APPENDIX G: LIFE CYCLE ANALYSIS AND PUBLIC HEALTH ASSESSMENT OF BIOFUEL PRODUCTION, TRANSPORTATION, AND USE IN NEW YORK STATE

RENEWABLE FUELS ROADMAP AND SUSTAINABLE BIOMASS FEEDSTOCK SUPPLY FOR NEW YORK

Final Report

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ABSTRACT

This appendix addresses the life cycle environmental and public health impacts of the Roadmap scenarios. To conduct this analysis, the New York Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (NY-GREET) model is applied. NY-GREET allows users to evaluate the total fuel-cycle (i.e., "well-to-wheels") emissions and energy use characteristics of different conventional and alternative fuel vehicles operating in New York State. NY-GREET is used to calculate "well-to-pump", per mile, and aggregate life cycle emissions for each Roadmap scenario. Based on this analysis, lignocellulosic ethanol (LCE) pathways in New York show potential to decrease greenhouse gas (GHG) emissions by millions of tons annually compared to gasoline. Moreover, these benefits are even greater under a distributed, localized biofuels industry (as modeled in Scenario 3). Corn ethanol and soy biodiesel production also reduce GHGs and petroleum consumption, though to a lesser degree than LCE. The tradeoffs associated with biofuels production include increased emissions of some air pollutants that may lead to increased public health concerns in locations where feedstock expansion and fuel production occur.

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Life cycle analysis (LCA) of biofuel production requires consideration of not only the energy, environmental, and health impacts associated with fuel consumption (i.e., "downstream effects"), but also the impacts that occur during feedstock production, fuel processing, and transportation and distribution of fuel (i.e., "upstream effects"). This appendix addresses these life cycle components through analysis and modeling of the biofuel pathway scenarios presented in Appendix L of this report.

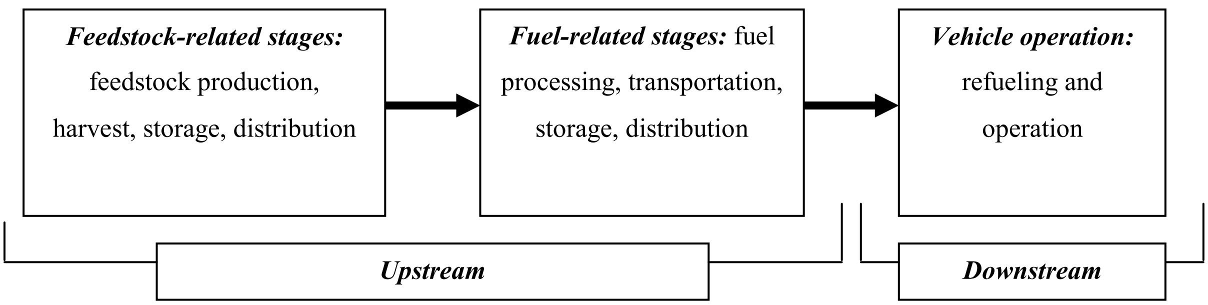
The analysis relies on the New York Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (NY-GREET) model (Winebrake and Meyer 2007; Winebrake, et al. 2009) to conduct the analysis. This model is based on the national GREET model developed at Argonne National Lab, but uses input assumptions relevant for New York State (such as electricity mix, fuel transportation distances, and agricultural assumptions). NY-GREET was recently upgraded to match the updated national version of GREET (version 1.8c published in May 2009). Using NY-GREET, the life cycle energy use and emissions associated with various biofuel pathways are explored and compared to other transportation fuels.

This appendix also discusses public health issues related to the increased production and use of biofuels in New York. Public health issues include potential health impacts in the downstream and upstream components of the fuel cycle. These public health impacts are presented through a review of the literature on this topic. Important research questions that should be addressed as the biofuels industry develops are also identified.

2 TOTAL FUEL CYCLE ANALYSIS MODELING

This appendix presents the results of a total fuel-cycle analysis of the energy and emissions impacts from the biofuel scenarios discussed previously. These analyses are sometimes referred to as a "well-to-wheels" (W2W) analysis, although with biofuels this could be called a "field-to-wheels" analysis. The analysis considers energy use and emissions from the production and extraction of fuel or feedstock (e.g., growing corn and harvesting from fields, herbaceous or woody biomass from fields and forests), the processing of that fuel (e.g., refining corn or lignocellulosic biomass into ethanol), and ultimately the distribution and use of the processed fuel in the vehicle itself. Figure G-1 identifies the components of a total fuel cycle, partitioned in "upstream" and "downstream" categories.

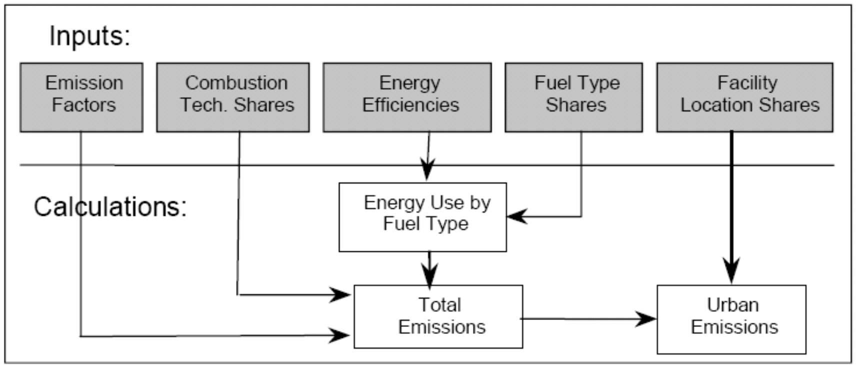
Figure G-1. Components of a total fuel-cycle from Winebrake, Wang, et al. (2001).



Each stage in the fuel-cycle in Figure G-1 includes activities that produce greenhouse gases (GHGs) and air 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.

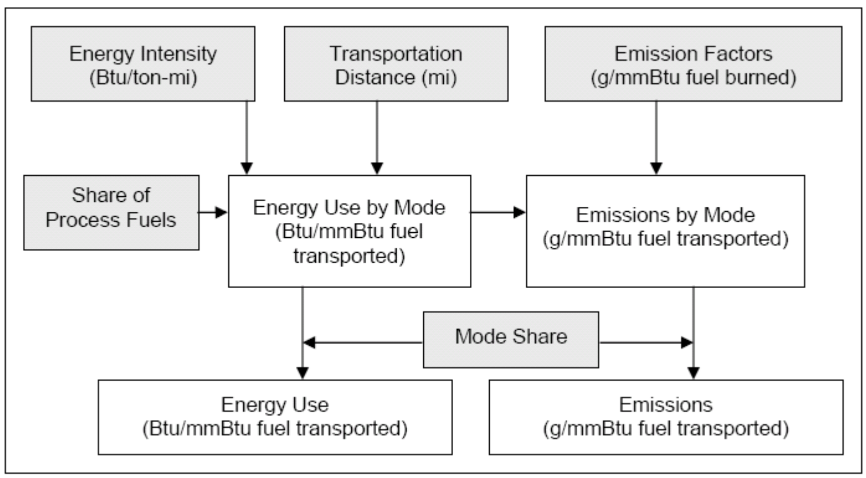
Process fuels consumed at each upstream stage (for example, diesel fuel used in farming and harvesting equipment, electricity and natural gas used in biofuel production and petroleum refining) also have their own fuel-cycle chains that must be considered. These processes are called "up-upstream" processes. 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 is called the "up-stream process" (Winebrake, Wang et al. 2001). The previously mentioned NY-GREET model was used to calculate emissions from up-stream and downstream fuel-cycle stages for each Roadmap scenario. More detailed information on NY-GREET can be found elsewhere (Winebrake and Meyer 2007). In general, each stage in the production of a given fuel is assessed based on the technologies, fuels, and other inputs used to produce the fuel. Figure G-2 and Figure G-3 show the general inputs and outputs to the model.

Figure G-2. Inputs and Outputs for NY-GREET.



Source: (Brinkman et al. 2005)

Figure G-3. Graphical Representation of Inputs and Outputs for T&D Aspects of NY-GREET.



Source: (Brinkman et al. 2005)

3 LCA FOR BIOFUEL ROADMAP SCENARIOS BY PRICE CASE

3.1 OVERVIEW

A LCA was conducted for each price case of the Roadmap scenarios. Each scenario included five lignocellulosic (LCE) feedstock-to-ethanol pathways (corn stover, willow, hardwood[1] forest residue, softwood[2] forest residue, and grass), a corn-to-ethanol pathway, and a soybean-to-biodiesel pathway.

The energy and environmental impacts addressed in this analysis include: energy (Btu), GHGs (namely, carbon dioxide [CO_2], nitrous oxide [N_2O], and methane [CH_4]), nitrogen oxides (NO_x), volatile organic compounds (VOCs), sulfur oxides (SO_x), and particulate matter with aerodynamic diameters of 10 microns or less (PM_{10}).

Results are presented by feedstock (LCE, corn, and soy). Within each feedstock, scenario results are shown. The scenarios represent the three Roadmap scenarios, with the letter "a" and "b" denoting the $3/gallon gasoline equivalent (gge) price base case and the $4/gge price case, respectively; in each scenario the base case (a) is the lower fuel price sensitivity case - unsubsidized direct competition with petroleum based fuels. This generates a total of six (6) cases (three scenarios with two cases each): 1a, 1b, 2a, 2b, 3a, 3b. The first five tables of each scenario describe the following:

(1) *Feedstock Production Inputs.* This table presents key input data for the feedstock production component of the LCA. These data are generated from New York sources and are based on analysis discussed in Appendix E of this report. The data differ from national averages and across scenarios. The data include farming energy use, fertilizer use, and direct land use emissions assumptions.

(2) *Feedstock Quantity and Transportation Data*. This table shows the amount of feedstock (in wet tons) transported to biorefineries based on an aggregation of all the feedstock flows for each scenario. These flows were generated through modeling work discussed in Appendix F of this report. The table shows total ton-miles by feedstock and average distances from field to biorefinery location for each feedstock.

(3) *Ethanol Production Quantities by Feedstock and Production Technology*. This table presents the amount of feedstock and ethanol production that occurs across all biorefinery locations, highlighting the portion of ethanol produced by each feedstock type.

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[1] Hardwood: One of the botanical groups of dicotyledonous trees that have broad leaves in contrast to the conifers or softwoods. The term has no reference to the actual hardness of the wood. The botanical name for hardwoods is angiosperms. Short-rotation, fast growing hardwood trees are being developed as future energy crops. Examples include: Hybrid poplars (*Populus sp*.), Hybrid willows (*Salix sp.*), Silver maple (Acer saccharinum), and Black locust (Robinia pseudoacacia).

[2] Generally, one of the botanical groups of trees that in most cases have needle-like or scale-like leaves; the conifers; also the wood produced by such trees. The term has no reference to the actual hardness of the wood. The botanical name for softwoods is gymnosperms.

(4) *Ethanol Production Quantities by Biorefinery and Fuel Transportation and Distribution (T&D) Distances*. This table shows the total amount of ethanol produced at each biorefinery location for a given scenario. The table also indicates the distance that this fuel must travel to the blending facility.

(5) *Ethanol v. Gasoline Well-to-Pump Energy Use and Emissions*. This table shows energy use and emissions that take place during feedstock and fuel production components of the total fuel cycle, and delivery to the fuel pump. This table excludes the energy use and emissions during vehicle operation. The data are presented in terms of energy use and emissions per delivery of one million Btu to the pump.

These are followed by a series of five graphs that show the results of our analysis. These graphs present the following:

(1) *Emissions by Pollutant and Fuel Cycle Stage for Biofuel Production and Use*. This graph shows the lifecycle emissions of GHGs, CO_2, N_2O, VOC, NO_x, PM_{10}, and SO_x for the biofuel (ethanol or biodiesel) production and use for each scenario. Here, emissions are divided by each of three major stages of the fuel cycle: feedstock production and transport; fuel production and transport; and fuel use in a light-duty vehicle optimized for E85/B20 or gasoline/diesel, as appropriate. The units for the Y-axis are metric tons (mt) with the exception of GHGs and CO_2 (in which case the units are in thousands of metric tons). The GHG value includes CO_2, N_2O, and CH_4 (not shown on the graph) in CO_2-equivalent units (CO_2eq) using a 100-year global warming potential.

(2) *Emissions by Pollutant for Conventional Fuel Production and Use*. This graph shows the lifecycle emissions for conventional fuels (gasoline or diesel).

(3) *Total Fuel Cycle Emissions Comparison between Biofuel and Conventional Fuel.* This graph compares emissions of biofuel v. conventional fuel under each scenario. These represent emissions changes for a given scenario due to the displacement of conventional fuel with the total biofuel production in said scenario.

(4) *Percentage Change in Emissions*. This graph shows the percentage change in each of the emissions types if conventional fuel were to be displaced by biofuel under each scenario.

(5) *Total Fuel Cycle Energy Consumption Comparison between Biofuel and Conventional Fuel.* This graph compares the total fuel cycle energy consumption of biofuel v. conventional fuel under each scenario.

The next section describes all the LCE feedstock cases, followed by the corn-to-ethanol pathway and the soybean-to-biodiesel pathway.

3.2 LIGNOCELLULOSIC ETHANOL (LCE) CASES

3.2.1 Scenario 1

Scenario 1 depicts a biofuels industry in which rapid development of a lignocellulosic biofuels industry occurs, circa 2020-2030. For this modeling exercise, rapid development of lignocellulosic feedstock resources is assumed on a portion of suitable and available rural lands. The available land base excludes all land currently in food production. Potential feedstock production is estimated to be as follows (millions of dry tons): Hardwood chips 3.44, softwood chips 1.37, warm-season grass 2.28, short-rotation willow 2.06, and corn stover 0.25. Wood chips would be from well-managed harvests primarily of low-value wood from existing forests. The grass and willow would use a combined 0.98 million acres of land currently in herbaceous cover that is not required to meet current agricultural needs. Indirect land use change is assumed to be negligible. Conversion technology is assumed to have met the cost and performance expectations for the first generation of lignocellulosic biorefineries (biochemical and thermochemical systems). In this scenario's base case four lignocellulosic biorefinery locations could be profitably built, producing ethanol at a total production capacity of 354 MGY at four sites selected as to be central to the resource producing regions of New York. Average capacity at each of the four sites is near 90 MGY. In addition, in all scenarios we show that the current corn ethanol capacity in New York should be able to continue to operate profitably, adding 154 MGY of grain ethanol.

Scenario #1a.

Table G-1. Scenario 1a LCE Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (Btu/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer [b]	$CaCO_3$ (g/bu or g/dt)[c]	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover[a]	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Willow	106,449	2,207.0	3.3%	0	0.0	0.0	18.5	0
Hardwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0

[a]These data are related to corn production, from which corn stover is derived. These values apply to a bushel (bu) of corn. Corn stover is considered a by-product of corn grain production. [b]GREET national default and IPCC approach assumes 1.3% of the sum of nitrogen in fertilizer and nitrogen in above and below ground biomass is converted to N_2O. Roadmap agricultural N_2O emissions calculations reflect only N in fertilizer (not N in biomass) thus the percentage is substantially higher (i.e. 3.6% of N fertilizer vs. 1.3% of N in fertilizer plus N in biomass). This note applies to all LCE scenarios and price cases. [c]$CaCO_3$ is calcium carbonate; P_2O_5 is phosphorus oxide; and K_2O is potassium oxide. These are all fertilizers used for crop production. [d] Btu = British thermal unit; bu= bushel; dt = dry ton; g = gram

Table G-2. Scenario 1a LCE Feedstock Quantity and Transportation.

	Corn Stover	Willow	Softwood	Hardwood
Wet Tons of Feedstock	32,540	2,760,960	1,517,240	3,383,400
Ton-Miles	792,137	128,487,736	57,653,257	125,753,001
Average Miles Feedstock to Biorefinery	24.34	46.54	38.00	37.17

Table G-3. Scenario 1a LCE Production by Feedstock.

Feedstock	Technology	Dry tons of feedstock	Yield (Gal/dt)	Gallons ethanol	% of total Ethanol	Electricity Export (kwh/gal)
Corn Stover	Gasification	28,310	75.8	2,145,898	0.6%	0
Willow	Gasification	1,518,530	83.4	126,645,402	35.8%	0
Hardwood	Gasification	1,860,870	83.0	155,196,558	43.8%	0
Softwood	Gasification	834,480	84.0	70,179,768	19.8%	0
Total				**354,167,626**		

Table G-4. Scenario 1a LCE Production and Fuel Transportation to Blending Terminal.

Biorefinery	Technology	Ethanol Yield (MGY)	% of Total Scenario 1a Ethanol	Distance to Blending Terminal (Miles)
D3678608	Gasification	96.5	27%	56.5
D3665255	Gasification	81.2	23%	27.9
D3654881	Gasification	85.0	24%	2.0
D3654716	Gasification	91.5	26%	22.4
Average Fuel Transportation Distance				**28.1**

Table G-5. Scenario 1a LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu (MMBtu) of Fuel Available at Pump.[3]

Item	Conventional	LCE Ethanol
Total Energy (Btu/MMBtu)	262,434	1,405,056
WTP Efficiency	79.2%	41.6%
Fossil Fuels (Btu/MMBtu)	221,724	211,295
Coal (Btu/MMBtu)	24,631	35,186
Natural Gas (Btu/MMBtu)	100,954	91,019
Petroleum (Btu/MMBtu)	96,139	85,090
CO_2 (g/MMBtu)	15,856	-52,483
CH_4 (g/MMBtu)	108	35
N_2O (g/MMBtu)	1.5	13
GHGs (gCO2eq/MMBtu)	18,998	-47,695
VOC (g/MMBtu)	27	30
CO (g/MMBtu)	17	143
NOx (g/MMBtu)	48	125
PM_{10} (g/MMBtu)	8	24
$PM_{2.5}$ (g/MMBtu)	4	11
SOx (g/MMBtu)	19	15

[3] Well-to-pump energy use and emissions refer to energy use and emissions that take place during feedstock and fuel production, and delivery to the fuel pump. Negative CO_2 and GHG values represent the role of feedstocks acting as carbon sinks during growth. These values do not include the energy use and emissions during vehicle operation.

Figure G-4. Scenario 1a Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

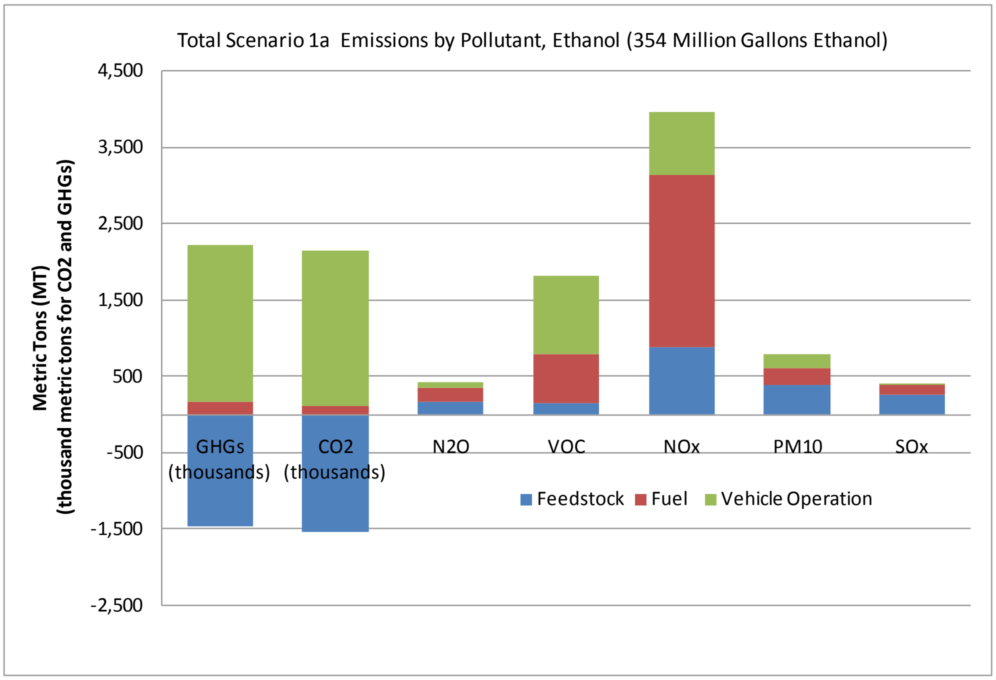


Figure G-5. Scenario 1a Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

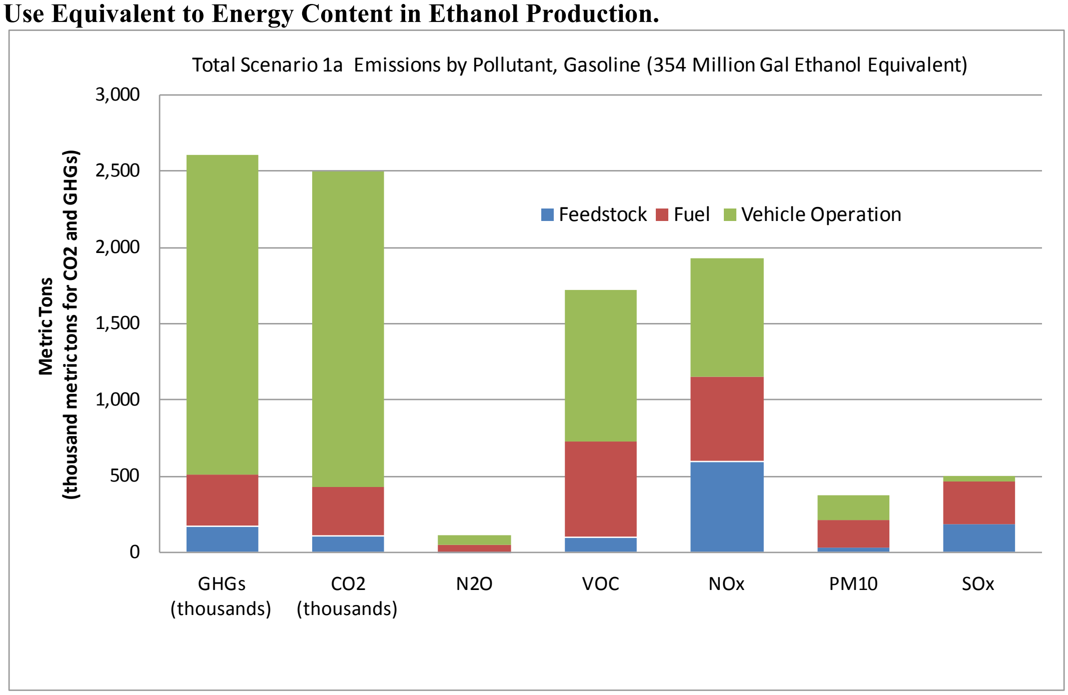


Figure G-6. Scenario 1a Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline Highlighting Differences (Gallons of Ethanol Equivalent—GEE).

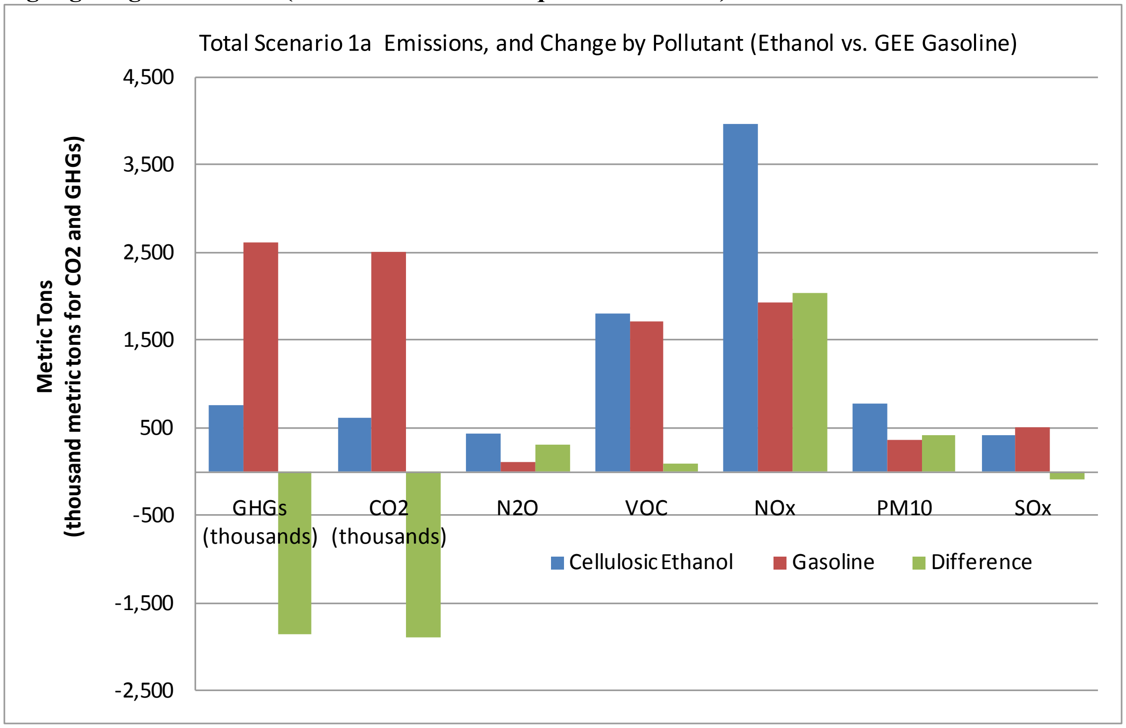


Figure G-7. Scenario 1a Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

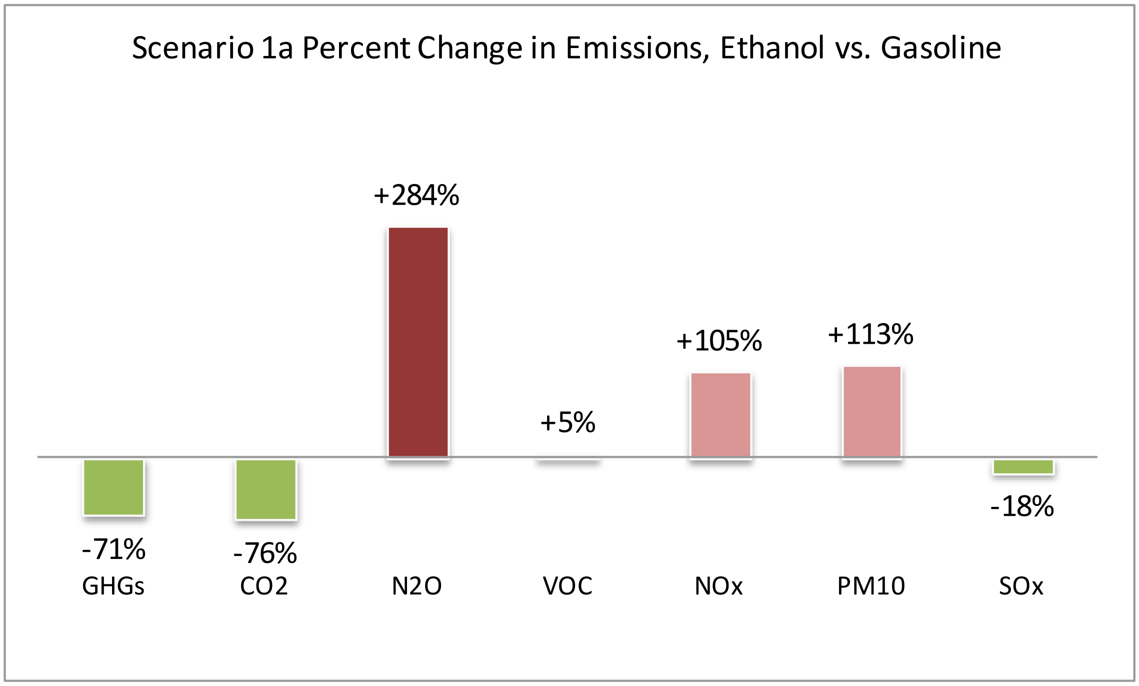
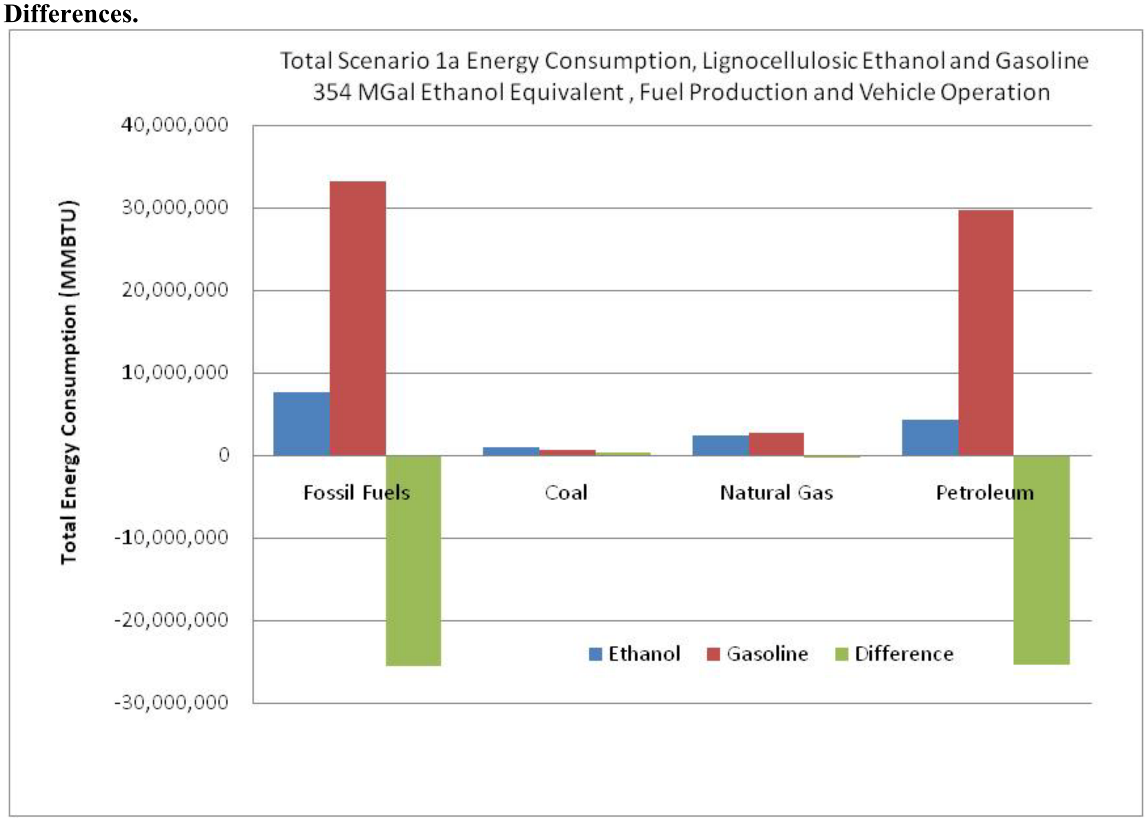


Figure G-8. Scenario 1a Comparison between Ethanol and Gasoline Energy Use Highlighting Differences.



Scenario #1b.

Table G-6. Scenario 1b Cellulosic Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (Btu/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer	$CaCO_3$ (g/bu or g/dt)	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Grasses	75,223	5,453.0	3.3%	8,078	582.0	7125.0	64.6	0
Willow	106,449	2,314.0	3.3%	0	0.0	0.0	24.0	0
Hardwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0

Table G-7. Scenario 1b LCE Feedstock Quantity and Transportation.

	Corn Stover	Grass	Willow	Softwood	Hardwood
Wet Tons of Feedstock	287,290	2,616,900	3,743,800	2,494,180	6,250,420
Ton-Miles	22,770,595	155,949,610	222,233,028	143,191,236	360,381,618
Average Miles Feedstock to Biorefinery	79.4	59.6	59.4	57.4	57.7

Table G-8. Scenario 1b LCE Production by Feedstock.

Feedstock	Technology	Dry tons of feedstock	Yield (Gal/dt)	Gallons ethanol	% of total Ethanol	Electricity Export (kWh/gal)
Corn Stover	Gasification	249,940	75.8	18,945,452	2.5%	0
Grass	Gasification	2,276,710	77.8	177,128,038	23.0%	0
Willow	Gasification	2,059,090	83.4	171,728,106	22.3%	0
Hardwood	Gasification	3,437,730	83.0	286,706,682	37.2%	0
Softwood	Gasification	1,371,800	84.0	115,368,380	15.0%	0
			Total Gallons Ethanol	**769,876,658**		

Table G-9. Scenario 1b LCE Production and Fuel Transportation to Blending Terminal.

Biorefinery	Technology	Ethanol Yield (MGY)	% of Total Scenario 1b Ethanol	Distance to Blending Terminal (Miles)
D3678608	Gasification	219.1	28%	56.5
D3665255	Gasification	148.2	19%	27.9
D3654881	Gasification	192.8	25%	2.0
D3654716	Gasification	209.7	27%	22.4
			Average Fuel Transportation Distance	**28.1**

Table G-10. Scenario 1b LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu of Fuel Available at Pump.

Item	Conventional Gasoline	LCE Ethanol
Total Energy (Btu/MMBtu)	262,687	1,447,263
WTP Efficiency	79.2%	40.9%
Fossil Fuels (Btu/MMBtu)	221,559	227,966
Coal (Btu/MMBtu)	24,622	36,602
Natural Gas (Btu/MMBtu)	100,649	95,972
Petroleum (Btu/MMBtu)	96,288	95,392
CO_2 (g/MMBtu)	15,459	-51,212
CH_4 (g/MMBtu)	108	36.618
N_2O (g/MMBtu)	1	22.035
GHGs (gCO2eq/MMBtu)	18,499	-43,730
VOC (g/MMBtu)	27	31
CO (g/MMBtu)	17	147
NOx (g/MMBtu)	42	129
PM_{10} (g/MMBtu)	8	24
$PM_{2.5}$ (g/MMBtu)	3	11
SOx (g/MMBtu)	17	17

Figure G-9. Scenario 1b Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

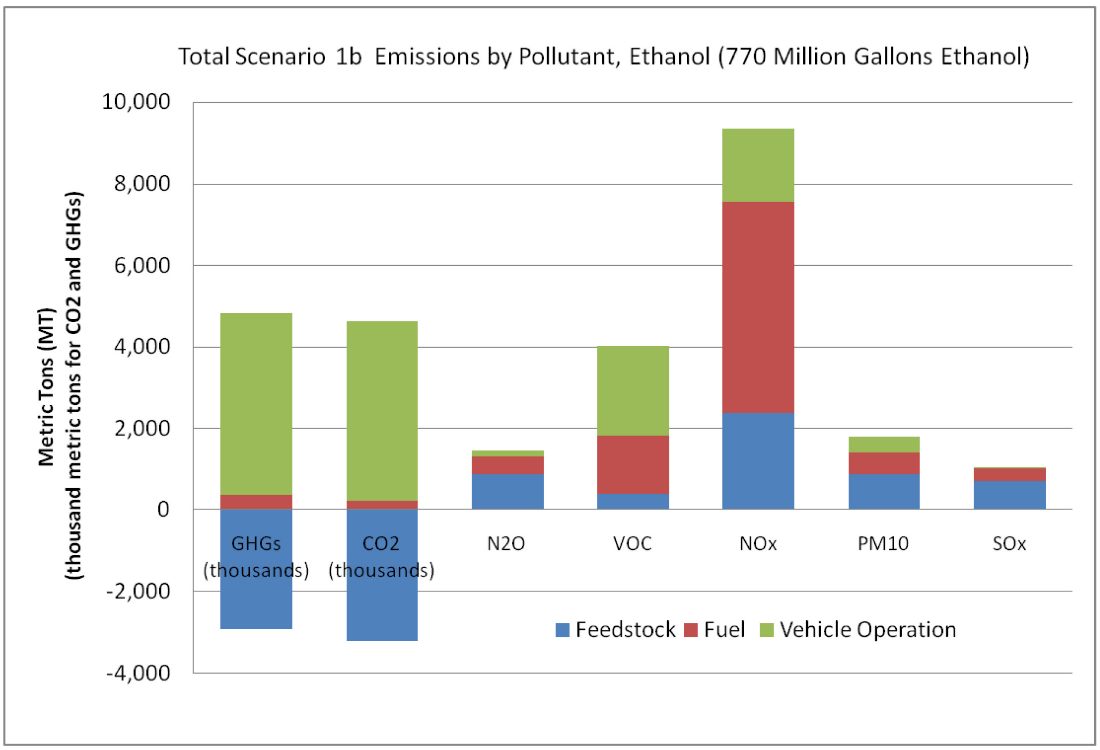


Figure G-10. Scenario 1b Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol (Gallons of Ethanol Equivalent—GEE).

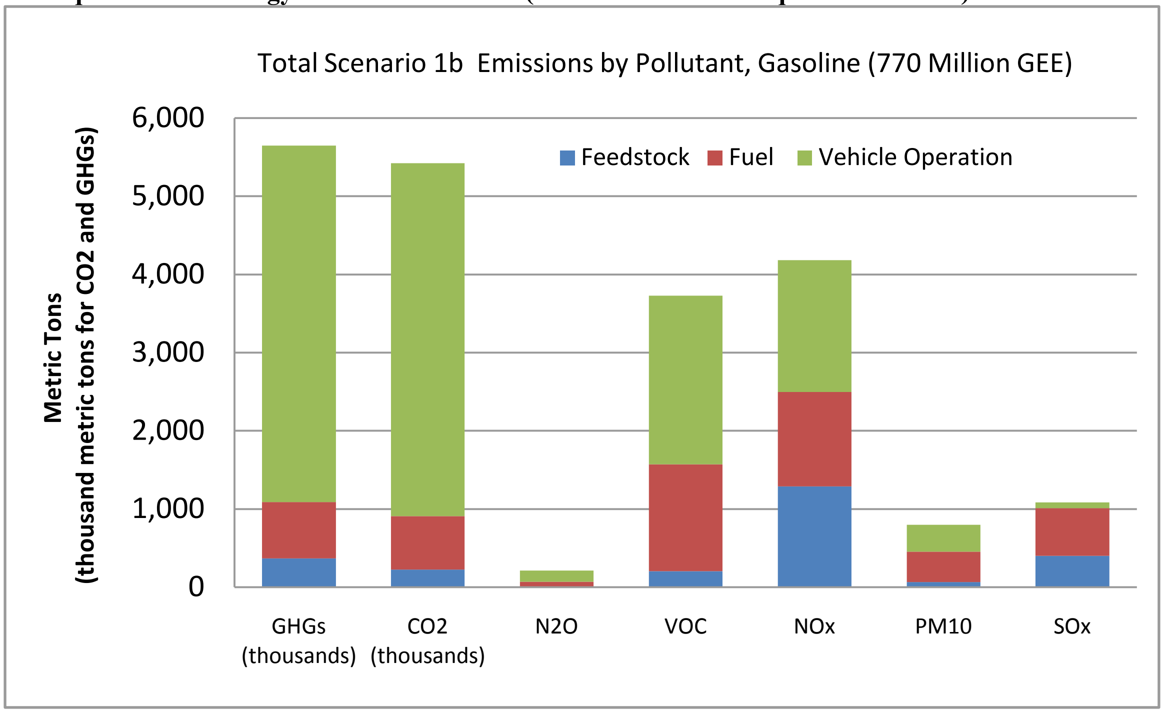


Figure G-11. Scenario 1b Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline Highlighting Differences.

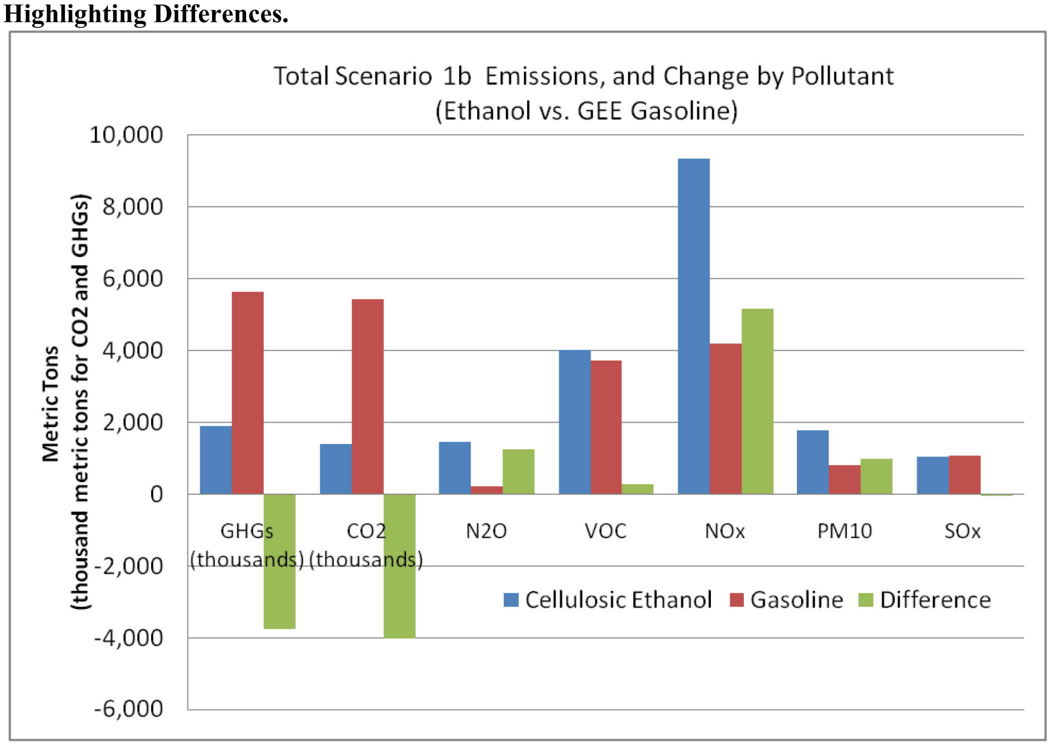


Figure G-12. Scenario 1b Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

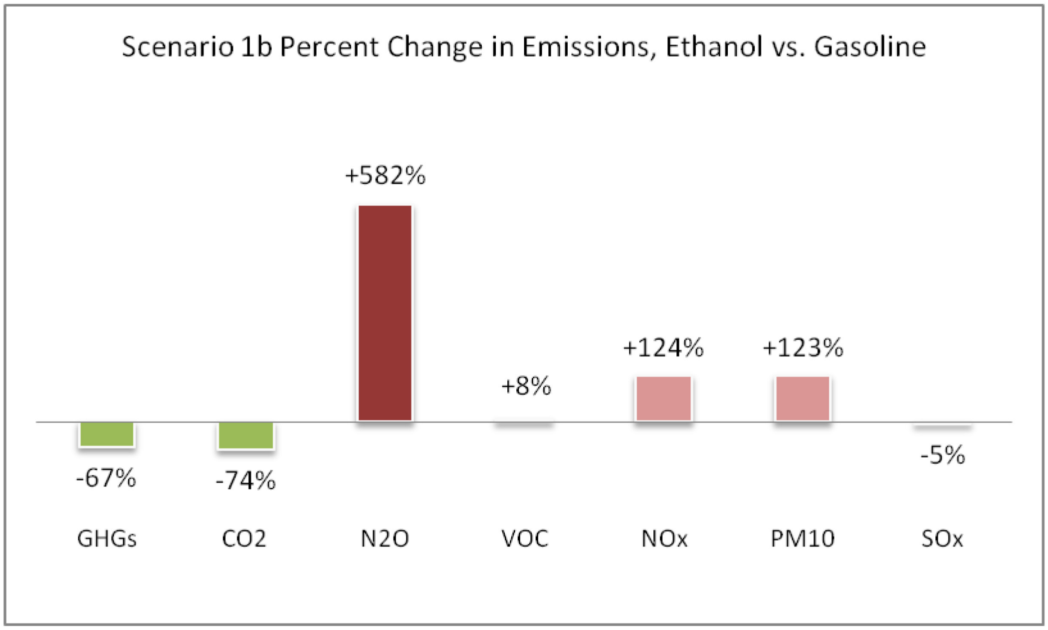
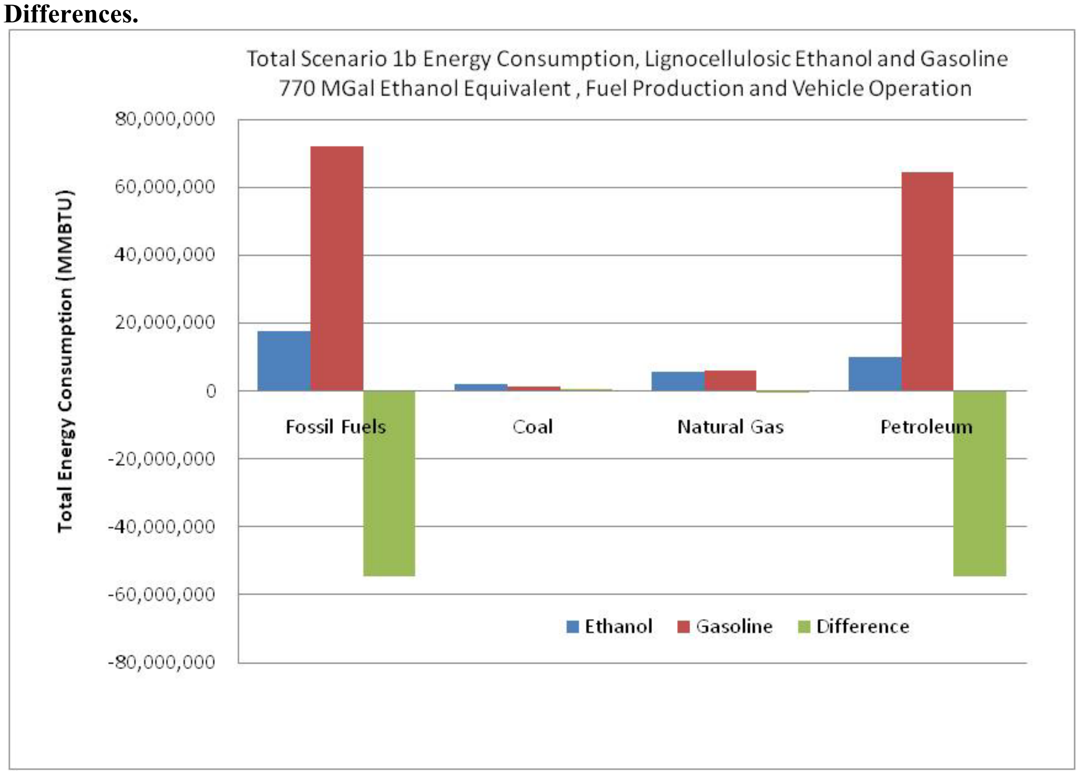


Figure G-13. Scenario 1b Comparison between Ethanol and Gasoline Energy Use, Highlighting Differences.



3.2.2 Scenario 2

Scenario 2 depicts very rapid development of a lignocellulosic biofuels industry, circa 2020-2030, requiring very rapid advances in feedstock production and conversion technologies. The land base for feedstock production is greater because of the use of cropland, which is estimated to become available due to increases in crop yield and milk yield per cow (allowing current crop and milk production to be maintained). Potential feedstock production is estimated to be (millions of dry tons): Hardwood chips 4.70, softwood chips 1.72, warm-season grass 4.59, short-rotation willow 3.32, and corn stover 0.25. Wood chips would be from well-managed harvests primarily of low-value wood from existing forests, with greater harvesting rates than in Scenario 1. Grass and willow would use a combined 1.68 million acres of land currently in herbaceous cover that is not required to meet current agricultural needs. Indirect land use change is assumed to be negligible. The second generation of lignocellulosic biorefineries (biochemical and thermochemical systems) are assumed ready for commercial deployment.

In this scenario, for the base case (unsubsidized direct competition with petroleum based fuels) ligno-cellulosic biorefineries producing ethanol at a total production capacity of 1,295 MGY could be profitably built and operated, or about four times the capacity projected for Scenario 1. The production units are modeled to be built at the same four sites as in Scenario 1 and average capacity at each site is near 325 MGY. They could be very large conversion systems or more likely multiple units operating at the same site (e.g. two 150 MGY units provide 300 MGY of total capacity). Total New York production of renewable gasoline substitutes including the grain derived ethanol would reach 1449 MGY. In the Scenario 2 base case, New York could meet about 16% of its transportation gasoline consumption with home grown biofuels.

Scenario #2a.

Table G-11. Scenario 2a Cellulosic Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (BTU/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	$CaCO_3$ (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Grass	75,223	6267.0	3.3%	668	8,189.0	9,284.0	74.3	-208,518
Willow	106,449	2,582.0	3.3%	0	0.0	0.0	24.0	-32,069
Hardwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0

Table G-12. Scenario 2a Cellulosic Ethanol Feedstock Quantity and Transportation to Biorefinery.

	Corn Stover	Grass	Willow	Softwood	Hardwood
Wet Tons of Feedstock	287,290	5,201,030	6,035,620	3,216,180	8,486,620
Truck Ton-Miles	22,789,888	362,468,154	367,557,375	179,727,869	520,878,947
Average Miles Feedstock to Biorefinery (Truck)	**79.3**	**69.7**	**60.9**	**57.5**	**61.4**

Table G-13. Scenario 2a Cellulosic Ethanol Production by Feedstock.

Feedstock	Technology	Yield (gal/dt)	Dry tons of feedstock	Gallons ethanol	% of total Ethanol	Electricity Export (kWh/gal)
Corn Stover	Fermentation	86.0	249,940	21,494,840	1.7%	1.76
Willow	Fermentation	91.9	3,319,590	305,070,321	23.6%	1.76
Hardwood	Fermentation	92.0	4,667,640	428,956,116	33.1%	1.76
Softwood	Fermentation	96.0	1,719,400	165,750,160	12.8%	1.76
Grass	Fermentation	82.6	4,524,900	373,756,740	28.9%	1.76
			Total	**1,295,028,177**	**100.0%**	

Table G-14. Scenario 2a Cellulosic Ethanol Production and Fuel Transportation to Blending Terminal.

Biorefinery	Ethanol Yield (MGY)	% of Total Scenario 2a Ethanol	Distance to Blending Terminal (Miles)
D3678608	116.3	9%	56.5
D3678608	104.5	8%	56.5
D3678608	117.5	9%	56.5
D3665255	111.4	9%	27.9
D3665255	119.1	9%	27.9
D3654881	117.1	9%	2.0
D3654881	99.7	8%	2.0
D3654881	116.3	9%	2.0
D3654716	115.6	9%	22.4
D3654716	61.3	5%	22.4
D3654716	104.5	8%	22.4
D3654716	112.0	9%	22.4
		Average Fuel Transportation Distance	**27.0**

Table G-15. Scenario 2a LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu of Fuel Available at Pump.

Item	Conventional Gasoline	LCE Ethanol
Total Energy (Btu/MMBtu)	254,849	1,161,425
WTP Efficiency	79.7%	46.3%
Fossil Fuels (Btu/MMBtu)	219,347	139,046
Coal (Btu/MMBtu)	23,840	7,334
Natural Gas (Btu/MMBtu)	99,406	49,156
Petroleum (Btu/MMBtu)	96,101	82,556
CO_2 (g/MMBtu)	15,271	-68,162
CH_4 (g/MMBtu)	107	24
N_2O (g/MMBtu)	1	28
GHGs (gCO2eq/MMBtu)	18,311	-59,306
VOC (g/MMBtu)	27	45
CO (g/MMBtu)	17	149
NOx (g/MMBtu)	42	138
PM_{10} (g/MMBtu)	8	30
$PM_{2.5}$ (g/MMBtu)	3	12
SOx (g/MMBtu)	17	7

Figure G-14. Scenario 2a Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

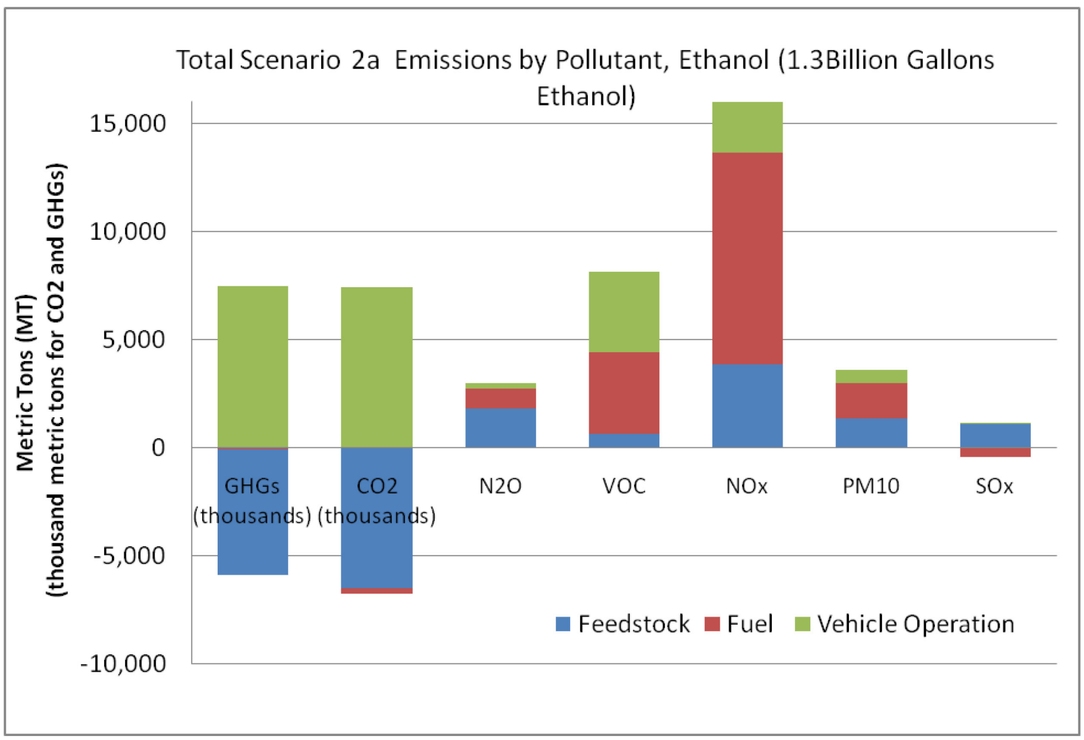


Figure G-15. Scenario 2a Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

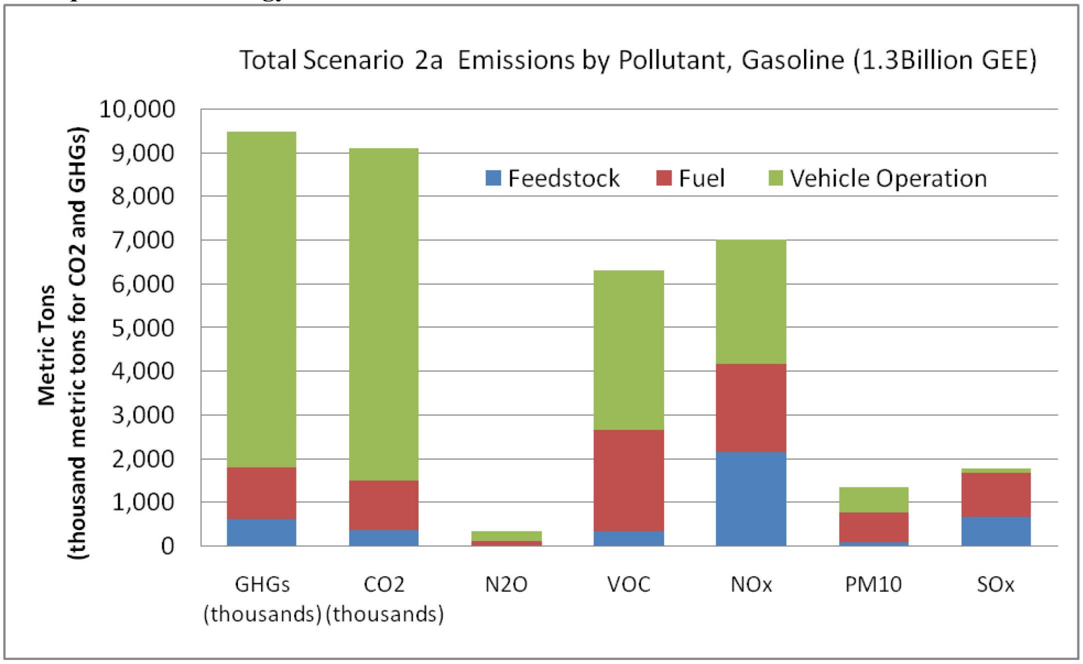


Figure G-16. Scenario 2a Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline, Highlighting Differences.

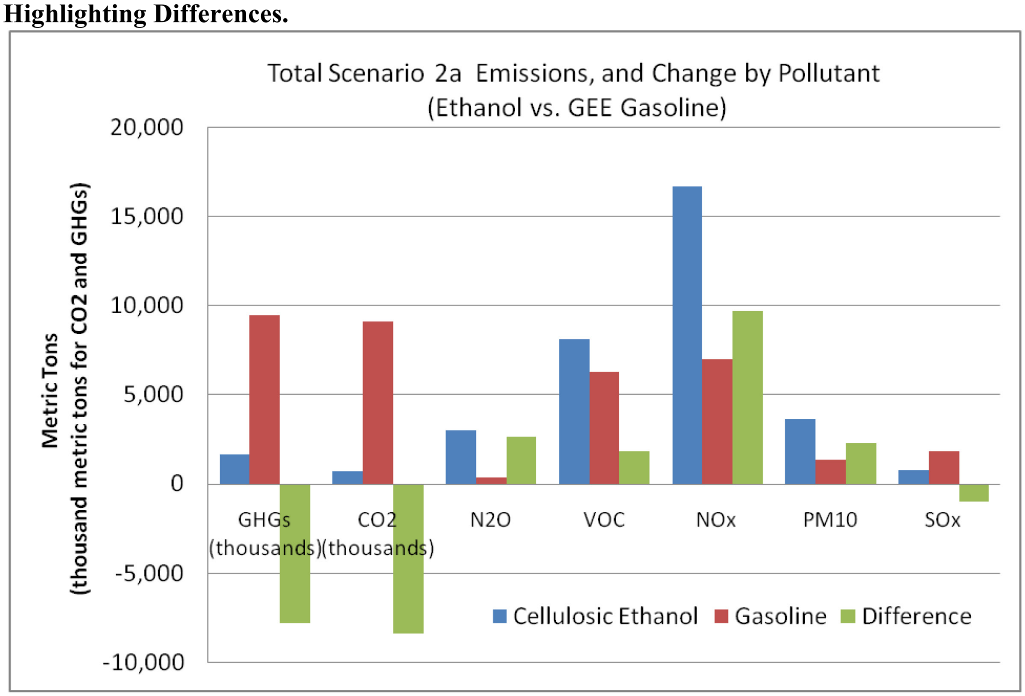


Figure G-17. Scenario 2a Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

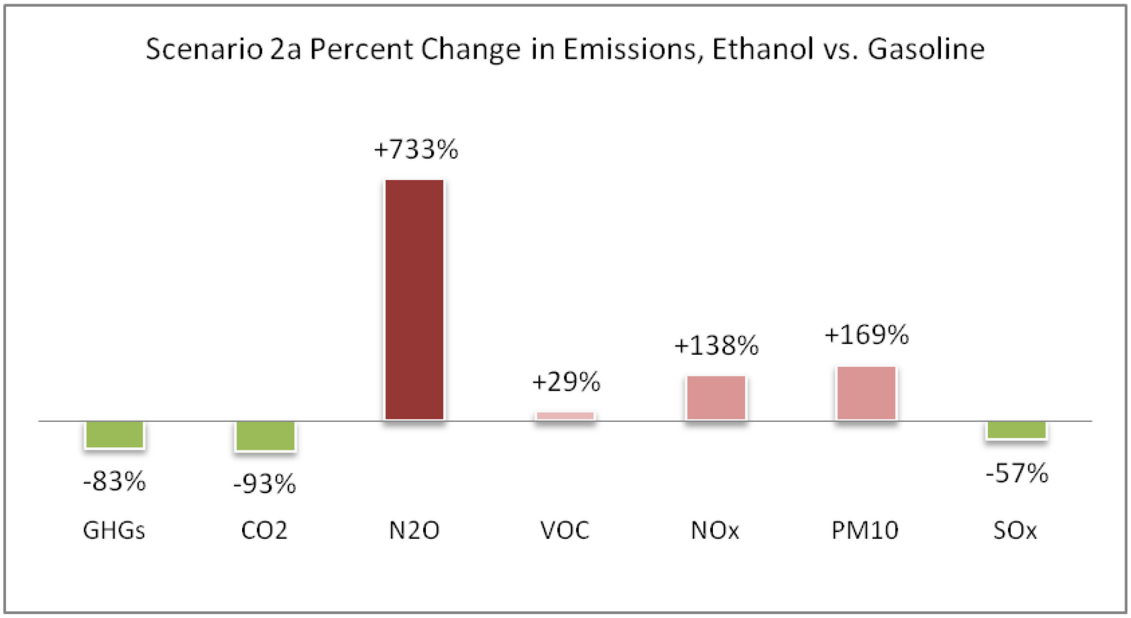
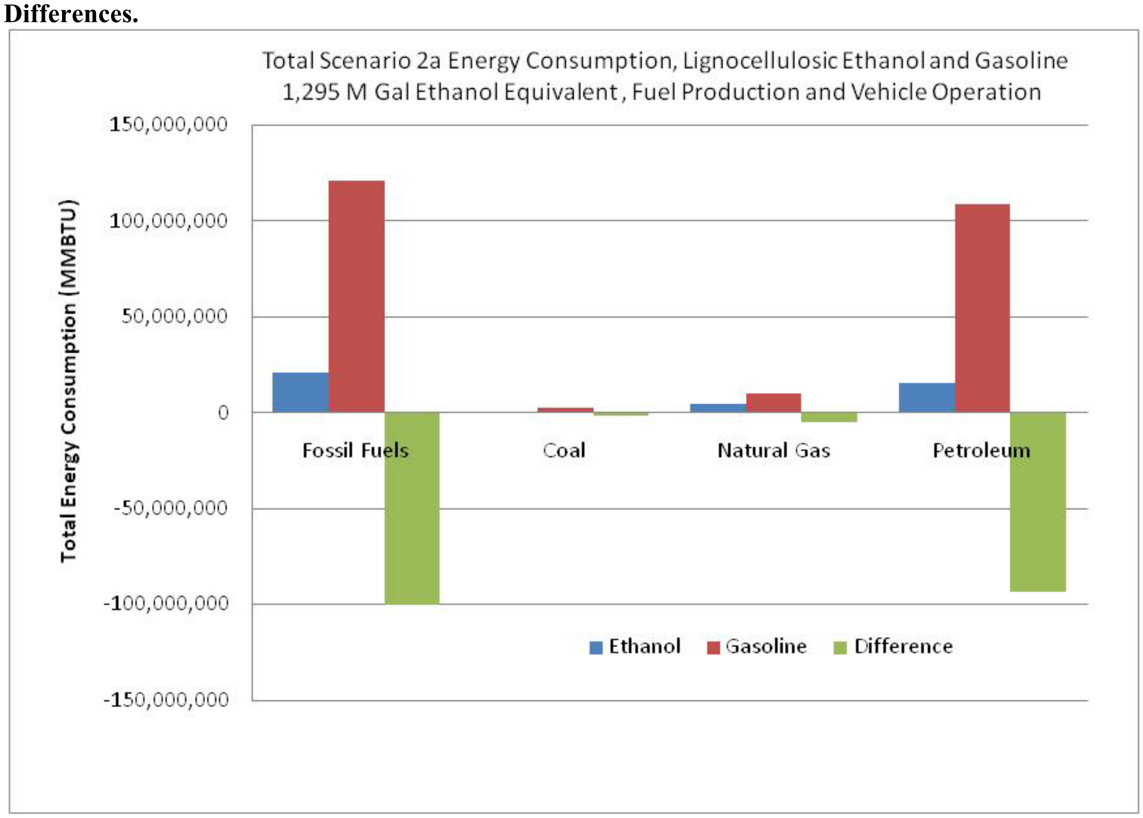


Figure G-18. Scenario 2a Comparison between Ethanol and Gasoline Energy Use, Highlighting Differences.



Scenario #2b.

Table G-16. Scenario 2b Cellulosic Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (Btu/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	$CaCO_3$ (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Grass	75,223	6267.0	3.3%	668	8,189	9,284.0	74.3	-208,518
Willow	106,449	2,582.0	3.3%	0	0.0	0.0	24.0	-32,069
Hardwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0

Table G-17. Scenario 2b Cellulosic Ethanol Feedstock Quantity and Transportation to Biorefinery.

	Corn Stover	Grass	Willow	Softwood	Hardwood
Wet Tons of Feedstock	287,290	5,272,000	6,035,620	3,216,180	8,486,620
Truck Ton-Miles	22,828,525	369,861,094	367,557,375	179,732,694	520,980,558
Average Miles Feedstock to Biorefinery (Truck)	**79.5**	**70.2**	**60.9**	**57.5**	**61.4**

Table G-18. Scenario 2b Cellulosic Ethanol Production by Feedstock.

Feedstock	Technology	Yield (Gal/dt)	Dry tons of feedstock	Gallons ethanol	% of total Ethanol	Electricity Export (kWh/gal)
Corn Stover	Fermentation	86.0	249,940	21,494,840	1.7%	1.76
Willow	Fermentation	91.9	3,319,590	305,070,321	23.5%	1.76
Hardwood	Fermentation	92.0	4,667,640	428,956,116	33.0%	1.76
Softwood	Fermentation	96.0	1,719,400	165,750,160	12.7%	1.76
Grass	Fermentation	82.6	4,586,640	378,856,464	29.1%	1.76
			Total	**1,300,127,901**		

Table G-19. Scenario 2b Cellulosic Ethanol Production and Fuel Transportation to Blending Terminal.

Biorefinery	Ethanol Yield (MGY)	% of Total Scenario 2b Ethanol	Distance to Blending Terminal (Miles)
D3678608	116.3	9%	56.5
D3678608	104.5	8%	56.5
D3678608	117.5	9%	56.5
D3665255	111.2	9%	27.9
D3665255	119.2	9%	27.9
D3654881	117.0	9%	2.0
D3654881	101.9	8%	2.0
D3654881	116.3	9%	2.0
D3654716	64.7	5%	22.4
D3654716	107.9	8%	22.4
D3654716	108.3	8%	22.4
D3654716	115.6	9%	22.4
Average Fuel Transportation Distance			**27.0**

Table G-20. Scenario 2b LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu of Fuel Available at Pump (Does not include vehicle operation).

Item	Conventional Gasoline	LCE Ethanol
Total Energy (Btu/MMBtu)	254,822	1,162,243
WTP Efficiency	79.7%	46.2%
Fossil Fuels (Btu/MMBtu)	219,376	138,995
Coal (Btu/MMBtu)	23,848	7,340
Natural Gas (Btu/MMBtu)	99,453	49,078
Petroleum (Btu/MMBtu)	96,076	82,577
CO_2 (g/MMBtu)	15,270	-68,232
CH_4 (g/MMBtu)	107	24
N_2O (g/MMBtu)	1	28
GHGs (gCO2eq/MMBtu)	18,323	-59,338
VOC (g/MMBtu)	27	45
CO (g/MMBtu)	17	153
NOx (g/MMBtu)	42	139
PM_{10} (g/MMBtu)	8	31
$PM_{2.5}$ (g/MMBtu)	3	12
SOx (g/MMBtu)	17	8

Figure G-19. Scenario 2b Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

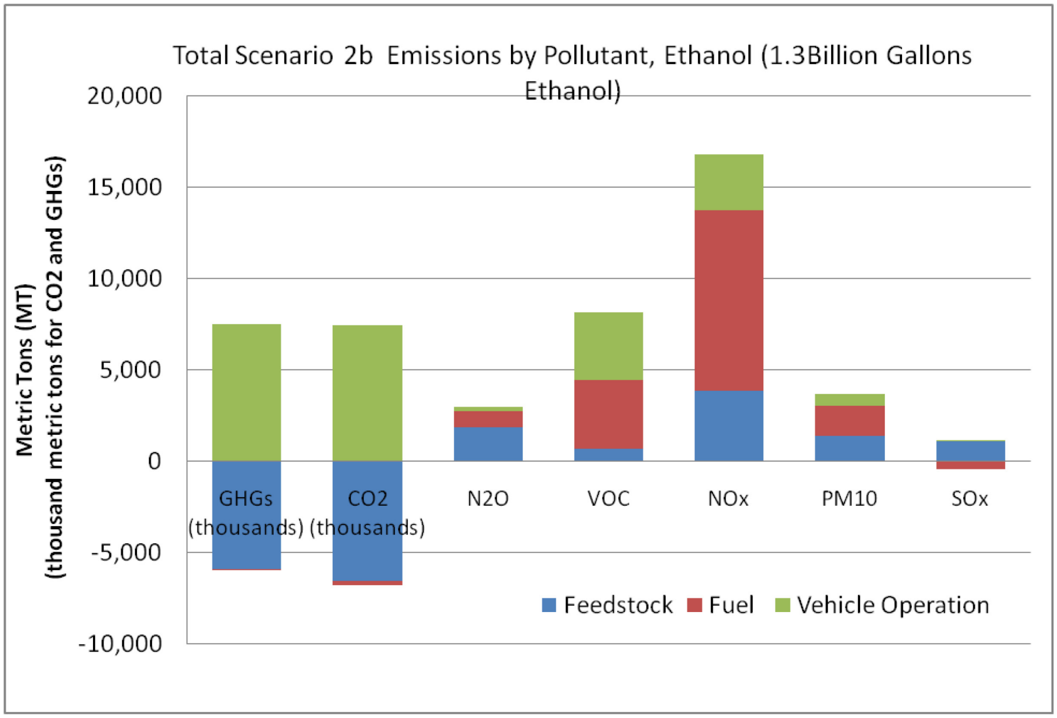


Figure G-20. Scenario 2b Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

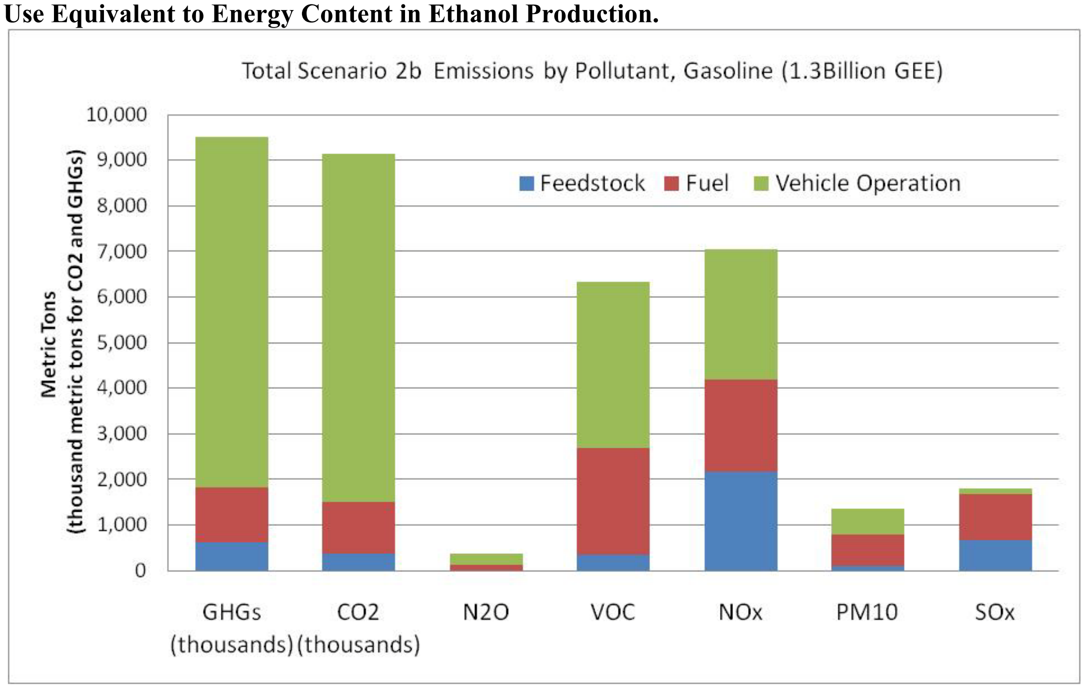


Figure G-21. Scenario 2b Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline, Highlighting Differences.

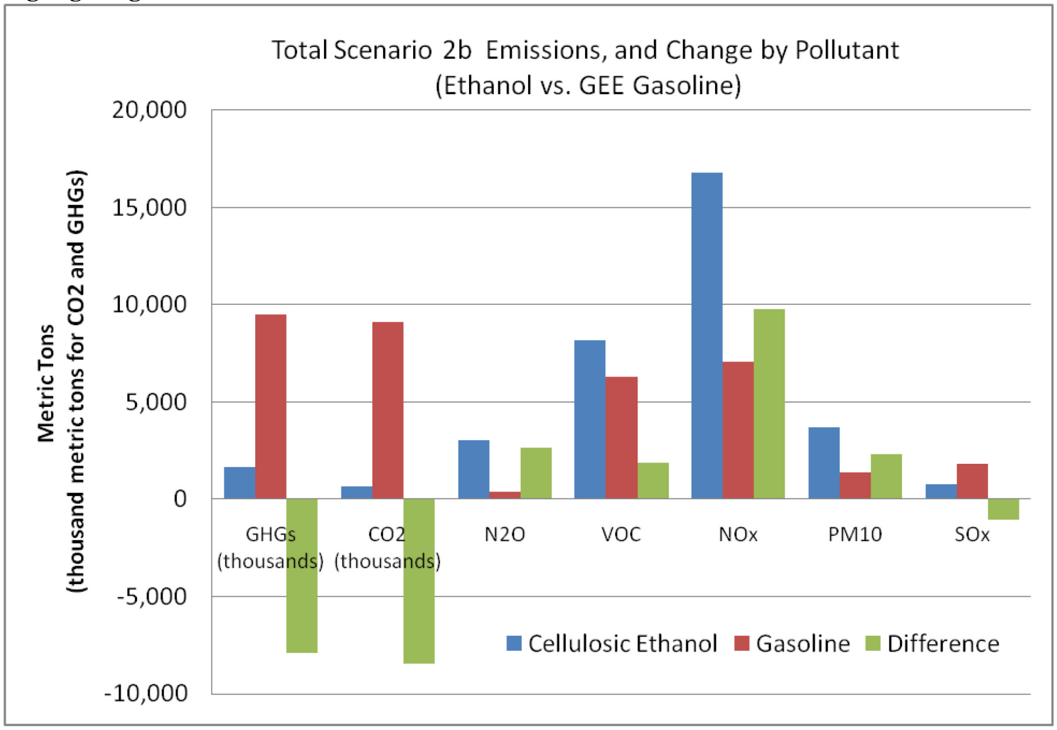


Figure G-22. Scenario 2b Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

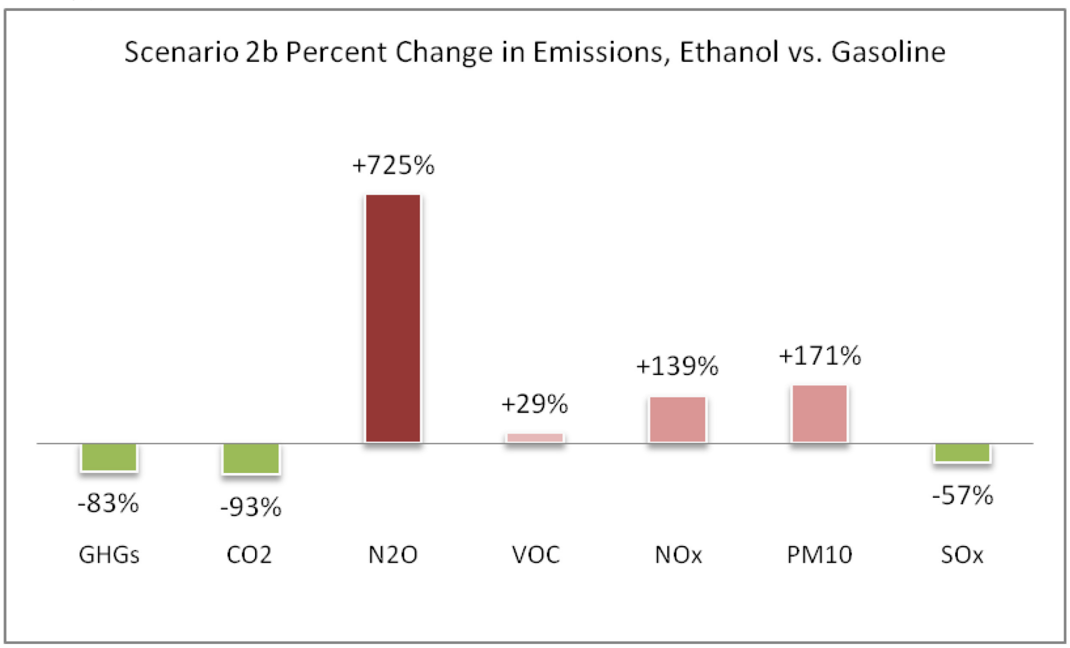
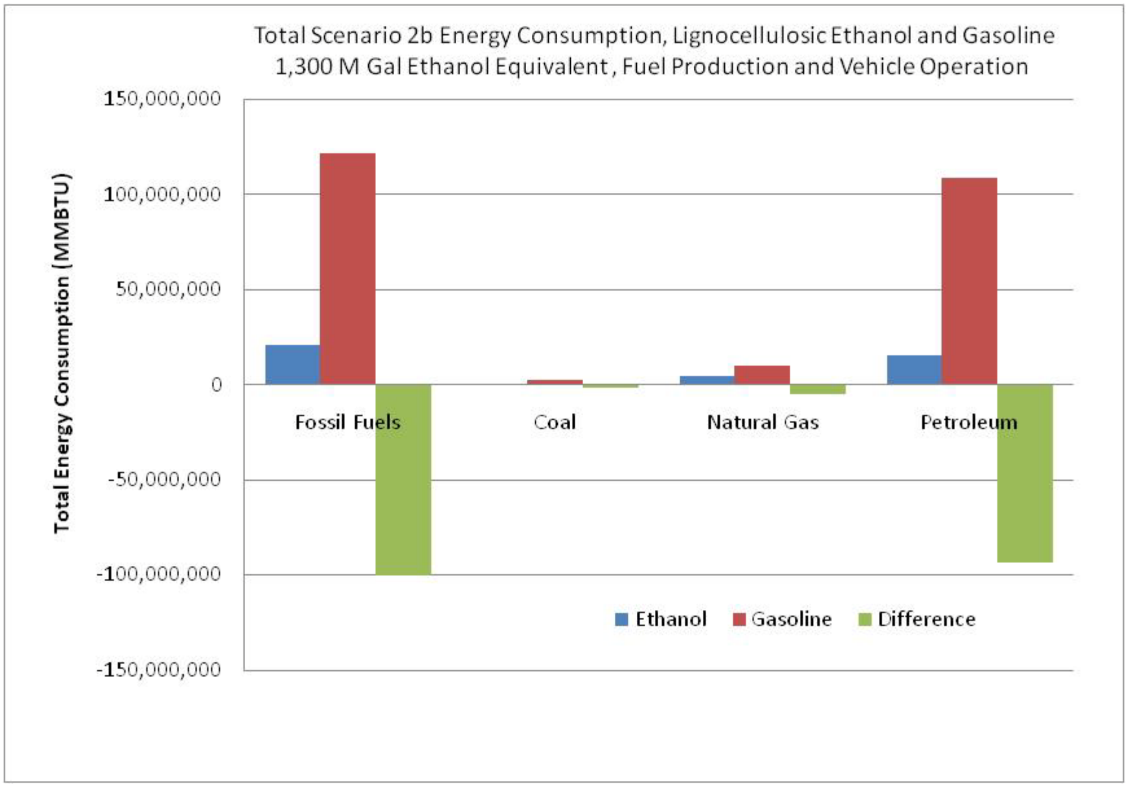


Figure G-23. Scenario 2b Comparison between Ethanol and Gasoline Energy Use, Highlighting Differences.



3.2.3 Scenario 3

This scenario envisions the same feedstock production and technology performance as for Scenario 2. However, there is a distributed industry with no biorefinery capacity exceeding 60 MGY, except for the existing grain ethanol biorefineries. While ethanol facilities currently in the planning stages are reaching the 300 MGY mark, the plant size was constrained to 20% of that scale in order to draw upon local biomass resources (typically, within a 30-mile radius) and to serve local markets or blending terminals; therefore, 24 biorefineries are assumed in Scenario 3. Smaller facilities are usually disadvantaged by both the economies of scale in physical plant and development costs, yet they represent less financial risk and tend to have proportionately lower impacts on local communities, such as road traffic congestion. In the following sections, we present assumptions and results of the Scenario 3 LCA for both price cases.

Scenario #3a.

Table G-21. Scenario 3a Cellulosic Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (Btu/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	$CaCO_3$ (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Grass	75,223	6267.0	3.3%	668	8,189.0	9,284.0	74.3	-208,518
Willow	106,449	2,582.0	3.3%	0	0.0	0.0	24.0	-32,069
Hardwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0	0	0.0	0.0	0.0	0

Table G-22. Scenario 3a Cellulosic Ethanol Feedstock Quantity and Transportation to Biorefinery.

	Corn Stover	Grass	Willow	Softwood	Hardwood
Wet Tons of Feedstock	287,290	5,270,000	6,035,620	3,216,180	8,486,620
Truck Ton-Miles	6,998,372	138,488,552	134,409,028	122,920,369	255,311,102
Average Miles Feedstock to Biorefinery (Truck)	**24.4**	**26.3**	**22.3**	**39.3**	**30.1**

Table G-23. Scenario 3a Cellulosic Ethanol Production by Feedstock.

Feedstock	Technology	Yield (Gal/dt)	Dry tons of feedstock	Gallons ethanol	% of total Ethanol	Electricity Export (kWh/gal)
Corn Stover	Fermentation	86.0	249,940	21,494,840	1.7%	1.76
Willow	Fermentation	91.9	3,319,590	305,070,321	23.5%	1.76
Hardwood	Fermentation	92.0	4,667,640	428,956,116	33.0%	1.76
Softwood	Fermentation	96.0	1,719,400	165,750,160	12.7%	1.76
Grass	Fermentation	82.6	4,585,500	378,762,300	29.1%	1.76
			Total	**1,300,033,737**		

Table G-24. Scenario 3a Cellulosic Ethanol Production and Fuel Transportation to Blending Terminal.

Biorefinery	Ethanol Yield (MGY)	% of Total Scenario 3a Ethanol	Distance to Blending Terminal (Miles)
D3603078	54.9	4%	21.0
D3604715	52.3	4%	33.7
D3604715	57.0	4%	33.7
D3606607	57.4	4%	5.9
D3611000	55.5	4%	4.0
D3613981	58.5	4%	57.3
D3618256	55.2	4%	29.5
D3624229	48.3	4%	20.6
D3638264	57.3	4%	21.6
D3646019	46.6	4%	102.0
D3650034	46.9	4%	1.6
D3654716	58.4	4%	22.4
D3654881	58.1	4%	2.0
D3655574	56.6	4%	36.6
D3659641	37.5	3%	2.6
D3663000	54.3	4%	4.1
D3663418	56.4	4%	17.9
D3665255	59.1	5%	27.9
D3665508	56.7	4%	18.0
D3673000	55.2	4%	13.4
D3675484	56.9	4%	1.2
D3676540	56.8	4%	3.1
D3678608	53.5	4%	56.5
D3678608	50.7	4%	56.5
		Average Fuel Transportation Distance	**24.5**

Table G-25. Scenario 3a LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu of Fuel Available at Pump.

Item	Conventional Gasoline	LCE Ethanol
Total Energy (Btu/MMBtu)	254,152	1,137,710
WTP Efficiency	79.7%	46.8%
Fossil Fuels (Btu/MMBtu)	218,710	114,592
Coal (Btu/MMBtu)	23,837	6,951
Natural Gas (Btu/MMBtu)	99,404	47,290
Petroleum (Btu/MMBtu)	95,469	60,350
CO_2 (g/MMBtu)	15,218	-70,146
CH_4 (g/MMBtu)	107	22.3
N_2O (g/MMBtu)	1	27.7
GHGs (gCO2eq/MMBtu)	18,269	-61,320
VOC (g/MMBtu)	27.044	44.413
CO (g/MMBtu)	16.419	149.489
NOx (g/MMBtu)	41.991	129
PM_{10} (g/MMBtu)	8	31
$PM_{2.5}$ (g/MMBtu)	3	12
SOx (g/MMBtu)	17	7

Figure G-24. Scenario 3a Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

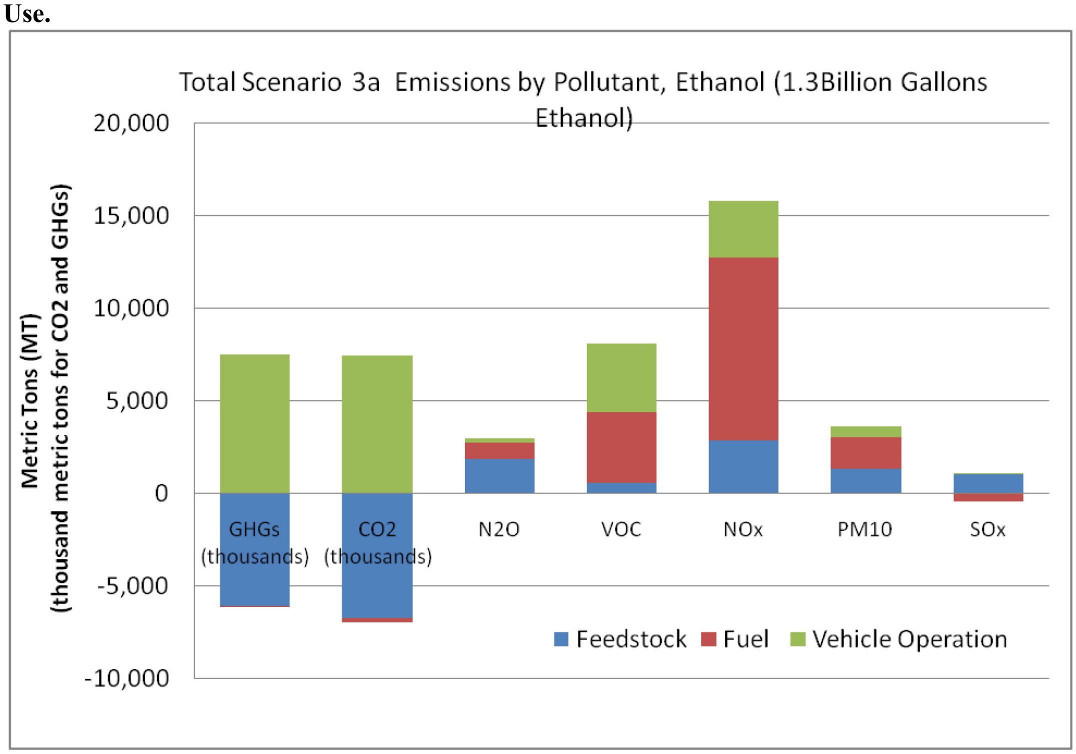


Figure G-25. Scenario 3a Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

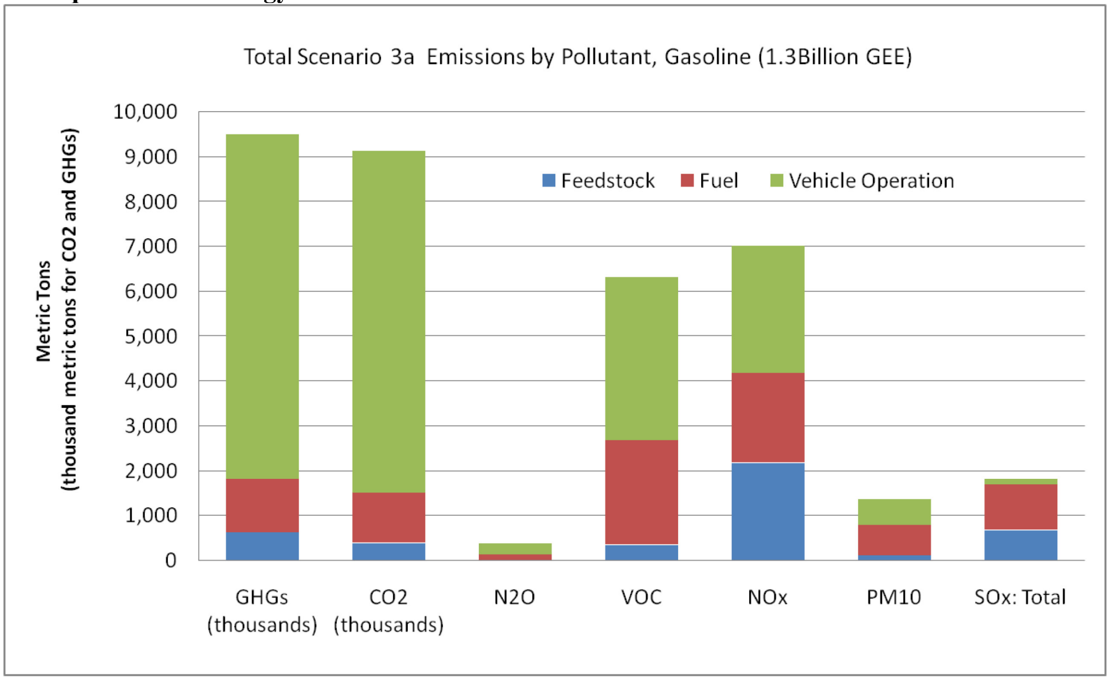


Figure G-26. Scenario 3a Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline, Highlighting Differences.

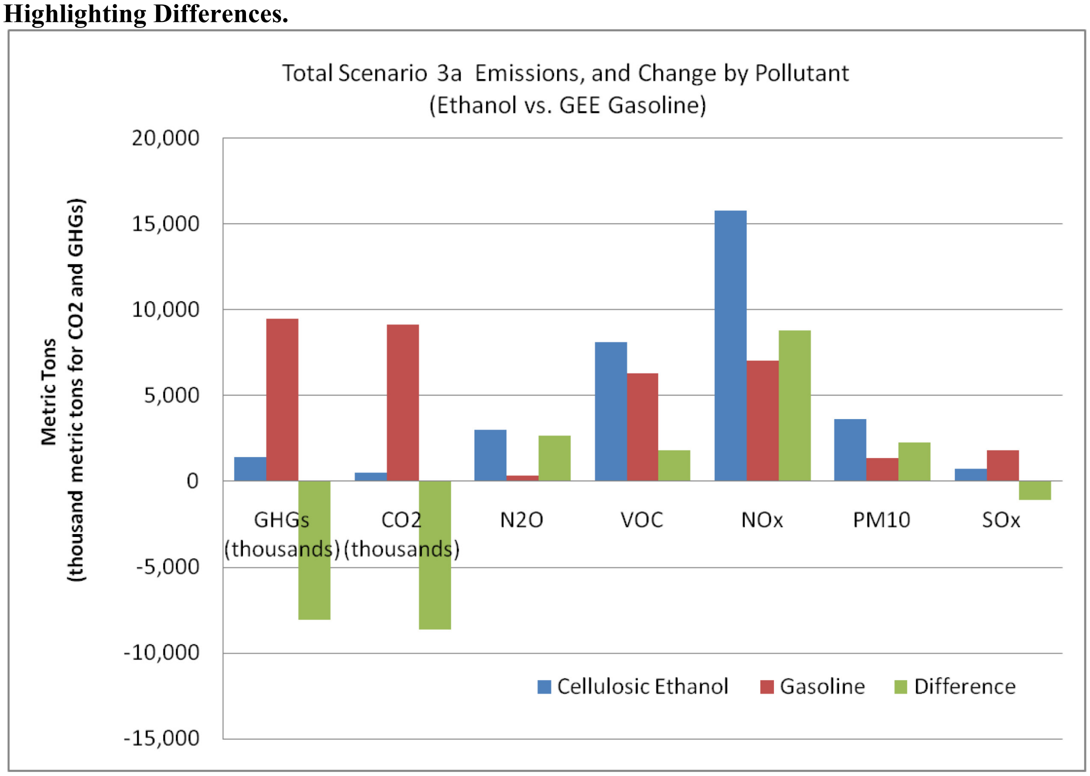


Figure G-27. Scenario 3a Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

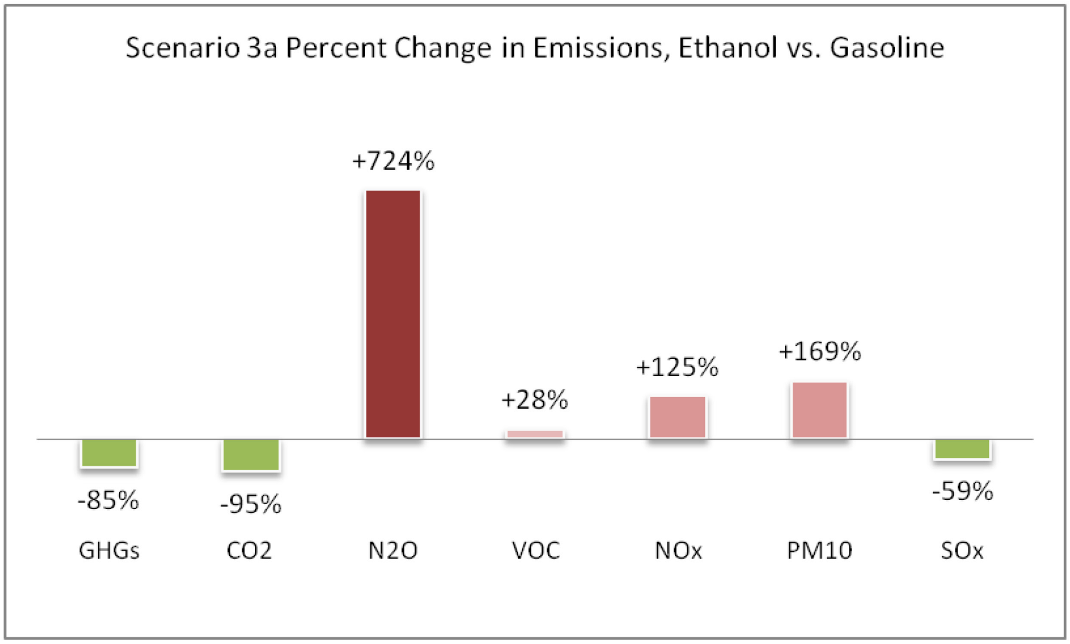
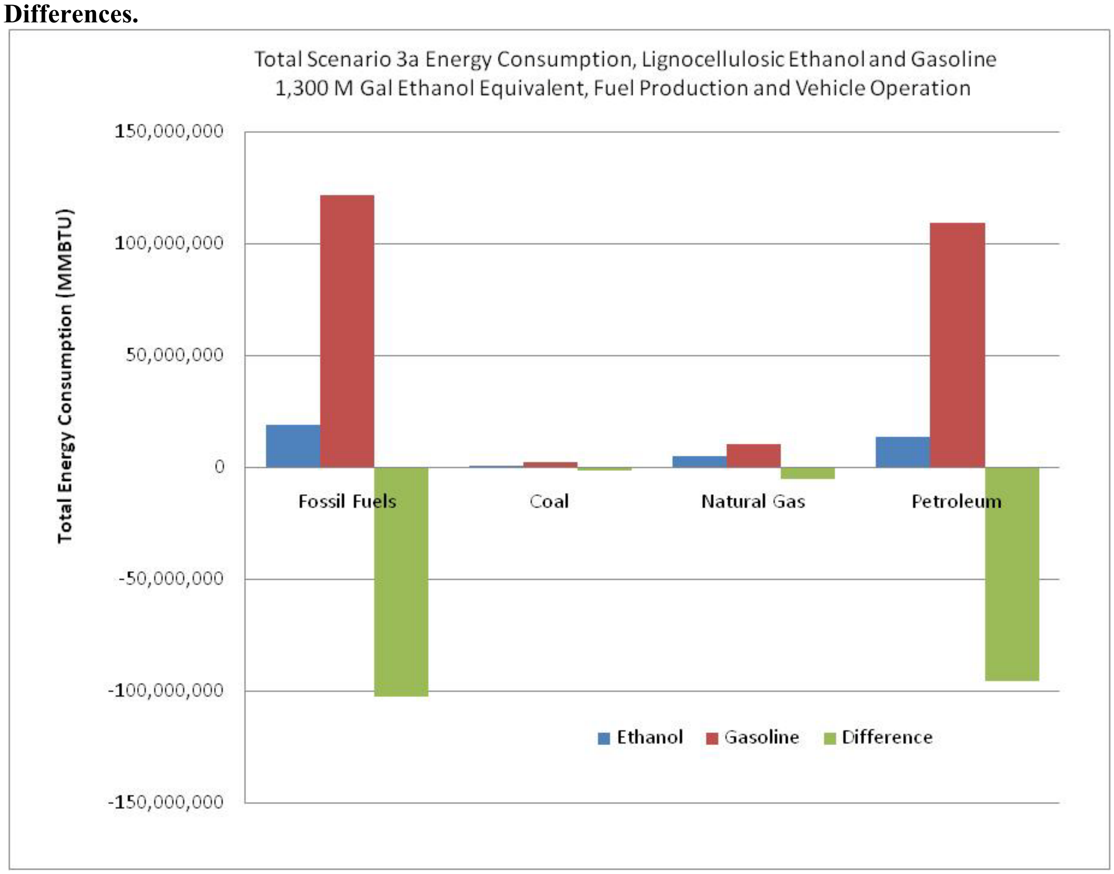


Figure G-28. Scenario 3a Comparison between Ethanol and Gasoline Energy Use, Highlighting Differences.



Scenario #3b

Table G-26. Scenario 3b Cellulosic Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Feedstock	Farming Energy Use (Btu/bu or dt)	Nitrogen Fertilizer (g/bu or g/dt)	N in N_2O as % N in Fertilizer	P_2O_5 (g/bu or g/dt)	K_2O (g/bu or g/dt)	$CaCO_3$ (g/bu or g/dt)	Herbicide (g/bu or g/dt)	CO_2 Emissions from Land Use Change
Corn Stover	17,887	431.5	3.6%	3752	161.3	90.0	17.6	0
Grass	75,223	6,267.0	3.3%	668	8,189.0	9,284.0	74.3	-208,518
Willow	106,449	2,582.0	3.3%	0	0.0	0.0	24.0	-32,069
Hardwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0
Softwood	123,444	0.0	0.0%	0	0.0	0.0	0.0	0

Table G-27. Scenario 3b Cellulosic Ethanol Feedstock Quantity and Transportation to Biorefinery.

	Corn Stover	Grass	Willow	Softwood	Hardwood
Wet Tons of Feedstock	287,290	5,272,000	6,035,620	3,216,180	8,486,620
Truck Ton-Miles	7,221,650	138,243,662	134,241,398	121,949,355	256,608,246
Average Miles Feedstock to Biorefinery (Truck)	**25.1**	**26.2**	**22.2**	**39.0**	**30.2**

Table G-28. Scenario 3b Cellulosic Ethanol Production by Feedstock.

Feedstock	Technology	Yield (Gal/dt)	Dry tons of feedstock	Gallons ethanol	% of total Ethanol	Electricity Export (kWh/gal)
Corn Stover	Fermentation	86.0	249,940	21,494,840	1.7%	1.76
Willow	Fermentation	91.9	3,319,590	305,070,321	23.5%	1.76
Hardwood	Fermentation	92.0	4,667,640	428,956,116	33.0%	1.76
Softwood	Fermentation	96.0	1,719,400	165,750,160	12.7%	1.76
Grass	Fermentation	82.6	4,586,640	378,856,464	29.1%	1.76
			Total	**1,300,127,901**		

Table G-29. Scenario 3b Cellulosic Ethanol Production and Fuel Transportation to Blending Terminal.

Biorefinery	Ethanol Yield (MGY)	% of Total Scenario 3a Ethanol	Distance to Blending Terminal (Miles)
D3603078	54.9	4%	21.0
D3604715	52.3	4%	33.7
D3604715	57.0	4%	33.7
D3606607	57.4	4%	5.9
D3611000	55.5	4%	4.0
D3613981	58.5	5%	57.3
D3618256	55.1	4%	29.5
D3624229	48.3	4%	20.6
D3638264	57.3	4%	21.6
D3646019	46.6	4%	102.0
D3650034	46.9	4%	1.6
D3654716	58.4	4%	22.4
D3654881	58.1	4%	2.0
D3655574	56.6	4%	36.6
D3659641	37.5	3%	2.6
D3663000	54.3	4%	4.1
D3663418	56.4	4%	17.9
D3665255	59.1	5%	27.9
D3665508	56.7	4%	18.0
D3673000	55.3	4%	13.4
D3675484	56.9	4%	1.2
D3676540	56.7	4%	3.1
D3678608	53.5	4%	56.5
D3678608	50.7	4%	56.5
Average Fuel Transportation Distance			**24.5**

Table G-30. Scenario 3b LCE v. Gasoline Well-to-Pump Energy Use and Emissions per Million Btu of Fuel Available at Pump (Does not include vehicle operation).

Item	Conventional Gasoline	LCE Ethanol
Total Energy (Btu/MMBtu)	253,915	1,137,702
WTP Efficiency	79.8%	46.8%
Fossil Fuels (Btu/MMBtu)	218,474	114,584
Coal (Btu/MMBtu)	23,834	6,951
Natural Gas (Btu/MMBtu)	99,389	47,290
Petroleum (Btu/MMBtu)	95,251	60,343
CO_2 (g/MMBtu)	15,198	-70,146
CH_4 (g/MMBtu)	107	22
N_2O (g/MMBtu)	1	28
GHGs (gCO2eq/MMBtu)	18,249	-61,320
VOC (g/MMBtu)	27	44.412
CO (g/MMBtu)	16	149
NOx (g/MMBtu)	42	129
PM_{10} (g/MMBtu)	8	31
$PM_{2.5}$ (g/MMBtu)	3	12
SOx (g/MMBtu)	17	7

Figure G-29. Scenario 3b Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

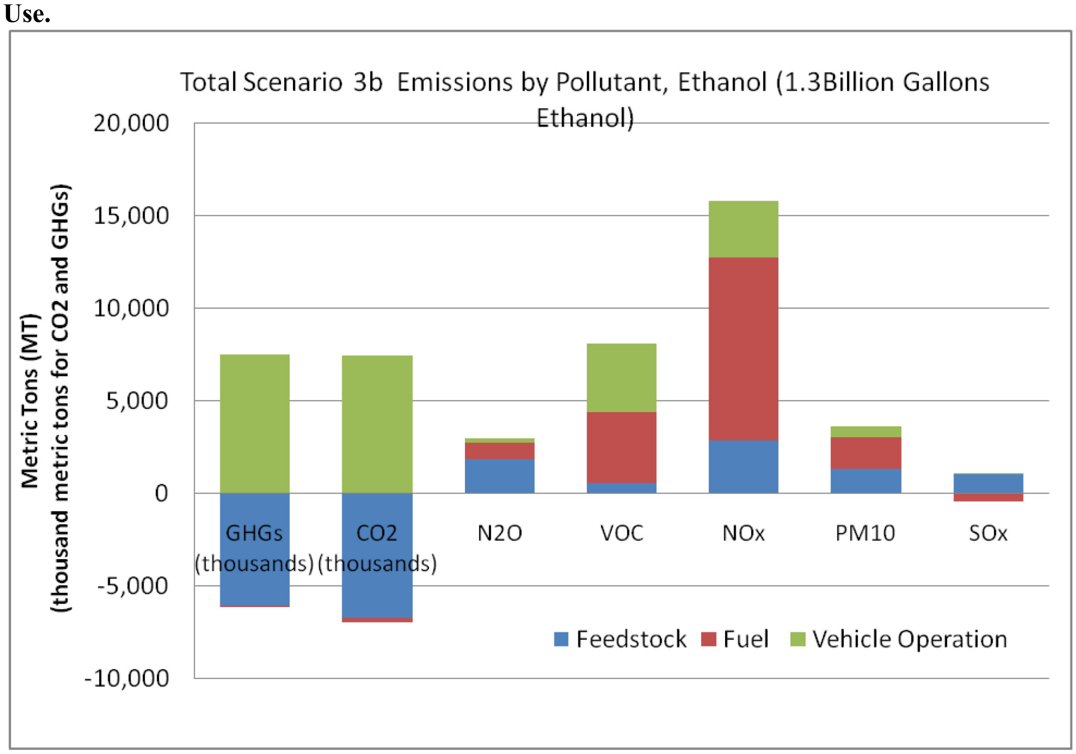


Figure G-30. Scenario 3b Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

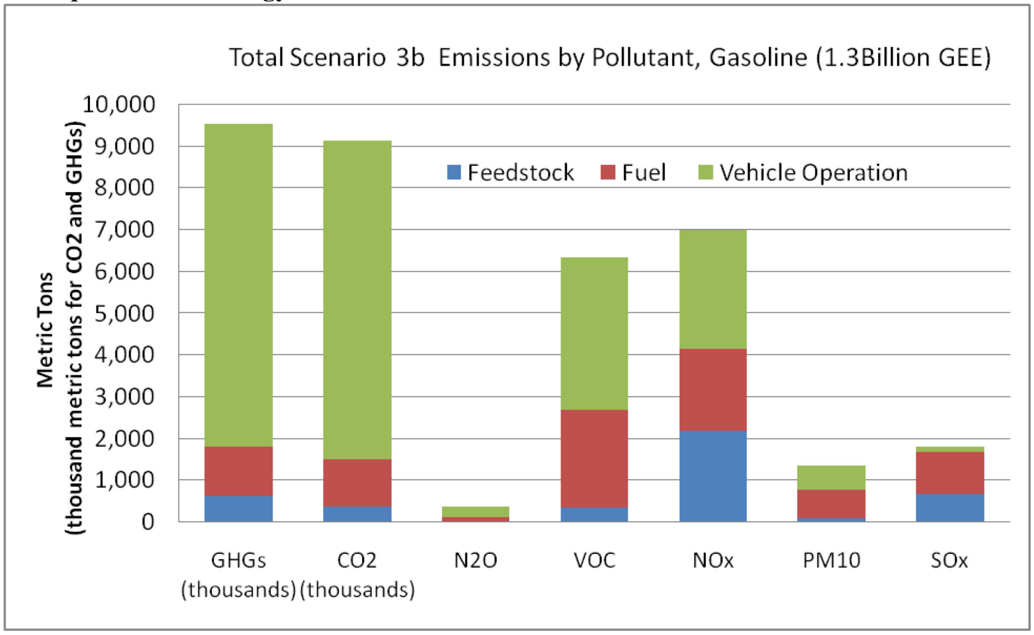


Figure G-31. Scenario 3b Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline, Highlighting Differences.

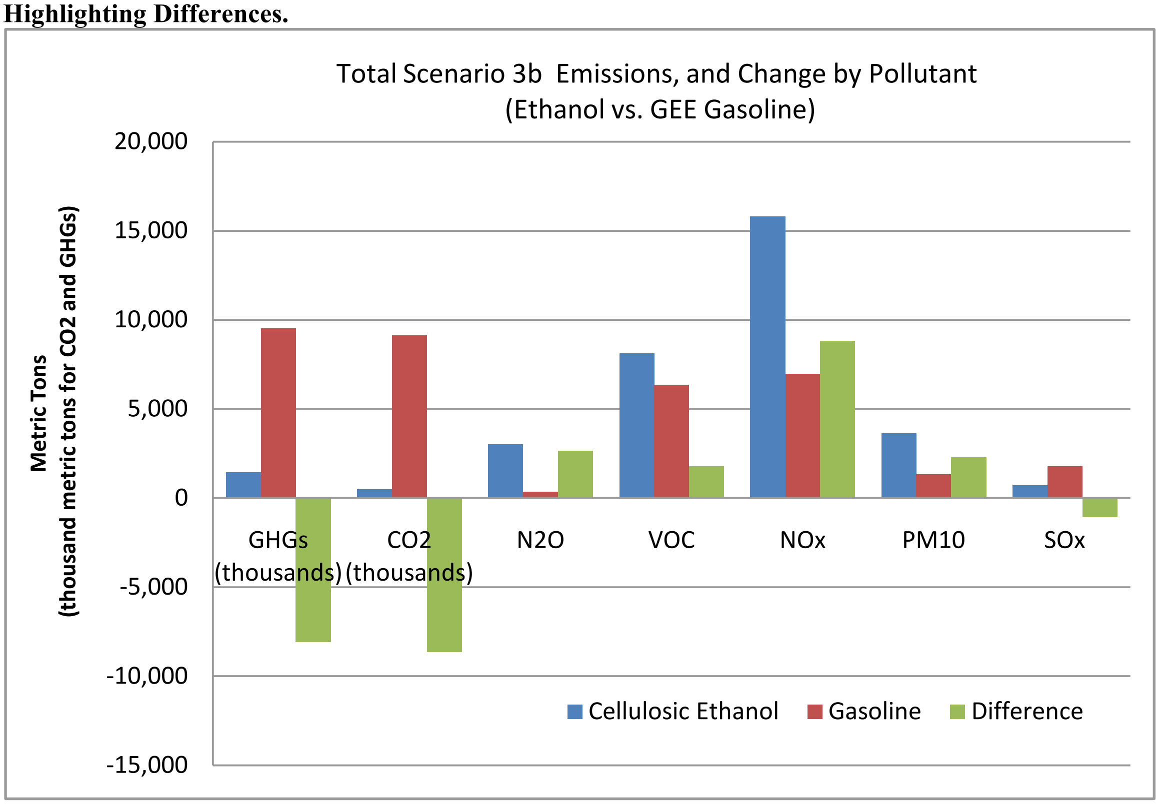


Figure G-32. Scenario 3b Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

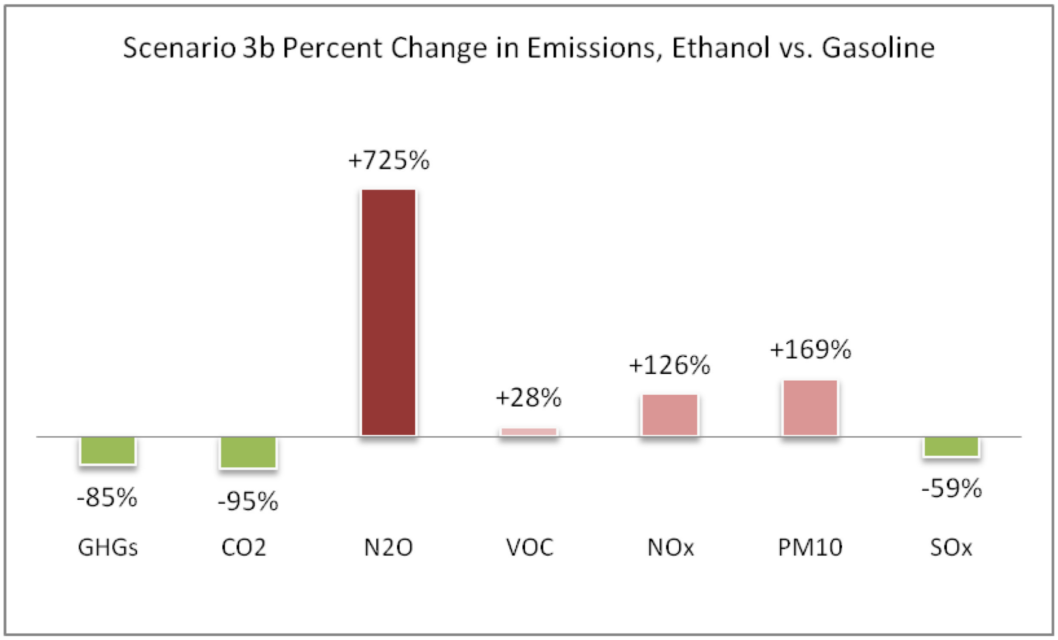
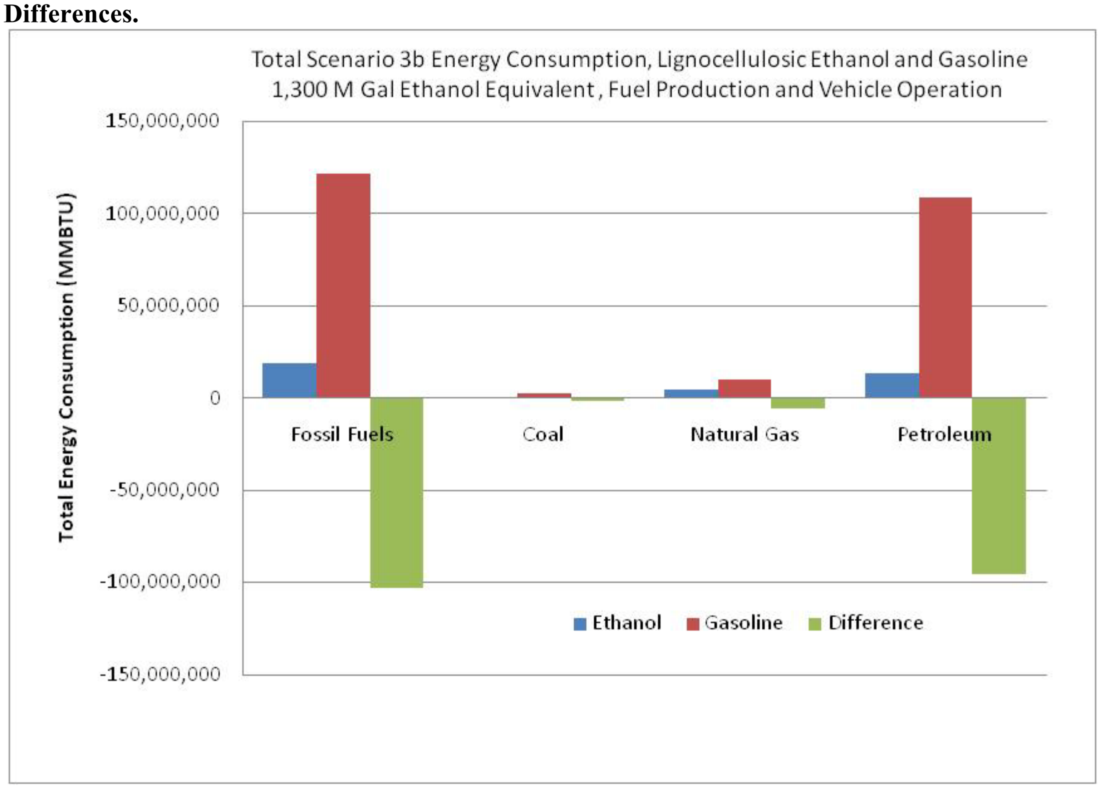


Figure G-33. Scenario 3b Comparison between Ethanol and Gasoline Energy Use, Highlighting Differences.



3.3 CORN-TO-ETHANOL PATHWAY

In the corn-to-ethanol pathway, ethanol production is assumed to continue at an operational plant in Shelby, NY (Western New York Energy), and ethanol production is assumed to commence at an existing plant in Fulton, NY (Sunoco). This section presents the total fuel cycle analysis for the corn-to-ethanol pathway under these assumptions.[4]

Table G-31. Corn Grain Ethanol Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Farming Energy Use (Btu/bu)	Nitrogen Fertilizer Application (g/bu)	N in N_2O as % N in Fertilizer	N Content in Biomass (g/bu)	$CaCO_3$ (g/bu)	P_2O_5 (g/bu)	K_2O (g/bu)	Herbicide (g/bu)	CO_2 Emissions from Land Use Change[a]
17,887	431.5	3.6%	0	3752	161.3	90.0	17.6	0

[a] Assumes zero emissions due to land use change as farmland is already used for corn production.

[4] Note that although we refer to the WNYE and Sunoco sites as our two example production facilities, we model corn to ethanol plants based on general data obtained for these types of facilities.

Table G-32. Corn Grain Ethanol Feedstock Quantity and Transportation.

	Corn Grain to WNYE (Medina)	Corn Grain to Sunoco (Fulton)	All Corn Grain NY State
Wet Tons of Feedstock	567,341	1,113,180	1,680,521
Ton-Miles	40,834,303	165,308,561	206,143,063
Average Miles Farm Gate to Biorefinery	72.0	148.5	122.7

Table G-33. Corn Grain Ethanol Production by Biorefinery.

Biorefinery	Technology	Bushels Corn (M bu/Year)	Ethanol Yield (gal/bul)	Energy Consumption (Btu/gal)	Energy Types Used at Biorefinery	Ethanol (Million Gal/ Year)
WNYE (Shelby)	Dry Milling	20.26	2.72	34,800	88% Natural Gas 12% Electricity	55.11
Sunoco (Fulton)	Dry Milling	38.07	2.72	34,800	88% Natural Gas 12% Electricity	108.14
Total (NY State)		**58.33**				**163.25**

Table G-34. Ethanol Production and Transport Distances by Biorefinery.

Biorefinery	M Gal Ethanol/Year	% of total Ethanol	Miles to Blending Terminal
WNYE (Shelby)	55.1	33.8%	44.5
Sunoco (Fulton)	108.1	66.2%	13.0
Total (NY State)	**163.2**	**100%**	**23.6**

Table G-35. Scenario Corn Grain Ethanol v. Gasoline Well-to-Pump Energy Use and Emissions per MMBtu of Fuel Available at Pump.

Item	Conventional Gasoline	Corn Grain Ethanol
Total Energy (Btu/MMBtu)	259,261	1,560,848
WTP Efficiency	79.4%	39.0%
Fossil Fuels (Btu/MMBtu)	233,509	730,347
Coal (Btu/MMBtu)	24,560	42,765
Natural Gas (Btu/MMBtu)	111,782	553,420
Petroleum (Btu/MMBtu)	97,166	134,163
CO_2 (g/MMBtu)	16,623	-17,917
CH_4 (g/MMBtu)	110	120
N_2O (g/MMBtu)	2	78
GHGs (gCO2eq/MMBtu)	20,061	8,435
VOC (g/MMBtu)	27	62
CO (g/MMBtu)	14	47
NOx (g/MMBtu)	41	112
PM_{10} (g/MMBtu)	8	24
$PM_{2.5}$ (g/MMBtu)	3	8
SOx (g/MMBtu)	18	52

Figure G-34. Corn Ethanol Emissions by Pollutant and Fuel Cycle Stage for Ethanol Production and Use.

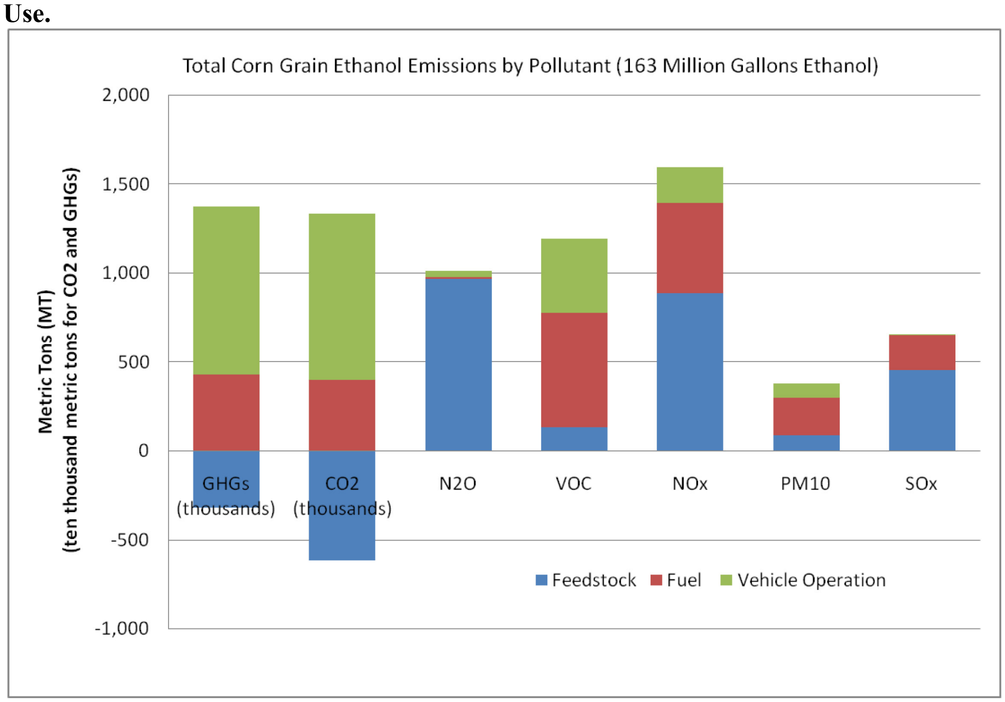


Figure G-35. Corn Ethanol Emissions by Pollutant and Fuel Cycle Stage for Gasoline Production and Use Equivalent to Energy Content in Ethanol Production.

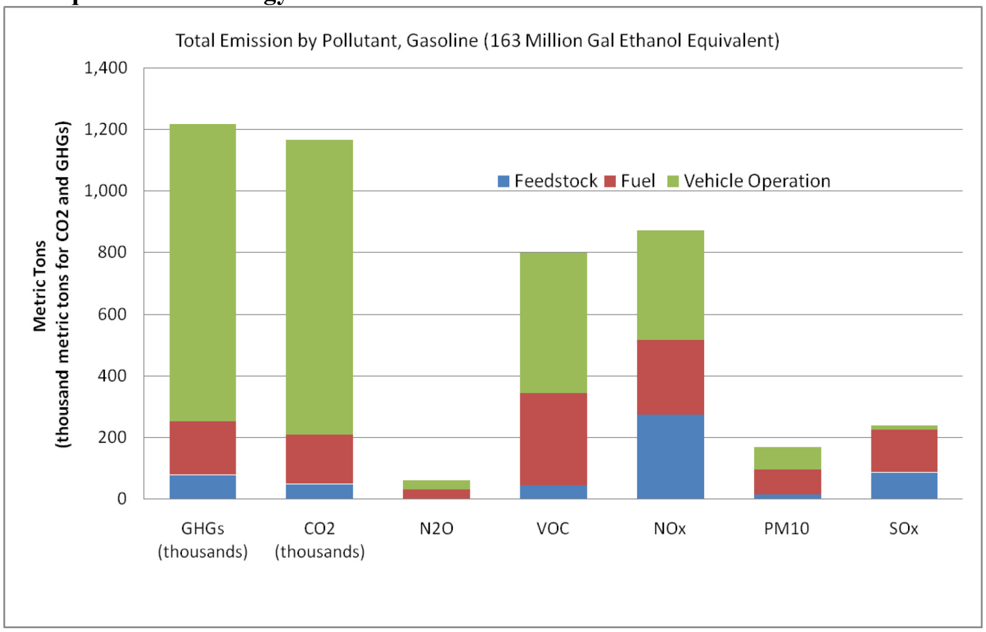


Figure G-36. Corn Ethanol Total Fuel Cycle Emissions Comparison between Ethanol and Gasoline, Highlighting Differences.

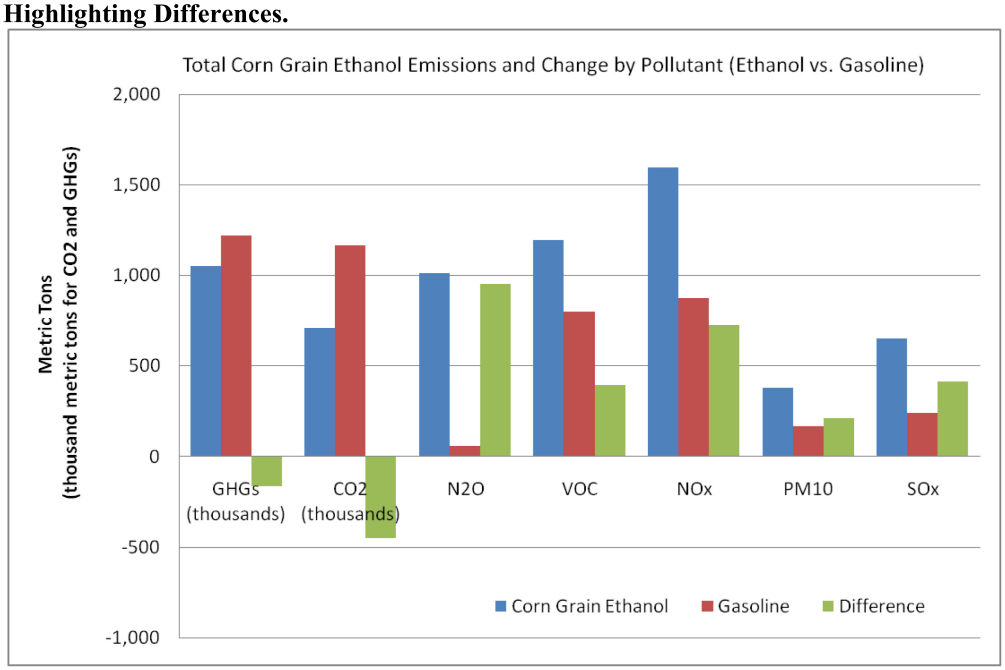


Figure G-37. Corn Ethanol Percentage Change in Emissions Assuming Displacement of Gasoline with Ethanol.

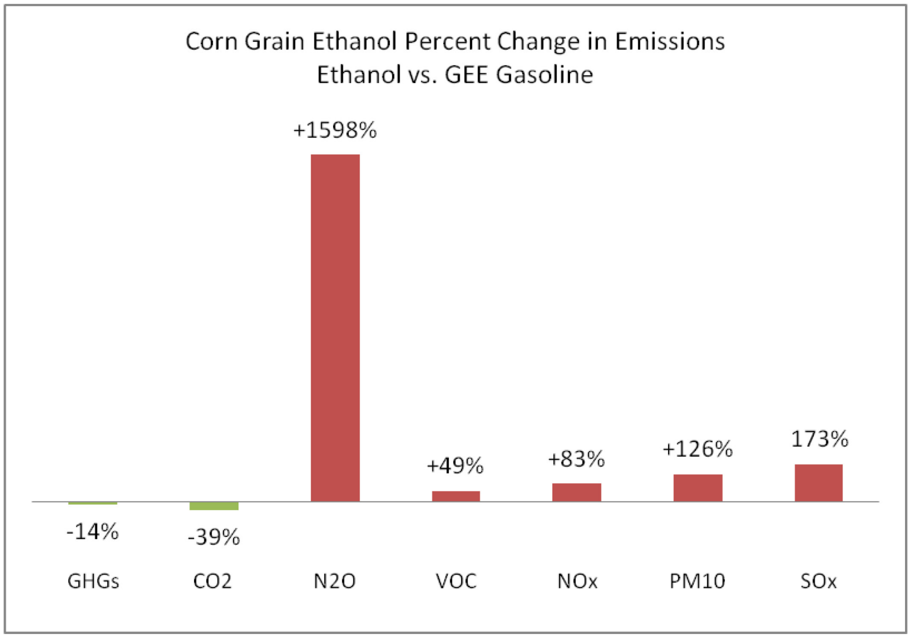
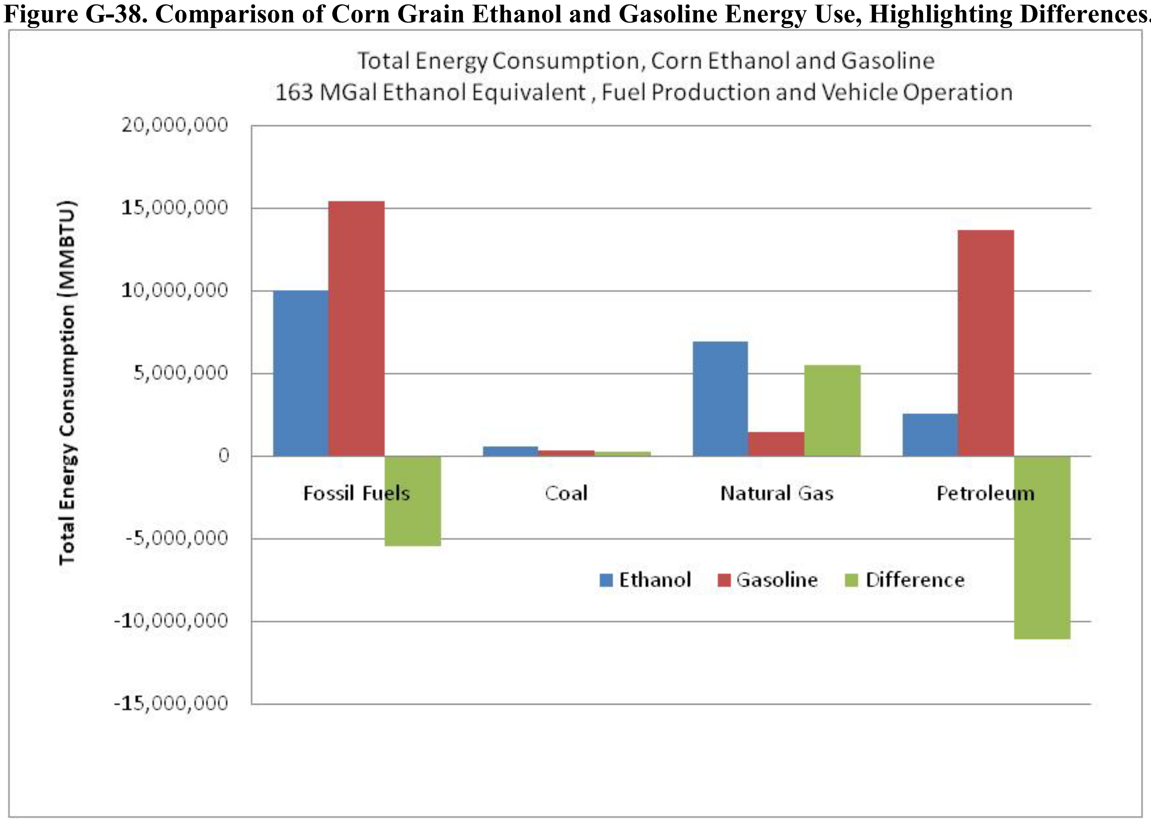


Figure G-38. Comparison of Corn Grain Ethanol and Gasoline Energy Use, Highlighting Differences.



3.4 SOYBEAN-TO-BIODIESEL PATHWAY

Table G-36. Soy Biodiesel Farming Energy and Fertilizer Use and Direct Land Use Emissions.

Farming Energy Use, Diesel Fuel (Btu/bu)	Nitrogen Fertilizer (g/bu)	N in N_2O as % N in Fertilizer	$CaCO_3$ (g/bu)	P_2O_5 (g/bu)	K_2O (g/bu)	Herbicide (g/bu)
21,405	113.5	39.1%*	11,350.0	351.9	431.3	7.7

Table G-37. Soybean Biodiesel Feedstock Quantity and Transportation.

	Soybeans to Crusher	Soy Oil Crusher to Biorefinery
Wet Tons	194,645	37,175
Ton-Miles	32,501,926	2,245,373
Average Distance (Miles)	167	60.4

Table G-38. Soy Biodiesel Production and Transportation.

Biorefinery	Technology	Feedstock Tons/Year	Yield	Annual Production	Distance (Miles)
Crushing Facility (Hamilton, Ontario Canada)		194,645 (Soybeans)	0.19 (lbs Oil/lbs Soybean)	37,175 (Tons Oil)	60.4 (to biorefinery)
Biodiesel Facility (the model assumed a facility in Buffalo, NY)	Base catalyzed transesterification	37,175 (Soy Oil)	0.134 (gal BD/ lbs Oil)	9,600,000 (gal BD)	0.5 (to blending terminal)

Table G-39. Soy Biodiesel v. Conventional Diesel Well-to-Pump Energy Use and Emissions per Million BTU of Fuel Available at Pump.

Item	Diesel	Soy Biodiesel
Total Energy (Btu/MMBtu)	201,121	1,963,846
WTP Efficiency	83.3%	33.7%
Fossil Fuels (Btu/MMBtu)	194,482	429,780
Coal (Btu/MMBtu)	20,703	27,864
Natural Gas (Btu/MMBtu)	91,190	254,853
Petroleum (Btu/MMBtu)	82,589	147,062
CO_2 (g/MMBtu)	15,387	-51,677
CH_4 (g/MMBtu)	105.2	57.9
N_2O (g/MMBtu)	0.3	129.2
GHGs (gCO2eq/MMBtu)	18,096	-11,728
VOC (g/MMBtu)	8	111
CO (g/MMBtu)	12	25
NOx (g/MMBtu)	37	66
PM_{10} (g/MMBtu)	6	10

$PM_{2.5}$ (g/MMBtu)	3	5
SOx (g/MMBtu)	16	55

Figure G-39. Soy Biodiesel Emissions by Pollutant and Fuel Cycle Stage for Biodiesel Production and Use.

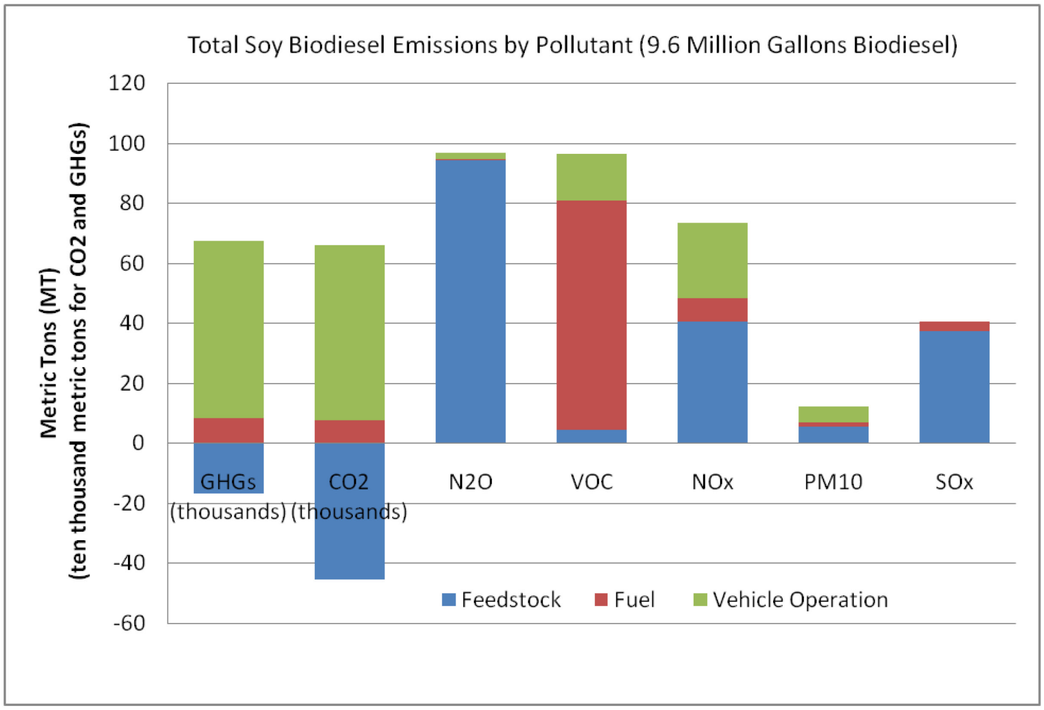


Figure G-40. Diesel Emissions by Pollutant and Fuel Cycle Stage for Diesel Production and Use Equivalent to Energy Content in Soy Biodiesel Production.

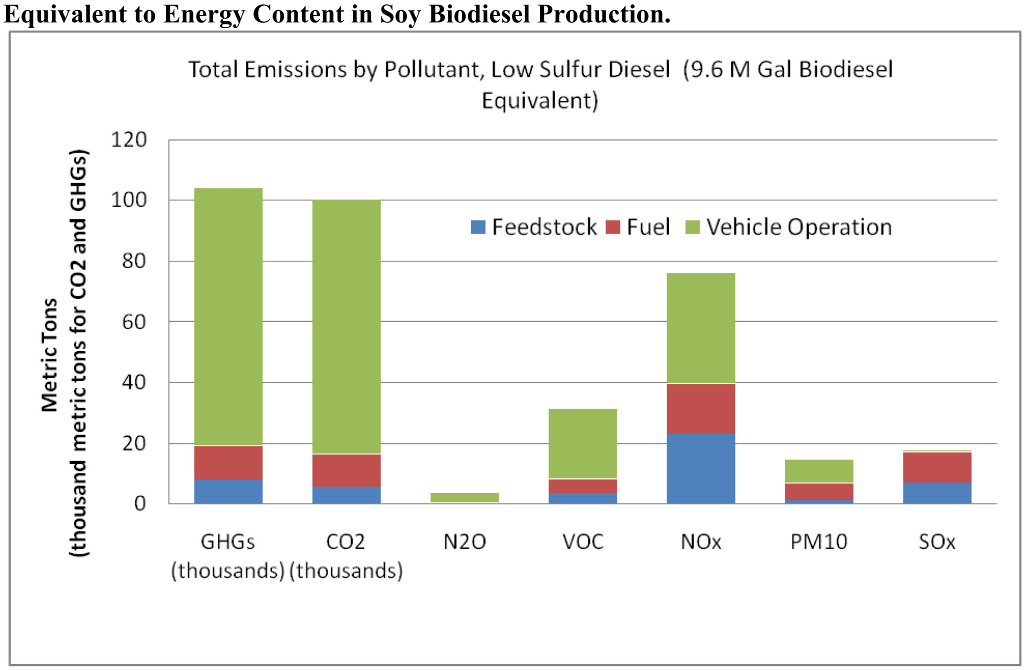


Figure G-41. Soy Biodiesel Total Fuel Cycle Emissions Comparison between Biodiesel and Conventional (Low-Sulfur) Diesel, Highlighting Differences.

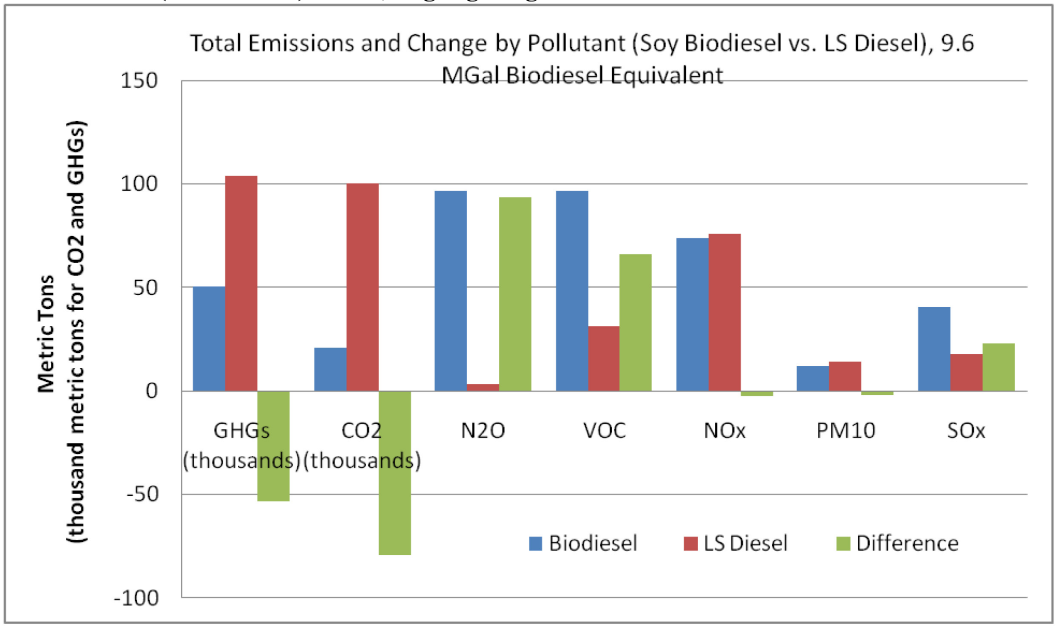


Figure G-42. Biodiesel Percentage Change in Emissions Assuming Displacement of Conventional (Low-Sulfur) Diesel with Biodiesel.

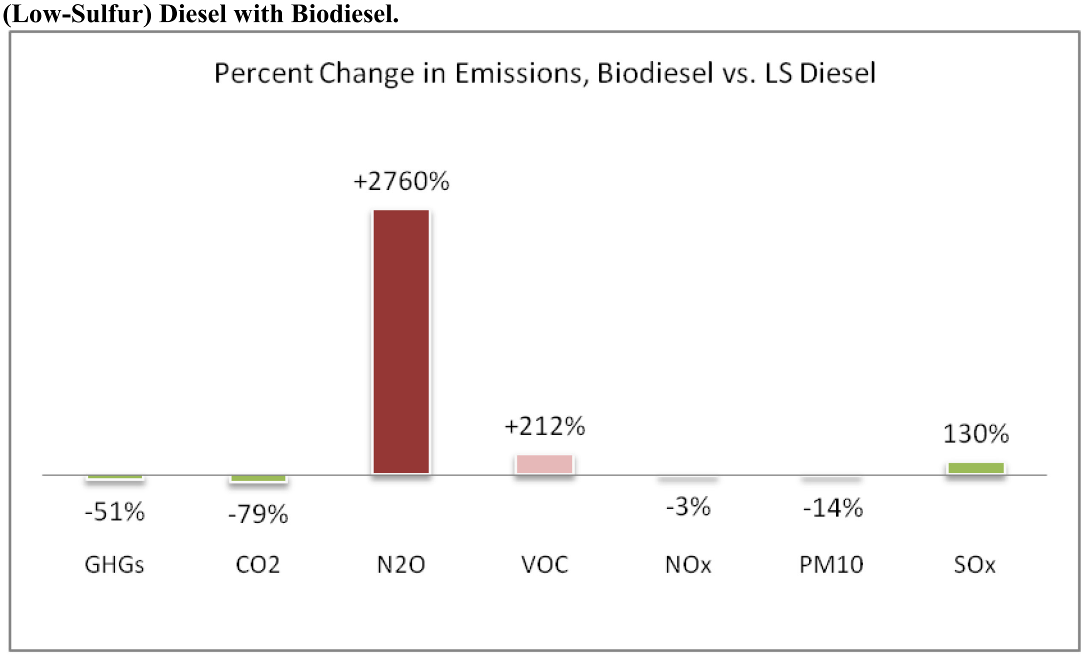
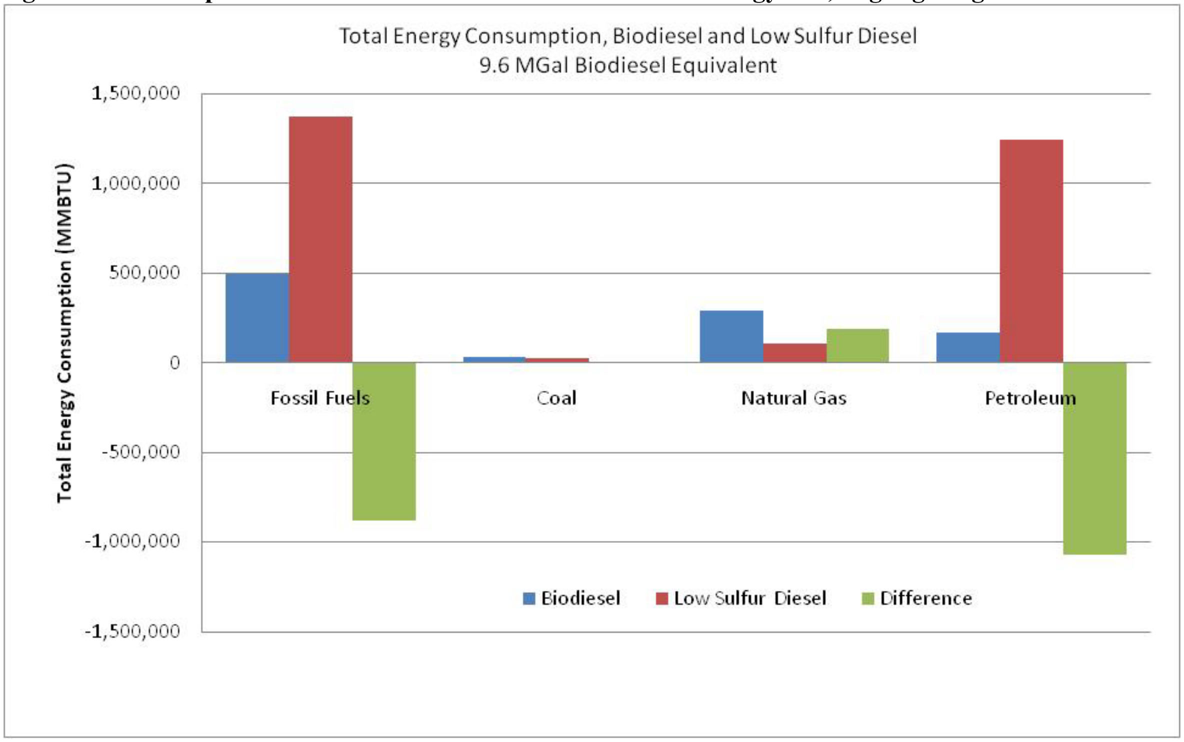


Figure G-43. Comparison of Biodiesel and Low Sulfur Diesel Energy Use, Highlighting Differences.



3.5 SUMMARY OF FINDINGS

3.5.1 LCE Findings

Overall, LCA results suggest that a shift from conventional gasoline to LCE will reduce emissions of GHGs by 67% to 85% compared to equivalent energy content of petroleum fuel. Results indicate that displacing gasoline with LCE produced in the State will reduce GHG emissions by 1.8 million metric tons (Mmt) in Scenario 1a to ~8 Mmt per year in Scenario 3a. We do not examine use of carbon capture and sequestration at the biorefinery, the use of which would result in even greater GHG reductions. LCE production and use will also reduce life-cycle emissions of sulfur oxides (SO_x), with reductions ranging from 90 metric tons in Scenario 1a to over 1,000 metric tons in Scenario 3 cases.

As shown in Figure G-45, LCA results also demonstrate that displacing petroleum fuels with LCE will reduce life-cycle consumption of fossil fuels, with reductions ranging from over 20 million MMBtu in Scenario 1a to roughly 100 million MMBtu in Scenario 2 and 3 cases (greater reduction in Scenario 3). Figure G-466 provides a frame of reference to illustrate energy savings by fuel type and scenario. The figure illustrates the physical quantity of each fuel type that would be displaced, derived from energy content shown in Figure G-455.[5] As shown in the figure, reductions in petroleum energy consumption equate to the annual displacement of over 200 million gallons of gasoline in Scenario 1a and over 800 million gallons gasoline in Scenario 3. Note that New Yorkers used almost 6,000 million gallons of

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[5] This figure is for illustrative purposes only, as petroleum energy includes not only gasoline but also diesel fuel and other petroleum products.

gasoline in 2007, so this represents displacement of approximately 5% to 15% of present-day gasoline consumption, respectively.

Displacing gasoline with LCE produced in the State will avoid GHG emissions, SO_x emissions, and fossil fuel consumption; however there are pollutant tradeoffs to LCE production and use in the State. Emissions of air pollutants (VOCs, NO_x, and PM) increase in all scenarios. Emissions of VOCs and PM increase by approximately 2,000 metric tons in Scenarios 2 and 3, though in Scenario 1 emissions increases are a fraction of that. Emissions of NO_x increase by 2,000 metric tons (Scenario 1a) to nearly 10,000 metric tons (Scenario 2 cases). The majority of VOC and NO_x emissions take place in the fuel production stage; advanced stationary source controls may be able to reduce these emissions in the future (application of advanced control technologies on biorefineries was not modeled). Finally, emissions of N_2O, a GHG that is also ozone-depleting, increase in all scenarios. Though N_2O is approximately 300 times as potent a GHG as CO_2, N_2O emissions are more than offset by reductions in CO_2. As discussed, earlier, net GHG emissions are reduced in all scenarios. We note that results for the vehicle-use stages of this analysis assume a light-duty vehicle operating on each fuel, and that future advancements in vehicle technology may improve emissions for both conventional and alternative fuel vehicles.

Results indicate a number of notable differences among Roadmap scenarios. LCE production and use in Scenario 1 produces the least change in emissions, due in large part to the smaller quantity of LCE produced. Increases in emissions of air pollutants are minimal compared to other scenarios; however, total GHG emission and petroleum use reductions are also minimal (about one-quarter the levels in Scenarios 2 and 3).

Scenario 2 and 3 are nearly identical in LCE production. Scenario 3 results in greater reductions in GHG emissions, SO_x emissions, and petroleum energy consumption, while producing fewer VOC, NO_x, and PM emissions. Results demonstrate that distributed biofuels industry and land use constraints such as those assumed in Scenario 3 are preferable from an environmental (emissions) and energy use perspective[6], but may not be as desirable for other economic or logistical reasons.

3.5.2 Corn Ethanol Findings

Results indicate that corn ethanol production and use in the State results in slight net GHG reductions (14%) compared to equivalent energy content of gasoline. Though CO_2 is reduced by 452,000 tons

[6] Note that local environmental impacts of biorefinery construction and siting were not examined; however, some of the economic impacts of these different biorefinery configurations are discussed in Appendix L. This Roadmap appendix was not designed to find the pathway that would have the fewest emissions as relates to biofuels production, but to quantify and describe the impacts of such development. What the authors of this Appendix did was to take the outputs from the biorefinery siting model (Appendix L) and conduct the LCA emissions and energy use calculations based on those outputs. No preference was given for selecting one feedstock, one mode of transportation, or one technology model over another in creating the biorefinery siting model; instead, the economic model employed in siting the biorefineries was a cost minimization model that indentified only the private costs of feedstock production, transportation, and fuel production. This model does not include potential social costs from biofuels production. In the future, this appendix could form part of a baseline for developing a social costs model that values the environmental and health impacts from the production, transportation and distribution of biofuels.

annually, N_2O is increased by 952 tons/year. Corn ethanol results in increased annual emissions of all air pollutants, including SO_x. Results also indicate that corn ethanol production will decrease annual petroleum consumption in the State by the energy equivalent of over 90 million gallons of gasoline. Corn ethanol will increase coal use slightly, due to electricity use at corn ethanol plants and the role of coal in grid-power production. [7]

Though LCA results of corn ethanol are less positive than LCE from an emissions and energy use perspective, results demonstrate that corn ethanol could displace petroleum fuel in the State while resulting in net GHG emissions reductions.

3.5.3 Soy Biodiesel Findings

As shown in Figure G-444, LCA results indicate that emissions impacts of soy biodiesel production and use[8] are minimal in comparison to ethanol cases—primarily due to the small quantity of biodiesel produced (9.6 million gallons per year). Results indicate a reduction of over 50,000 metric tons of GHG emissions (51% compared to low-sulfur petroleum diesel). Emissions of N_2O, VOCs, and SO_x increase, while NO_x and PM are reduced.

Results indicate that soy biodiesel production and use will decrease petroleum consumption by the equivalent of over 9.2 million gallons of gasoline—a small fraction of petroleum displacement from LCE scenarios. Overall, emissions and energy use impacts of biodiesel production in the State under these scenarios are minimal compared to lignocellulosic and corn ethanol production.

[7] If natural gas or biomass were to displace coal in the future, these numbers would decrease.
[8] Yellow grease (as a feedstock for biodiesel production) was not modeled in the Roadmap.

Figure G-44. Comparison of Net Change in Emissions by Scenario.

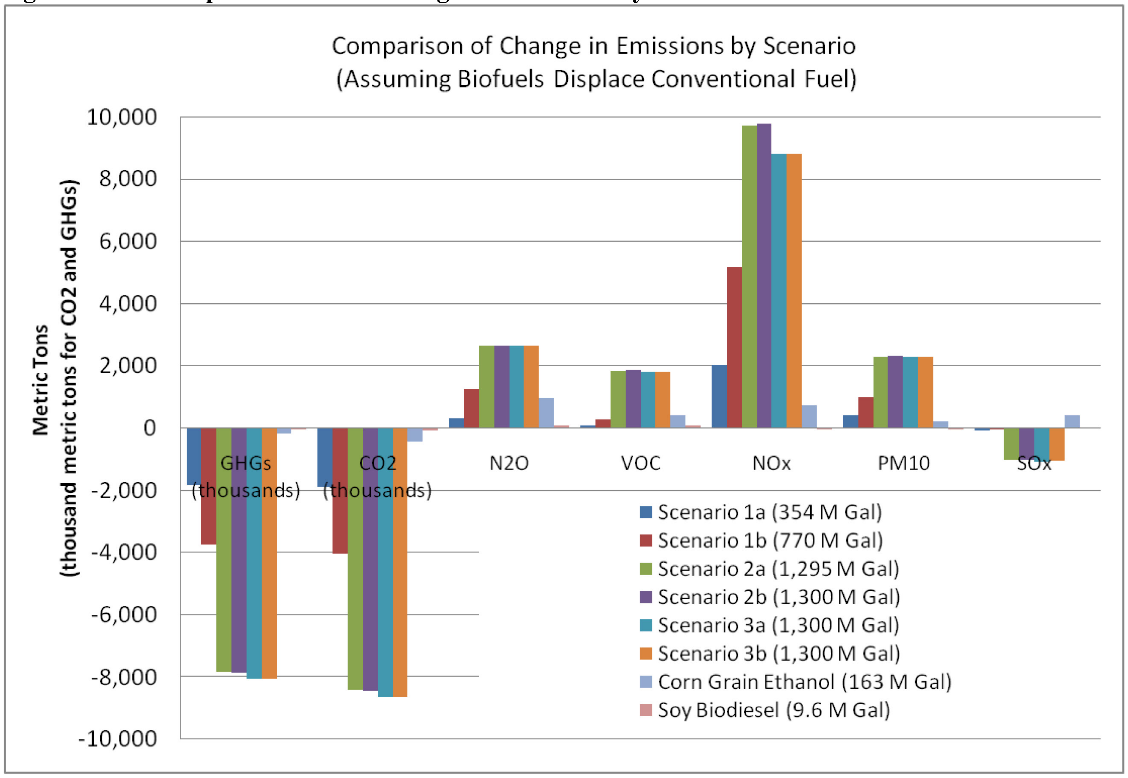


Figure G-45. Comparison of Change in Energy Consumption by Scenario.

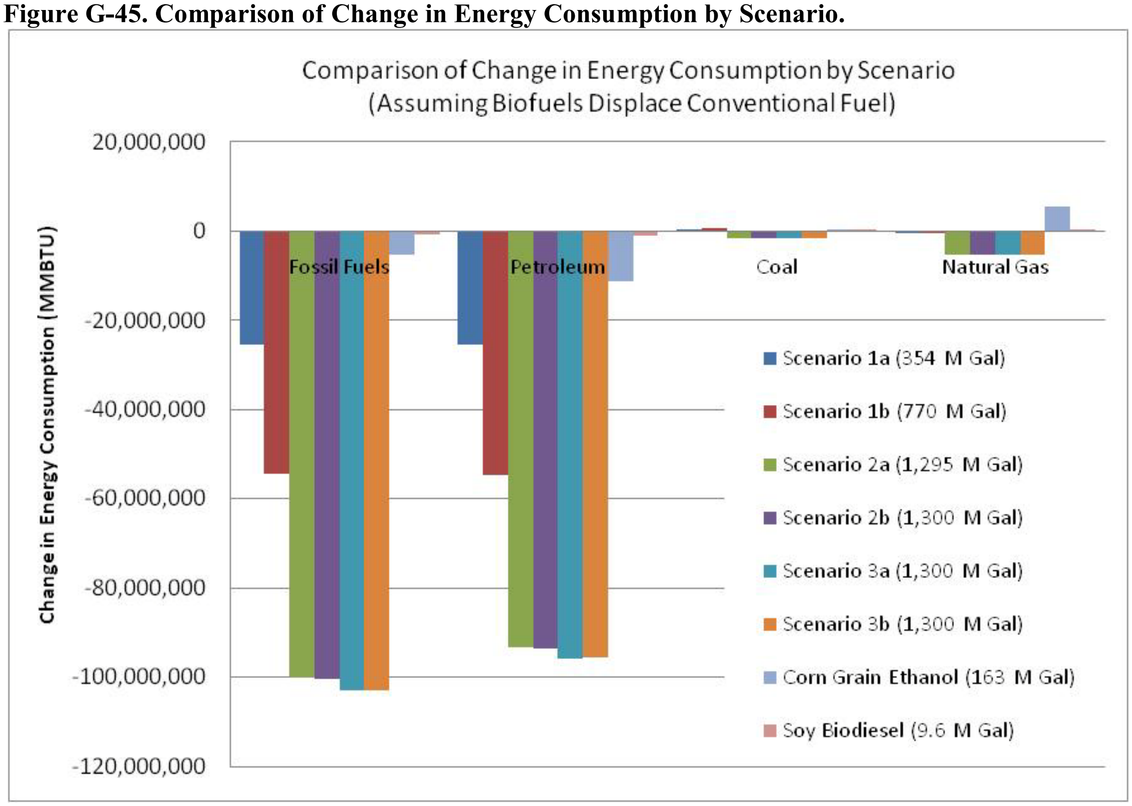
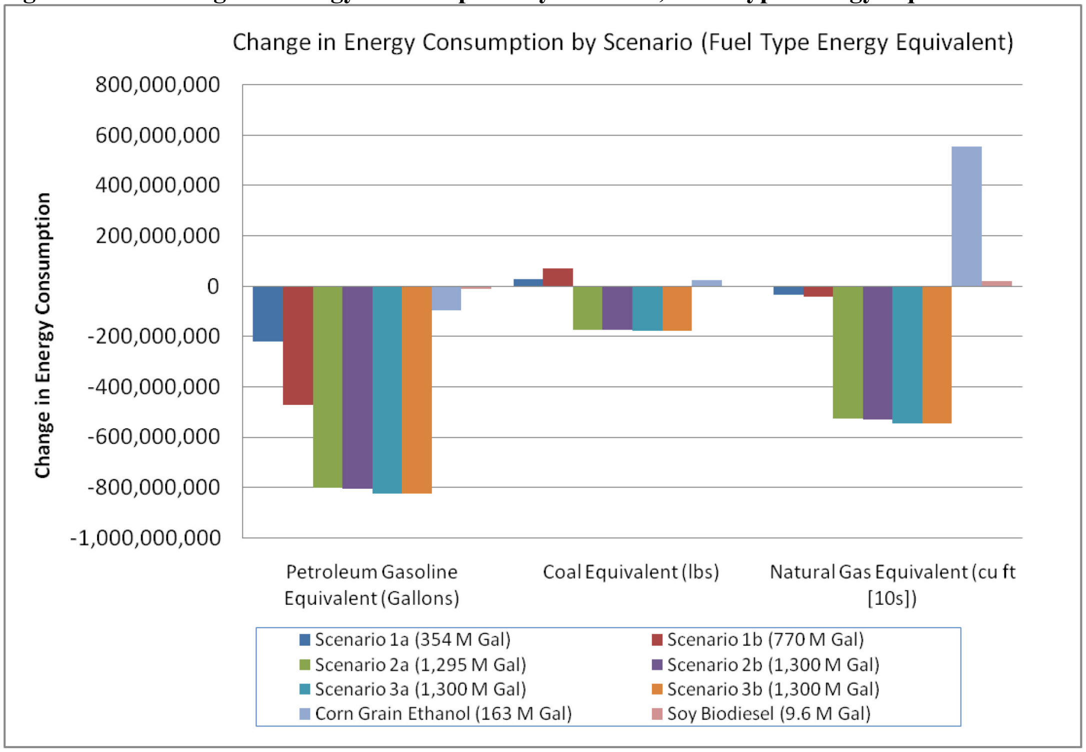


Figure G-46. Change in Energy Consumption by Scenario, Fuel Type Energy Equivalent.



4 PUBLIC HEALTH IMPACTS OF BIOFUELS PRODUCTION AND USE

4.1 OVERVIEW

Emissions from biofuel production and use have the potential to negatively affect human health (NYSERDA 2009). These emissions may occur either at the farm or fuel production facilities (upstream emissions) or at the tailpipe of the vehicle (downstream emissions). In both cases the direct emissions from production or use (*primary emissions*) can be harmful to exposed human populations. In addition, some of these primary emissions are transformed in the atmosphere to form *secondary emissions*. Detailed quantitative modeling of the atmospheric fate and transport of such pollutants is beyond the scope of this project. Instead, the public health impacts are discussed through a presentation of the literature on this topic, which is then connected with the LCA results presented above.[9]

4.2 UPSTREAM LCA RESULTS: AIR POLLUTANT EMISSIONS AT FEEDSTOCK AND FUEL PRODUCTION STAGES

The LCA presented in this appendix covers the following air pollutants:

- **Volatile organic compounds (VOCs):** Volatile organic compounds are airborne toxics and precursors to ground-level ozone, which is linked to a number of negative health effects including aggravation of asthma, bronchitis, and emphysema, reduced lung function, and pain while breathing. Repeated exposure to ground-level ozone has been linked to premature mortality (EPA 2009a).
- **Particulate matter (PM):** An EPA criteria pollutant,[10] PM includes particles with an aerodynamic diameter of 10 micrometers or smaller (PM_{10} and $PM_{2.5}$) – particles that are small enough to reach into the lower respiratory tract and lungs, causing adverse health effects. Numerous studies have linked increased concentrations of PM to negative health effects for exposed populations. PM has been linked to damages to respiratory systems and lungs, chronic bronchitis, cancer, asthma, heart attacks, and premature mortality. Environmental effects of PM include decreased visibility (haze), alteration of nutrient balance, acidification of water, and damage to forests and crops (Nel 2005; EPA 2008a).
- **Nitrogen oxides (NO_x):** An EPA criteria pollutant, nitrogen oxides are associated with respiratory problems including asthma and respiratory-related hospital admissions and contribute to ground-level ozone and particulate matter formation (EPA 2009b). NO_x emissions also contribute to acidification and eutrophication of soil and water (NYSERDA 2009).

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[9] A detailed discussion of potential health and environmental impacts of biofuels production and use in the State can be found in NYSERDA (2009), *The Environmental Impacts of Biofuels in New York State*. Another NYSERDA study, "Applying the Northeast Regional Multi-Pollutant Policy Analysis Framework to New York: An Integrated Approach to Future Air Quality Planning," will propose mitigation options for air quality. Because the study is not complete, results will be assessed in the annual Roadmap updates.

[10] Criteria pollutants (particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead) are six common air pollutants, which are prevalent throughout the United States, and can be harmful to human health and the environment. These pollutants are termed "criteria" air pollutants because the EPA regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) that set allowable levels of the pollutants. (USEPA)

- **Sulfur oxides (SO_x):** An EPA criteria pollutant, sulfur oxides, including sulfur dioxide (SO_2), react with water vapor and airborne particles to form acidic compounds and sulfates, which are harmful to human health and the environment. Long-term exposure to SO_2 is linked with respiratory problems and disease, while exposure to sulfate particles is linked to respiratory problems and premature mortality (EPA 2009c).

As shown in Figure G-47 total life-cycle emissions of VOCs, NO_x, and PM increase State-wide compared to conventional fuels for all scenarios, and SO_x emissions decrease in all LCE scenarios, but increase in corn ethanol and soy biodiesel cases. Note that there may be *localized* pollution inventory shifts (increases and/or decreases) that are not accounted for in this analysis. Although it is difficult to quantify the relative public health impacts from these emission profiles, more than half of the emissions occur in the upstream stages of the fuel cycle (see, for example, Figure G-48 and 49 below for *Scenario 2b*, or see figures presented earlier in this Appendix for other scenarios). For biofuels, these upstream emissions will occur in New York; however, for conventional fuels, these emissions will occur mostly outside New York in locations where petroleum fuel is extracted and/or refined. For that reason, biofuel use is expected to increase total pollution inventories for New York, particularly in those counties that expand feedstock production or operate biorefineries. A geospatial characterization of upstream emission locations and transportation activities can be found on maps located in Appendix F of this report. Those maps depict counties where feedstock extraction and biorefinery activity is likely to expand for each scenario studied. Potential health impacts of increased emissions include a range of respiratory problems, asthma, heart attacks, cancer, and premature mortality. More research is needed to quantify the health impacts from these emissions, through the application of atmospheric dispersion and population exposure models, to characterize the health risk to exposed populations in these regions.

Figure G-47. Change in Air Pollutant Emissions by Scenario.

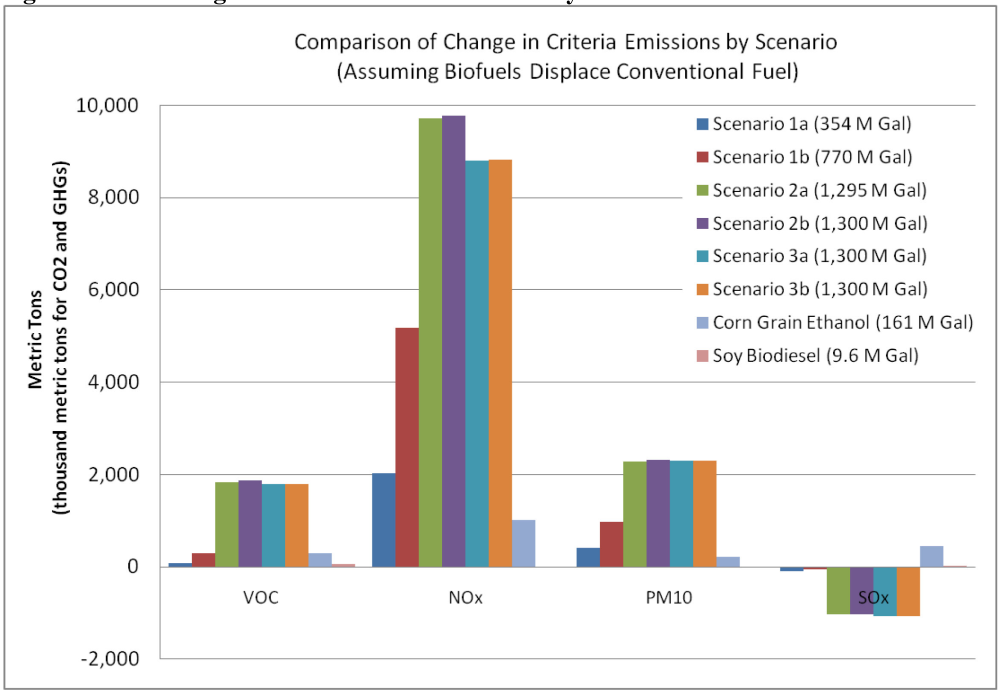


Figure G-48. Percentage of Total Scenario 2b LCE Emissions Contribution by Fuel-Cycle Stage.

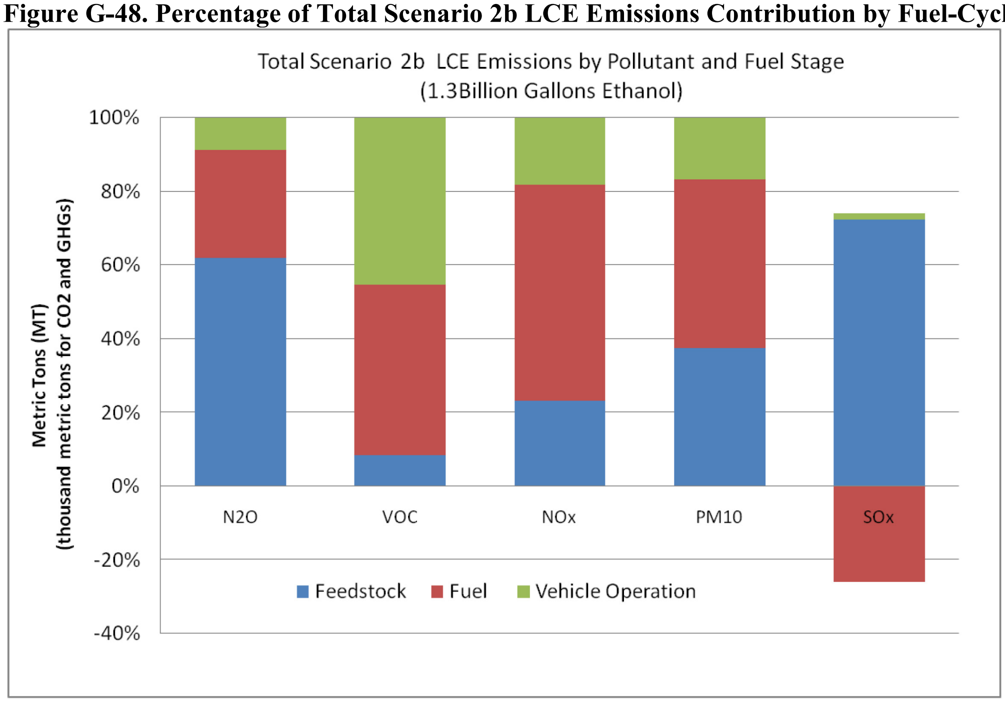
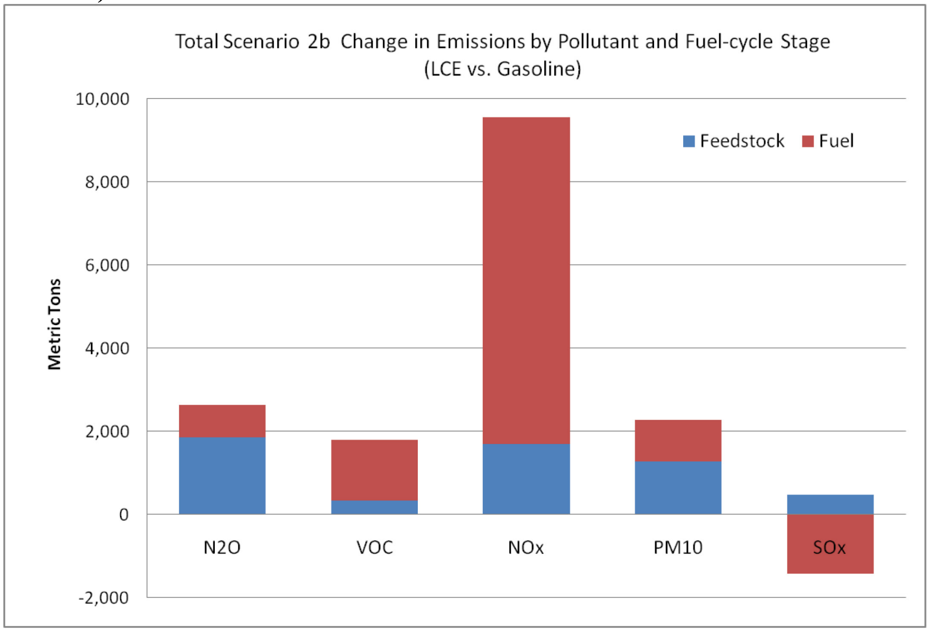


Figure G-49. Total Scenario 2b Change in Criteria Pollutant Emissions by Fuel Cycle Stage (LCE vs. Gasoline).



4.3 DOWNSTREAM EMISSIONS OF AIR POLLUTANTS: POTENTIAL CHANGES DUE TO BIOFUEL USE IN THE STATE

4.3.1 Downstream Emission Types

Downstream (tailpipe and evaporative) emissions may present the greatest risks to public health, as these emissions are often released in more densely-populated urban and residential areas. It is beyond the scope of this study to quantitatively model the health effects of downstream emissions, as we do not have data on precisely where fuel would be consumed and in what quantities. However, we can qualitatively discuss potential changes in tailpipe emissions and resulting human health impacts due to a shift from conventional fuel to biofuels. For this qualitative assessment, the EPA criteria pollutant CO and toxic air pollutants (also known as hazardous air pollutants, HAPS) are included (EPA 2000; EPA 2008b; EPA 2009d; EPA 2009e; EPA 2009f; EPA 2009g; Winebrake, Wang and He 2001), in addition to the pollutants listed in the upstream emissions section, above:

- **Carbon monoxide (CO):** Carbon monoxide can reduce oxygen delivery to the body, exacerbating existing cardiovascular problems and producing negative central nervous system effects. At very high levels CO may cause death. CO is also a contributor to ground-level ozone, which can cause respiratory problems.
- **Acetaldehyde:** Acetaldehyde has been identified as a *probable human carcinogen* by the EPA, due to presence of tumors in rats exposed to acetaldehyde. Non-cancer effects include eye and respiratory tract irritation, coughing, and burning in nose and eyes. High exposure levels may lead

to pulmonary edema and necrosis. Depressed respiratory rate and elevated blood pressure have been seen in experiments with animals.

- **Formaldehyde:** Formaldehyde is classified as a *probable human carcinogen* by the EPA based on evidence in humans, rats and monkeys. Non-cancer effects include burning and irritation in eyes and throat, coughing, nausea, fatigue, skin rash, and allergic reactions. At high levels formaldehyde can cause difficulty breathing and may trigger asthma attacks. Like acetaldehyde it can be produced through primary combustion and secondary formation through reactions of organic compounds.
- **Benzene:** Benzene is classified as a *known human carcinogen* by the EPA based on epidemiologic studies, causing leukemia by all routes of exposure. Non-carcinogenic effects include eye, skin and respiratory irritation, drowsiness and dizziness and even unconsciousness at high levels. Long-term exposure to benzene has also been linked to non-cancer blood disorders and reproductive effects. Benzene is emitted from vehicles as both exhaust gas and through evaporative emissions.
- **1, 3 Butadiene:** 1,3 butadiene is characterized as carcinogenic to humans by inhalation, and is classified as a *known human carcinogen* by the U.S. government. Non-carcinogenic effects of 1, 3 butadiene include eye, throat, lung, and nasal passage irritation; also exposure may be linked to cardiovascular diseases.

4.3.2 Ethanol.

The potential health effects of ethanol use in the State are highly uncertain as the use of ethanol has been found to increase tailpipe emissions of certain VOC species, while decreasing emissions of others. Vehicle type, vehicle operation, combustion conditions (temperature-pressure relationships), and environmental conditions all influence ethanol emissions relative to conventional petroleum fuel. Adding further uncertainty, the literature examining ethanol tailpipe and evaporative emissions is often conflicting (DOE, 2009), partly due to non-fuel factors listed above and to the variety of ethanol fuel blends. In this discussion general findings are presented on downstream emissions from ethanol use, and the potential implications on public health in New York State are discussed.

Figure G-50 shows the findings of Niven (2005), who performed a review of environmental impacts of ethanol in gasoline. As shown in the figure, tailpipe emissions from E10 (10% ethanol, 90% gasoline) tend to reduce emissions of CO; hydrocarbons (HC, of which VOCs are a component); PM; 1, 3 butadiene; benzene; and non-methane hydrocarbons (NMHC); while increasing acetaldehyde, and having mixed impacts on NO_x and formaldehyde emissions. Considering tailpipe and evaporative emissions, E10 has been found to increase HC, NO_x, formaldehyde, acetaldehyde, NMHC, and ozone-forming potential; CO emissions are reduced. E85 reduces emissions of benzene and butadiene, while increasing formaldehyde and acetaldehyde; E85 reduces NO_x and has mixed impacts on CO emissions (Jacobson 2007).

Figure G-50. Change in Emissions, E10 Compared to Gasoline.

Pollutant	E10 Tailpipe	E10 Tailpipe Plus Evaporative*
CO	Reduce	Reduce
HC	Reduce	Increase
PM	Reduce	NA
NO_x	Increase (mixed)	Increase
1,3-Butadiene	Reduce	NA
Benzene	Reduce	NA
Formaldehyde	Mixed**	Increase
Acetaldehyde	Increase	Increase
Ozone forming potential	NA	Increase
NMHC	Reduce	Increase

Notes: *When assessing evaporative emissions, there are caveats that make it less ubiquitous and consistent than tailpipe emissions. The results shown in this table do not reflect these caveats.
**In a follow-up study, formaldehyde emissions were found to change according to temperature.

Source: DOE (2009), reporting findings of Niven (2005)

High blends of ethanol generally reduce tailpipe emissions of NO_x compared to petroleum fuels, with E85 NO_x reductions averaging 20-40% (NYSERDA 2009). In E10 spark-ignited (Otto cycle) vehicles, NO_x emissions have been shown to increase or decrease compared to gasoline (DOE, 2009; Karman, 2003). Ethanol-diesel blends may reduce NO_x compared to diesel fuel in auto-ignited engines (Diesel cycle), or may vary according to engine conditions and speeds (He et al. 2003; Huang et al. 2009). Most of the discussion of research here refers to studies of ethanol in Otto cycle engines; the next subsection addresses biodiesel.

E10 and E20 tend to produce lower CO tailpipe emissions (Niven 2005). Higher blends of ethanol (E85) have been shown to increase tailpipe emissions of CO compared to gasoline, with a total life-cycle increase in CO emissions of 2-3% (NYSERDA 2009; Wu et al. 2005; Brinkman 2005); CO emissions have been found to increase or decrease when used in ethanol-diesel blends (He et al. 2003; Huang et al. 2009).

Though total life cycle PM_{10} emissions of corn ethanol are increased substantially compared to gasoline, the majority of PM emissions occur at upstream stages; changes in tailpipe PM emissions of ethanol are uncertain or have been shown to be negligible (Jacobson 2007; Niven, 2005; Mazurek 2007, as quoted in NYSERDA 2009).

Ethanol has been shown to increase tailpipe and evaporative emissions of formaldehyde and acetaldehyde (Jacobson 2007; Niven 2005; Winebrake et al. 2001), toxics that are also ozone precursors. Compared to gasoline, E85 increases tailpipe and evaporative emissions of acetaldehyde by 1250% to over 4300%, and formaldehyde by 20% to over 250% (Jacobson, 2007; NYSERDA, 2009; Winebrake et al., 2001). E10 also increases acetaldehyde and formaldehyde emissions, but to a smaller degree (Niven 2005; NYSERDA 2009).

Emissions of benzene and butadiene—both known carcinogens—are reduced in ethanol compared to gasoline. Benzene is reduced by 62-87% in E85 and by 11% to 41% in E10 compared to gasoline, though benzene emissions may increase in E10 compared to reformulated gasoline.[11] Butadiene emissions are decreased 0% to 79% with E85, and by 6-19% with E10 (Jacobson 2007; Karman 2003; Niven 2005; NYSERDA 2009; Winebrake, He, and Wang 2000; Winebrake, Wang, and He 2001). The relative toxicity of these pollutants is important to consider, as benzene and butadiene are considered much more toxic (with respect to cancer risk) than formaldehyde and acetaldehyde by EPA's CURE (Cancer Unit Risk Estimate) scale. Use of ethanol will likely increase aldehyde toxics and reduce benzene and butadiene (NYSERDA 2009; Winebrake, He, and Wang 2000). A decrease in toxic emissions in urban areas from benzene and butadiene would be a positive sign with respect to cancer impacts from the use of ethanol in the State, although it is tempered by the likely increase in other toxics, which are associated with other health impacts.

The variation in emissions impacts by ethanol fuel blends may provide an opportunity to minimize potential negative public health impacts in the State. For instance, E10 has been shown to increase tailpipe NO_x and benzene emissions compared to reformulated gasoline, while E85 has been shown to decrease benzene and NO_x emissions. To curtail potential cancer cases and ozone development in urban areas, E85 blends may be preferable to E10 blends in densely populated regions.

The net effects of ethanol use on public health are uncertain, as the scale, location of emissions, and affected populations are unknown—as are future regulations of air pollutants and toxics. However, recent research may shed light on potential scale of health impacts from certain pollutants. A 2007 study examined the toxics, and ozone-related cancer, hospitalization, and mortality impacts of a nationwide switch from gasoline to E85 for the year 2020. Compared to 100% gasoline use, the study found that E85 would increase ozone-related mortality, hospitalization, and asthma in the U.S. by 4%, and in Los Angeles by 9% (increases in Los Angeles were partially offset by decreased mortalities in other regions of the country). Using CURE values, little change in cancer risk was found (Jacobson 2007). Another study compared health effects of $PM_{2.5}$ emissions from corn ethanol, cellulosic ethanol, and gasoline, finding that cellulosic ethanol resulted in the lowest health impacts, while corn ethanol resulted in higher PM emissions and health impacts than gasoline, regardless of corn ethanol process fuel (Hill et al. 2009); the study did not examine ozone concentrations or toxics.

<u>4.3.3 Biodiesel.</u>

As with ethanol, the health effects of biodiesel use in the State are uncertain as biodiesel increases tailpipe emissions of certain pollutants, while decreasing emissions of others. Vehicle type, vehicle operation, combustion conditions (temperature-pressure relationships), fuel blend, and environmental conditions all

[11] Reformulated gasoline (RFG) is specially refined gasoline with low levels of smog-forming VOCs and low levels of hazardous air pollutants (HAPs).

influence biodiesel emissions relative to diesel fuel. In this section general findings are presented on biodiesel tailpipe emissions as compared to diesel fuel, and public health implications are discussed.

Figure G-511 shows findings of NREL (2003), which include a review of literature on biodiesel emissions' impacts in heavy-duty vehicles (HDVs). As shown in the figure, compared to conventional diesel, B20 (20% biodiesel) increases tailpipe emissions of NO_x while decreasing emissions of PM, CO, VOC, and SO_2 (SO_x). Higher biodiesel concentrations (e.g., B100) yield greater changes in emissions, as shown in Figure G-511. Nevertheless, actual emissions results are very much dependent on vehicle type. Load profiles are affected by high-temperature, high-pressure combustion conditions found with auto-ignition. Some studies indicate NO_x emissions increases to be negligible for B20, while others show NO_x decreases (McCormick 2005).

Figure G-51. Average Change in HDV Emissions, Biodiesel Fuel vs. Petroleum Diesel.

Biodiesel Fuel	NOx	PM	CO	VOC	SO_2
B20	+2.4%	-8.9%	-13.1%	-17.9%	-20%
B100	+13.2%	-55.3%	-42.7%	-63.2%	-100%

Source: NREL (2003)

Variability in location of emissions, and reaction of pollutants with other airborne substances also contributes to uncertainty. A 2003 study examined scenarios of 100% B20 penetration and 50% B20 penetration in the HDV fleet in Southern California, Las Vegas, the Northeast corridor, and Lake Michigan. Even at 100% penetration of B20, changes in modeled ambient concentrations of ozone, CO, $PM_{2.5}$ and PM_{10} were extremely small (<± 1%) in all study regions. Ozone concentrations changed (+/-) by less than one part per billion (ppb), and CO decreased by less than 0.2%. Changes in ozone and CO concentrations were low enough that the study determined *no measurable health impacts would occur from use of biodiesel*. In the Las Vegas study region, B20-related changes in PM were found to reduce exposure to annual and 24-hour exceedance of the PM_{10} standard by 4% and 7%, respectively. PM from B20 is less toxic than diesel PM; accordingly, the use of B20 was estimated to reduce risk associated with toxics by 5% in the Southern California study region (NREL 2003). The extent of biodiesel use in New York State is currently much lower than the levels of penetration examined in the study; therefore emissions in New York are assumed to be even lower, and negative health impacts are likely to be less significant than listed in the study, above.

In the preceding sections we have discussed the potential health impacts of biofuel production and use in the State. It is important to note that competing uses of biomass for energy are also associated with negative health impacts. For instance, residential use of firewood produces emissions of PM and VOCs, and potentially carcinogenic pollutants (EPA 2009h). These pollutants are linked to respiratory problems, lung damage, and cancer.

4.4 WATER, SOIL, AND OTHER ENVIRONMENTAL IMPACTS OF BIOFUELS

Expansion of the biofuels industry in the State could potentially result in other negative environmental impacts, including: soil erosion, impaired water quality, acidification of water and soil, eutrophication of bodies of water, damage to plants and animals, reduced biodiversity, and loss of habitat. Nitrogen (e.g., as fertilizer, N_2O, or NO_x) and ozone in particular have been linked to a number of negative environmental impacts. Findings in Appendix E indicate that nitrogen fertilizer use, NO_x and VOCs (precursors to ozone) will increase in the State, thus negative environmental impacts such as those listed above might be anticipated. Odor issues near farms and biorefineries might also be expected from a large-scale biofuels industry in the State. Though energy use and emissions estimates are quantifiable on a LCA basis, currently no research has examined the life-cycle environmental impacts of biofuels on soil, water, and habitat, etc. (NYSERDA 2009). Further, detailed geographical and local information is required to assess the potential impacts to soil and water in the State; such research should be supported in counties that have been identified as potential contributors to feedstock production under an expanded New York State biofuels industry. A comprehensive discussion of the potential soil, water, and other environmental impacts of biofuel production and use in the State can be found in *The Environmental Impacts of Biofuels in New York State* (NYSERDA 2009).

5 FUTURE RESEARCH NEEDS

There are a number of future research needs associated with the lifecycle energy and emissions impacts of biofuel production and use that emerge from this appendix.[12] In particular, we recommend additional research in the following areas:

- *Sensitivity and best practices*. Total LCA emissions of biofuel production are sensitive to input parameters at the farm and the biorefinery. For example, it has been shown that nitrogen fertilizer application rates may greatly influence the total GHG emissions associated with feedstock production for biofuel. Additional research is needed to analyze the sensitivity of final results to variations in input factors, to determine how these input factors can be affected by best practices, and to consider how policies can influence these best practices.
- *Advanced ethanol pathways*. This Roadmap explored a variety of biofuel production pathways that are possible in the mid- and long-term. However, there are other potential biofuel pathways that could be considered but were not, including liquid transportation fuels from algae or the production of biodiesel from yellow grease. More research is needed to define and characterize these pathways and include them in a New York biofuel analysis.
- *Competing use analysis for biofuel*. Biofuel feedstock has many uses and many stakeholders have expressed interest in comparing the use of biofuel for liquid transportation fuels versus "competing uses" such as biofuel for electricity production. These "competing uses" have their

[12] Some of these research needs may best be addressed at the national level.

own lifecycle impacts. More research is needed to quantify the effects of various competing uses so that a full comparison of biofuel options can be evaluated.

- *Health impacts*. In this appendix, we have discussed the potential health effects from increased ethanol production and use in the state. However, we have not conducted a detailed health risk assessment that applies geospatial air chemistry and dispersion models and population data to determine potential health effects of this production and use. More research is needed to explore these health effects, using such models. Also, health impacts for other competing use pathways (compared to biofuels) should be conducted.
- *Indirect land use*. This analysis does not account for indirect land use effects, which have been shown to potentially influence lifecycle results for biofuels. More research is needed to better integrate New York ethanol LCA with indirect land use models.
- *Rebound effects*. Additional ethanol fuel in the market would create a downward pressure on prices for other transportation fuels (e.g., gasoline). These reduced prices may incentivize drivers to drive more. This has been dubbed the "rebound effect" in the literature. We do not account for such effects in this modeling effort. More research is needed to characterize this rebound effect and apply it to the results indicated herein.
- *Corn, agricultural markets, and ethanol production*. There has been much discussion and debate about how new demands for corn from ethanol producers might affect agricultural markets and ultimately land-use both domestically and abroad. This an extremely important area of research, and links missions and policies of various state and federal agencies as well as other stakeholders. A comprehensive research study is needed to evaluate the impact that increased ethanol production would have on corn production generally. Included in this research should be an exploration of other indirect effects, such as dietary shifts away from meat (e.g., it takes 6-7 pounds of corn to produce a pound of beef), indirect land use (see above), effects on human health, and co-benefits, to name a few.

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