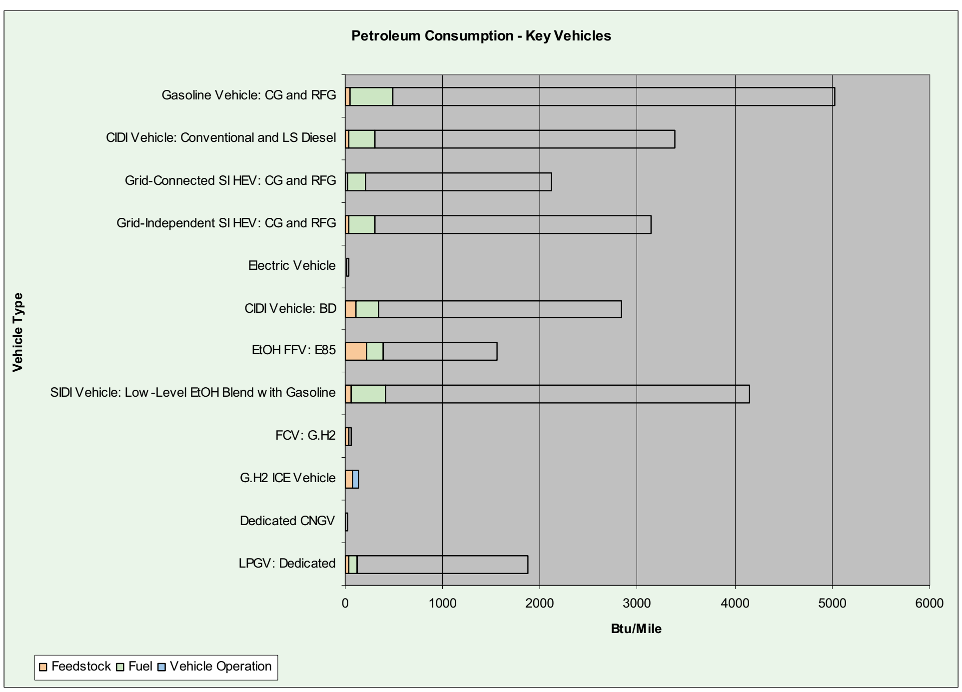


Figure 24: Scenario 7 Greenhouse Gas Emissions for Key Vehicles

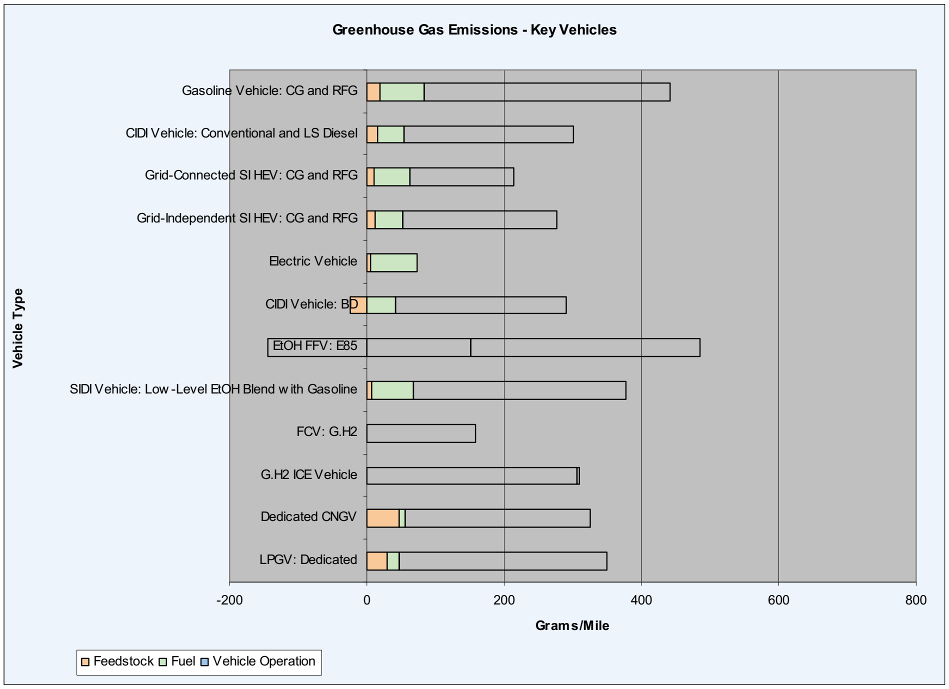


Figure 25: Scenario 8 Total Energy Consumption for Key Vehicles

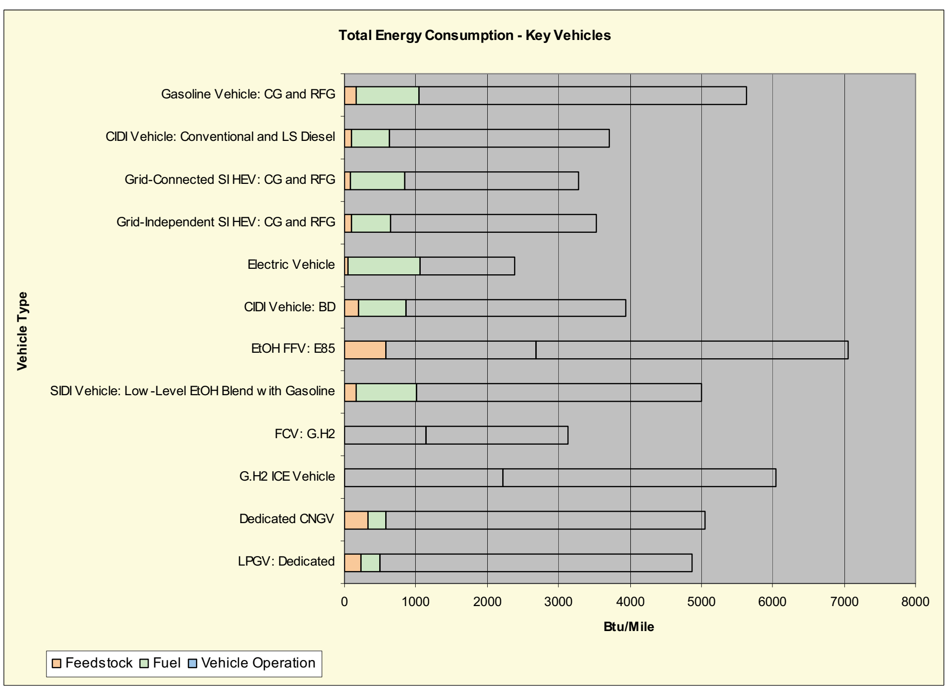


Figure 26: Scenario 8 Petroleum Consumption for Key Vehicles

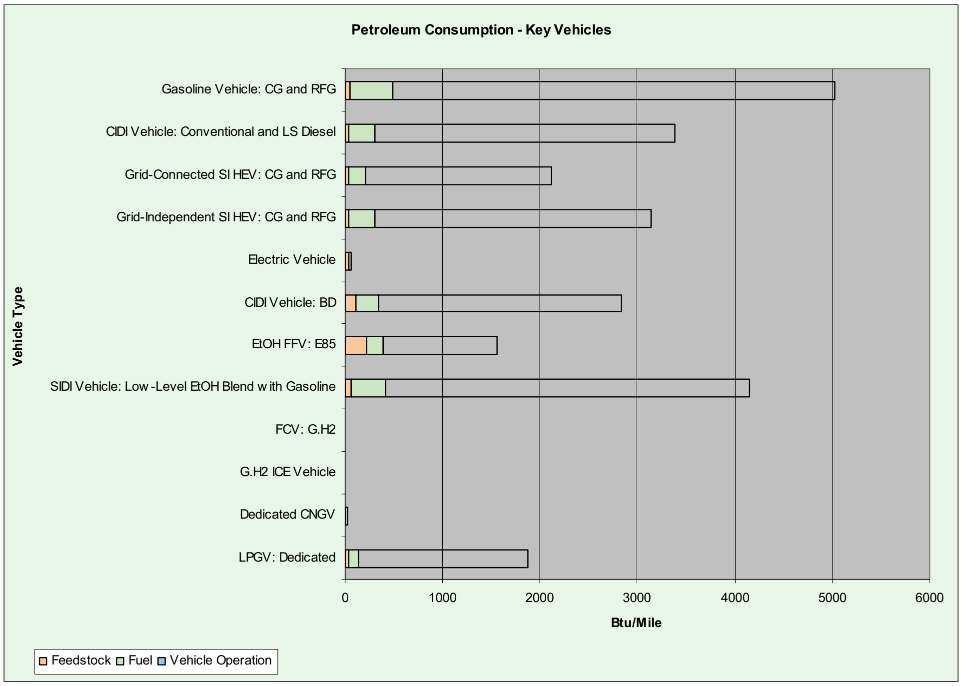


Figure 27: Scenario 8 Greenhouse Gas Emissions for Key Vehicles

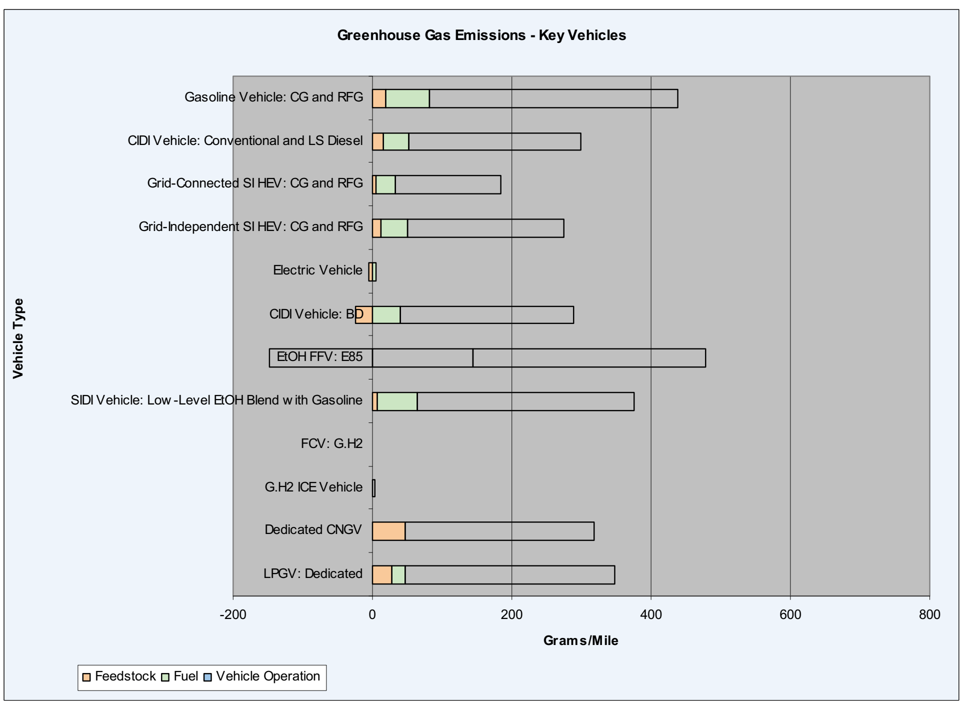


Figure 28: Scenario 9 Total Energy Consumption for Key Vehicles

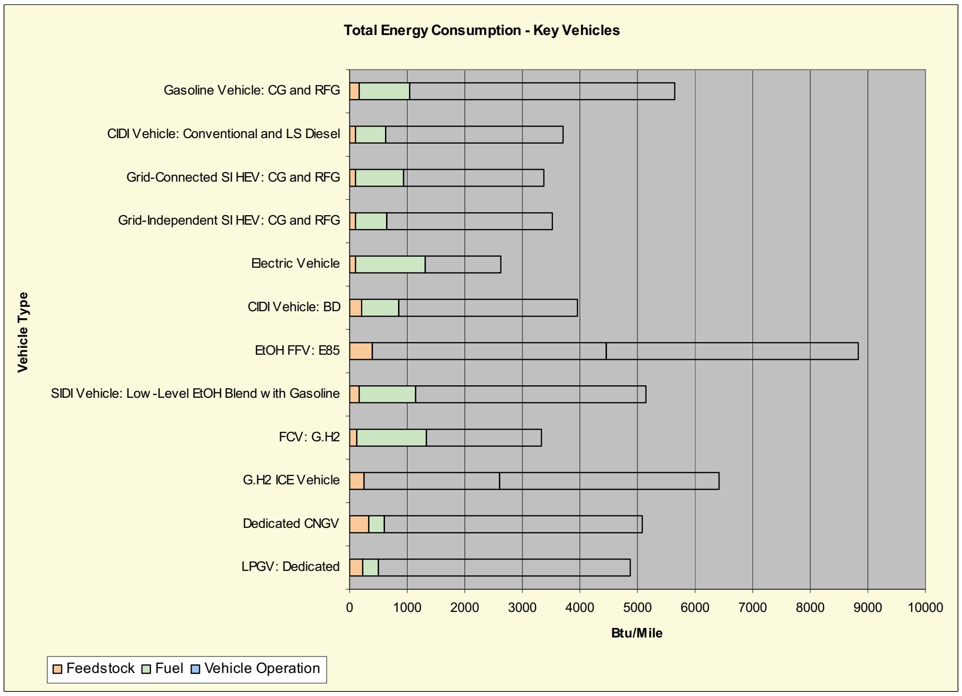


Figure 29: Scenario 9 Petroleum Consumption for Key Vehicles

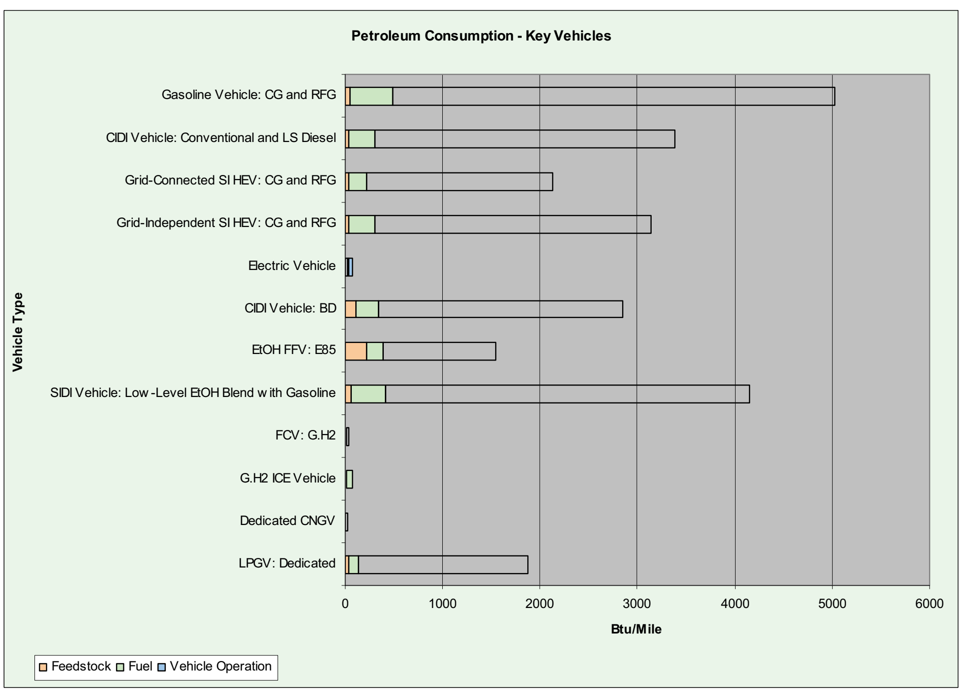


Figure 30: Scenario 9 Greenhouse Gas Emissions for Key Vehicles

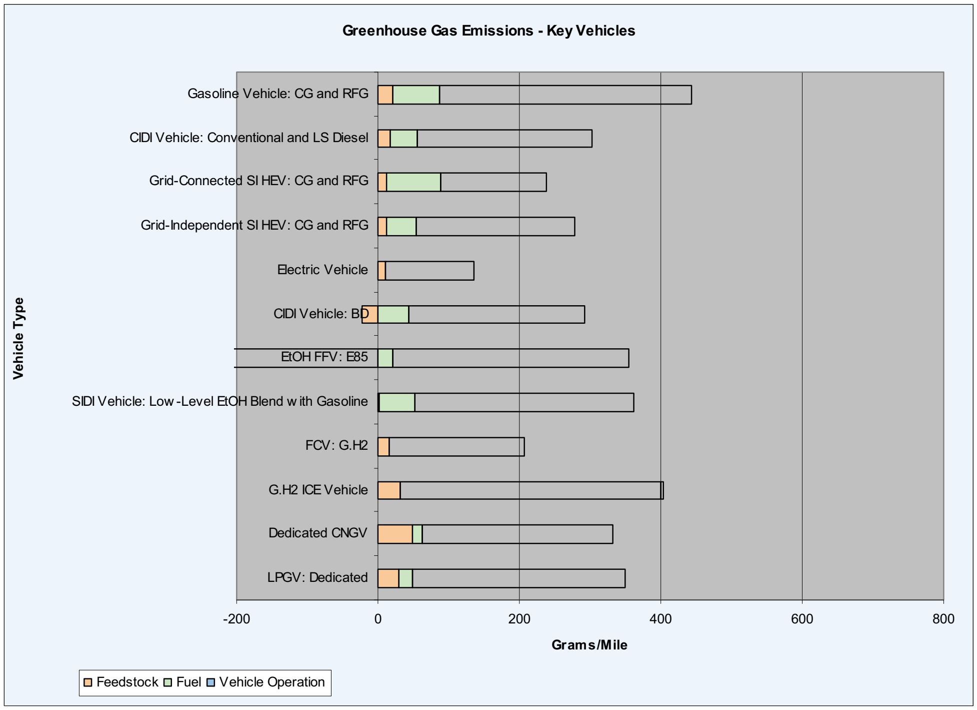


Figure 31: Scenario 10 Total Energy Consumption for Key Vehicles

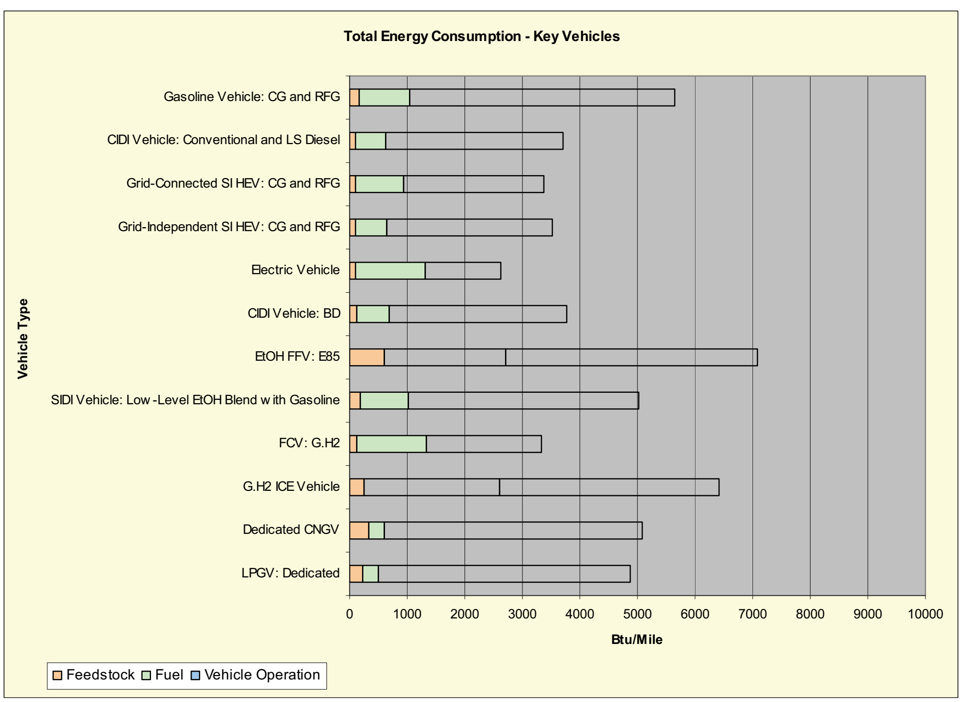


Figure 32: Scenario 10 Petroleum Consumption for Key Vehicles

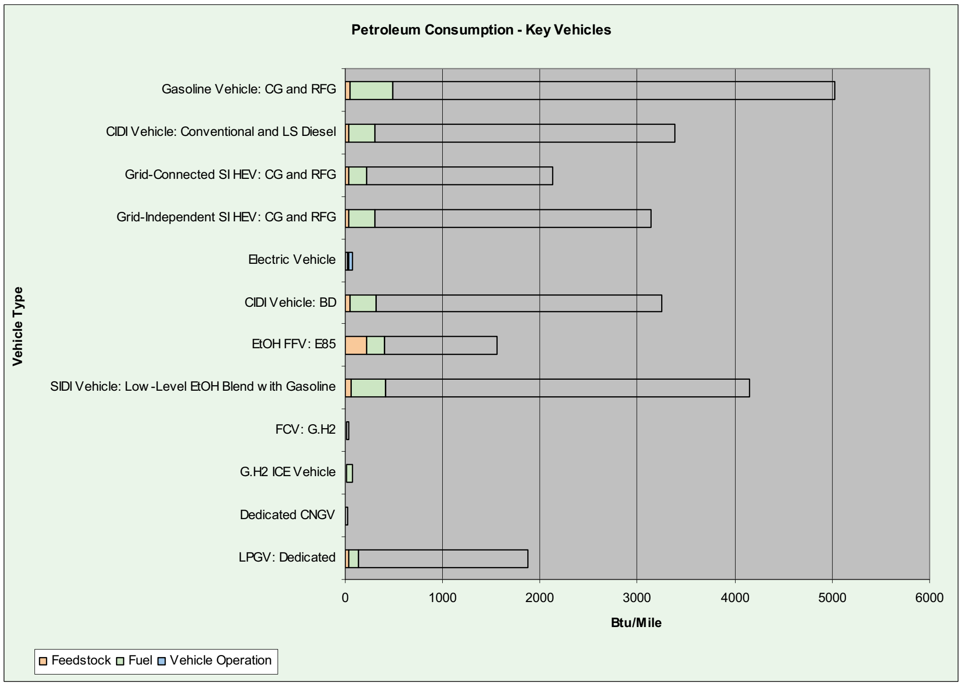


Figure 33: Scenario 10 Greenhouse Gas Emissions for Key Vehicles

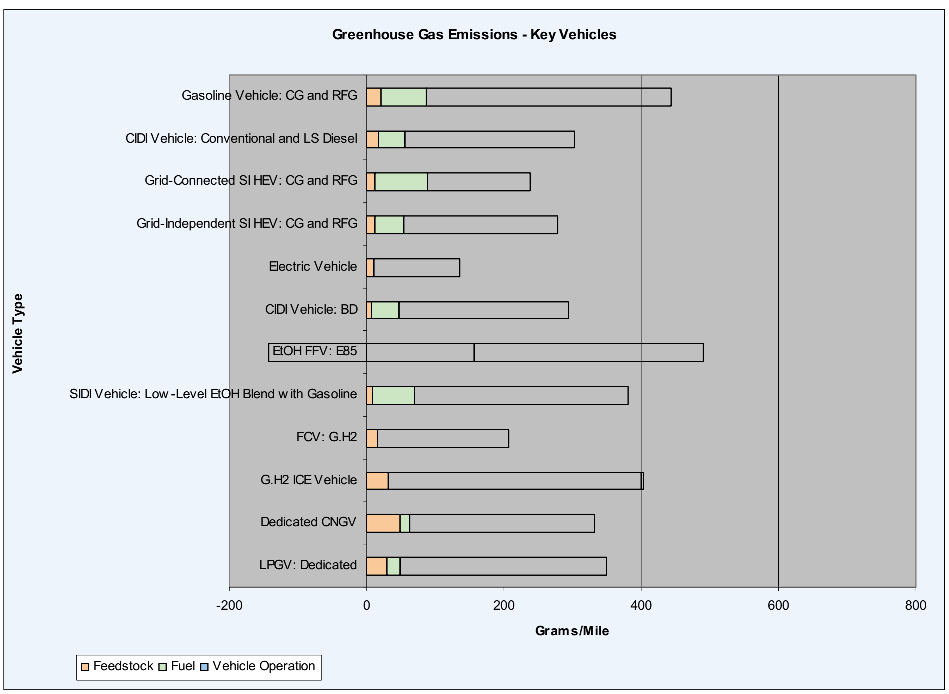


Figure 34: Scenario 11 Total Energy Consumption for Key Vehicles

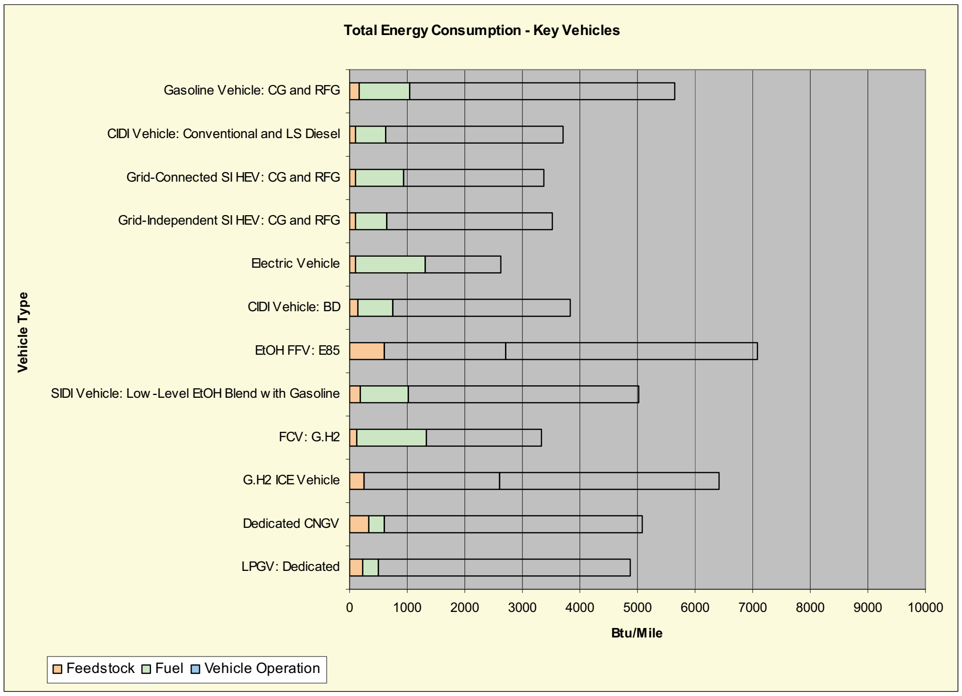


Figure 35: Scenario 11 Petroleum Consumption for Key Vehicles

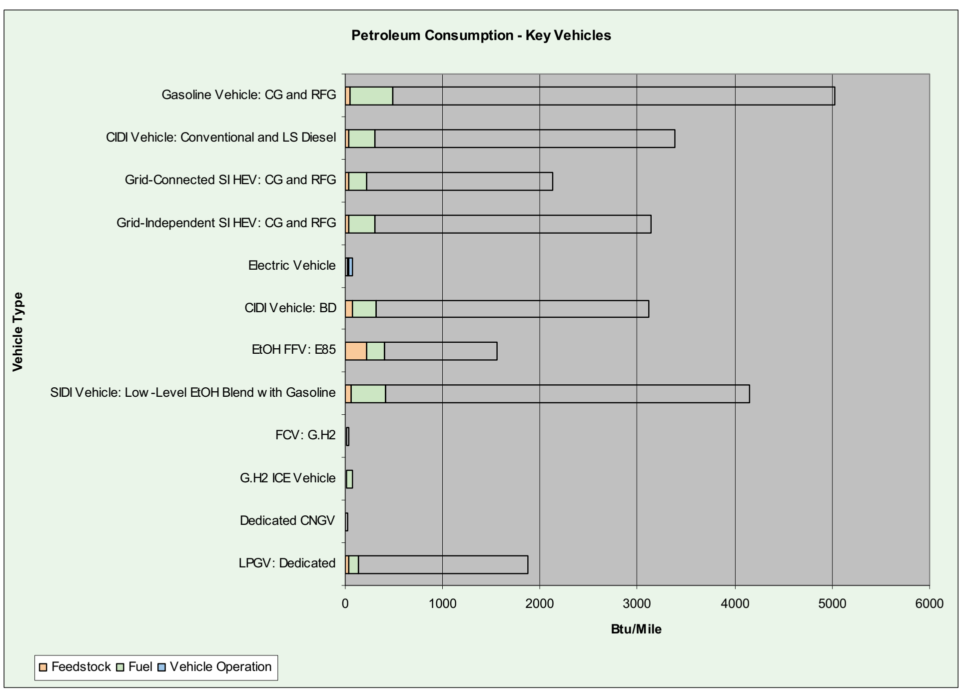


Figure 36: Scenario 11 Greenhouse Gas Emissions for Key Vehicles

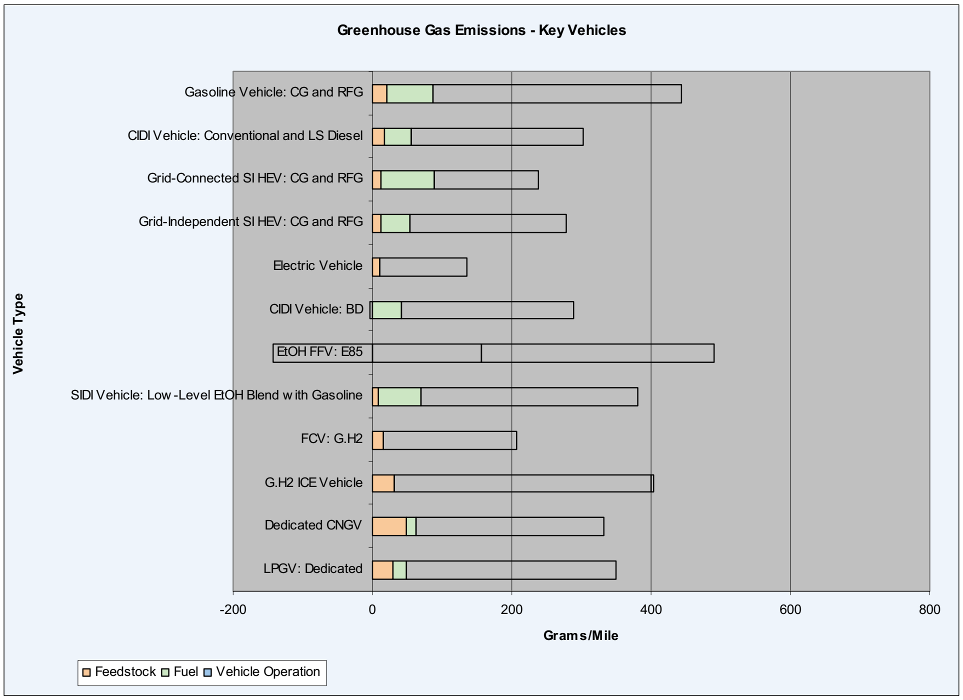


Figure 37: Scenario 12 Total Energy Consumption for Key Vehicles

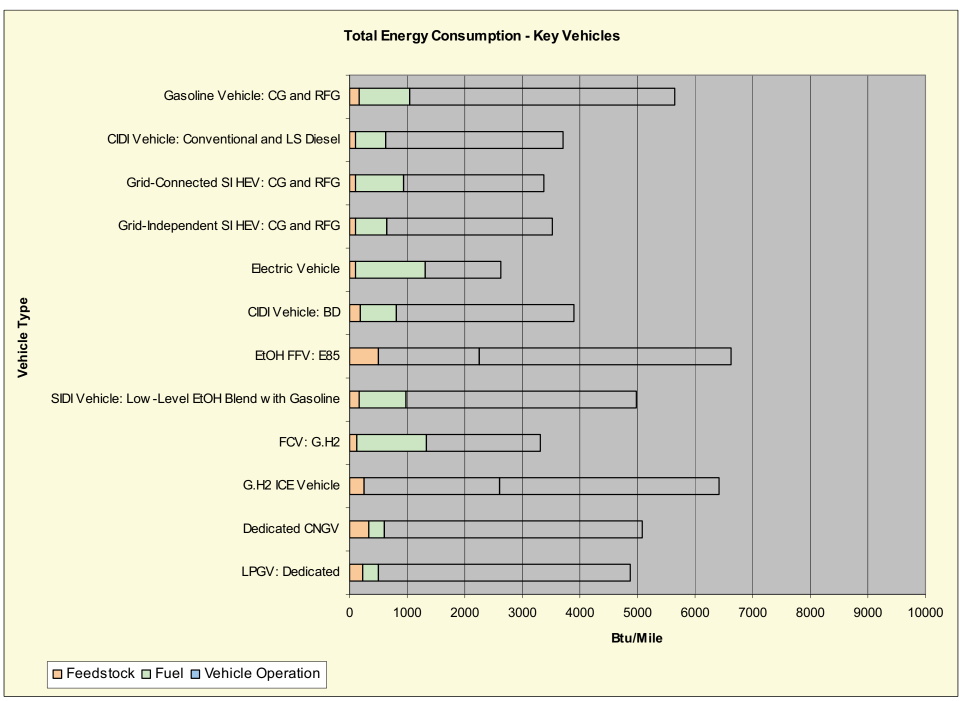


Figure 38: Scenario 12 Petroleum Consumption for Key Vehicles

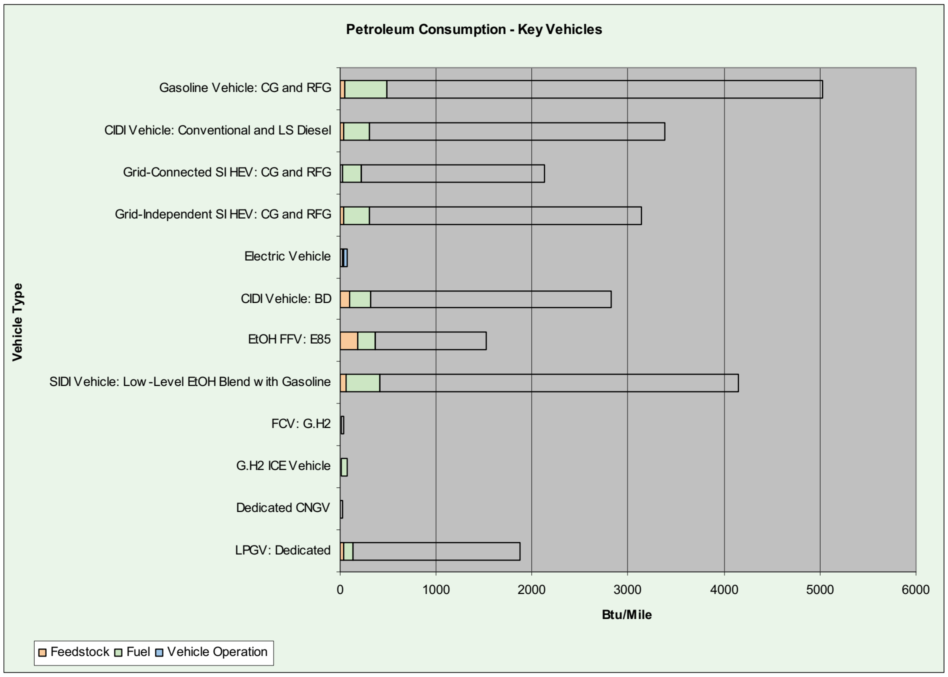
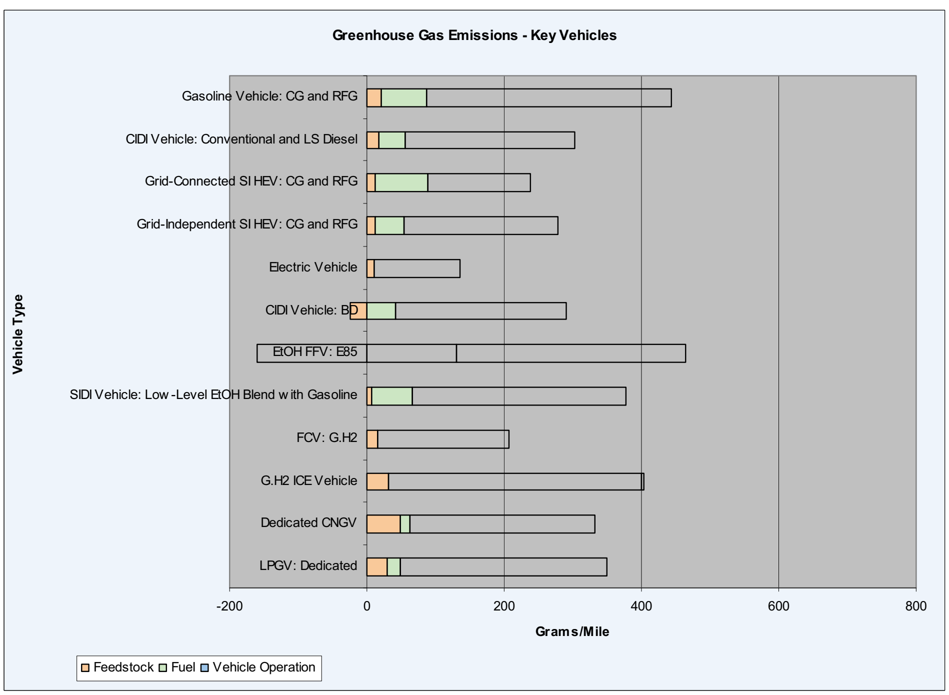


Figure 39: Scenario 12 Greenhouse Gas Emissions for Key Vehicles



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Development and Use of NY-GREET

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