Fossil and Biogenic Fuel Greenhouse Gas Emission Factors

Final Report | Report Number 22-23 | September 2022
Revised May 2023

NEW YORK STATE | NYSERDA

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NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

NYSERDA Record of Revision

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Revision Date	Description of Changes	Revision on Page(s)
May 2023	Correction of data in Tables 2, 3, and A-1. Data values and data labels for many non-road fuels used in the Transportation sector were mismatched. Tables were updated to correct the mismatched labels and values. Changes are shown with double underline.	8,12,A-2

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Final Report

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Abstract

This whitepaper identifies the greenhouse gas emission factors associated with changes in fossil fuel and biogenic fuel use in energy demand sectors in New York State and describes how to estimate the value associated with those changes when applying a GHG damages-based method.

Keywords

Fossil fuel, biofuel, renewable fuel, greenhouse gas emission factors, New York, Climate Act, CLCPA

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Acronyms and Abbreviations

Btu	British thermal units
Climate Act	New York Community Leadership and Climate Protection Act
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CH_4	methane
EPA	United States Environmental Protection Agency
GHG	greenhouse gas
GWP	global warming potential
HFC	hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
MMBtu	million British thermal units
N_2O	nitrous oxide
NYSERDA	New York State Energy Research and Development Authority
NYSDEC	New York State Department of Environmental Conservation
PV	present value

Executive Summary

This whitepaper identifies the greenhouse gas emission factors associated with changes in fossil fuel and biogenic fuel use in energy demand sectors in New York State and describes how to estimate the value associated with those changes when applying a GHG damages-based method. Emission factors are provided under New York's 'gross' and 'net' accounting approaches.

1 Introduction

This whitepaper identifies the greenhouse gas (GHG) emissions from changes in fossil fuel and biogenic fuel use in energy demand sectors in New York State and describes how to estimate the value associated with those changes when applying a GHG damages-based method. We focus on primary fuel use by sector (residential and commercial buildings, industry, transportation, electricity generation). Electric sector emission factors associated with electricity use and the ensuing value of avoided GHGs are treated in a separate whitepaper.[1] The focus here is specifically on emissions of three GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are linked to fuel use. Other emissions and costs and benefits, not addressed in this paper, such as changes in health impacts associated with emissions other than GHGs or expenditures on infrastructure and fuels, should be included as appropriate when assessing emissions and the total benefit and cost associated with fuel use and the commitments to Disadvantaged Communities. Other GHGs would also be included as relevant when considering the totality of the State's emission requirements.

The aim of this whitepaper is to (a) identify emission factors consistent with the accounting used for New York State's Climate Leadership and Community Protection Act (Climate Act)[2]. The monetized value of GHG emissions associated with fuel use is the product of the quantity of fuel consumed, the GHG emission factors for the fuel and application, and the per-unit value of GHG emissions. This whitepaper provides GHG emission factors for fuels used in New York State and describes the appropriate per-unit value of those GHG emissions.

This whitepaper is not intended to create any legal requirement and does not supersede or replace the Statewide GHG emission inventory report developed by DEC pursuant to Environmental Conservation Law (ECL) Section 75-0105, the DEC emission limit regulation in 6 NYCRR Part 496 established pursuant to ECL Section 75-0107, or any guidance of the appropriate agencies for any legal or regulatory requirement or submittals. In providing these emission factors, NYSERDA recommends that that the inventory report, Part 496, and relevant agencies and their guidance be consulted, as appropriate or required. Furthermore, these emission factors address certain fuel use emissions only. In many cases it may be appropriate to include additional pollutants and their value depending on the project, program, policy, or action being evaluated.

2 New York State's Climate Act Emissions Accounting

Many states and the federal government account for GHGs using the Intergovernmental Panel on Climate Change (IPCC) protocol.[3] The 2019 annual New York State Emissions Report, (GHG inventory, published in 2021) takes a different approach,[4] as required by the Climate Act, which includes accounting for pollutants from upstream fossil fuel emissions as well as from sources outside state borders associated with the extraction, production, and delivery of fossil fuels.

The most important difference between IPCC accounting and Climate Act accounting relevant to avoided GHG emissions from fossil fuels is the Climate Act's mandate to include impacts of upstream emissions from fossil fuels, including the emissions associated with extraction, production, and transportation of the fuel occurring outside state boundaries. The most important difference between IPCC accounting and Climate Act accounting relevant to avoided GHG emissions from biogenic fuels is the Climate Act's use of two emissions accounting conventions: the Climate Act sets statewide "gross" emissions limits, as well as a 2050 "net" zero target for statewide emissions. When considering these dual emission perspectives, the GHG inventory notes that when considering emissions for biogenic fuels, "…biogenic sources of CO_2 are included in gross emission totals but omitted in net totals." Under both accounting conventions, the State applies a 20-year global warming potential when combining GHG emissions to carbon dioxide equivalent units (CO_2e). Further discussion of the accounting approach can be found in 6 New York Codes, Rules and Regulations (NYCRR) Part 496, and associated regulatory support documents such as the Revised Regulatory Impact Statement and Assessment of Public Comments.[5]

There are two primary uses for emission factors applying the gross and net emission conventions:

- **Comparing emission reductions with reduction targets**, such as the economy-wide 40%-by-2030 Climate Act mandate. Those targets apply the gross accounting method. Consistent with New York State's GHG approach, all combustion related GHG emissions are included, as are upstream GHG emissions related to fossil fuel extraction, production, and delivery.
- **Assessing the value of emission reductions**. The full value would apply the net accounting method. Consistent with New York State's accounting approach, the assumption is that while combustion related CH_4 and N_2O are incremental (and therefore included), CO_2 emissions from combustion are offset by the sequestration of carbon associated with feedstock production (and therefore excluded). Upstream GHG emission related to fossil fuel extraction, production, and delivery are included as well.

Therefore, this white paper provides both types of emission factors. More details on the emission components are provided in the following section.

3 Fuel Emission Factors

3.1 Applicable Sources

Climate Act accounting considers GHG emissions from fuel combusted within New York State, from leakage of CH_4 within the state (most relevant for renewable and fossil natural gas), and from the upstream out-of-state systems for fuel extraction, production, and delivery to the state (relevant only for fossil fuels).

The following describes how we address emission factors for each of these components (combustion, in-state leakage, and upstream out-of-state) for different applications:

- *Combustion*: What are the GHG emissions from the combustion of one unit of fossil fuel or biogenic fuel?
    - Fossil Fuels: Consistent with Climate Act accounting, we can directly specify an emission factor attributed to combustion as the amount of CO_2, CH_4, and N_2O released during the combustion of the relevant fossil fuel. We use data from the GHG inventory to calculate these combustion emission factors; the technical documentation on estimating energy sector emissions clarifies that fuel carbon content and combustion emission factors are sourced from the *United States Environmental Protection Agency (U.S. EPA) Inventory of Greenhouse Gas Emissions and Sink*.[6,7] Note that combustion emission factors are sector- and fuel-specific since the combustion of fuels in different settings results in different emissions of CH_4 and N_2O per unit of fuel.
    - Biogenic Fuels: The combustion emissions from biogenic fuels vary according to New York's net versus gross accounting convention: under the net convention, the biogenic CO_2 combustion-related emissions are netted out by the corresponding carbon sink, so we set the CO_2 emissions from combustion to zero. We do not do so for CH_4, and N_2O, as those GHGs are still emitted in combustion (while carbon is sequestered by plants, thus removing CO_2 from the atmosphere, there is no corresponding CH_4 or N_2O sink). Under the gross accounting convention, we do not consider any carbon sink and include combustion emissions from CO_2, CH_4, and N_2O.
- *In-state leakage*: Which GHG emissions within the intra-state natural gas pipeline system should be attributed to natural gas usage?

- Unlike combustion, the GHG emissions from methane leakage from in-state fuel delivery systems do not scale directly with the quantity of fuel consumed. The leakage of the natural gas in the in-state delivery system is correlated with not only the throughput but also with the physical size of the system (e.g., the number of miles of pipes, joints, connections, devices connected to the system, etc.). Therefore, we do not recommend including any unitary reduction from in-state natural gas leakage when considering avoided GHGs from reduced natural gas use. The GHG inventory considers the natural gas system as a sector and addressing the benefit of avoided gas leakage is accounted for separately from the use of natural gas in end-use devices; [8,9,10] we recommend applying the same approach when considering the avoided GHG benefits of reduced in-state natural gas usage. Note that if estimates of reduced leakage associated with removal or improvement of a local system or local distribution are available, those can be included separately and explicitly. However, these indirect emissions could be estimated separately by using factors in the GHG inventory or segment-specific factors in the NYSERDA Oil and Gas Methane Inventory.

- *Out-of-state*: What are the GHG emissions associated with the extraction, production, and out-of-state transportation of fossil fuels?
  - We seek to align our measurement of avoided GHG emissions with how the State measures progress towards Climate Act limits. This measurement allocates out-of-state emissions to in-state fossil fuel consumption; hence, if in-state consumption decreases, we will also lower the quantity of out-of-state emissions attributed to that consumption. Therefore, we propose using out-of-state fossil fuel emission factors for each relevant fossil fuel. We use data from the GHG inventory to calculate these out-of-state emission factors.[11,12,13] Upstream, out-of-state emission factors are provided for a limited set of fuels in that report, and where an upstream fuel source was not defined for a relevant fuel, we chose appropriate alternates (e.g., use "Coal" to provide upstream emission factors for "Coal: Coking" and "Coal: Other").
  - Note that the out-of-state emission factors vary as the supply chain of fossil fuels that are imported into New York State varies. For example, if natural gas is imported in the state from basins that have very high leakage rates, then the out-of-state leakage value for natural gas will be high, but if those basins implement measures to significantly reduce leakage, or if the import origins change, that leakage value may change. Therefore, this out-of-state emission factor should be expected to vary over time. New York State Department of Environmental Conservation (NYSDEC) has not published a forecast of out-of-state emission factors for future years, so we recommend using the most recent emission factors published in the latest GHG inventory and holding them constant for future years, absent any state guidance on updated emission factors.

- We consider no out-of-state production emissions from purely biogenic fuels. However, upstream emission factors are relevant for calculating fuel factors for biogenic fuel blends, which are the most-used biogenic fuels currently (such as E10 ethanol, or B5 biodiesel). To estimate the upstream emission factors for blended biogenic fuels, we apply a fraction of the upstream fossil fuel emission factors based on the percentage of the fossil fuel in the blended fuel on an energy basis. For example, we would count 93% of the fossil gasoline upstream fuel emission factors toward E10 ethanol upstream fuel emission factors, since E10 ethanol contains 93% fossil gasoline on an energy basis.

The two relevant emission components identified above—combustion and out-of-state upstream—are added together to form fuel cycle emissions per energy unit. A high-level summary of the gross and net biogenic emissions accounting conventions is provided in Table 1, while lists of fuel cycle emission factors are included in Table 2 (containing net emissions factors) and Table 3 (containing gross emission factors).

Table 1. Gross versus Net Biogenic CO_2 Emissions Accounting Convention

Application	Biogenic CO_2 Accounting	CO_2	CH_4 and N_2O
Evaluating State GHG Emission Reduction Limits	Gross	Combustion: Include emissions from fossil and biogenic fuels. Upstream out-of-state: include emissions from fossil fuels only.	
Monetizing Value of Avoided GHGs	Net	Combustion: Include emissions from fossil fuel only. Upstream out-of-state: Include emissions from fossil fuels only.	Combustion: Include emissions from fossil and biogenic fuels. Upstream out-of-state: include emissions from fossil fuels only.

* **Note:** upstream out-of-state state excludes in-state leakage of natural gas, which does not scale with fuel use and is accounted for and mitigated separately.

3.2 Emission Factors by Sector and Fuel

We include two tables below, summarizing fuel cycle emission factors specified by fuel and sector for common fuels, under both the net and gross biogenic accounting conventions. As described above, net emission accounting is appropriate for evaluating the value of GHG reductions using the damages-based approach. Gross accounting is appropriate for use when comparing reductions in emissions with economy-wide reductions needed to achieve New York State's GHG emissions limits—40% by 2030 and 85% by 2050 relative to 1990 emissions.

3.2.1 Net CO_2 Accounting Convention

Table 2 includes sector and fuel specific fuel cycle emission factors for common fuels under the net accounting convention. As described in Table 1, the net accounting convention is used in tracking progress toward the Climate Act's net goal and when estimating the monetized value of avoided GHGs but is not used for evaluating emissions relative to the statewide emissions limits, which apply the gross accounting method. Users should consult guidance from relevant regulatory agencies when determining the appropriate use of these factors and whether additional sources or components should be evaluated.

Table 2. Sector- and Fuel-Specific Fuel Cycle GHG Emission Factors for Common Fuels (metric ton/MMBtu) under Net Biogenic Accounting Convention

See definition of fuel-cycle[a] and definitions regarding emission[b] below
May 2023 revisions are underlined

Sources: Data from US EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks"; Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, "Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act."

Sector	Fuel	CO_2	CH_4	N_2O
Residential and Commercial Buildings	Natural Gas	6.50E-02	3.62E-04	2.46E-07
	Renewable Natural Gas[c]	0	5.28E-06	1.06E-07
	Heating Oil - Fossil[d][e][f]	8.93E-02	1.32E-04	8.94E-07
	B5 Heating Oil Blend[d][e][f]	8.52E-02	1.26E-04	8.81E-07
	B10 Heating Oil Blend[d][e][f]	8.10E-02	1.20E-04	8.69E-07
	B20 Heating Oil Blend[d][e][f]	7.27E-02	1.09E-04	8.45E-07
	B50 Heating Oil Blend[d][e][f]	4.78E-02	7.53E-05	7.73E-07
	B100 (100% biogenic heating oil) or Renewable Diesel[d][e][f]	0	1.06E-05	6.34E-07
	Residual Fuel	8.69E-02	1.22E-04	8.24E-07
	LPG	8.02E-02	1.26E-04	3.76E-07
	Kerosene	8.33E-02	1.20E-04	8.04E-07
	Wood	0	3.17E-04	4.22E-06
Electricity Generation[j]	Coal	9.89E-02	3.65E-04	3.90E-06
	Distillate	8.93E-02	1.22E-04	6.82E-07
	Natural Gas	6.50E-02	3.58E-04	4.57E-07
	Petroleum Coke	1.14E-01	1.13E-04	4.00E-06
	Residual Fuel	8.69E-02	1.12E-04	5.07E-07
	Wood and Waste	0	1.16E-05	7.39E-06
Industrial	Natural Gas	6.50E-02	3.58E-04	2.46E-07
	Renewable Natural Gas	0	1.06E-06	1.06E-07
	Coal	9.89E-02	3.75E-04	1.68E-06
	Diesel and Distillate[e]	8.93E-02	1.24E-04	8.94E-07
	B100 (100% biogenic diesel/distillate) or Renewable Diesel[e][f]	0	3.17E-06	6.34E-07
	Kerosene	8.33E-02	1.12E-04	8.04E-07
	LPG	8.02E-02	1.22E-04	3.76E-07
	Petroleum coke	1.14E-01	1.15E-04	8.34E-07
	Residual Fuel	8.69E-02	1.14E-04	8.24E-07
	Wood	0	3.17E-05	4.22E-06

Table 2 continued

Sector	Fuel	CO_2	CH_4	N_2O
Transportation[i]	Motor Gasoline[h]	8.46E-02	1.45E-04	8.75E-06
	E85[h]	2.55E-02	6.22E-05	8.54E-06
	Motor Diesel[f][g]	8.93E-02	1.25E-04	4.38E-06
	B2 Diesel Blend[f][g]	8.76E-02	1.23E-04	4.37E-06
	B5 Diesel Blend[f][g]	8.52E-02	1.19E-04	4.37E-06
	B20 Diesel Blend[f][g]	7.27E-02	1.09E-04	8.45E-07
	B80 Diesel Blend[f][g]	2.29E-02	3.51E-05	4.18E-06
	B100 (100% biogenic diesel) or Renewable Diesel[f][g]	0	4.12E-06	4.12E-06
	Aviation Gasoline	8.88E-02	1.91E-04	1.28E-06
	Jet Fuel	8.23E-02	1.09E-04	2.81E-06
	Railroad Diesel	8.93E-02	1.27E-04	2.11E-06
	Military Diesel	8.93E-02	1.68E-04	1.51E-06
	Military Residual	8.69E-02	1.19E-04	2.39E-06
	Bunker Vessel Diesel	8.93E-02	1.68E-04	1.51E-06
	Bunker Vessel Residual	8.69E-02	1.19E-04	2.39E-06
	Other Nonroad Diesel	8.93E-02	1.28E-04	6.60E-06
	Gasoline in Industrial/Commercial 4-stroke Equipment[h]	8.46E-02	1.44E-04	1.42E-05
	Gasoline in Construction/Mining 4-stroke Equipment[h]	8.46E-02	1.44E-04	1.42E-05
	Gasoline in Airport 4-stroke Equipment[h]	8.46E-02	1.51E-04	1.80E-05
	Gasoline in Lawn and Garden 4-stroke Equipment[h]	8.46E-02	1.42E-04	1.28E-05
	Gasoline in 4-stroke Ships and Boats 4[h]	8.46E-02	1.38E-04	3.77E-07
	Gasoline in Recreational 4-stroke Equipment[h]	8.46E-02	1.55E-04	1.88E-05
	100% biogenic Jet Fuel	0	0	2.64E-06
	100% biogenic Railroad Diesel or Renewable Diesel	0	5.79E-06	1.85E-06
	100% biogenic Military Diesel or Renewable Diesel	0	4.65E-05	1.25E-06
	100% biogenic Bunker Vessel Diesel or Renewable Diesel	0	4.65E-05	1.25E-06
	100% biogenic Other Nonroad Diesel or Renewable Diesel	0	6.83E-06	6.34E-06
	100% biogenic Gasoline in Industrial/Commercial 4-stroke Equipment	0	2.53E-05	1.39E-05
	100% biogenic Gasoline in Construction/Mining 4-stroke Equipment	0	2.52E-05	1.39E-05
	100% biogenic Gasoline in Airport 4-stroke Equipment	0	3.23E-05	1.77E-05
	100% biogenic Gasoline in Lawn and Garden 4-stroke Equipment	0	2.28E-05	1.25E-05
	100% biogenic Gasoline in 4-stroke Ships and Boats	0	1.86E-05	6.97E-08
	100% biogenic Gasoline in Recreational 4-stroke Equipment	0	3.58E-05	1.85E-05

Table notes are on the next page

(a) Fuel cycle emissions in this table are defined as combustion and upstream emissions from extraction, production, and delivery to state boundaries, excluding in-state leakage of natural gas.

(b) Emission factors are provided in units of metric tons of each pollutant. To combine GHG emissions, the New York GHG inventory accounts for pollutants using a 20-year global warming potential (GWP), which measures the GHG impact of each pollutant in units of carbon dioxide equivalent (CO_2e), accounting for the induced warming that each pollutant produces over a 20-year period, relative to the warming that a unit of CO_2 would produce. The 2030 and 2050 state-wide GHG emission limits are set in CO_2e, but this does not affect the value of avoided GHG emissions since the avoided GHGs are measured on an absolute basis for each pollutant, not based on CO_2e.

When considering the value of avoided GHGs from the use of biogenic fuels, this table focuses on the net emissions accounting convention. The accounting approach used in the GHG inventory, and consistent with 6 NYCRR Part 496 and supporting rulemaking documents,[14,15] suggests that for purposes of estimating the value of GHG emissions, CO_2 emissions are netted out due to the biogenic sources of carbon creating a CO_2 sink equivalent to the quantity of CO_2 emitted during the fuel cycle of the fuel. Thus, the net CO_2 emission factor for purely biogenic fuels is zero. This does not hold for other GHGs—combustion of biogenic fuels produces incremental CH_4 and N_2O emissions.

(c) Note these emission factors represent pipeline-quality renewable natural gas, not unrefined biogas.

(d) *The Heating Oil–Fossil* value is recommended for heating oil used in the following cases, unless a specific biofuel blend is being used:

- New York City prior to October 2017.
- Long Island and Westchester counties prior to July 2018.
- New York State excluding New York City, Long Island, and Westchester County prior to July 2023.

Heating oil biofuel blends are denoted as B*X* where *X* represents the percent of biofuel blended with the fossil heating oil by volume. Starting October 1, 2017, New York City requires at least a 5% biofuel blend.[16] Beginning July 1, 2018, state law requires heating oil used in Long Island and Westchester County include at least a 5% biofuel blend.[17] Starting in July 2023, heating oil with at least a 5% biofuel blend is required for all heating oil statewide,[18, 19] escalating to 10% by July 2025 and 20% by July 2030.

Therefore, unless other specific blends are being used, we recommend assuming the following blends for heating oil:

- *B5 Heating Oil Blend* for heating oil in New York City from October 2017 – June 2025.
- *B5 Heating Oil Blend* for heating oil in Long Island, and Westchester counties from July 2018 – June 2025.
- *B5 Heating Oil Blend* for heating oil statewide from July 2023 – June 2025.
- *B10 Heating Oil Blend* for all heating oil used in New York State from July 2025 – June 2030.
- *B20 Heating Oil Blend* for all heating oil used in New York State starting in July 2030.

We have also included a 50% blend (B50) and 100% biofuel oil (B100). Blends are calculated by taking a weighted average of the emission factors for pure fossil distillate and pure biogenic (B100) distillate respectively. Note that all blends in this table refer to fossil diesel with biodiesel by volume, but factors are presented by energy content. Biodiesel has a slightly lower heat rate than conventional diesel.[20]

(e) Note that heating oil in residential, commercial, and industrial sectors most commonly is No. 2 and No. 4 distillate. The GHG inventory includes one upstream emission factor for fossil distillate across all sectors and defines one set of combustion emission factors for a representative distillate or diesel fuel in each sector.[21] Consistent with GHG inventory data, this table does not distinguish between emission factors for No. 2 and No. 4 distillate.

(f) Renewable diesel, which has the same heating content as conventional fossil diesel, would yield the same emission factors when calculating blends with fossil diesel on a volumetric or energy basis. Renewable diesel blends are not presented in the table. To calculate emission factors for a renewable diesel blend with fossil diesel, calculate the percent blend of renewable diesel on an energy basis and blend the 100% biodiesel and pure fossil diesel (either motor diesel or heating oil – fossil) factors appropriately.

(g) Diesel can be sold with varying quantities of biofuel, up to 5% biodiesel blend in motor applications by volume. The specific blend is not standard, can include zero or very little biodiesel, and can vary by location and time, so by default, we recommend assuming industrial diesel and motor diesel are 100% fossil. Note that all blends refer to fossil diesel with biodiesel. Biodiesel has a slightly lower heat rate than conventional diesel,[22] and therefore calculating a blend by volume and a blend by energy will yield different emission factors. We have provided emission factors consistent with common biodiesel blends by volume, such as B2 (2% biogenic), B5 (5% biogenic), B20 (20% biogenic), B80 (80% biogenic), and B100 (100% biogenic) for reference.

(h) Motor gasoline sold at the pump has varying biogenic fuel quantities, driven primarily by ethanol blending. In 2019, the GHG inventory notes the biogenic quantity of motor gasoline in New York was 6.9% blend by energy, so we have calculated a motor gasoline set of emission factors consistent with this blend. In addition, we have included a set of emission factors for E85. As discussed in the GHG inventory, E85 can include a range of ethanol by volume, but for this table, consistent with the inventory, we have assumed 85% blend of ethanol by volume (equivalent to 72% by energy) with the remainder being fossil gasoline; we have calculated E85 emission factors consistent with this blend ratio.

(i) The New York GHG inventory provided multiple methods of calculating emissions for on-road vehicles. The published inventory used a hybrid approach in which data from the U.S. EPA's National Emissions Inventory were combined with data from U.S. EPA's MOtor Vehicle Emission Simulator (MOVES) model runs.[23] The MOVES model does not include fuel specific emission factors for on-road vehicles, calculating emissions using vehicle miles traveled (VMT) and per-mile emission factors, specific to vehicle class and vintage. An alternate emission calculation methodology specified in the inventory (called the fuel consumption method) applied US-specific carbon content data from the latest US GHG inventory, and methane and N_2O emission factors using data from the IPCC. For this white paper, we apply this fuel consumption method as it allows the estimation of emission factors using fuel consumption data, regardless of vehicle vintage or class. While this methodology may result in different CH_4 and N_2O emissions relative to the inventory approach, these errors should be a very small fraction of the total fuel cycle GHG emissions, and is a reasonable approach given the data limitation of the hybrid approach.

(j) Note electricity generation factors are for estimating emissions associated with electricity generating units. For emissions associated with electricity consumption by end use, apply the factors published in NYSERDA's grid emission factors white paper.[24]

3.2.2 Gross CO_2 Accounting Convention

Table 3 includes sector and fuel specific fuel cycle emission factors for common fuels under the gross biogenic accounting convention. As described in Table 1, the gross accounting convention is used when estimating changes in emissions in the context of statewide emissions limits or other reductions targets, but is not used for estimating the monetized value of avoided GHGs which uses the net accounting method including the sequestration associated with biogenic fuel feedstocks. Users should consult guidance from relevant regulatory agencies when determining the appropriate use of these factors and whether additional sources or components should be evaluated.

Table 3. Sector- and Fuel-Specific Fuel Cycle GHG Emission Factors for Common Fuels (metric ton/MMBtu), under Gross Biogenic Accounting Convention

See definition of fuel-cycle[a] and definitions regarding emission[b] below
May 2023 revisions are underlined

Sources: Data from US EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks"; Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, "Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act."

Sector	Fuel	CO_2	CH_4	N_2O
Residential and Commercial Buildings	Natural Gas	6.50E-02	3.62E-04	2.46E-07
	Renewable Natural Gas[c]	5.29E-02	5.28E-06	1.06E-07
	Heating Oil - Fossil[d][e][f]	8.93E-02	1.32E-04	8.94E-07
	B5 Heating Oil Blend[d][e][f]	8.86E-02	1.26E-04	8.81E-07
	B10 Heating Oil Blend[d][e][f]	8.79E-02	1.20E-04	8.69E-07
	B20 Heating Oil Blend[d][e][f]	8.65E-02	1.09E-04	8.45E-07
	B50 Heating Oil Blend[d][e][f]	8.23E-02	7.53E-05	7.73E-07
	B100 (100% biogenic heating oil) or Renewable Diesel[d][e][f]	7.41E-02	1.06E-05	6.34E-07
	Residual Fuel	8.69E-02	1.22E-04	8.24E-07
	LPG	8.02E-02	1.26E-04	3.76E-07
	Kerosene	8.33E-02	1.20E-04	8.04E-07
	Wood	1.03E-01	3.17E-04	4.22E-06
Electricity Generation[j]	Coal	9.89E-02	3.65E-04	3.90E-06
	Distillate	8.93E-02	1.22E-04	6.82E-07
	Natural Gas	6.50E-02	3.58E-04	4.57E-07
	Petroleum Coke	1.14E-01	1.13E-04	4.00E-06
	Residual Fuel	8.69E-02	1.12E-04	5.07E-07
	Wood and Waste	1.03E-01	1.16E-05	7.39E-06
Industrial	Natural Gas	6.50E-02	3.58E-04	2.46E-07
	Renewable Natural Gas	5.29E-02	1.06E-06	1.06E-07
	Coal	9.89E-02	3.75E-04	1.68E-06
	Diesel and Distillate[e]	8.93E-02	1.24E-04	8.94E-07
	B100 (100% biogenic diesel/distillate) or Renewable Diesel[e][f]	7.41E-02	3.17E-06	6.34E-07
	Kerosene	8.33E-02	1.12E-04	8.04E-07
	LPG	8.02E-02	1.22E-04	3.76E-07
	Petroleum coke	1.14E-01	1.15E-04	8.34E-07
	Residual Fuel	8.69E-02	1.14E-04	8.24E-07
	Wood	9.39E-02	3.17E-05	4.22E-06

Table 3 continued

Sector	Fuel	CO_2	CH_4	N_2O
Transportation[i]	Motor Gasoline[h]	8.96E-02	1.45E-04	8.75E-06
	E85[h]	7.68E-02	6.22E-05	8.54E-06
	Motor Diesel[f][g]	8.93E-02	1.25E-04	4.38E-06
	B2 Diesel Blend[f][g]	8.90E-02	1.23E-04	4.37E-06
	B5 Diesel Blend[f][g]	8.86E-02	1.19E-04	4.37E-06
	B20 Diesel Blend[f][g]	8.65E-02	1.09E-04	8.45E-07
	B80 Diesel Blend[f][g]	7.80E-02	3.51E-05	4.18E-06
	B100 (100% biogenic diesel) or Renewable Diesel[f][g]	7.41E-02	4.12E-06	4.12E-06
	Aviation Gasoline	8.88E-02	1.91E-04	1.28E-06
	Jet Fuel	8.23E-02	1.09E-04	2.81E-06
	Railroad Diesel	8.93E-02	1.27E-04	2.11E-06
	Military Diesel	8.93E-02	1.68E-04	1.51E-06
	Military Residual	8.69E-02	1.19E-04	2.39E-06
	Bunker Vessel Diesel	8.93E-02	1.68E-04	1.51E-06
	Bunker Vessel Residual	8.69E-02	1.19E-04	2.39E-06
	Other Nonroad Diesel	8.93E-02	1.28E-04	6.60E-06
	Gasoline in Industrial/Commercial 4-stroke Equipment[h]	8.96E-02	1.44E-04	1.42E-05
	Gasoline in Construction/Mining 4-stroke Equipment[h]	8.96E-02	1.44E-04	1.42E-05
	Gasoline in Airport 4-stroke Equipment[h]	8.96E-02	1.51E-04	1.80E-05
	Gasoline in Lawn and Garden 4-stroke Equipment[h]	8.96E-02	1.42E-04	1.28E-05
	Gasoline in 4-stroke Ships and Boats 4[h]	8.96E-02	1.38E-04	3.77E-07
	Gasoline in Recreational 4-stroke Equipment[h]	8.96E-02	1.55E-04	1.88E-05
	100% biogenic Jet Fuel	7.22E-02	0	2.64E-06
	100% biogenic Railroad Diesel or Renewable Diesel	7.41E-02	5.79E-06	1.85E-06
	100% biogenic Military Diesel or Renewable Diesel	7.41E-02	4.65E-05	1.25E-06
	100% biogenic Bunker Vessel Diesel or Renewable Diesel	7.41E-02	4.65E-05	1.25E-06
	100% biogenic Other Nonroad Diesel or Renewable Diesel	7.41E-02	6.83E-06	6.34E-06
	100% biogenic Gasoline in Industrial/Commercial 4-stroke Equipment	7.14E-02	2.53E-05	1.39E-05
	100% biogenic Gasoline in Construction/Mining 4-stroke Equipment	7.14E-02	2.52E-05	1.39E-05
	100% biogenic Gasoline in Airport 4-stroke Equipment	7.14E-02	3.23E-05	1.77E-05
	100% biogenic Gasoline in Lawn and Garden 4-stroke Equipment	7.14E-02	2.28E-05	1.25E-05
	100% biogenic Gasoline in 4-stroke Ships and Boats	7.14E-02	1.86E-05	6.97E-08
	100% biogenic Gasoline in Recreational 4-stroke Equipment	7.14E-02	3.58E-05	1.85E-05

Table notes are on the next page

(a) Fuel cycle emissions in this table are defined as combustion and upstream emissions from extraction, production, and delivery to state boundaries, excluding in-state leakage of natural gas.

(b) Emission factors are provided in units of metric tons of each pollutant. To combine GHG emissions, the New York GHG inventory accounts for pollutants using a 20-year global warming potential (GWP), which measures the GHG impact of each pollutant in units of carbon dioxide equivalent (CO_2e), accounting for the induced warming that each pollutant produces over a 20-year period, relative to the warming that a unit of CO_2 would produce. The 2030 and 2050 state-wide GHG emission limits are set in CO_2e, but this does not affect the value of avoided GHG emissions since the avoided GHGs are measured on an absolute basis for each pollutant, not based on CO_2e. See Appendix A, Table A-1 for emission factors calculated using CO_2e.

When considering the GHGs from use of biogenic fuels, this table includes emission factors consistent with gross emissions accounting convention. Under the gross emissions accounting convention, emissions from upstream out-of-state stages are excluded for biogenic fuels, but combustion emissions of CO_2, CH_4, and N_2O are included for biogenic fuels as well as fossil fuels.

(c) Note these emission factors represent pipeline-quality renewable natural gas, not unrefined biogas.

(d) *The Heating Oil – Fossil* value is recommended for heating oil used in the following cases, unless a specific biofuel blend is being used:

- New York City prior to October 2017.
- Long Island and Westchester counties prior to July 2018.
- New York State excluding New York City, Long Island, and Westchester County, prior to July 2023.

Heating oil biofuel blends are denoted as B*X* where *X* represents the percent of biofuel blended with the fossil heating oil by volume. Starting October 1, 2017, New York City requires at least a 5% biofuel blend.[25] Beginning July 1, 2018, state law requires heating oil used in Long Island and Westchester counties include at least a 5% biofuel blend.[26] Starting in July 2023, heating oil with at least a 5% biofuel blend is required for all heating oil statewide,[27, 28] escalating to 10% by July 2025 and 20% by July 2030.

Therefore, unless other specific blends are being used, we recommend assuming the following blends for heating oil:

- B5 Heating Oil Blend for heating oil in New York City from October 2017 – June 2025.
- B5 Heating Oil Blend for heating oil in Long Island, and Westchester counties from July 2018–June 2025.
- B5 Heating Oil Blend for heating oil statewide from July 2023 – June 2025.
- B10 Heating Oil Blend for all heating oil used in New York State from July 2025-June 2030.
- B20 Heating Oil Blend for all heating oil used in New York State starting in July 2030.

We have also included a 50% blend (B50) and 100% biofuel oil (B100). Blends are calculated by taking a weighted average of the emission factors for pure fossil distillate and pure biogenic (B100) distillate respectively. Note that all blends in this table refer to fossil diesel with biodiesel by volume, but factors are presented by energy content. Biodiesel has a slightly lower heat rate than conventional diesel.[29]

(e) Note that heating oil in residential, commercial, and industrial sectors most commonly is No. 2 and No. 4 distillate. The GHG inventory includes one upstream emission factor for fossil distillate across all sectors and defines one set of combustion emission factors for a representative distillate or diesel fuel in each sector.[30] Consistent with GHG inventory data, this table does not distinguish between emission factors for No. 2 and No. 4 distillate.

(f) Renewable diesel, which has the same heating content as conventional fossil diesel, would yield the same emission factors when calculating blends with fossil diesel on a volumetric or energy basis. Renewable diesel blends are not presented in the table. To calculate emission factors for a renewable diesel blend with fossil diesel, calculate the percent blend of renewable diesel on an energy basis and blend the 100% biodiesel and pure fossil diesel (either motor diesel or heating oil – fossil) factors appropriately.

(g) Diesel can be sold with varying quantities of biofuel, up to 5% biodiesel blend in motor applications by volume. The specific blend is not standard, can include zero or very little biodiesel, and can vary by location and time, so by default, we recommend assuming industrial diesel and motor diesel are 100% fossil. Note that all blends refer to fossil diesel with biodiesel. Biodiesel has a slightly lower heat rate than conventional diesel,[31] and therefore calculating a blend by volume and a blend by energy will yield different emission factors. We have provided emission factors consistent with common biodiesel blends by volume, such as B2 (2% biogenic), B5 (5% biogenic), B20 (20% biogenic), B80 (80% biogenic), and B100 (100% biogenic) for reference.

(h) Motor gasoline sold at the pump has varying biogenic fuel quantities, driven primarily by ethanol blending. In 2019, the GHG inventory notes the biogenic quantity of motor gasoline in New York was 6.9% blend by energy, so we have calculated a motor gasoline set of emission factors consistent with this blend. In addition, we have included a set of emission factors for E85. As discussed in the GHG inventory, E85 can include a range of ethanol by volume, but for this table, consistent with the inventory, we have assumed 85% blend of ethanol by volume (equivalent to 72% by energy) with the remainder being fossil gasoline; we have calculated E85 emission factors consistent with this blend ratio.

(i) The New York GHG inventory provided multiple methods of calculating emissions for on-road vehicles. The published inventory used a hybrid approach in which data from the U.S. EPA's National Emissions Inventory were combined with data from U.S. EPA's MOtor Vehicle Emission Simulator (MOVES) model runs.[32] The MOVES model does not include fuel specific emission factors for on-road vehicles, calculating emissions using vehicle miles traveled (VMT) and per-mile emission factors, specific to vehicle class and vintage. An alternate emission calculation methodology specified in the inventory (called the fuel consumption method) applied US-specific carbon content data from the latest US GHG inventory, and methane and N_2O emission factors using data from the IPCC. For this white paper, we apply this fuel consumption method as it allows the estimation of emission factors using fuel consumption data, regardless of vehicle vintage or class. While this methodology may result in different CH_4 and N_2O emissions relative to the inventory approach, these errors should be a very small fraction of the total fuel cycle GHG emissions, and is a reasonable approach given the data limitation of the hybrid approach.

(j) Note electricity generation factors are for estimating emissions associated with electricity generating units. For emissions associated with electricity consumption by end use, apply the factors published in NYSERDA's grid emission factors white paper.[33]

4 Applying the Value of Avoided Greenhouse Gases

To calculate the benefit of avoided GHGs per-unit of fuel, we apply the values provided in NYSDEC's value of carbon guidance.[34] In brief, NYSDEC established a value of GHGs using a marginal damages approach. A damages-based approach estimates the damages caused by a marginal increase in GHG emissions in economic terms, estimating the total future costs ($) associated with one unit of GHG emissions (ton) each year. When assessing the value of GHG damage, it is important to consider the appropriate discount rate to use. The discounting of a future cost or benefit is the reduction in value of that cost or benefit when adjusted for comparison with a current cost or benefit. The annual values provided in the value of carbon guidance are produced by applying this discount rate to damages occurring from GHG emissions in any given year (through 2300) and summing the total to produce the present value (PV) associated with those damages in the year the emissions occurred. The value of carbon guidance includes a more detailed discussion of discounting and provides a variety of total values of avoided GHG emissions corresponding with different discount rates. We note that NYSDEC presented a range of values, 1%, 2%, and 3%, and recommended that State entities apply the value of avoided GHGs consistent with a central estimate of 2% for decision making, though users of this methodology should be attentive to relevant regulatory requirements covering their analysis. Users may also wish to evaluate and present a full range of the value of GHG, including values based on 1%, 2%, and 3% as recommended in NYSDEC's value of carbon guidance. All social cost of avoided GHG emissions used in this paper are based on that central estimate. The central value of GHG emissions increased from roughly $120 per ton in 2020 to $180 in 2050 (in 2020$) for CO_2, from $3,000 to $5,000 per ton for CH_4, and $40,000 to $60,000 per ton for N_2O.

To summarize the total value of avoided GHG emissions over multiple years throughout the lifetime of a given action, program, or system, we recommend calculating the PV of the annual values of GHG for all emission years. Consistent with the New York State Climate Action Council 2021 *Draft Scoping Plan* analysis,[35] we currently recommend using a 3.6% real discount rate and taking the PV over the expected lifetime analyzed, discounted to the first year of the analysis. Other discount rates may also be appropriate, depending on the use case and purpose of the analysis.

While this white paper focuses on the value of GHG emissions associated with fuel use, most benefit-cost analyses will include other components, such as fuel cost savings, electricity costs and benefits, health benefits associated with reduction in pollutants other than GHG, and more.

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Appendix A. Gross Emission Factors with CO_2e

Below, we include a table of sector and fuel specific fuel cycle emission factors for common fuels under the gross biogenic accounting convention, including a column with the CO_2e factor using GWP values consistent with Climate Act accounting:

- CO_2: 1
- CH_4: 84
- N_2O: 264

Table A-1. Sector- and Fuel-Specific Fuel Cycle GHG Emission Factors for Common Fuels (metric ton/MMBtu), under Gross Biogenic Accounting Convention

See definition of fuel-cycle[a] and definitions regarding emission[b] below
May 2023 revisions are underlined

Sources: Data from US EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks"; Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, "Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act."

Sector	Fuel	CO_2	CH_4	N_2O	CO_2e
Residential and Commercial Buildings	Natural Gas	6.50E-02	3.62E-04	2.46E-07	9.55E-02
	Renewable Natural Gas[c]	5.29E-02	5.28E-06	1.06E-07	5.34E-02
	Heating Oil - Fossil[d][e][f]	8.93E-02	1.32E-04	8.94E-07	1.01E-01
	B5 Heating Oil Blend[d][e][f]	8.86E-02	1.26E-04	8.81E-07	9.94E-02
	B10 Heating Oil Blend[d][e][f]	8.79E-02	1.20E-04	8.69E-07	9.82E-02
	B20 Heating Oil Blend[d][e][f]	8.65E-02	1.09E-04	8.45E-07	9.59E-02
	B50 Heating Oil Blend[d][e][f]	8.23E-02	7.53E-05	7.73E-07	8.88E-02
	B100 (100% biogenic heating oil) or Renewable Diesel[d][e][f]	7.41E-02	1.06E-05	6.34E-07	7.52E-02
	Residual Fuel	8.69E-02	1.22E-04	8.24E-07	9.73E-02
	LPG	8.02E-02	1.26E-04	3.76E-07	9.09E-02
	Kerosene	8.33E-02	1.20E-04	8.04E-07	9.35E-02
	Wood	1.03E-01	3.17E-04	4.22E-06	1.31E-01
Electricity Generation[j]	Coal	9.89E-02	3.65E-04	3.90E-06	1.31E-01
	Distillate	8.93E-02	1.22E-04	6.82E-07	9.97E-02
	Natural Gas	6.50E-02	3.58E-04	4.57E-07	9.52E-02
	Petroleum Coke	1.14E-01	1.13E-04	4.00E-06	1.24E-01
	Residual Fuel	8.69E-02	1.12E-04	5.07E-07	9.64E-02
	Wood and Waste	1.03E-01	1.16E-05	7.39E-06	1.06E-01
Industrial	Natural Gas	6.50E-02	3.58E-04	2.46E-07	9.52E-02
	Renewable Natural Gas	5.29E-02	1.06E-06	1.06E-07	5.30E-02
	Coal	9.89E-02	3.75E-04	1.68E-06	1.31E-01
	Diesel and Distillate[e]	8.93E-02	1.24E-04	8.94E-07	1.00E-01
	B100 (100% biogenic diesel/distillate) or Renewable Diesel[e][f]	7.41E-02	3.17E-06	6.34E-07	7.46E-02
	Kerosene	8.33E-02	1.12E-04	8.04E-07	9.29E-02
	LPG	8.02E-02	1.22E-04	3.76E-07	9.05E-02
	Petroleum coke	1.14E-01	1.15E-04	8.34E-07	1.24E-01
	Residual Fuel	8.69E-02	1.14E-04	8.24E-07	9.67E-02
	Wood	9.39E-02	3.17E-05	4.22E-06	9.76E-02

Table A-1 continued

Sector	Fuel	CO_2	CH_4	N_2O	CO_2e
Transportation[i]	Motor Gasoline[h]	8.96E-02	1.45E-04	8.75E-06	1.04E-01
	E85[h]	7.68E-02	6.22E-05	8.54E-06	8.43E-02
	Motor Diesel[f][g]	8.93E-02	1.25E-04	4.38E-06	1.01E-01
	B2 Diesel Blend[f][g]	8.90E-02	1.23E-04	4.37E-06	1.00E-01
	B5 Diesel Blend[f][g]	8.86E-02	1.19E-04	4.37E-06	9.98E-02
	B20 Diesel Blend[f][g]	8.65E-02	1.09E-04	8.45E-07	9.59E-02
	B80 Diesel Blend[f][g]	7.80E-02	3.51E-05	4.18E-06	8.21E-02
	B100 (100% biogenic diesel) or Renewable Diesel[f][g]	7.41E-02	4.12E-06	4.12E-06	7.56E-02
	Aviation Gasoline	8.88E-02	1.91E-04	1.28E-06	1.05E-01
	Jet Fuel	8.23E-02	1.09E-04	2.81E-06	9.22E-02
	Railroad Diesel	8.93E-02	1.27E-04	2.11E-06	1.01E-01
	Military Diesel	8.93E-02	1.68E-04	1.51E-06	1.04E-01
	Military Residual	8.69E-02	1.19E-04	2.39E-06	9.75E-02
	Bunker Vessel Diesel	8.93E-02	1.68E-04	1.51E-06	1.04E-01
	Bunker Vessel Residual	8.69E-02	1.19E-04	2.39E-06	9.75E-02
	Other Nonroad Diesel	8.93E-02	1.28E-04	6.60E-06	1.02E-01
	Gasoline in Industrial/Commercial 4-stroke Equipment[h]	8.96E-02	1.44E-04	1.42E-05	1.05E-01
	Gasoline in Construction/Mining 4-stroke Equipment[h]	8.96E-02	1.44E-04	1.42E-05	1.05E-01
	Gasoline in Airport 4-stroke Equipment[h]	8.96E-02	1.51E-04	1.80E-05	1.07E-01
	Gasoline in Lawn and Garden 4-stroke Equipment[h]	8.96E-02	1.42E-04	1.28E-05	1.05E-01
	Gasoline in 4-stroke Ships and Boats 4[h]	8.96E-02	1.38E-04	3.77E-07	1.01E-01
	Gasoline in Recreational 4-stroke Equipment[h]	8.96E-02	1.55E-04	1.88E-05	1.08E-01
	100% biogenic Jet Fuel	7.22E-02	0	2.64E-06	7.29E-02
	100% biogenic Railroad Diesel or Renewable Diesel	7.41E-02	5.79E-06	1.85E-06	7.51E-02
	100% biogenic Military Diesel or Renewable Diesel	7.41E-02	4.65E-05	1.25E-06	7.84E-02
	100% biogenic Bunker Vessel Diesel or Renewable Diesel	7.41E-02	4.65E-05	1.25E-06	7.84E-02
	100% biogenic Other Nonroad Diesel or Renewable Diesel	7.41E-02	6.83E-06	6.34E-06	7.64E-02
	100% biogenic Gasoline in Industrial/Commercial 4-stroke Equipment	7.14E-02	2.53E-05	1.39E-05	7.72E-02
	100% biogenic Gasoline in Construction/Mining 4-stroke Equipment	7.14E-02	2.52E-05	1.39E-05	7.71E-02
	100% biogenic Gasoline in Airport 4-stroke Equipment	7.14E-02	3.23E-05	1.77E-05	7.87E-02
	100% biogenic Gasoline in Lawn and Garden 4-stroke Equipment	7.14E-02	2.28E-05	1.25E-05	7.66E-02
	100% biogenic Gasoline in 4-stroke Ships and Boats	7.14E-02	1.86E-05	6.97E-08	7.29E-02
	100% biogenic Gasoline in Recreational 4-stroke Equipment	7.14E-02	3.58E-05	1.85E-05	7.92E-02

Table notes are on the next page

(a) Fuel cycle emissions in this table are defined as combustion and upstream emissions from extraction, production, and delivery to state boundaries, excluding in-state leakage of natural gas.

(b) Emission factors are provided in units of metric tons of each pollutant, as well as a carbon dioxide equivalent (CO_2e) factor for reference. To combine GHG emissions, the New York GHG inventory accounts for pollutants using a 20-year global warming potential (GWP), which measures the GHG impact of each pollutant in units of CO_2e, accounting for the induced warming that each pollutant produces over a 20-year period, relative to the warming that a unit of CO_2 would produce. The 2030 and 2050 state-wide GHG emission limits are set in CO_2e, but this does not affect the value of avoided GHG emissions since the avoided GHGs are measured on an absolute basis for each pollutant, not based on CO_2e.

When considering the GHGs from use of biogenic fuels, this table includes emission factors consistent with gross emissions accounting convention. Under the gross emissions accounting convention, emissions from upstream out-of-state stages are excluded for biogenic fuels, but combustion emissions of CO2, CH4, and N2O are included for biogenic fuels as well as fossil fuels.

(c) Note these emission factors represent pipeline-quality renewable natural gas, not unrefined biogas.

(d) *The Heating Oil – Fossil* value is recommended for heating oil used in the following cases, unless a specific biofuel blend is being used:

- New York City prior to October 2017.
- Long Island and Westchester counties prior to July 2018.
- New York State excluding New York City, Long Island, and Westchester counties, prior to July 2023.

Heating oil biofuel blends are denoted as B*X* where *X* represents the percent of biofuel blended with the fossil heating oil by volume. Starting October 1, 2017, New York City requires at least a 5% biofuel blend.[36] Beginning July 1, 2018, state law requires heating oil used in Long Island and Westchester counties include at least a 5% biofuel blend.[37] Starting in July 2023, heating oil with at least a 5% biofuel blend is required for all heating oil statewide,[38, 39] escalating to 10% by July 2025 and 20% by July 2030.

Therefore, unless other specific blends are being used, we recommend assuming the following blends for heating oil:

- B5 Heating Oil Blend for heating oil in New York City from October 2017 – June 2025.
- B5 Heating Oil Blend for heating oil in Long Island, and Westchester counties from July 2018 – June 2025.
- B5 Heating Oil Blend for heating oil statewide from July 2023 – June 2025.
- B10 Heating Oil Blend for all heating oil used in New York State from July 2025-June 2030.
- B20 Heating Oil Blend for all heating oil used in New York State starting in July 2030.

We have also included a 50% blend (B50) and 100% biofuel oil (B100). Blends are calculated by taking a weighted average of the emission factors for pure fossil distillate and pure biogenic (B100) distillate respectively. Note that all blends in this table refer to fossil diesel with biodiesel by volume, but factors are presented by energy content. Biodiesel has a slightly lower heat rate than conventional diesel.[40]

(e) Note that heating oil in residential, commercial, and industrial sectors most commonly is No. 2 and No. 4 distillate. The GHG inventory includes one upstream emission factor for fossil distillate across all sectors and defines one set of combustion emission factors for a representative distillate or diesel fuel in each sector.[41] Consistent with GHG inventory data, this table does not distinguish between emission factors for No. 2 and No. 4 distillate.

(f) Renewable diesel, which has the same heating content as conventional fossil diesel, would yield the same emission factors when calculating blends with fossil diesel on a volumetric or energy basis. Renewable diesel blends are not presented in the table. To calculate emission factors for a renewable diesel blend with fossil diesel, calculate the percent blend of renewable diesel on an energy basis and blend the 100% biodiesel and pure fossil diesel (either motor diesel or heating oil – fossil) factors appropriately.

(g) Diesel can be sold with varying quantities of biofuel, up to 5% biodiesel blend in motor applications by volume. The specific blend is not standard, can include zero or very little biodiesel, and can vary by location and time, so by default, we recommend assuming industrial diesel and motor diesel are 100% fossil. Note that all blends refer to fossil diesel with biodiesel. Biodiesel has a slightly lower heat rate than conventional diesel,[42] and therefore calculating a blend by volume and a blend by energy will yield different emission factors. We have provided emission factors consistent with common biodiesel blends by volume, such as B2 (2% biogenic), B5 (5% biogenic), B20 (20% biogenic), B80 (80% biogenic), and B100 (100% biogenic) for reference.

(h) Motor gasoline sold at the pump has varying biogenic fuel quantities, driven primarily by ethanol blending. In 2019, the GHG inventory notes the biogenic quantity of motor gasoline in New York was 6.9% blend by energy, so we have calculated a motor gasoline set of emission factors consistent with this blend. In addition, we have included a set of emission factors for E85. As discussed in the GHG inventory, E85 can include a range of ethanol by volume, but for this table, consistent with the inventory, we have assumed 85% blend of ethanol by volume (equivalent to 72% by energy) with the remainder being fossil gasoline; we have calculated E85 emission factors consistent with this blend ratio.

(i) The New York GHG inventory provided multiple methods of calculating emissions for on-road vehicles. The published inventory used a hybrid approach in which data from the U.S. EPA's National Emissions Inventory were combined with data from U.S. EPA's MOtor Vehicle Emission Simulator (MOVES) model runs.[43] The MOVES model does not include fuel specific emission factors for on-road vehicles, calculating emissions using vehicle miles traveled (VMT) and per-mile emission factors, specific to vehicle class and vintage. An alternate emission calculation methodology specified in the inventory (called the fuel consumption method) applied US-specific carbon content data from the latest US GHG inventory, and methane and N_2O emission factors using data from the IPCC. For this white paper, we apply this fuel consumption method as it allows the estimation of emission factors using fuel consumption data, regardless of vehicle vintage or class. While this methodology may result in different CH_4 and N_2O emissions relative to the inventory approach, these errors should be a very small fraction of the total fuel cycle GHG emissions, and is a reasonable approach given the data limitation of the hybrid approach.

(j) Note electricity generation factors are for estimating emissions associated with electricity generating units. For emissions associated with electricity consumption by end use, apply the factors published in NYSERDA's grid emission factors white paper.[44]

Endnotes

[1] Energy and Environmental Economics prepared for New York State Energy Research and Development Authority, *Calculating Grid Emission Factors for New York State*.

[2] NY State Senate, Bill S6599 of 2019 - An act to amend the environmental conservation law, the public service law, the public authorities law, the labor law and the community risk and resiliency act, in relation to establishing the New York state climate leadership and community protection act.

[3] US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks

[4] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[5] New York State Department of Environmental Conservation, Adopted Part 496, Statewide Greenhouse Gas Emission Limits

[6] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[7] US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks.

[8] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[9] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[10] New York State Department of Environmental Conservation, 2021 NYS Greenhouse Gas Emissions Report Sectoral Report #1: Energy.

[11] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[12] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[13] New York State Department of Environmental Conservation, 2021 NYS Greenhouse Gas Emissions Report Sectoral Report #1: Energy.

[14] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[15] New York State Department of Environmental Conservation, Adopted Part 496, Statewide Greenhouse Gas Emission Limits

[16] New York City Council Local Law 119 of 2016 - Use of clean heating oil.

[17] NY State Senate, Bill S5422A of 2017 - An act to amend the environmental conservation law and the tax law, in relation to bioheating fuel.

[18] NY State Senate, Bill S3321A of 2021 - An act to amend the environmental conservation law, in relation to bioheating fuel requirements.

[19] New York State Department of Environmental Conservation, Enforcement Discretion Related to ECL § 19-0327(3) Bioheating Fuel· Requirements June 30, 2022.

[20] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[21] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[22] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[23] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[24] Energy and Environmental Economics prepared for New York State Energy Research and Development Authority, *Calculating Grid Emission Factors for New York State*.

[25] New York City Council Local Law 119 of 2016 - Use of clean heating oil.

[26] NY State Senate, Bill S5422A of 2017 - An act to amend the environmental conservation law and the tax law, in relation to bioheating fuel.

[27] NY State Senate, Bill S3321A of 2021 - An act to amend the environmental conservation law, in relation to bioheating fuel requirements.

[28] New York State Department of Environmental Conservation, Enforcement Discretion Related to ECL § 19-0327(3) Bioheating Fuel· Requirements, June 30, 2022.

[29] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[30] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[31] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[32] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[33] Energy and Environmental Economics prepared for New York State Energy Research and Development Authority, *Calculating Grid Emission Factors for New York State*.

[34] New York State Department of Environmental Conservation, *Establishing a Value of Carbon*.

[35] New York State Climate Action Council, *Climate Action Council Draft Scoping Plan*.

[36] New York City Council, Local Law 119 of 2016 - Use of clean heating oil.

[37] NY State Senate, Bill S5422A of 2017 - An act to amend the environmental conservation law and the tax law, in relation to bioheating fuel.

[38] NY State Senate, Bill S3321A of 2021 - An act to amend the environmental conservation law, in relation to bioheating fuel requirements.

[39] New York State Department of Environmental Conservation, Enforcement Discretion Related to ECL § 19-0327(3) Bioheating Fuel· Requirements June 30, 2022.

[40] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[41] New York State Department of Environmental Conservation, *NYS Statewide GHG Emissions Report: Summary Report.*

[42] United States Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison.

[43] Eastern Research Group prepared for New York State Energy Research & Development Authority and New York State Department of Environmental Conservation, *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act*.

[44] Energy and Environmental Economics prepared for New York State Energy Research and Development Authority, *Calculating Grid Emission Factors for New York State*.

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