2 Energy (NIR Chapter 3)

For this methodology report, energy emissions are broken into two main categories: emissions associated with fuel use—including fossil fuel combustion (FFC) and nonenergy use (NEU)—and fugitive emissions mainly from fuel production. The energy emissions presented here include some categories that are not added to energy sector totals in the national *Inventory* but are instead presented as memo items, including international bunker fuels (IBFs)[11] and biomass emissions,[12] consistent with UNFCCC reporting guidelines. This approach directly affects state-level energy sector estimates and, in some cases, may account for differences with official estimates published by individual state governments. For more information on energy sector emissions, see Chapter 3 of the national *Inventory*. Table 2-1 summarizes the different approaches used to estimate state-level energy emissions and completeness across states. Geographic completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

Table 2-1. Overview of Approaches for Estimating State-Level Energy Sector GHG Emissions

Category	Gas	Approach	Geographic Completeness [a]
FFC	CO_2, CH_4, N_2O	Hybrid approach • Approach 1 used for most fuels and sectors • Approach 2 proxy data used to allocate national totals for some fuels and sectors	Includes emissions from all states, the District of Columbia, tribal lands, and territories (i.e., American Samoa, Guam, Puerto Rico, , Northern Mariana Islands, U.S. Virgin Islands and other outlying minor islands) as applicable.
NEUs of Fossil Fuels	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories (i.e., American Samoa, Guam, Puerto Rico, , Northern Mariana Islands, U.S. Virgin Islands and other outlying minor islands) as applicable.
Geothermal Emissions	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
Incineration of Waste	CO_2, CH_4, N_2O	Hybrid approach • 2011–2021: Approach 1 • 1990–2010: Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
IBFs (memo item)	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.
Wood Biomass and Biofuels Consumption (memo item)	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
Coal Mining	CH_4	Approach 1: Active Underground Mines	Includes emissions from all states and the District of Columbia as applicable.[a]

[11] Emissions from IBFs are not included specifically in summing energy sector totals. The values are presented for informational purposes only, in line with the *2006 IPCC Guidelines* and UNFCCC reporting obligations.

[12] Emissions from wood biomass, ethanol, and biodiesel consumption are not included specifically in summing energy sector totals. The values are presented for informational purposes only, in line with the *2006 IPCC Guidelines* and UNFCCC reporting obligations. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

Category	Gas	Approach	Geographic Completeness [a]
		Approach 1: Surface Mining and Post-mining Activities	
Abandoned Underground Coal Mines	CH_4	Hybrid	Includes emissions from all states and the District of Columbia as applicable.[a]
Petroleum and Natural Gas Systems	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, and territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands, and other outlying minor islands) as applicable.[a]
Abandoned Oil and Gas Wells	CO_2, CH_4	Approach 2	Includes emissions from all states, the District of Columbia, and territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands, and other outlying minor islands) as applicable.[a]

[a] Emissions are not likely occurring in U.S. territories; due to a lack of available data and the nature of this category, territories not listed are not estimated.

2.1 Emissions Related to Fuel Use

This section presents the methodology used to estimate the fuel use portion of emissions, which consists of the following sources:

- FFC (CO_2, CH_4, N_2O)
- Carbon emitted from NEUs of fossil fuels (CO_2)
- Geothermal emissions (CO_2)
- Incineration of waste (CO_2, CH_4, N_2O)
- IBFs (CO_2, CH_4, N_2O)
- Wood biomass and biofuels consumption (CO_2)

2.1.1 Fossil Fuel Combustion (NIR Section 3.1)

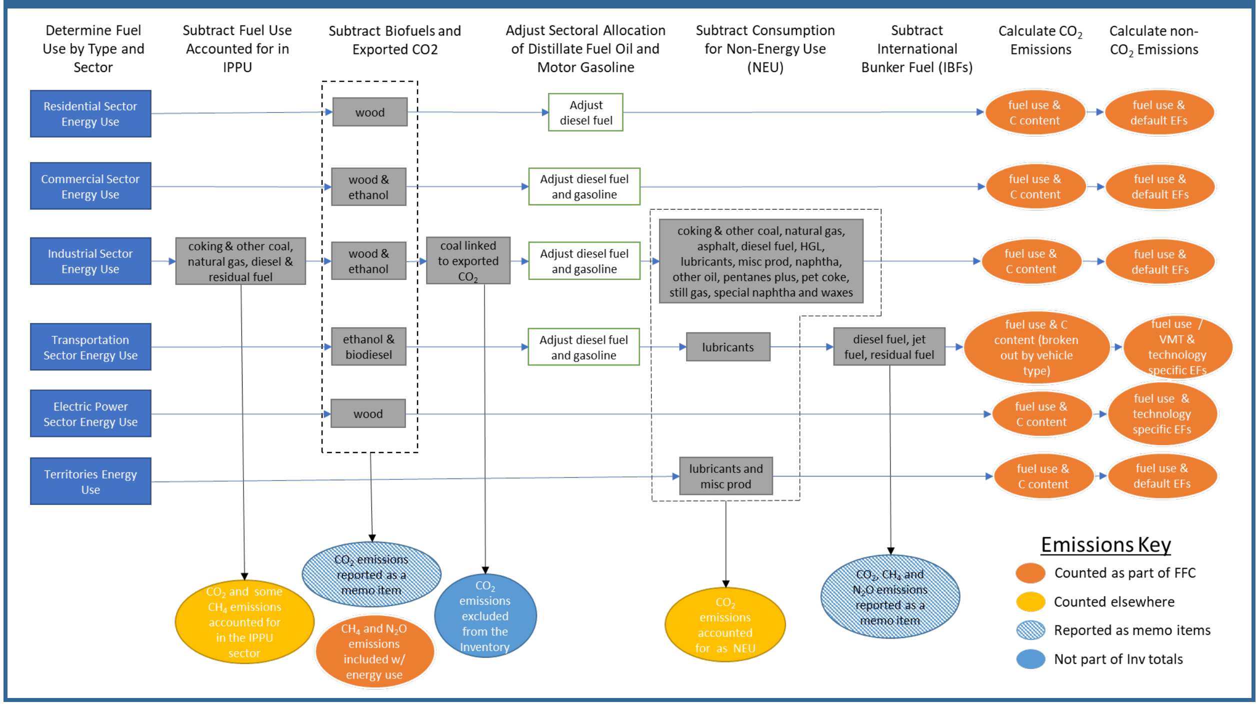
2.1.1.1 Background

Emissions from FFC include the GHGs CO_2, CH_4, and N_2O. CO_2 is the primary gas emitted from FFC and represents the largest share of U.S. total GHG emissions. The methods to estimate CO_2 emissions from FFC and the methods to estimate CH_4 and N_2O emissions from stationary and mobile combustion rely in large part on the same underlying data. However, there are some differences; therefore, the methods used to estimate CO_2 and non-CO_2 emissions are presented separately.

2.1.1.2 Methods/Approach

The approach for determining national-level FFC emissions is based on multiplying emissions factors times activity data on fuel consumption. The activity data on fuel consumption were taken from national-level energy balances prepared for EIA's *Monthly Energy Review* (MER) estimates (EIA 2023a). EIA prepares national-level energy statistics that consider energy production imports/exports and stock changes to determine energy supply/consumption. The fuel consumption information is used as a starting point for determining emissions.[13] The approach starts with determining fuel use by fuel type because different types of fuels have different carbon content (C content) and therefore different emissions factors. The information is also broken out by energy-consuming sectors of U.S. society to provide more detail and information on trends; the sectors included are residential, commercial, industrial, transportation, and electric power. Data from U.S. territories were also included in the analysis per international reporting requirements. Several adjustments were made to the data to account for fuel use and emissions that are either excluded or reported in other parts of the national *Inventory*, as shown in Figure 2-1.

Figure 2-1. Adjustments to Energy Consumption for Emissions Estimates



This section describes how national-level estimates for FFC were disaggregated to the state level for the following separate sources:

- FFC CO_2
- Stationary non-CO_2 emissions
- Mobile non-CO_2 emissions

This section also discusses how energy use data were broken out at the state level as part of the adjustments noted in Figure 2-1 and then used to report emissions elsewhere in the national *Inventory*. Emissions from energy use that were excluded from FFC are discussed in other sections of the report as follows:

- For energy used in the IPPU sector, see Chapter 3.
- For biofuel use, see Section 2.1.6.
- For NEUs of fuels, see Section 2.1.2.

[13] The energy balance data include information on all energy sources. Emissions estimates exclude data on non-emitting sources (e.g., nuclear, wind, solar); however, those data are considered when looking at overall energy use and efficiency.

- For IBFs, see Section 2.1.5.

Disaggregating FFC emissions to the state level largely followed the same process and energy consumption data that are used at the national level. However, in several instances, the data used to develop national estimates are not available at the state level, and additional steps were needed to distribute national-level emissions across the states while maintaining consistency with national-level totals. Therefore, Approach 3, the Hybrid approach as described in Section 1.3 of the Introduction chapter, was used to determine state-level emissions for FFC, including some data that were directly used in the national *Inventory* and some surrogate data as discussed in the following sections.

2.1.1.2.1. FFC CO_2 State-Level Breakout

CO_2 emissions from FFC at the national level are estimated with a Tier 2 method described by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). As discussed above, this method is based on multiplying activity data on fuel use (that have been adjusted to allocate and report data consistent with UNFCCC reporting guidelines and avoid double counting) by emissions factors to determine emissions.

Determining adjusted fuel use activity data is based on the seven steps discussed in Table 2-2 below. The result of these seven steps is an adjusted amount of fuel use activity data that are then used to determine FFC CO_2 emissions. In Appendix A to this document (included as separate Excel files), the "National 2021 FFC CO_2" Tab provides more details on an example of the adjustments made to the national-level energy use data to determine adjusted fuel use activity data for 2021. Three additional steps (Steps 8–10 in Table 2-2) are required to determine CO_2 emissions in the national *Inventory,* also discussed below.

Ideally, to determine state-level FFC CO_2 emissions estimates, the same approach could be used, and adjusted energy use, as shown in the "National 2021 FFC CO_2" Tab of Appendix A, could be developed for each state. However, the national-level emissions were developed based on multiple factors and inputs, some of which were not available or readily published at the state level. Therefore, a Hybrid approach was taken where state-level data were used when available. In cases where state-level data were not available, national-level estimates were used with available surrogate data to determine state-level percentages of each fuel use. Table 2-2 shows a high-level comparison of the different data sources used for the different steps to determine national-level and state-level estimates.

Table 2-2. Comparison of Approaches/Data Sources Used to Determine FFC Emissions

Calculation Step	National-Level Estimates	State-Level Estimates
Determine Activity Data		
Step 1: Determine Total Fuel Consumption by Fuel Type and Sector	Based on EIA MER	Based on EIA SEDS (adjusted to match national totals as applicable)
Step 2: Subtract Uses that are Accounted for in the IPPU Sector	Taken from industry data or based on national-level emissions	National-level data allocated to states based on state-level emissions estimates for each IPPU category in question as calculated in Chapter 3
Step 3: Adjust for Biofuels and Petroleum Denaturant	Based on national-level data from EIA MER	Not needed (see Step 5)
Step 4: Adjust for CO_2 Exports	Based on industry data and Canadian import data	Based on industry data and Canadian import data
Step 5: Adjust Sectoral Allocation of Diesel Fuel and Gasoline	Based on bottom-up transportation sector data on fuel use by vehicle type	National-level data (already excluding biofuels) allocated to states based on

Calculation Step	National-Level Estimates	State-Level Estimates
		state-level fuel use data (not vehicle specific)
Step 6: Subtract Consumption for NEUs	Based on data from EIA MER	National-level data allocated to states based on SEDS
Step 7: Subtract Consumption of IBFs	Based on data from Federal Aviation Administration (FAA) and other national-level sources	National-level data allocated to states based on SEDS and other sources
Calculate CO_2 Emissions		
Step 8: Determine the Carbon content of each fuel consumed	National-level average C content values	National-level average C content values
Step 9: Estimate CO_2 Emissions	Multiply C content by activity data and oxidation percentage	Multiply C content by activity data and oxidation percentage
Step 10: Allocate transportation emissions by vehicle type	Allocated at the national level based on data from Step 5	Not done

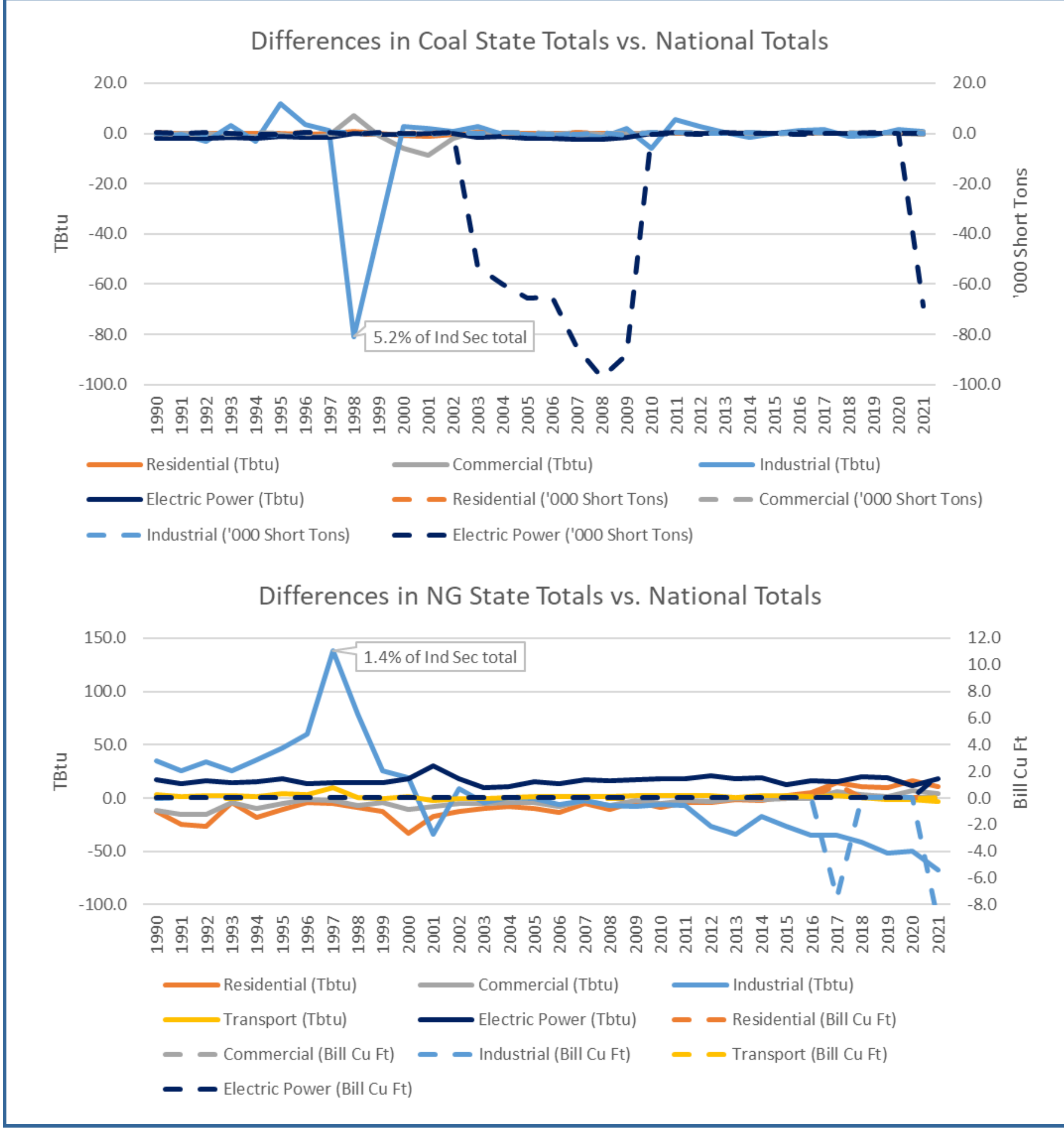
The following discussion details what data were used for each step in Table 2-2 to determine national- and state-level FFC emissions. Appendix A, Table A-1 in the "State FCC CO_2" Tab, provides more details on where state-level data were used directly and where other data were used to make adjustments to disaggregate national numbers across fuel types and sectors for each of the steps identified.

2.1.1.2.2. Step 1: Determine Total Fuel Consumption by Fuel Type and Sector

As discussed above, national-level data on fuel supply/consumption comes from EIA's MER. Because not all fuel supplied/consumed directly results in GHG emissions, or it could be included as part of other emissions reporting in the national *Inventory*, adjustments have to be made as shown above in Table 2-2 and described in the following steps. State-level energy data are available from EIA's State Energy Data System (SEDS). Those data are broken out by fuel type and sector (residential, commercial, industrial, transportation, and electric power) and are available for the years 1960–2021 (EIA 2023b). SEDS estimates energy consumption using data from surveys of energy suppliers that report consumption, sales, or distribution of energy at the state level. Most SEDS estimates rely directly on collected state-level consumption data. For example, SEDS uses state-level sales survey data and other proxies of consumption to allocate the national petroleum product supplied totals to the states. The sums of the state estimates equal the national totals as closely as possible for each energy type and end-use sector, and energy consumption estimates are generally comparable to the national statistics in EIA's MER because both data sets rely largely on the same survey returns for producers and consumers.

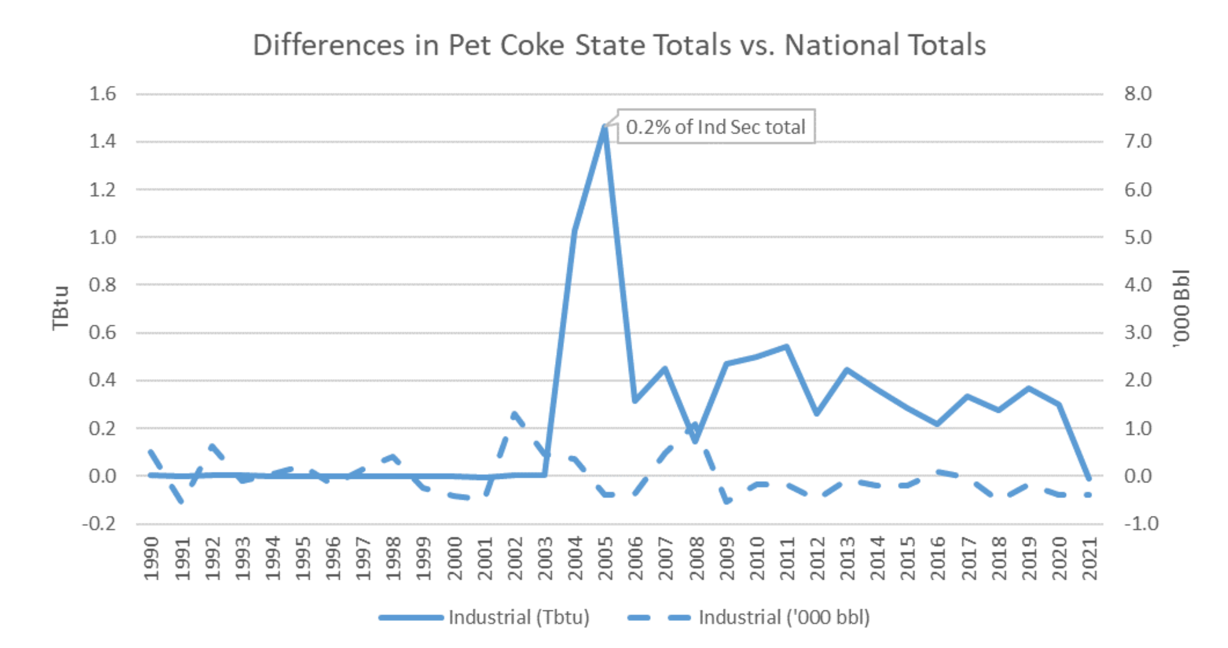
However, the totals across all states (and the District of Columbia) from SEDS do not always match the U.S. total energy data used in the national *Inventory*, which is based on the EIA February 2023 MER estimates (EIA 2023b). The main differences are for coal and natural gas and primarily in the industrial sector, as shown in Figure 2-2 below. For coal, there are differences in both energy content and short tons, but the differences are not consistent across time or sectors. For natural gas, the difference is mainly in the energy content. The reason for the differences is that SEDS uses state-level energy content conversion factors for coal and natural gas, while the MER uses national-level conversion factors. These different calculations sometimes cause the sums of the SEDS states to be different than the MER values. Although the percentage differences are not large (max 5.2% for coal and 1.4% for natural gas in the industrial sector), they cause noticeable differences when comparing emissions totals across all states to national totals, especially by sector.

Figure 2-2. Differences Between State-Level and National Total Energy Use for Coal and Natural Gas



The petroleum categories generally line up well across state-level and national totals. There are only minor differences in petroleum coke, mainly in the industrial sector, as shown in Figure 2-3 below. For petroleum coke, there are differences in energy content and barrels, but the difference in energy content appears in 2004, which is when petroleum coke heating values were changed from a constant value to values based on marketable and catalyst coke. Again, this difference is because of different national-level and state-level conversion factors. Since 2004, the MER has used an annual national-level "quantity-weighted" average petroleum coke conversion factor (instead of a fixed factor). SEDS applies the marketable and catalyst coke conversion factors to the state-level consumption of each petroleum coke category within each state.

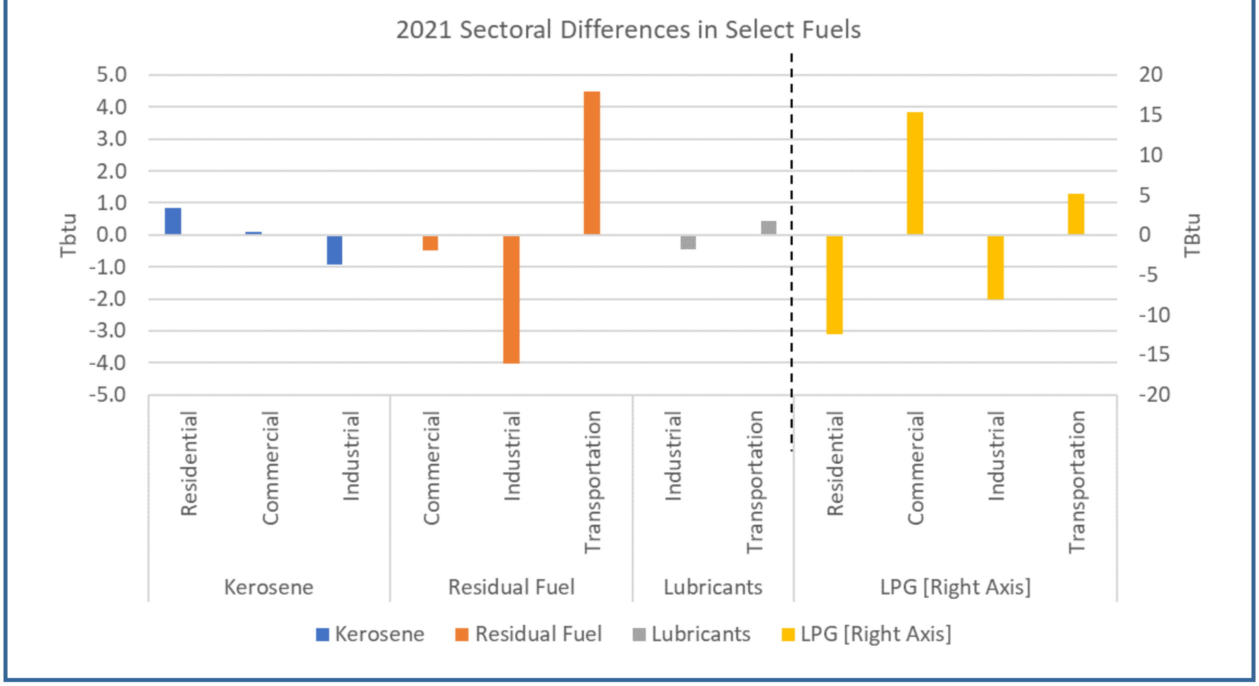
Figure 2-3. Differences Between State-Level and National Total Energy Use for Petroleum Coke



For diesel fuel and gasoline, the totals generally line up, but there are differences across sectors. These differences are discussed in Step 5 below.

In addition to the differences in gasoline and diesel fuel across sectors over the time series, there are also differences in some petroleum fuels across sectors, specifically in 2021. This is because the SEDS represents the latest data from EIA in terms of sector breakouts that were not reflected in the national *Inventory* 2021 values that relied on older EIA data. Again, the totals for the fuels line up, but there are differences across sectors, as shown in Figure 2-4 below. The updated SEDS data were used in the state-level breakout because they represent the latest data available. This results in differences in 2021 results across sectors for the state totals versus the national *Inventory*. However, the national *Inventory* numbers will be updated to match the 2021 SEDS data during the next national *Inventory* cycle.

Figure 2-4. 2021 Differences Between Sectors for Petroleum Fuels (SEDS—National *Inventory*)



Furthermore, some of the fuel use reported in SEDS is different from the reporting in the national *Inventory*. For example, natural gas reported in SEDS includes supplemental gas, which is included in the national *Inventory* under the primary fuel used to make the supplemental gas, so including supplemental gas in state level results would result in double counting. Liquefied petroleum gas (LPG) in SEDS is reported differently over time, including as total hydrocarbon gas liquids (HGLs) that include natural gasoline and as a mix of different gases. Natural gasoline (called pentanes plus in the national *Inventory*) is accounted for separately from other HGLs in the national *Inventory*. Gasoline and distillate fuels in SEDS include biofuels (fuel ethanol, biodiesel and renewable diesel, and other biofuels are included in the MER but not estimated in SEDS yet), which were reported separately in the national *Inventory*. These differences make it difficult to use the SEDS data directly to determine state-level fuel use data, in a manner consistent with the national *Inventory*.

Therefore, the following approach was used in determining fuel use by type by sector at the state level:

- If SEDS data totals matched the national totals and there were no further adjustments needed (as per Steps 2–7), the SEDS data were used directly to represent state-level energy use.
- For fuels where the SEDS totals did not match the national totals (i.e., coal, natural gas, and petroleum coke), fuel use in each sector was adjusted to match the national totals used in the national *Inventory*. This calculation was based on the percentage of each fuel used in each state from the SEDS data. For the industrial sector, this adjustment was made after subtracting for uses in the IPPU sector (see Step 2 below).
- For other fuels where sector totals did not match up (e.g., gasoline and diesel fuel), totals for each fuel type were generally taken from the national *Inventory* (see Step 5), and the SEDS data or other proxy data sources were used to determine state-level percentages of each fuel use.

This approach generally results in state-level energy use data that are consistent with national totals used in the national *Inventory*. More details on further adjustments made during the different steps are discussed below.

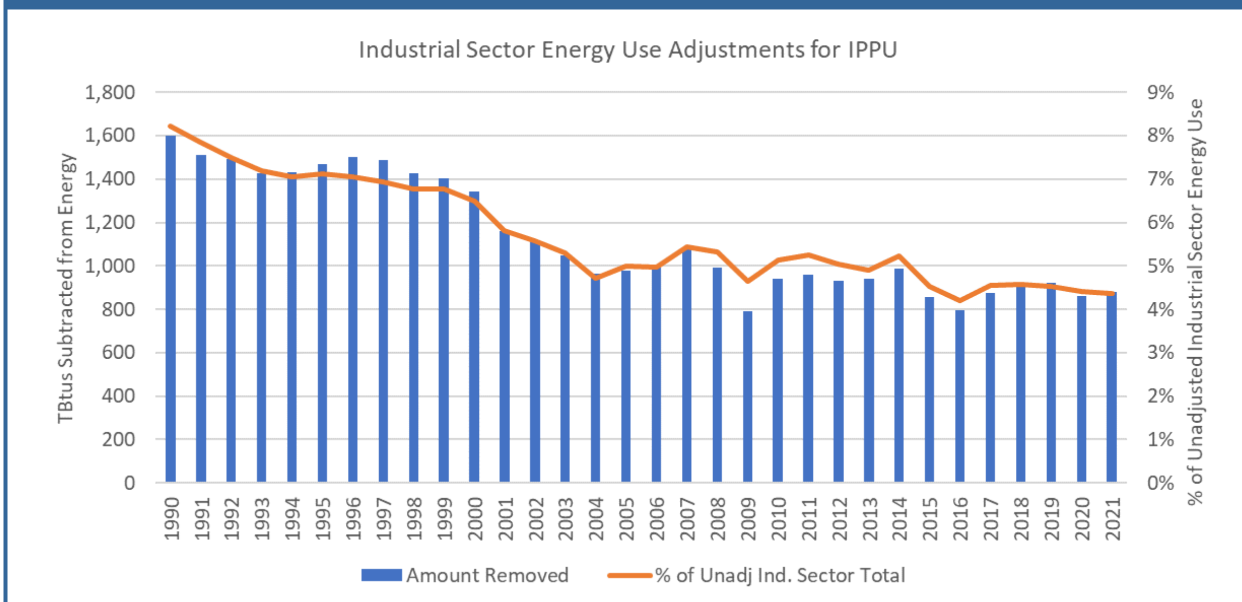
Appendix A has details on how the SEDS data were adjusted to determine state-level energy use by fuel type and sector. Tables A-2 through A-6 in the "FFC CO_2 Residential" Tab describe the residential sector adjustments. Tables A-9 through A-13 in the "FFC CO_2 Commercial" Tab describe the commercial sector adjustments. Tables A-44 through A-47 in the "FFC CO_2 Industrial" Tab describe the industrial sector adjustments for petroleum coke and HGL; the remaining industrial sector adjustments are described further in Steps 2 and 3 below. Tables A-50 and A-51 in the "FFC CO_2 Transportation" Tab describe the transportation sector adjustments. Tables A-52 through A-56 in the "FFC CO_2 Electricity" Tab describe the electricity production sector adjustments.

2.1.1.2.3. Step 2: Subtract Uses That Are Accounted for in the IPPU Sector

In the national *Inventory*, portions of fuel consumption data for several fuel categories (coking coal, other coal, natural gas, residual fuel, and distillate fuel) are reallocated from the energy sector to the sector because these portions were consumed as raw materials during nonenergy-related industrial processes. As per IPCC Guidelines that distinguish between the energy and IPPU sector reporting, emissions from fuels used as raw materials are presented as part of IPPU and are removed from the energy use estimates (IPCC 2006, Volume 3, Chapter 1). Portions of fuel use were therefore subtracted from the industrial sector fuel consumption data before determining combustion emissions. Note that other adjustments were also made to the NEU calculations to reflect energy use accounted for under IPPU; see Step 6 and the NEU emissions discussion below.

The adjustments vary over time and represent from about 4% to 8% of total unadjusted industrial sector energy use, as shown in Figure 2-5.

Figure 2-5. Adjustments Made to Industrial Sector Energy Use to Account for Emissions Reported in IPPU



Adjustments for each fuel type were made based on industry data or assumptions about fuel use based on emissions reported under IPPU. The following bullets discuss the assumptions made regarding the different industrial sector fuel types at the national and state levels to reflect their use in IPPU:

- **Coking coal.** Coking coal is used to make coke that, in turn, is used in industrial processes. The national total amount of coking coal used in IPPU was back-calculated based on the amount of coking coal needed to make the coke used as input to iron and steel (I&S) and lead and zinc production (approximately 94% is used in I&S). National-level coke use in I&S production was based on industry data that are not available at the state level. Coke used in lead and zinc production was based on the amount of carbon emitted from the processes and Is also not available specifically at the state level. Therefore, the national total amount of coking coal used in IPPU was allocated per state based on the percentage of total coking coal used per state from the SEDS data. This approach assumes that coke use in I&S and lead and zinc production is proportional to the amount of coking coal used in a state. This assumption may not be the case because state-level coking coal use is based on coke production in a given state, not necessarily coke use. The coke could be produced in one state and shipped for use in another state. However, given the lack of specific data, coking coal use was determined to be a good surrogate for coke use within a given state because coke production is often integrated with I&S production where the coke is used. As one further adjustment, if the amount of coking coal used in IPPU was greater than the total coking coal reported in the national energy statistics, the amount of coking coal used in the energy sector results were zeroed out to avoid negative values (this only occurs in 1990, 1991, 1992, and 1997), and additional other coal use was subtracted to make up the difference (see "Other coal" below). Appendix A, Tables A-19 and A-20 in the "FFC CO_2 Industrial" Tab, describe the coking coal used in IPPU.

- **Other coal.** Two adjustments were made to account for other coal used in the industrial sector. The first adjustment was to subtract the extra amount of coking coal required for years where the coking coal adjustment was more than the coking coal total (see above). Similar to coking coal, this adjustment was based on the percentage of coking coal consumption per state from SEDS. Appendix A, Tables A-21 and A-22 in the "FFC CO_2 Industrial" Tab, describe this adjustment. The second adjustment was to subtract coal directly used in the I&S sector. In addition to being used indirectly to produce coke, coal can be used directly as a process input to I&S production; note that this does not include coal combusted at I&S facilities to produce power. Other national-level coal used in I&S production was based on industry data that are not available at the state level. Therefore, this adjustment was based on the percentage of I&S emissions per state. I&S emissions per state were taken from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for basic oxygen furnaces (BOFs) was assumed to best represent other coal use in I&S. BOF emissions were determined to be a good surrogate for other coal direct use in I&S because coal is primarily used in the BOF process and would be proportional to emissions from the process. Appendix A, Table A-24 in the "FFC CO_2 Industrial" Tab, describes this adjustment. An IPPU-adjusted other coal total was then calculated by subtracting the adjustments described above (note: this also included the adjustments for conversion of fuels and CO_2 exports as described in Step 4 below). Appendix A, Table A-25 in the "FFC CO_2 Industrial" Tab, shows this total. The total other coal use was then adjusted to match the total other coal from the national *Inventory* (as per Step 1); this adjustment was based on the percentage of other coal used after the IPPU adjustment. Appendix A, Table A-26 in the "FFC CO_2 Industrial" Tab, describes this adjustment.
- **Natural gas.** Two adjustments were made to account for natural gas used in the industrial sector. The first adjustment was to subtract the amount of natural gas consumption that was used in ammonia production from energy sector natural gas use. The national-level natural gas used in ammonia production was back-calculated based on assumed CO_2 emissions from ammonia production and calculations on the amount of C content in natural gas needed to produce those CO_2 emissions. Therefore, the state-level natural gas used for ammonia was based on the percentage of ammonia emissions per state. Ammonia emissions per state were taken from the IPPU breakout for ammonia, as described in Section 3.2.1. Appendix A, Tables A-27 through A-29 in the "FFC CO_2 Industrial" Tab, describe this adjustment. The second adjustment was to subtract natural gas directly used in I&S. National-level natural gas used in I&S production was based on industry data that are not available at the state level. Therefore, similar to other coal, the adjustment was based on the percentage of I&S emissions per state from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for BOFs was assumed to best represent natural gas use in I&S. Similar to other coal direct use, BOF emissions were determined to be a good surrogate for natural gas direct use

in I&S. Appendix A, Table A-30 in the "FFC CO_2 Industrial" Tab, describes this adjustment. An IPPU-adjusted natural gas total was then calculated by subtracting the adjustments described above. Appendix A, Table A-31 in the "FFC CO_2 Industrial" Tab, shows this total. The total natural gas use was then adjusted to match the total natural gas use from the national *Inventory* (as per Step 1); this adjustment was based on the percentage of natural gas used after the IPPU adjustment. Appendix A, Table A-32 in the "FFC CO_2 Industrial" Tab, describes this adjustment.

- **Residual fuel.** The residual fuel use was adjusted to subtract the amount of residual fuel used in carbon black production. Carbon black was the only IPPU use of residual oil. The national-level residual oil used in IPPU was based on NEUs of residual oil from EIA data, which are not available at the state level. Therefore, the residual oil IPPU state-level adjustment was based on the percentage of carbon black emissions per state. Carbon black emissions per state were taken from the IPPU breakout for petrochemicals, as described in Section 3.2.9, and the percentage for carbon black specifically was used. Carbon black emissions were determined to be a good surrogate for residual oil use because the emissions from carbon black production would be directly proportional to residual oil use. Appendix A, Tables A-33 and A-34 in the "FFC CO_2 Industrial" Tab, describe this adjustment. An IPPU-adjusted residual fuel total was then calculated. Appendix A, Table A-35 in the "FFC CO_2 Industrial" Tab, shows this total. The total residual fuel use was then adjusted to match the total residual fuel from the national *Inventory* (similar to what was done for coal and natural gas in Step 1); this adjustment was based on the percentage of residual fuel used after the IPPU adjustment. After the adjustment, the residual fuel use summed across states did not match the national totals anymore (likely due to the distribution of adjustment based on petrochemical production, which resulted in negative emissions in some states that were then zeroed out). Appendix A, Table A-36 in the "FFC CO_2 Industrial" Tab, describes this adjustment.
- **Distillate fuel.** Distillate fuel use was adjusted to subtract the amount of distillate fuel directly used in I&S production. National-level diesel fuel used in I&S production was based on industry data that are not available at the state level. Therefore, similar to other coal and natural gas direct use in I&S, the adjustment was based on the percentage of I&S emissions per state from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for BOFs was assumed to best represent distillate fuel use. Similar to other coal and natural gas direct use in I&S, BOF emissions were determined to be a good surrogate for diesel fuel direct use in I&S. Appendix A, Tables A-37 and A-38 in the "FFC CO_2 Industrial" Tab, describe this adjustment. An IPPU-adjusted distillate fuel total was then calculated. Appendix A, Table A-39 in the "FFC CO_2 Industrial" Tab, shows this total. This total was adjusted further based on reallocation of diesel fuel use across sectors, as shown in Step 5 below.

2.1.1.2.4. Step 3: Adjust for Biofuels and Petroleum Denaturant

Fuel consumption estimates used for CO_2 calculations were adjusted downward to exclude fuels with biogenic origins consistent with the IPCC Guidelines. CO_2 emissions from ethanol and biodiesel consumption are not included in fuel combustion totals in line with the 2006 IPCC Guidelines and UNFCCC reporting obligations to avoid double counting with net carbon fluxes from changes in biogenic carbon reservoirs accounted for in the estimates for LULUCF. CO_2 emissions from biogenic fuels under fuel combustion are estimated separately and reported as memo items for informational purposes under the energy sector. Furthermore, for several years of the time series, denaturant used in ethanol production was double counted in both transportation and industrial sector energy use statistics. It was therefore subtracted from transportation sector energy use to avoid double counting. Fuels with biogenic origins (ethanol and biodiesel) and ethanol denaturant adjustments at the state level are handled by adjusting gasoline and diesel fuel use based on the total non-biogenic components of those fuels only (which also include any adjustments for denaturant), as described in Step 5 below. So, in effect, the state-level energy use calculations used to determine FFC emissions for gasoline and diesel fuel combine this Step 3 with Step 5 below. See Section 2.1.6 for more detail on biofuel use at the state level used to calculate biomass CO_2 as a memo item.

2.1.1.2.5. Step 4: Adjust for CO_2 Exports

Since October 2000, the Dakota Gasification Plant has been exporting CO_2 produced in a coal gasification process to Canada by pipeline. Because this CO_2 is not emitted to the atmosphere in the United States, the coal that is gasified to create the exported CO_2 is subtracted from fuel consumption statistics used to calculate combustion emissions in the national *Inventory*. Consistent with the approach currently used in the national *Inventory*, the coal used to produce exported CO_2 from the Dakota gas plant to Canada was subtracted from other coal use to determine state-level emissions. This was all assumed to be subtracted from North Dakota, the location of the Dakota gas plant. Appendix A, Table A-23 in the "FFC CO_2 Industrial" Tab, describes this adjustment.

2.1.1.2.6. Step 5: Adjust Sectoral Allocation of Distillate Fuel Oil and Motor Gasoline

Motor gasoline and diesel fuel are used across all sectors. The total amount of motor gasoline and diesel fuel consumed as reported in the MER is based on petroleum supply data from refineries. Gasoline use is allocated across the sectors in proportion to aggregations of categories reported in the U.S. Department of Transportation's Federal Highway Administration (FHWA) highway statistics data (FHWA 1996–2021).[14] Diesel fuel use is allocated to the electric power sector based on industry surveys. The remaining diesel fuel use is allocated across the remaining sectors in a similar way to gasoline use based on sales data to different categories. Through 2020, the allocation was based on data from EIA's fuel oil and kerosene sales (FOKS) data (EIA 2022). EIA suspended the FOKS report after data year 2020. Starting in 2021, diesel fuel use is allocated to sectors based on data from SEDS. For 2021 forward, SEDS uses several external sources, regressions, and historical sector and state shares to estimate the data that were in the FOKS report. For the national *Inventory*, data are needed on fuel use by vehicle type to determine emissions, so a bottom-up method is used to estimate transportation sector gasoline and diesel fuel use. The national *Inventory* determines gasoline and diesel fuel use by vehicle type based on FHWA data and outputs from EPA's MOtor Vehicle Emissions Simulator (MOVES) model (EPA 2022). The national *Inventory* then allocates the remaining fuel use to the remaining sectors based on the proportions in the EIA data. The differences in the EIA and national *Inventory* gasoline and diesel fuel allocation approach across sectors are shown below in Figure 2-6 and Figure 2-7, including information on the categories of use included in each sector and data for 2021 as an example.

[14] FHWA forms MF-21 and MF-24 are used in the calculations. For 2021, form MF-24 is not available yet, so values for 2020 were used in the calculations shown.

Figure 2-6. Comparison of Gasoline Sector Allocation

EIA National Energy Balance

From the MER, Based on Refinery Supply Data

Total Supply	2021 ('000 Gal)
Motor Gasoline	135,149,280

From FHWA Data

Commercial Sector	2021 ('000 Gal)	% of Total
Public non-highway	100,136	
Lawn and garden*	3,028,675	
Misc.	27,062	
Sector Total:	**3,155,873**	**2.3**

Industrial Sector	2021 ('000 Gal)	% of Total
Ag	134,866	
Construction	389,428	
Ind. & comm.	1,766,839	
Sector Total:	**2,291,133**	**1.7**

Transportation Sector	2021 ('000 Gal)	% of Total
Highway	128,909,697	
Boating	2,326,171	
Rec. vehicles*	1,691,428	
Sector Total:	**132,927,296**	**96.1**

Total	2021 ('000 Gal)
Motor Gasoline	138,374,302

National Sector Split

Commercial Sector	2021 ('000 Gal)
Motor Gasoline	3,111,990

Industrial Sector	2021 ('000 Gal)
Motor Gasoline	2,207,520

Transportation Sector	2021 ('000 Gal)
Motor Gasoline	129,829,770

Non-Transportation Percent

59%

41%

* Note FHWA added the lawn and garden and recreational vehicle use categories in 2015 which causes a time series discontinuity in the split between the different sectors. EPA for the national Inventory back calculated fuel use for those categories and adjusts the FHWA data accordingly.

EPA National Inventory

From the MER, Based on Refinery Supply Data

Total Supply	2021 ('000 Gal)
Motor Gasoline	135,149,280

From FHWA & DOT Data

Remaining
4,902,912

Transportation Sector	2021 ('000 Gal)
Automobiles	45,646,648
Motorcycles	937,387
Buses	361,098
Light Trucks	78,495,932
Other Trucks	3,468,633
Boats (Recreational)	1,336,671
Sector Total:	**130,246,368**

Non-Transportation Percent from EIA

59%

41%

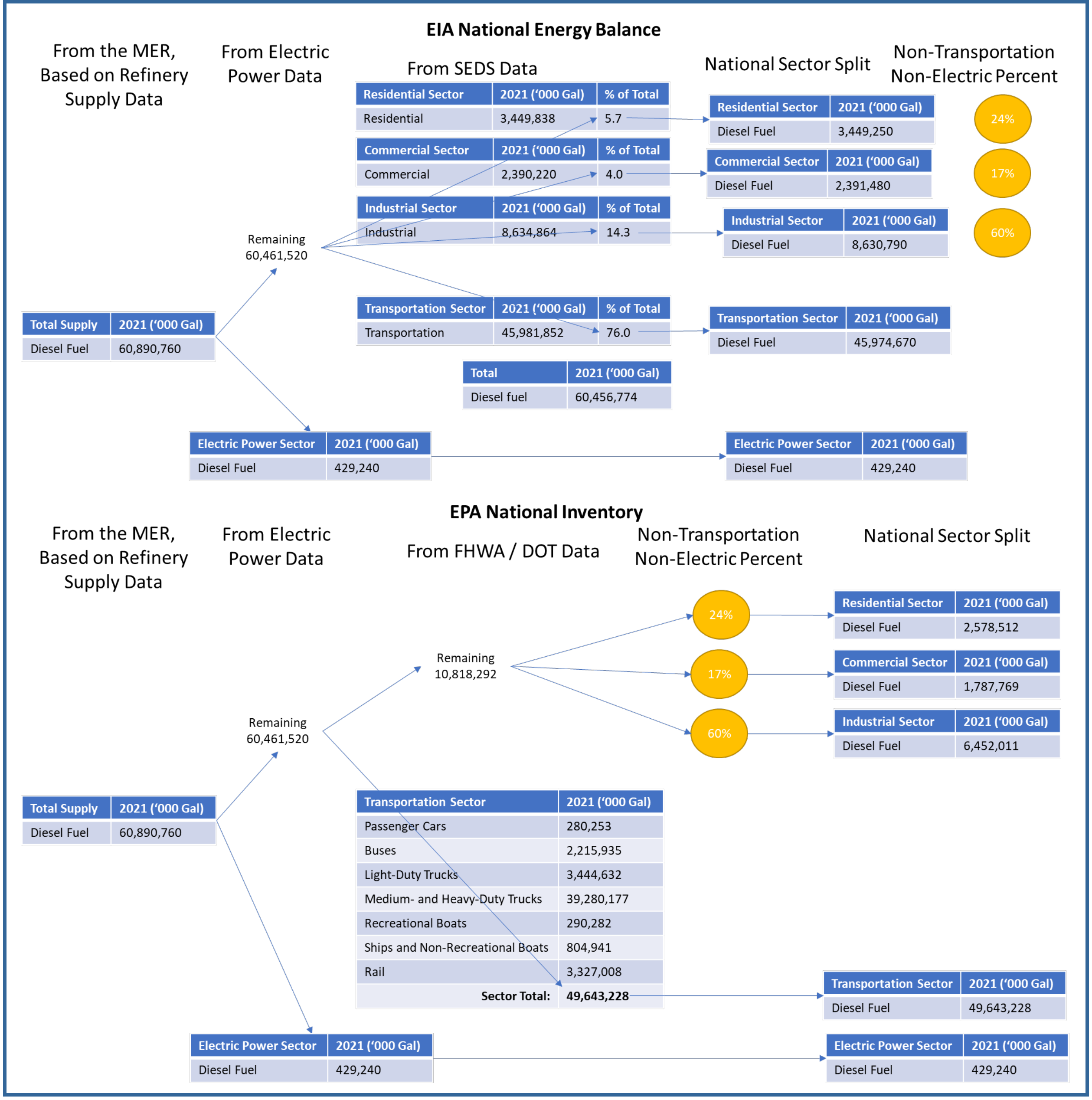
National Sector Split

Commercial Sector	2021 ('000 Gal)
Motor Gasoline	2,868,274

Industrial Sector	2021 ('000 Gal)
Motor Gasoline	2,034,638

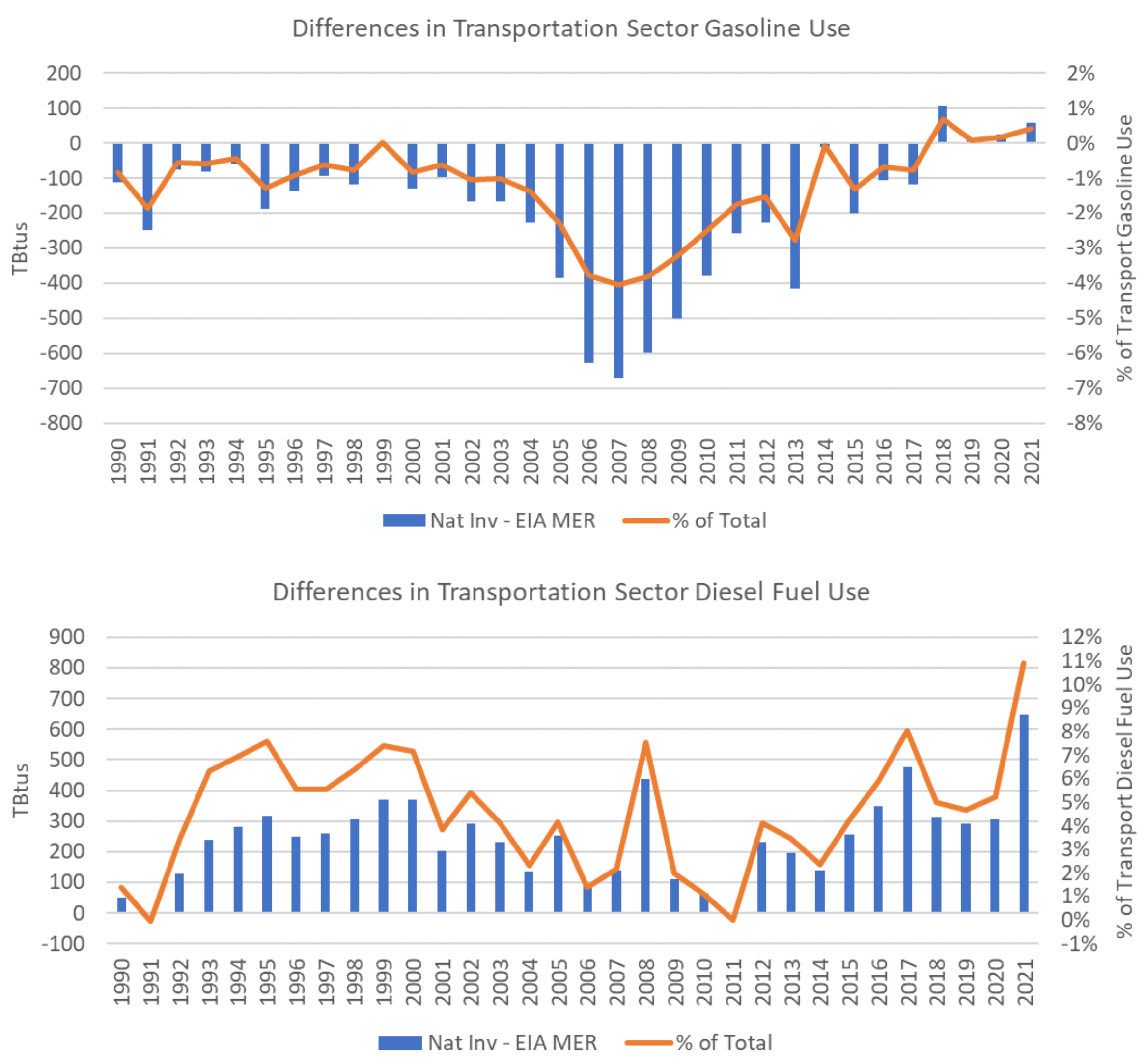
Transportation Sector	2021 ('000 Gal)
Motor Gasoline	130,246,368

Figure 2-7. Comparison of Diesel Fuel Sector Allocation



The bottom-up approach used by the national *Inventory* to determine transportation sector fuel use generally results in less allocation of gasoline to the transportation sector (and more to other sectors) and more diesel fuel allocated to the transportation sector (and less to other sectors) compared with the original MER energy balance data, as shown below in Figure 2-8.

Figure 2-8. Comparison of Transportation Sector Fuel Use



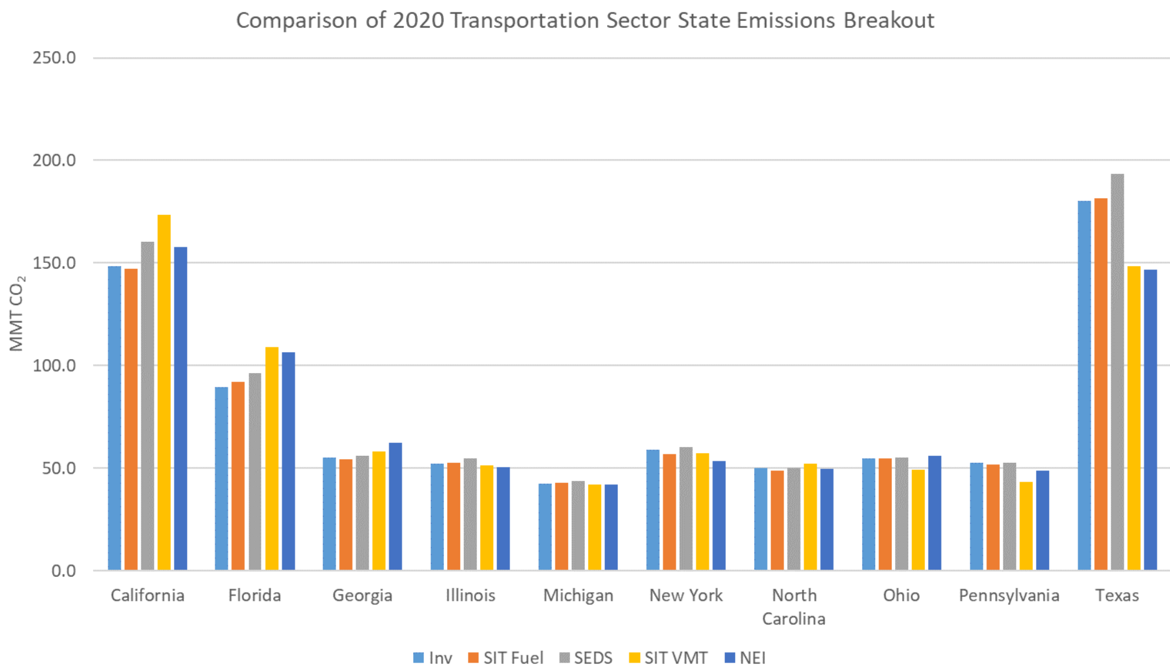
The national-level data on gasoline and diesel fuel use by vehicle type used in the bottom-up analysis was not readily available at the state level. Therefore, the following assumptions and adjustments were made to distillate fuel and motor gasoline consumption at the state level across the different sectors to reflect the national *Inventory* bottom-up transportation fuel use approach:

- **Transportation sector.** The total amount of distillate fuel and motor gasoline used in the transportation sector was taken from the national *Inventory* totals (these totals already subtract biofuel use, subtract denaturants if needed, and are based on multiple factors to determine transportation sector fuel use). This total amount of distillate fuel and motor gasoline use and emissions was allocated across states based on the percentage of fuel use by state in gallons from FHWA data (FHWA 2021a, 2021b). For distillate fuel, the total was based on FHWA form MF-225, and the motor gasoline total was based on FHWA form MF-226, both of which have time series of fuel use by state. Appendix A, Tables A-48 and A-49 in the "FFC CO_2 Transportation" Tab, describe this adjustment. The FHWA data reflect on-highway fuel use, but, as seen in Figure 2-6 and Figure 2-7 above, the transportation sector fuel use includes some mobile sources that are considered off-highway (e.g., recreational boating, railroads). However, because the majority of the motor gasoline and diesel fuel use is for on-highway purposes, using FHWA data to allocate transportation sector fuel use to the state level is reasonable. Note that FHWA state-level fuel consumption data are representative of the point-of-sale and not the point-of-use, so fuel sold in one state that may be combusted in other states is assigned to the state where the fuel was purchased. This approach is consistent with IPCC Guidelines (IPCC 2006) for country-level reporting that indicate that "where cross-border transfers take place in vehicle tanks, emissions from road vehicles should be attributed to the country where the fuel is loaded into the vehicle." Therefore, when applying the IPCC approach to the state-level inventory, vehicle emissions are attributed to the state where the vehicle fuel is sold. This approach could introduce some differences in state-level transportation sector fuel use and emissions allocations reported here and those reported by individual states. For example, in addition to fuel sales data, state-level vehicle miles traveled (VMT) data are another potential surrogate for allocating fuel use to the state level, but that approach does not account for vehicle and fleet fuel economy variability between states. EPA will consider alternative or complementary approaches to allocate transportation fuel across states, including VMT data and other sources. For example, the National Emissions Inventory (NEI) uses county-level fleet and activity data to generate a bottom-up inventory (EPA 2017).[15] Figure 2-9 shows the transportation sector emissions in 2020[16] from the top 10 emitting states using different allocation approaches. As seen in the figure, the approach used will lead to different allocations across states.

[15] Note the NEI uses a bottom-up method for determining transportation sector fuel use and emissions based on VMT and assumed vehicle fleet fuel efficiency at the county level through the MOVES model. However, applying that approach across all states could lead to differences with national totals. The approach used here is to allocate national totals to states and not perform a bottom-up analysis for each state.

[16] 2020 is shown because that is the latest year of NEI data that are produced every three years.

Figure 2-9. Transportation Sector State-Level Allocation Examples



- **Residential sector.** The total amount of distillate fuel used in the residential sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the residential sector per state from SEDS. Appendix A, Tables A-7 and A-8 in the “FFC CO_2 Residential” Tab, describe this adjustment. Based on the reallocation of sector fuel use, the residential sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS may not represent exactly the fuel values from the national *Inventory*. However, residential sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., home heating); therefore, the SEDS state-level breakout is assumed to be representative.
- **Commercial sector.** The total amount of distillate fuel and motor gasoline used in the commercial sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the commercial sector per state from SEDS. Appendix A, Tables A-14 to A-18 in the “FFC CO_2 Commercial” Tab, describe this adjustment. Based on the reallocation of sector fuel use, the commercial sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS may not represent the exact fuel values from the national *Inventory*. However, commercial sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., construction equipment); therefore, the SEDS state-level breakout is assumed to be representative.
- **Industrial sector.** The total amount of distillate fuel and motor gasoline used in the industrial sector was taken from the national *Inventory* totals. Distillate fuel was allocated across states based on the percentage of existing fuel use in the industrial sector per state after the IPPU adjustments described in Step 2. Motor gasoline was allocated across states based on the percentage of existing fuel use in the industrial sector per state from SEDS. Appendix A, Tables A-40 and A-43 in the “FFC CO_2 Industrial” Tab, describe this adjustment. Based on the reallocation of sector fuel use, the industrial sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS

may not represent the exact fuel values from the national *Inventory*. However, industrial sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., process energy use); therefore, the SEDS state-level breakout is assumed to be representative.

- **Electric power sector.** The total amount of distillate fuel used in the electric power sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the electric power sector per state from SEDS. Appendix A, Tables A-57 and A-58 in the "FFC CO_2 Electricity" Tab, describe this adjustment. The electric power sector fuel use was not adjusted in the national *Inventory* compared with what is represented in SEDS; therefore, the SEDS state-level breakout is considered representative.

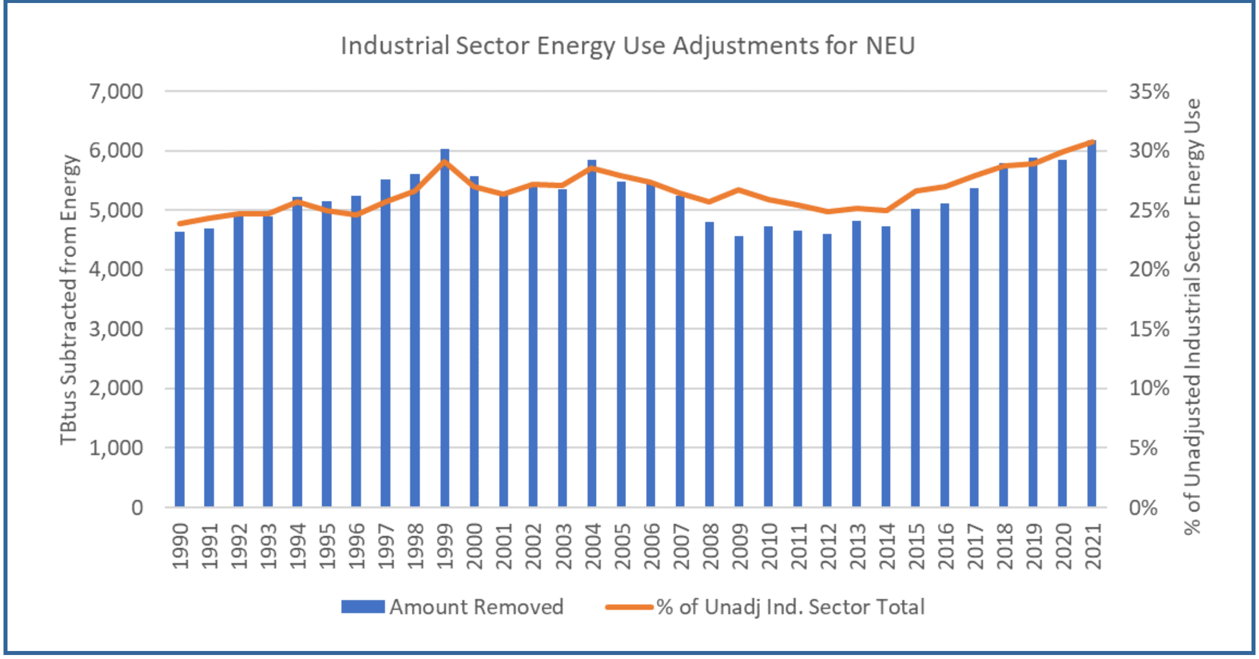
2.1.1.2.7. Step 6: Subtract Consumption for NEU

The energy statistics include consumption of fossil fuels for nonenergy purposes. Most fossil fuels consumed are combusted to produce heat and power. However, some are used directly for NEU as construction materials, chemical feedstocks, lubricants, solvents, and waxes.[17] For example, asphalt and road oil are used for roofing and paving, and hydrocarbon gas liquids are used to create intermediate products. In the national *Inventory*, emissions from these NEUs are estimated separately under the Carbon Emitted and Stored in Products from NEUs source category. Therefore, the amount of fuels used for nonenergy purposes needs to be subtracted from fuel consumption data for determining combustion emissions.

The adjustments vary over time and represent about 25% to 30% of total unadjusted industrial sector energy use, as shown in Figure 2-10.

[17] Under IPCC Inventory guidance, emissions from these nonenergy sources should be reported as part of IPPU. However, because of national circumstances and the inability to separate these uses from the national energy balance, the United States reports these emissions as part of energy. This is an area for future planned improvement as part of the national *Inventory*, and any updates will be carried over to the state-level reporting.

Figure 2-10. Adjustments Made to Industrial Sector Energy Use to Account for Emissions Reported as NEUs



Adjustments for each fuel type were made at the national level based on data and assumptions from EIA as used in the national energy balance. More detail on the amount and types of fuels used for NEU at the national level are shown in Appendix A in the "National 2021 NEU CO_2" Tab.

The following approaches were taken to determine the amounts of different fuels used for NEUs that needed to be subtracted from energy combustion estimates at the state level. The subtractions were all made in the industrial sector except for lubricants; those subtractions were used in both the industrial and transportation sectors and for NEU from territories. The fuels requiring subtraction are:

- **Coking coal.** As per the national *Inventory*, the amount of coking coal used for NEUs was determined to be the total of the adjusted coking coal (after subtracting for IPPU use, per Step 2). Therefore, the state-level totals from Step 2 for coking coal were used to represent NEUs. Appendix A, Table A-59 in the "NEU" Tab, shows this state-level breakout.
- **Other coal.** The coal used to produce synthetic natural gas at the Eastman gas plant (based on data from the national *Inventory*) was assumed to be used for chemical feedstock and therefore was accounted for under NEU. This other coal NEU was allocated across states by assuming it all occurred in Tennessee, the location of the Eastman facility. Appendix A, Table A-60 in the "NEU" Tab, shows this state-level breakout.
- **Natural gas.** The total national-level amount of natural gas used for NEUs was taken from the national *Inventory* (based on data from EIA) and represents natural gas used for chemical plants and other uses. Natural gas used for NEUs was allocated across states based on the percentage of petrochemical emissions per state. This is an area where there was not any specific data on natural gas used for NEU in chemical plants and other uses by state. Using petrochemical emissions to allocate natural gas NEU use by state was considered a reasonable approach as emissions are a good indication of petrochemical production in a state, and therefore a good indication of how much NEU fuel was used in that state. Petrochemical emissions per state were taken from the IPPU breakout for petrochemicals, as described in

Section 3.2.9, and the total percentage for all petrochemicals was used. Appendix A, Table A-61 in the "NEU" Tab, shows this state-level breakout.

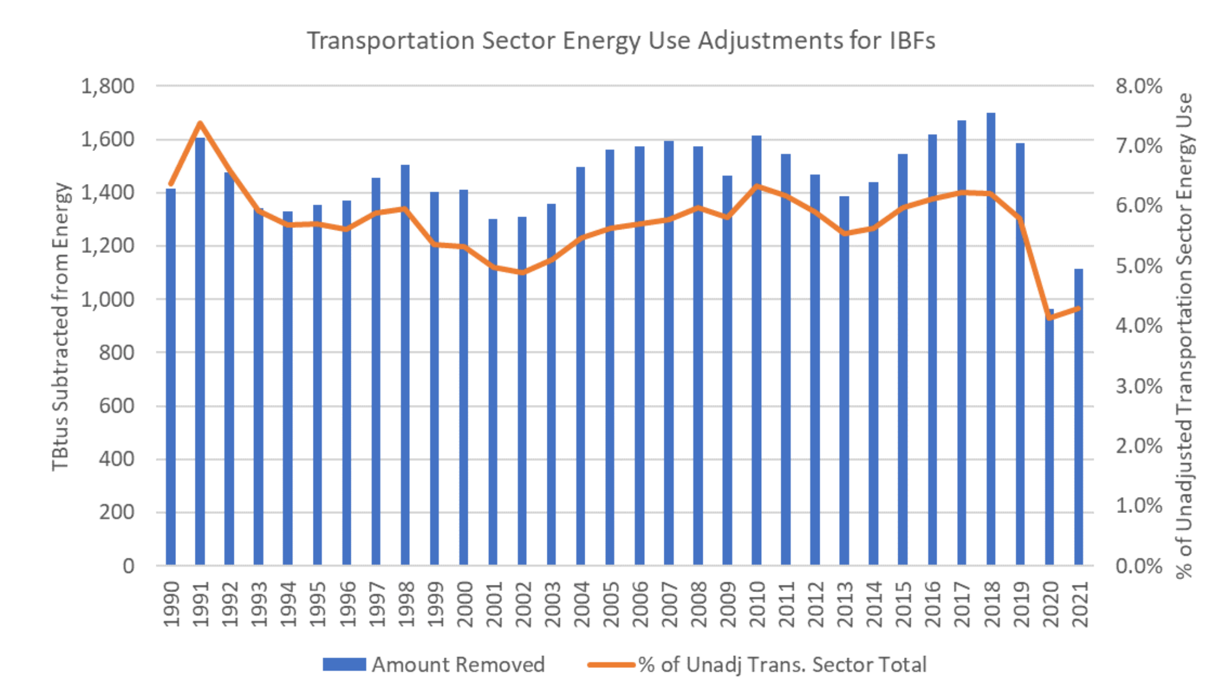
- **LPG, pentanes plus, still gas, and petroleum coke.** The national-level amount of each of these fuels used for NEUs was taken from the national *Inventory* (from EIA data) and assumed to be used primarily as chemical feedstocks. The amount of NEUs for each fuel was allocated across states based on the percentage of each total fuel use in the industrial sector per the original state-level data from SEDS. The SEDS data includes NEU and fuel combustion uses of fuel so this approach assumes that the percentage of these fuel products used in NEU applications per state are proportional to the fuel combustion uses of these fuel products in a given state. This assumption was considered reasonable as the fuel combustion and NEU applications of these fuel products are likely to be in the same types of chemical facilities. Appendix A, Tables A-63 through A-65 and Tables A-69 through A-72 in the "NEU" Tab, show these state-level breakouts.
- **Distillate fuel.** The total national-level amount of distillate fuel used for NEUs was taken from the national *Inventory* (based on data from EIA). Distillate fuel used for NEUs was allocated across states based on the percentage of distillate fuel use in the industrial sector per state after IPPU adjustments described in Step 2. As per the previous group of fuel products, this approach assumed that the percentage of distillate fuel used in NEU applications per state is proportional to fuel combustion uses of distillate fuel in a given state. The national-level data on distillate fuel used in NEU applications are based on industry surveys for nonfuel uses in the chemical industry. Therefore, the assumption that NEUs of distillate fuel are proportional to the total industrial sector amount of distillate fuel use in a given state may not be completely representative because fuel or other uses of distillate fuel in the industrial sector could be very broad. However, it was felt to be a reasonable approach because specific state-level distillate fuel used in NEU applications was not readily available and the percentage of NEUs of distillate fuel was a small fraction of overall industrial sector distillate fuel use (less than 1%). EPA will continue to examine other possible sources for distillate fuel NEU state-level data for future reports. Appendix A, Table A-74 in the "NEU" Tab, shows this state-level breakout.
- **Asphalt and road oil, lubricants (in both the industrial and transportation sectors), naphtha (<401 °F), other oil (>401 °F), special naphtha, waxes and miscellaneous products.** As per the national *Inventory*, the total amounts of these fuel products were all assumed to be used in NEUs. Therefore, the total state-level data from SEDS were used to represent NEUs for these fuel products. Appendix A, Tables A-62, A-66 through A-68, A-73, and A-75 through A-77 in the "NEU" Tab, show these state-level breakouts.

Emissions associated with NEUs were calculated and reported separately from FFC emissions. Some further adjustments were made to NEU, and carbon factors were applied; see further discussion in Section 2.1.2 below.

2.1.1.2.8. Step 7: Subtract Consumption of IBFs

The energy statistics include consumption of fossil fuels that are ultimately used for international bunkers. In the national *Inventory*, emissions from IBF consumption are not included in national totals and are instead reported separately as a memo item, as required by the IPCC and UNFCCC inventory reporting guidelines. There are other international organizations, including the International Civil Aviation Organization and the International Maritime Organization, that consider global action from these sectors. Therefore, the amount of each fuel type used for international bunkers was subtracted from fuel consumption data when determining fuel combustion emissions. The adjustments vary over time and represent about 4% to 7% of total unadjusted transportation sector energy use, as shown in Figure 2-11.

Figure 2-11. Adjustments Made to Transportation Sector Energy Use to Account for IBFs



Adjustments for each fuel type were made at the national level based on data and assumptions from different data sources, including FAA flight data and information on international shipping; see the national *Inventory* report for more details. More details on the amount and types of fuels used for IBFs at the national level are shown in Appendix A in the "National 2021 FFC CO_2" Tab.

The following approaches were taken to determine the state-level amounts of different fuels used for IBFs that needed to be subtracted from energy combustion estimates. The subtractions were all made in the transportation sector:

- **Residual fuel and distillate fuel.** The total national-level amount of residual and distillate fuel used for IBF was taken directly from the national *Inventory* (IBF subtractions). The fuels used for IBF were allocated across states based on the percentage of fuel use for bunkers from the EIA FOKS data (EIA 2022). This approach was considered reasonable because the FOKS data have information directly on bunker fuel used at the state level.[18] Appendix A, Table A-78 and Table A-79 in the "IBF" Tab, show these state-level breakouts.
- **Jet fuel.** The total national-level amount of jet fuel used for IBF was taken directly from the national *Inventory* (IBF subtractions). Jet fuel used for IBF was allocated across states based on the percentage of total jet fuel use in the transportation sector by state per the original state-level data from SEDS. Appendix A, Table A-80 and Table A-81 in the "IBF" Tab, show that state-level breakout data on jet fuel specifically used for international flights were difficult to find at the state level. The approach used here to allocate IBFs by state based on the total amount of jet fuel used by state could potentially lead to an overestimation of IBF emissions for some states with below-average international flight activity or underestimation for other states with significantly greater than average international flight activity. This is

[18] Note that the FOKS data publication was suspended with the 2020 data release; for this cycle, the same percentage by state for 2020 was applied to 2021.

an area of future planned improvements. Also note that this adjustment is for IBFs. Fuel use and emissions from interstate flights are still included in the national- and state-level FFC emissions. They were allocated to the state where the jet fuel is purchased/sold as per the SEDS data.

The result of these previous seven steps is 2-22adjusted amount of fuel use activity data that is then used to determine FFC CO_2 emissions. Three additional steps are then required to determine CO_2 emissions, as discussed further below.

2.1.1.2.9. Step 8: Determine the C Content of All Fuels

To determine emissions, the amount of carbon per unit of energy in each fuel was needed. Because different fuels have different C contents, a different factor was determined for each fuel type. The total carbon estimate defines the maximum amount of C that could potentially be released to the atmosphere if all of the carbon in each fuel was converted to CO_2. Fuel-specific C content coefficients for each fuel type were taken from the national *Inventory*; see Annex 2 of the national *Inventory* for more details on carbon factors used. The national total factors for each fuel used in the national *Inventory* were applied for fuel use at the state level. This was considered a reasonable assumption since fossil fuels are widely traded and regulated, and C contents within the United States do not vary appreciably. Two possible exceptions to this are coal and gasoline where state-specific C contents could vary based on the type of coal used and the gasoline blend and grade used. Those fuel emissions factors in the national *Inventory* were based on weighted averages of state-level factors. For these factors, EPA will look into using specific state-level factors in the state-level estimates in future reports.

2.1.1.2.10. Step 9: Estimate CO_2 Emissions

Total CO_2 emissions for each fuel are the product of the adjusted energy consumption (from the previous methodology Steps 1–7), the C content of the fuels consumed (from Step 8), and the fraction of carbon that is oxidized. Carbon emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to carbon (44/12) and the fraction of carbon that was oxidized to obtain total CO_2 emitted from FFC. The fraction oxidized was assumed to be 100% for petroleum, coal, and natural gas.

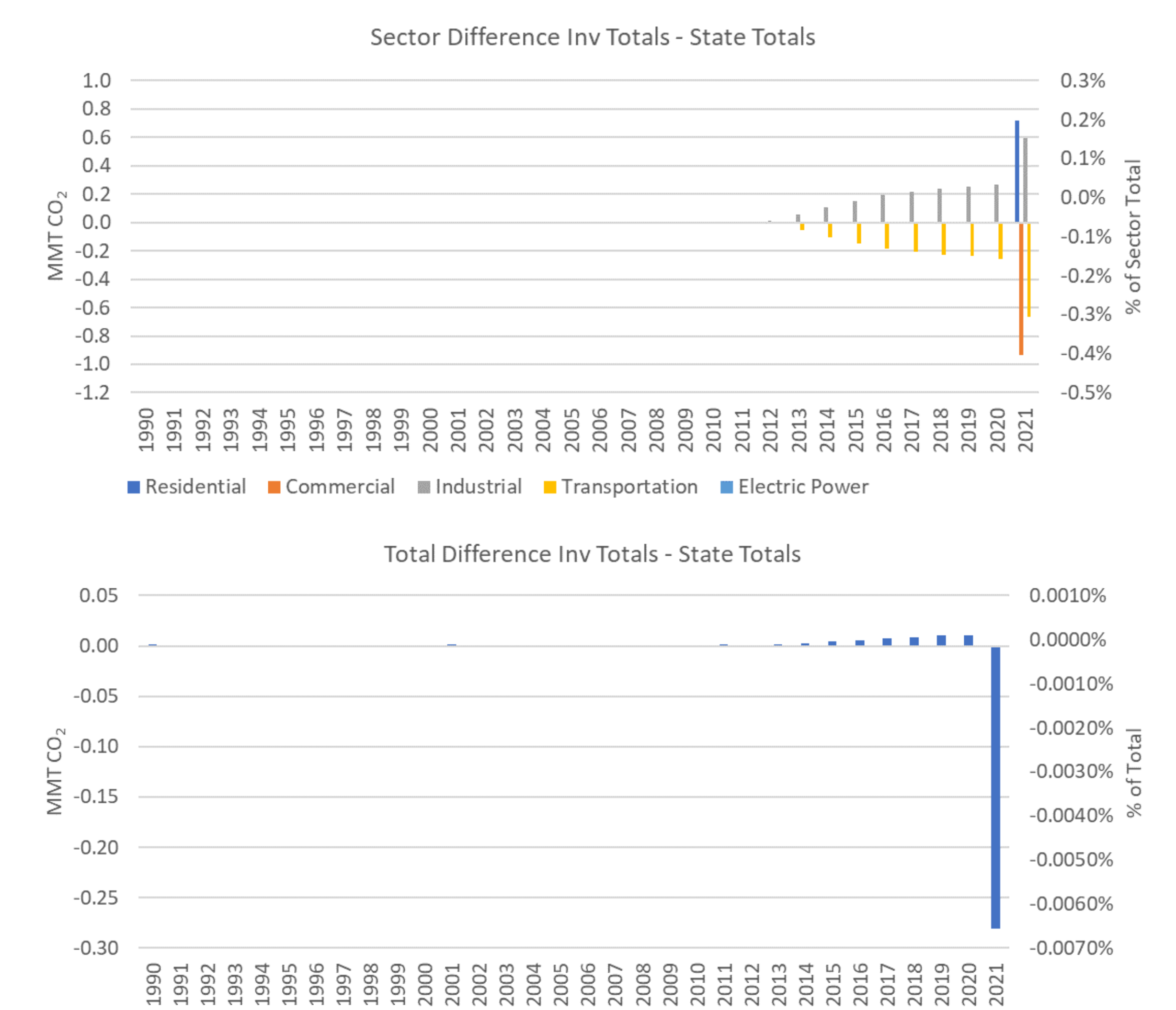
State-level fuel use by fuel type per sector from Steps 1–7 was multiplied by national-level carbon factors from Step 8 (and also multiplied by molecular weight ratios and oxidation fractions) to determine state-level emissions by fuel type and by sector.

2.1.1.2.11. Step 10: Allocate Transportation Emissions by Vehicle Type

As discussed in Step 5 above, fuel use at the national level was determined by specific vehicle type in the transportation sector because non-CO_2 emissions differ by vehicle type, and activity data were needed by vehicle type to use higher tier methods for non-CO_2 emissions. The national *Inventory* is, therefore, also able to provide the same level of detail for CO_2 emissions by specific vehicle type from transportation. For fuel types other than jet fuel, fuel consumption data by vehicle type and transportation mode were used to allocate emissions by fuel type calculated for the transportation end-use sector in the national *Inventory*. However, as also discussed in Step 5 above, state-level information on fuel use by vehicle type was not readily available. For CO_2 emissions, vehicle type is not critical for determining emissions because they are based primarily on fuel use; therefore, vehicle type by state was not specifically needed for the state-level calculations, and a state-level CO_2 emissions breakout by vehicle type was not done at this time. This is an area of future planned improvements.

The above calculations resulted in state-level GHG estimates that generally add up to the total estimates in the national *Inventory*, with small differences occurring at the more disaggregated sector level, as shown below in Figure 2-12 for FFC CO_2 emissions. The differences are due to the vintage of the different data sources used. As discussed above in Step 1, the national *Inventory* was based on the February 2023 MER, while the state-level values were based on the June 2023 SEDS. The SEDS used updated information on the sector allocation of some fuels, which will be reflected in the next national *Inventory* report. There is also a minor difference in total emissions due to the differences in emissions factors for LPG across sectors. The updated SEDS data shows more LPG in the industrial sector, which has a higher emissions factor than LPG use in other sectors, so the result is slightly higher total emissions in the state-level estimates. The percentage differences in the 2021 sector totals are small: a 0.2% difference in the residential sector, 0.4% in the commercial sector, 0.1% in the industrial sector, and 0.3% in the transportation sector. The percentage difference in total emissions is also very minor, a 0.007% difference.

Figure 2-12. Differences in State-Level Total and National Total FFC CO_2 Emissions



2.1.1.2.12. Stationary Non-CO_2 State-Level Breakout

Stationary non-CO_2 emissions include CH_4 and N_2O emissions from four energy consumption sectors (residential, commercial, industrial, and electric power) and four fuel types (coal, fuel oil, natural gas, and wood).

Non-CO_2 emissions from FFC at the national level were estimated in line with Tier 1 and 2 methods described by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). For most categories, a Tier 1 approach was used, which multiplies the adjusted activity data on fuel use by default emissions factors to determine emissions. The electric power sector used a Tier 2 approach that relied on the adjusted fuel use activity data and country-specific emissions factors by combustion technology type.

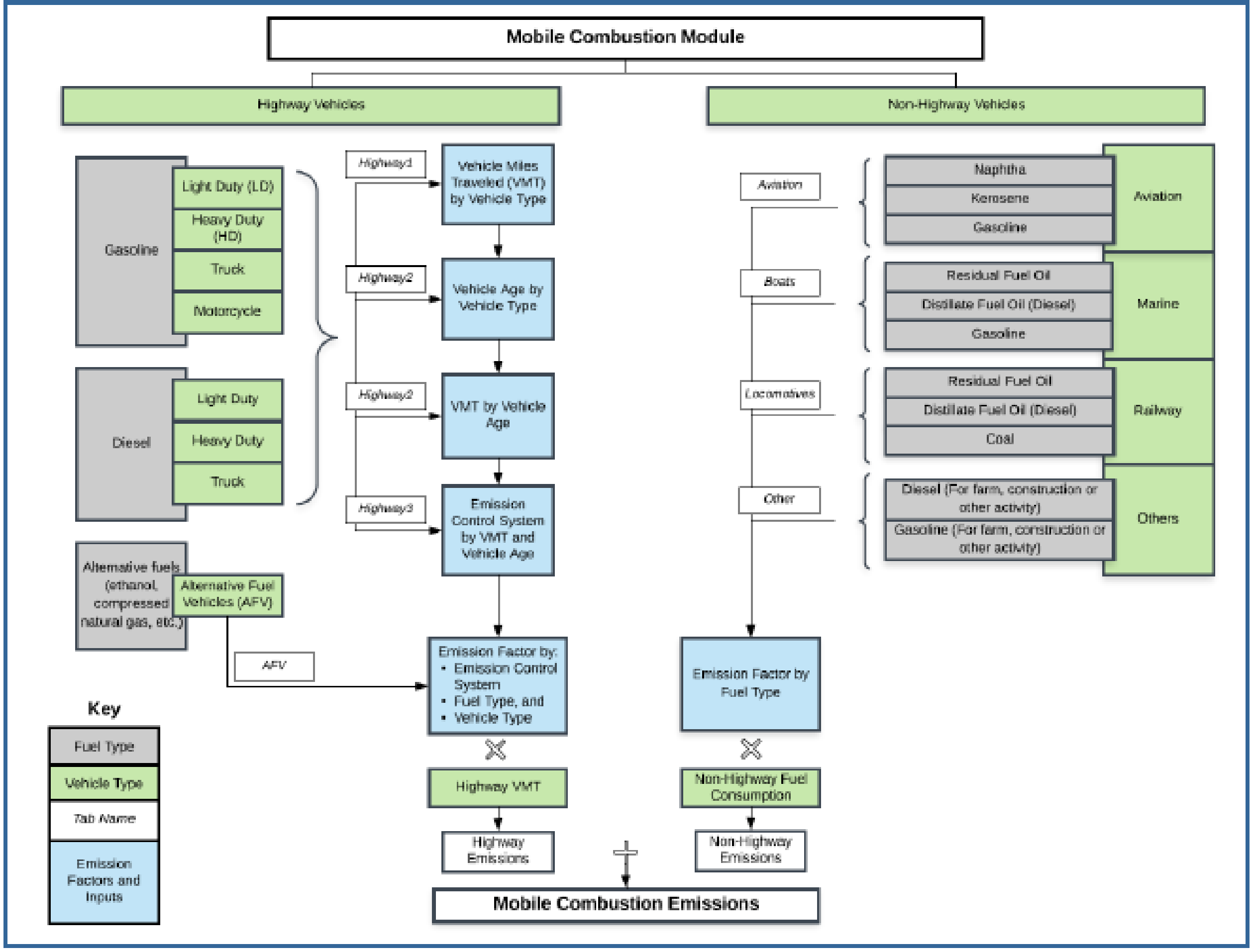
National-level emissions for all sectors were allocated across states based on the same percentage as CO_2 emissions from those sectors and fuel types, as described in the previous section. Appendix A, Tables A-89 through A-104 in the "Stationary non-CO2" Tab, show the percentage breakout of each fuel across sectors that were used in the analysis. For the residential, commercial, and industrial sectors, it is reasonable to assume non-CO_2 emissions by fuel type would be proportional to CO_2 emissions across states because the fuel use activity data are the same and only one non-CO_2 emissions factor was applied per fuel type per category for each gas.

Electric power sector non-CO_2 emissions could differ across states based on the type of combustion technology used, but the analysis was unable to assess these potential differences. The overall impact of these simplifying assumptions on total state combustion emissions is expected to be small.

2.1.1.2.13. Mobile Non-CO_2 State-Level Breakout

Mobile non-CO_2 emissions include CH_4 and N_2O emissions. National-level estimates of CH_4 and N_2O emissions from mobile combustion are calculated by multiplying emissions factors by measures of activity for each fuel and vehicle type (e.g., light-duty gasoline trucks). Activity data include VMT for onroad vehicles and fuel consumption for nonroad mobile sources. State-level mobile non-CO_2 emissions were calculated for four main categories of mobile source emissions: gasoline highway, diesel highway, alternative fuel highway, and nonhighway. More detail on the approach and what is included under each of the categories is shown in Figure 2-13 below (EPA 2020).

Figure 2-13. Mobile Source Non-CO_2 Calculation Methodology



The approach to estimate mobile non-CO_2 emissions was to develop state-level estimates by fuel type/category and use those estimates to develop the percentage of emissions by state. The percentage of emissions by state were then applied to the national totals from the national *Inventory* to disaggregate national totals at the state level. Table 23 shows the default data type and source used in developing the state-level estimates. Appendix A, Tables A-105 through A-116 in the "Mobile non-CO_2" Tab, show the percentages of emissions by vehicle type by state that were used in the analysis.

Table 2-3: Default Data Sources for Mobile Source Non-CO_2 Emissions

Source/Category	Type of Input	Default Source
Highway Vehicles—Emissions Factors and VMT	CH_4 and N_2O emissions factors (g/km traveled) for each type of control technology	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	State total VMT, 1990–present, for all vehicle types	VMT by state for each year from FHWA Table VM-2. Apportioned to vehicle type based on national vehicle type distributions from FHWA Table VM-1. The fuel type distribution within each vehicle type (i.e., the distribution

Source/Category	Type of Input	Default Source
		between gasoline and diesel) was taken from the national *Inventory*
Highway Vehicles—Allocating VMT by Model Year	Annual vehicle mileage accumulation (miles) for each model year in use and age distribution of vehicles (%) in the current year	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
Highway Vehicles—Allocating Control Technology by Model Year	Percentage of vehicles with each control type, 1960–present	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
Aviation	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Aviation fuel consumption (million BTU), 1990–present by fuel type	EIA SEDS (EIA 2023a)
Marine	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Marine fuel consumption (gallons), 1990–present	Gasoline from FHWA Highway Statistics, Table MF-24, boating column; other fuels from EIA SEDS
Locomotive	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Locomotive fuel consumption (gal or tons), 1990–present	EIA FOKS
Other Nonhighway	N_2O and CH_4 emissions factors (g/kg fuel) for diesel and gasoline tractors, construction equipment, and other equipment	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Fuel consumption (gal), 1990–present, for agriculture equipment	Gasoline from FHWA Table MF-24, agriculture column, diesel fuel from EIA FOKS
	Fuel consumption (gal), 1990–present, for construction equipment	Gasoline from FHWA Table MF-24, construction column, diesel fuel total from the national *Inventory* apportioned based on gasoline percentage
	Fuel consumption (gal), 1990–present, for other equipment	Gasoline from FHWA Table MF-24, industrial and commercial column plus totals from other small sources from the national *Inventory*, diesel fuel from EIA FOKS
Alternative Fuel Vehicles	CH_4 and N_2O emissions factors (g/km traveled) for each type of alternative fuel (methanol, ethanol, LPG, liquefied natural gas, compressed natural gas)	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	State total VMT, 1990–present, for alternative fuel vehicles	Based on national totals and assumptions on alternative fuel vehicle use by state from EIA alternative fuel vehicle data

The bottom-up approach to develop mobile source non-CO_2 state-level estimates by fuel type/category described above results in a different overall emissions total compared with the national *Inventory* values. That is why the estimates are used to develop the percentage of emissions by state that are applied to the national totals from the national *Inventory* to disaggregate national totals at the state level. The approach above could also overestimate or underestimate state emissions by assuming a national average of vehicle age distribution across states when each state could have a different mix of vehicle fleet age distribution. However, the approach is considered reasonable, and the overall impact of these simplifying assumptions on state emissions is expected to be small.

2.1.1.2.14. Breaking Out Data by Economic Sector

The EIA data used for this analysis report fuel use for five sectors (residential, commercial, industrial, transportation, and electric power). The reporting of emissions at the state level in this analysis also included emissions from FFC in the agriculture economic sector (which is not the case with the agriculture sector as defined by the IPCC). Agriculture sector fuel use at the national level was based on supplementary sources of data because EIA includes agriculture equipment in the industrial fuel-consuming sector. State-level agriculture fuel use estimates were obtained from USDA survey data. Agricultural operations are based on annual energy expense data from the Agricultural Resource Management Survey (ARMS) conducted by the National Agricultural Statistics Service (NASS) of the USDA. NASS uses the annual ARMS to collect information on farm production expenditures, including expenditures on diesel fuel, gasoline, LPG, natural gas, and electricity use. A USDA publication (USDA 2020) shows national totals, as well as select states and ARMS production regions. State estimates were survey-derived for 15 states (Alaska, California, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Minnesota, Missouri, North Carolina, Nebraska, Texas, Washington, and Wisconsin) and model-derived for the remaining states using data and methods developed by the Economic Research Service of USDA.

These supplementary data were subtracted from the industrial fuel use reported by EIA to obtain agriculture fuel use. CO_2 emissions from FFC as well as CH_4 and N_2O emissions from stationary and mobile combustion were then apportioned to the agriculture economic sector based on agricultural fuel use.

2.1.1.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and non-CO_2 emissions from FFC was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2020 for FFC were −2%/+4% for CO_2, −34%/+127% for stationary source CH_4, −26%/+51% for stationary source N_2O, −4%/+29% for mobile source CH_4, and −8%/+19% for mobile source N_2O.

The uncertainty estimates for the national *Inventory* largely account for uncertainty in the magnitude of emissions and consider uncertainty in activity data and emissions factors used to develop the national estimates. State-level estimates of annual emissions will likely have a higher relative uncertainty compared with these national estimates as a result of the additional requirement in some cases of apportioning national emissions to each state using spatial proxy and supplemental surrogate data sets. As discussed above, the steps involved in determining state-level FFC emissions could result in some overestimation or underestimation of state-level emissions. The sources of uncertainty for this category are consistent over time because the same approaches are applied across the entire time series. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and the underlying data sets and methodologies improves.

2.1.1.4 Recalculations

Consistent with recalculations at the national level, EIA updated energy consumption statistics across the time series relative to the previous *Inventory*. In addition, consistent with the national *Inventory*, the current state-level CO_2 equivalent emissions of CH_4 and N_2O from stationary and mobile sources have been revised to reflect the 100-year GWPs provided in the IPCC AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the IPCC Fourth Assessment Report (AR4), which was used in the previous inventories (IPCC 2007). The AR5 GWPs have been applied across the entire time series for consistency. Prior state inventories used GWPs of 25 and 298 for CH_4 and N_2O, respectively. These values have been updated to 28 and 265, respectively.

2.1.1.5 Planned Improvements

For coking coal, the percentage subtracted by state could be based on other factors like BOF I&S production in each state, as opposed to the percentage of total coking coal use. In some cases, a state could have negative emissions for all fuels if the amount subtracted, as determined from assumed distribution, was greater than consumption data from SEDS for that state. These negative values were corrected to zero, but alternative ways to readjust them across other states will be considered.

For petrochemical feedstocks, natural gas NEU was allocated across states based on GHGRP petrochemicals emissions data per state, while other fuels' NEUs were allocated based on the underlying SEDS data. Allocating across states based on the underlying SEDS data ensures that in no states is NEU larger than in the original SEDS data, which would result in negative numbers associated with subtracting NEU (it is not an issue for natural gas because use is so high overall compared with NEU). However, EPA will explore different percentages or a way to use GHGRP petrochemical data without resulting in negative use in any given state.

EPA will look into using state-level bottom-up data for bunkers directly from FOKS, as opposed to basing IBF on top-down estimates from the national *Inventory* and allocating to states based on the FOKS percentage, taking into account how FOKS data line up with national *Inventory* totals. We will look for better ways to allocate jet fuel bunker data across states as opposed to basing it on percentage of total use (e.g., FAA data, assumptions based on states with international airports and flights).

EPA will look into more state-level activity data for different mobile combustion sources to better allocate mobile non-CO_2 emissions.

The coal carbon factors in the national *Inventory* are based in part on state-level data. It might be possible to build out weighted state-level coal carbon factors that would still amount to the national totals. For natural gas, state-level heat content data could be used to develop state-level carbon factors for natural gas, but they would have to be compared with national totals. It might be possible to develop gasoline and distillate fuel factors per state for the transportation sector, but EPA would have to ensure they are consistent with the national-level factors.

EPA will look into allocating power sector non-CO_2 emissions based on other sources like eGRID and EPA Air Markets Program Data, for instance.

The national *Inventory* distributes electricity emissions across end-use sectors to present results with electricity distributed by sector. That calculation was not done at the state level. The national *Inventory* also breaks out transportation sector emissions by vehicle type; that calculation was also not done at the state level. EPA will look into reporting these disaggregated data in future state-level reports.

2.1.1.6 References

EIA (U.S. Energy Information Administration) (2022) *Fuel Oil and Kerosene Sales*. U.S. Department of Energy. Available online at: http://www.eia.gov/petroleum/fueloilkerosene.

EIA (2023a) *February 2023: Monthly Energy Review*. DOE/EIA-0035(2023/2). U.S. Department of Energy. Available online at: https://www.eia.gov/totalenergy/data/monthly/previous.php.

EIA (2023b) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php.

EPA (U.S. Environmental Protection Agency) (2017) *2017 National Emissions Inventory (NEI) Data*. Available online at: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

EPA (U.S. Environmental Protection Agency) (2020) *User's Guide for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion Using the State Inventory Tool.* Available online at: https://www.epa.gov/sites/default/files/2020-10/documents/mobile_combustion_users_guide.pdf.

EPA (2022) *MOtor Vehicle Emissions Simulator (MOVES3)*. Available online at https://www.epa.gov/moves.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

FHWA (Federal Highway Administration) (1996–2021) *Highway Statistics*. U.S. Department of Transportation. Available online at: http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm.

FHWA (2021a) *Private and Commercial Highway Use of Special Fuel, by State, 1949–2020*. Table MF-225. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf225.cfm.

FHWA (2021b) *Highway Use of Gasoline by State, 1949–2020*. Table MF-226. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf226.cfm.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press.

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USDA (U.S. Department of Agriculture) (2020) *Farm Production Expenditures Annual Summary*. Available online at: https://usda.library.cornell.edu/concern/publications/qz20ss48r?locale=en.

2.1.2 Carbon Emitted from NEUs of Fossil Fuel (NIR Section 3.2)

2.1.2.1 Background

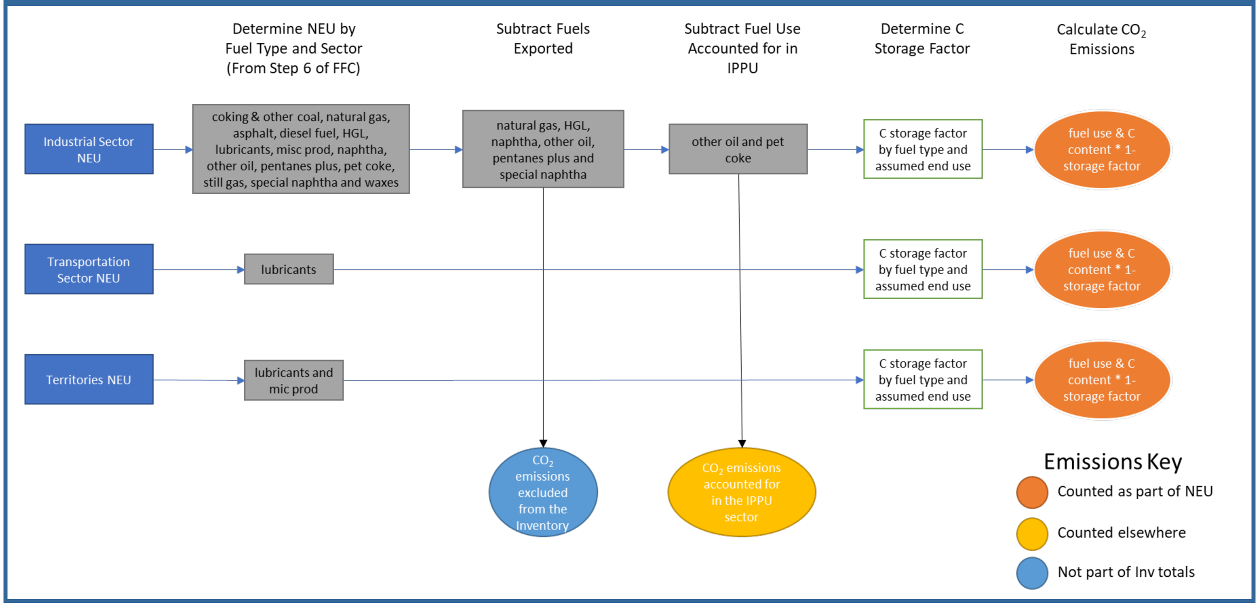
In addition to being combusted for energy, fossil fuels are consumed for NEUs. The fuels used for these purposes and the nonenergy applications of these fuels are diverse, including feedstocks for manufacturing plastics, rubber, synthetic fibers, and other materials; reducing agents for producing various metals and inorganic products; and products such as lubricants, waxes, and asphalt. CO_2 emissions arise via several pathways. Emissions may occur when manufacturing a product, as is the case in producing plastics or rubber from fuel-derived feedstocks. Additionally, emissions may occur during a product's lifetime, such as during solvent use. As discussed above in the FFC section, emissions from these NEUs are estimated separately and, therefore, the amount of fuels used for nonenergy purposes are subtracted from fuel consumption data. Given the linkages between NEUs and combustion emissions, the NEU adjustments and calculations are presented here.

2.1.2.2 Methods/Approach

FFC CO_2 emissions calculations discussed above (as per Step 6) were adjusted for fuels used for NEUs. CO_2 emissions arise from NEUs via several pathways, including emissions from the manufacture of a product and during the product's useful lifetime and ultimate disposal. The approach for determining national-level NEU emissions is based for the most part on NEU activity data, C contents and assumed C storage factors. The activity data on NEU by fuel were taken from the FFC adjustments. Then, several adjustments were made to the data to account for fuel exports and IPPU emissions that are either excluded or reported in other parts of the national

Inventory, as shown in Figure 214. C storage factors are based on the end use of the fuel and assumed fate of the carbon in the products. Appendix A in the "National 2021 NEU CO_2" Tab provides more details on an example of the adjustments made to the national-level NEU data to determine adjusted NEU activity data for 2021.

Figure 2-14. Adjustments to Energy Consumption for Emissions Estimates



NEU emissions at the state level were calculated based on the same approach as used to determine national-level NEU emissions. The following steps describe the approach used to determine state-level NEU emissions.

2.1.2.2.1. Step 1: Determine Total NEU by Fuel Type and Sector

State-level NEU energy data by sector and fuel type were calculated from Step 6 of the FFC calculations, as discussed above. The NEU adjustments to the FFC data were used as the input to the NEU calculations. The same state-level breakout of the NEU data used in the FFC calculations was used here.

2.1.2.2.2. Step 2: Adjust for Portions of NEU in Exported Products

State-level NEU energy data calculated from Step 6 above were adjusted to account for exports. Natural gas, HGL, pentanes plus, naphtha (<401 °F), other oil (>401 °F), and special naphtha were adjusted down to subtract out net exports of these products that are not reflected in the raw NEU data from EIA. Consumption values were also adjusted to subtract net exports of HGL components (e.g., propylene, ethane). Similar to exported CO_2 discussed in the FFC calculations, because any potential CO_2 emissions from exported products are not emitted to the atmosphere in the United States, the fuel used to create the exported products is subtracted from statistics used to calculate NEU emissions. The national-level total export energy adjustment data were taken from the national *Inventory*. The export adjustments were allocated to states based on the total amount of NEU fuel use by state from Step 1 under the simplifying assumption that the share of nonenergy fuels exported matched the amount of nonenergy fuels used by a given state. This assumption could lead to an overestimation or underestimation of NEU emissions in a given state based on the actual amount of product exported. However, it was felt to be reasonable given the lack of export data by state and the small overall adjustment made (2021 export adjustments represent 5.1% of unadjusted nonenergy fuel use). Appendix A, Tables A-82 through A-86 and Table A-88 in the "NEU Adj" Tab, show these adjusted totals.

2.1.2.2.3. Step 3: Adjust for Portions of NEU Accounted for in IPPU

State-level NEU energy data were also adjusted down to account for other oil (>401 °F) and petroleum coke use in IPPU. As per Step 2 in the FFC calculations, emissions from fuels used as raw materials presented as part of IPPU were removed from the NEU estimates. Portions of nonenergy fuel use were, therefore, subtracted from the industrial sector nonenergy fuel consumption data before determining NEU emissions. The national-level total IPPU energy adjustment data for NEU were taken from the national *Inventory*. The IPPU adjustments were allocated to states based on the total amount of nonenergy fuel use by state from Step 1 under the simplifying assumption that the share of nonenergy fuels used in IPPU matched the amount of nonenergy fuels used by a given state. This assumption could lead to an overestimation or underestimation of NEU emissions in a given state based on the actual amount of fuel used in IPPU. However, it was felt to be reasonable given the lack of data by state on NEU fuels used in IPPU and the small overall adjustment made (2021 IPPU adjustments represent 1.0% of unadjusted NEU fuel use). Appendix A, Tables A-86 and A-87 in the “NEU Adj” Tab, show these adjusted totals.

2.1.2.2.4. Step 4: Determine C Storage Factor by Fuel Type

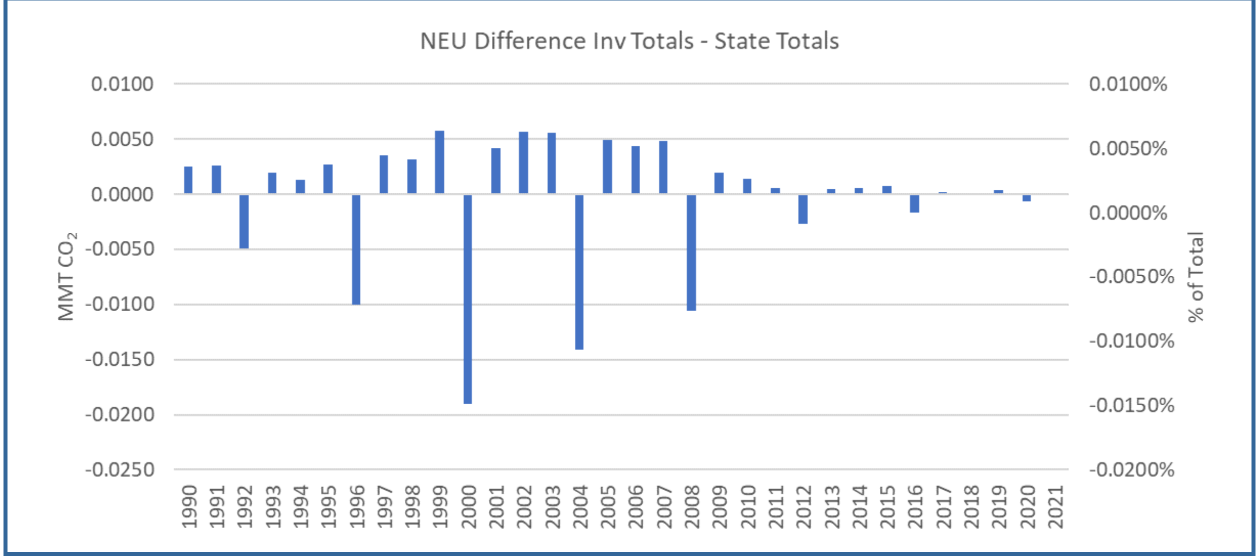
CO_2 emissions can arise from NEUs via several pathways. Emissions may occur when manufacturing a product, as is the case when producing plastics or rubber from fuel-derived feedstocks, or emissions may occur during the product’s lifetime, such as during solvent use. Carbon can also be stored from NEUs such as in a final product like plastics or asphalt. Overall, at a national level, about 64% of the total carbon consumed for NEUs is stored in products (e.g., plastics) and not released to the atmosphere. For state-level calculations, the storage factors per fuel type were taken from the national *Inventory* values and vary across fuel types and, for some fuels, over time. See Annex 2.3 of the national *Inventory* for more details on storage factors used.

2.1.2.2.5. Step 5: Calculate NEU CO_2 Emissions

Emissions from NEUs were calculated based on multiplying the adjusted NEU fuel use by state (from Steps 1–3) by the national-level carbon factors by fuel type (same as used in the FFC calculations, including oxidation and molecular weight ratio with the exception that HGLs and still gas have separate carbon factors for combustion and NEUs) and by the fraction of C emitted which is equal to 1 minus the storage factor of each fuel type (from Step 4). See Annex 2.2 of the national *Inventory* for more details on carbon factors used.

There are some small differences in the NEU-calculated state-level emissions totals compared with what is reported in the national *Inventory*, as shown in Figure 2-15 below. As with FFC, these differences represent a very small percentage of total NEU emissions (the maximum percentage difference over time is around 0.015% of total NEU emissions).

Figure 2-15. Differences in State-Level and National Total NEU CO_2 Emissions



2.1.2.3 Uncertainty

The overall uncertainty associated with the 2020 national estimates of CO_2 from NEUs was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2020 were −42%/+46% for CO_2. State-level estimates are expected to have a higher uncertainty because some of the national-level data were apportioned to each state. For example, the allocations of export and IPPU adjustments are likely to add to the uncertainty at a state level compared with the national totals.

2.1.2.4 Recalculations

Consistent with national estimates, EIA updated energy consumption statistics across the time series relative to the previous national *Inventory.*

2.1.2.5 Planned Improvements

Planned improvements for state level NEU estimates are consistent with those EPA has planned for improving national estimates for NEUs which are discussed in Section 3.2 of the national *Inventory* report (EPA 2023). EPA will also look into the export and IPPU adjustments to see if they could be done based on state-level data, if these data are available, as opposed to assuming the percentage based on SEDS state-level totals.

2.1.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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2.1.3 Geothermal Emissions

2.1.3.1 Background

Although not a fossil fuel, geothermal energy does cause CO_2 emissions, which are included in the national *Inventory*. The source of CO_2 is non-condensable gases in subterranean heated water that is released during the process.

2.1.3.2 Methods/Approach

National-level geothermal electricity production emissions were estimated by multiplying technology-specific net generation by technology-specific C contents based on geotype (i.e., flash steam and dry steam).

For state-level geothermal emissions, the total national-level geothermal emissions were taken from the national *Inventory* (EPA 2023) and allocated across states based on the amount of geothermal energy consumed by each state from the SEDS data (EIA 2023). All geothermal emissions were assumed to be in the electricity sector. Almost every state reported some level of geothermal energy consumption across the time series. The top five states in 2021 were California, Nevada, Florida, Michigan, and Indiana, accounting for about 75% of all geothermal energy consumption.

2.1.3.3 Uncertainty

Given its small contribution to the overall FFC portion of the national *Inventory* (0.009% in 2021), an uncertainty analysis was not performed for CO_2 emissions from geothermal production.

2.1.3.4 Recalculations

No recalculations were applied for this current report.

2.1.3.5 Planned Improvements

EPA will consider if geothermal emissions could be allocated by the type of geothermal production per state (because different types have different emissions factors) if that data are available.

2.1.3.6 References

EIA (U.S. Energy Information Administration) (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

2.1.4 Incineration of Waste (NIR Section 3.3)

2.1.4.1 Background

In the context of this section, waste includes all municipal solid waste (MSW) and scrap tires. In the United States, incineration of MSW tends to occur at waste-to-energy facilities or industrial facilities where useful energy is recovered; thus, emissions from waste incineration are accounted for as part of the energy sector. Similarly, scrap tires are combusted for energy recovery in industrial and utility boilers, pulp and paper mills, and cement kilns. Incinerating waste results in conversion of the organic inputs to CO_2. Thus, the CO_2 emissions from waste incineration are calculated by estimating the quantity of waste combusted and an emission factor based on the fraction of the waste that is carbon-derived from fossil sources.

2.1.4.2 Methods/Approach

The different categories of national-level waste incinerations emissions include CO_2 emissions from MSW fossil components (plastics, synthetic rubber, and synthetic fibers), tire fossil components (synthetic rubber and carbon black), and non-CO_2 emissions of CH_4 and N_2O from total waste combustion. Any net CO_2 that ultimately results from incinerated biogenic waste is counted through C stock change methodologies in the agriculture and LULUCF sectors discussed in Chapters 4 and 5 of this report.

National emissions from all the categories were allocated to states based on the percentage of total MSW combusted. The amount of waste combusted by state was estimated based on several different sources depending on the year of data, as shown in Table 2-4. This is the same approach as currently used in the national *Inventory* (EPA 2023a). The national *Inventory* has more information on the data sources used.

Table 2-4. Summary of Approaches to Disaggregate Waste Incineration Emissions Across Time Series

Time Series Range	Summary of Data Used
1990–2005	• Waste combusted by state was based on BioCycle report data.
2006–2010	• Waste combusted was based on data from BioCycle, EPA, EIA and the Energy Recovery Council (ERC) on waste combustion.
2011–2021	• Waste combustion data were based on the U.S. EPA GHGRP.

The methodology used for 1990–2005 was to estimate waste combusted by state based on data from multiple years of BioCycle reports.

The methodology used for 2006–2010 was to estimate waste combusted by state based on data from the BioCycle reports, EPA Facts and Figures, EIA (EIA 2006-2010), and Energy Recovery Council data.

The methodology used for 2011–2021 was to estimate waste combustion based on EPA's GHGRP (EPA 2023b). The GHGRP reports facility-level emissions of GHG by fuel type from Subpart C data. The CH_4 and N_2O data from MSW combustion by facility/unit can be divided by default CH_4 and N_2O emissions factors to back-calculate tons of MSW combusted.

See Appendix A, Table A-117 in the "Waste Incineration" Tab, for the percent of MSW combusted assumed by state by year from the different sources, as well as the national *Inventory* report, for more information on the data sources and methodology used.

The approach used assumed that individual states' waste combustion emissions are proportional to their share of waste combusted. This assumption is considered reasonable because currently there is no distinction in the national *Inventory* on different MSW compositions and fossil component (e.g., plastics) percentages across states. There could potentially be differences in waste compositions and, therefore, emissions across states (e.g., because of state waste management policies). The EPA update to the national-level waste incineration emissions estimates could provide more information on state-level CO_2 emissions factors per ton of MSW. This is an area for future work. Assuming scrap tire emissions are produced in proportion to MSW combustion per state could lead to overestimating or underestimating tire combustion emissions at the state level. However, given the lack of readily available data, the assumption that tire combustion emissions occur in proportion to MSW tons combusted in a given state is considered reasonable.

2.1.4.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and N_2O from waste incineration was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023a), levels of uncertainty in the national estimates in

2021 were −17%/+19% for CO_2 and −54%/+163% for N_2O. State-level estimates are expected to have a higher uncertainty because the national-level data were apportioned to each state based on MSW tonnage. In particular, assuming emissions are proportional to total MSW combusted adds uncertainty associated with different waste compositions across different states. Furthermore, assuming tire combustion emissions are proportional to MSW tonnage also adds uncertainty associated with the differences in tire and MSW combustion across states.

2.1.4.4 Recalculations

Consistent with the national *Inventory*, recalculations in state-level waste incineration include updates to the methods for calculating national level CO_2 emissions. In addition, consistent with the national *Inventory*, the current state-level CO_2-equivalent emissions of CH_4 and N_2O from waste incineration have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4, which was used in the previous inventories (IPCC 2007). The AR5 GWPs have been applied across the entire time series for consistency. Prior state inventories used GWPs of 25 and 298 for CH_4 and N_2O, respectively. These values have been updated to 28 and 265, respectively.

2.1.4.5 Planned Improvements

EPA will look into separating emissions by state based on the category of emissions (e.g., MSW combustion versus tire combustion). EPA will also consider developing state-level MSW carbon factors based on the GHGRP state-level data.

2.1.4.6 References

EIA (U.S. Energy Information Administration) (2006-2010) *Form EIA-923 detailed data with previous form data (EIA-906/920))*. U.S. Department of Energy. Available online at: https://www.eia.gov/electricity/data/eia923/.

EPA (U.S. Environmental Protection Agency) (2023a) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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2.1.5 International Bunker Fuels (NIR Section 3.10)

2.1.5.1 Background

Emissions resulting from the combustion of fuels used for international transport activities, termed IBFs under the UNFCCC, are not included in national emissions totals but are reported separately based on the location of the fuel sales. Two transport modes are addressed under the IPCC definition of IBFs: aviation and marine. GHGs emitted from the combustion of IBFs, like other fossil fuels, include CO_2, CH_4, and N_2O for marine transport modes and CO_2 and N_2O for aviation transport modes. Emissions from ground transport activities—by road vehicles and trains—even when crossing international borders are allocated to the country where the fuel was loaded into the vehicle and, therefore, are not counted as IBF emissions.

Although reporting on IBFs is a memo item in national-level reports, it does affect the total jet fuel emissions that are reported because it is a subtraction from total jet fuel use. The same is true at the state level, where subtracting IBFs affects jet fuel emissions that are reported in a given state (see Step 7 of the FFC emissions calculations).

2.1.5.2 Methods/Approach

As noted, emissions resulting from the combustion of IBFs are not included in national emissions totals but are reported separately as a memo item based on the location of fuel sales. The same approach was used at the state level, where estimates of bunker fuels were determined by state and reported as memo items. Although bunker fuels are memo items and do not affect state-level total GHG emissions, the allocation of bunker fuels across states could affect the total amount of jet fuel used per state, including domestic jet fuel use and emissions. Bunker fuel emissions include CO_2, CH_4, and N_2O emissions from jet fuel, diesel fuel, and residual fuel. The jet fuel emissions are broken into commercial and military use. See Appendix A, Tables A-78 through A-81 in the "IBF" Tab, for details on IBF energy use breakout by state.

The approach used here at the state level to allocate and report IBF and other cross state transportation sector emissions to the state where the fuel is sold is considered reasonable. However, it is an accounting decision and may differ from how individual states account for those cross state and international fuel use emissions in their own inventories.

2.1.5.2.1. Jet Fuel

National-level jet fuel CO_2 emissions from commercial aircraft came directly from FAA emissions data. CO_2 emissions from military use were based on fuel use data multiplied by the national *Inventory* CO_2 emissions factor. National-level CH_4 and N_2O emissions were based on fuel use data multiplied by an emissions factor, and CH_4 emissions from jet fuel use were assumed to be zero. N_2O emissions were split between commercial and military based on the percentage of total CO_2 emissions.

Jet fuel emissions from bunker fuels were allocated to states based on jet fuel use sales data from SEDS (EIA 2023).

2.1.5.2.2. Residual and Diesel Fuel

National-level residual and diesel fuel emissions were based on fuel use data multiplied by emissions factors for the different emissions. The emissions were allocated to states based on EIA FOKS data for bunker fuel use for diesel and residual fuels (EIA 2022).[19]

2.1.5.3 Uncertainty

A quantitative uncertainty analysis associated with the national estimates of CO_2, CH_4, and N_2O from IBFs was not calculated because the estimates are only considered memo items. However, there is a qualitative discussion of uncertainty associated with national-level IBF emissions in the national *Inventory*. State-level estimates are expected to have a higher uncertainty because of the assumptions related to allocating IBF fuels to the state level. For example, a high degree of uncertainty is associated with allocating jet fuel bunkers to states based on the total amount of jet fuel used per state.

2.1.5.4 Recalculations

No recalculations were applied for this current report.

[19] Note that the FOKS data were suspended with the 2020 data. For this cycle, the same percentage by state for 2020 was applied to 2021.

2.1.5.5 Planned Improvements

As discussed previously, the approach used here to allocate bunker fuels by state based on the total amount of jet fuel used by state could potentially lead to an overestimation or underestimation of bunker fuel emissions for some states. Therefore, EPA will look into data specific to jet fuel bunkers by state, such as flight-level data on departures and destinations.

Currently, the approach used here allocates total IBF use to the 50 states and the District of Columbia. EPA will examine if it is possible to allocate some jet fuel and marine bunkers to territories as they are also covered as part of the National *Inventory*.

2.1.5.6 References

EIA (U.S. Energy Information Administration) (2022) *Fuel Oil and Kerosene Sales*. U.S. Department of Energy. Available online at: http://www.eia.gov/petroleum/fueloilkerosene.

EIA (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

2.1.6 Wood Biomass and Biofuels Consumption (NIR Section 3.11)

2.1.6.1 Background

In line with the reporting requirements for national-level inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion are estimated separately from fossil fuel CO_2 emissions and are not directly included in the energy sector contributions to U.S. totals. In accordance with IPCC methodological guidelines, any such emissions are calculated by accounting for net carbon fluxes from changes in biogenic carbon reservoirs in the agriculture, land use change, land use change and forestry sector. Biomass non-CO_2 emissions are reported as part of emissions totals and are included under fossil fuel non-CO_2 emissions for both stationary and mobile sources.

2.1.6.2 Methods/Approach

The combustion of biomass fuels—such as wood, charcoal, and biomass- and wood waste–based fuels such as ethanol, biogas, and biodiesel—generates CO_2 in addition to the CH_4 and N_2O covered earlier. In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not directly included in the energy sector contributions to U.S. totals. In accordance with IPCC methodological guidelines, any such emissions were calculated by accounting for net carbon fluxes from changes in biogenic carbon reservoirs in the agriculture, land use, land use change, and forestry sector.

Therefore, CO_2 emissions from wood biomass and biofuel consumption were not included specifically in summing energy sector totals. However, they are presented here for informational purposes and to provide detail on wood biomass and biofuels consumption. See Appendix A, Tables A-118 through A-129 in the "Biomass CO_2" Tab, for the breakout of biomass CO_2 emissions by fuel type and sector.

2.1.6.2.1. Biomass—Ethanol, Transportation

National-level ethanol CO_2 emissions from the transportation sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the transportation sector by state, which is based on FHWA data (FHWA 2021a).

2.1.6.2.2. Biomass—Ethanol, Industrial

National-level ethanol CO_2 emissions from the industrial sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the industrial sector by state, which is based on SEDS data (EIA 2023).

2.1.6.2.3. Biomass—Ethanol, Commercial

National-level ethanol CO_2 emissions from the commercial sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the commercial sector by state, which is based on SEDS data (EIA 2023).

2.1.6.2.4. Biomass—Biodiesel, Transportation

National-level biodiesel CO_2 emissions from the transportation sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of diesel fuel used in the transportation sector by state, which is based on FHWA data (FHWA 2021b).

2.1.6.2.5. Biomass—Wood, Industrial/Residential/Commercial/Electric Power

National-level wood CO_2 emissions from all sectors were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of wood used in each sector by state, which is based on SEDS data (EIA 2023).

2.1.6.3 Uncertainty

A quantitative uncertainty analysis associated with the national estimates of CO_2, CH_4, and N_2O from wood biomass and biofuels combustion has not been considered a priority and has not been estimated. The priority is to estimate uncertainty for estimates that get rolled into national totals as opposed to estimates that are considered memo items. However, a qualitative discussion of uncertainty is associated with national-level wood biomass and biofuels combustion emissions in the national *Inventory*. State-level estimates are expected to have a higher uncertainty because of the assumptions related to allocating emissions to the state level based on fuel use data.

2.1.6.4 Recalculations

No recalculations were applied for this current report.

2.1.6.5 Planned Improvements

For CO_2 emissions from wood fuels, there is likely considerable variation among states. EPA will look into other data sources, including from the USFS, on wood used as a fuel.

EPA will look into variability in ethanol consumption across states. It is not likely that ethanol is blended in the same percentage annually across all states.

2.1.6.6 References

EIA (U.S. Energy Information Administration) (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

FHWA (Federal Highway Administration) (2021a) *Highway Use of Gasoline by State, 1949–2020*. Table MF-226. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf226.cfm.

FHWA (2021b) *Private and Commercial Highway Use of Special Fuel, by State, 1949–2020*. Table MF-225. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf225.cfm.

2.2 Fugitive Emissions

This section presents the methodology used to estimate the fugitive portion of energy emissions and consists of the following sources:

Coal mining (CH_4, CO_2)

- Abandoned underground coal mines (CH_4)
- Petroleum and natural gas systems (CO_2, CH_4, N_2O)
- Abandoned oil and gas wells (CO_2, CH_4)

2.2.1 Coal Mining (NIR Section 3.4)

2.2.1.1 Background

Three types of coal mining–related activities release CH_4 to the atmosphere: underground mining, surface mining, and post-mining (i.e., coal-handling) activities. For the national *Inventory*, EPA compiles emissions estimates for each mine into a national total for active underground mines and compiles coal production data to estimate emissions from surface coal mining and post-mining activity.

2.2.1.2 Methods/Approach

The methods used to determine state-level estimates for coal mining fugitive emissions consists of two separate sources consistent with the national *Inventory*:

- Active underground mines
- Surface mining and post-mining activities

2.2.1.2.1. Active Underground Mines

To compile national estimates of CH_4 emissions from active underground coal mines for the national *Inventory*, EPA develops emissions estimates for each mine and sums them to a national total. The approach to arrive at state-by-state estimates of CH_4 emissions from active underground mines is consistent with the national methods (i.e., using Approach 1 as defined in the Introduction of this report). Rather than summing estimates to a national total, EPA instead totals these mine-specific estimates into a state-level total for each state, based on the estimates for each of the mines located in a state. In prior years, these estimates have been published in Annex 3.4 to the national *Inventory* (EPA 2023).

As described in Section 3.4 of the national *Inventory*, EPA uses an IPCC Tier 3 method for estimating CH_4 emissions from underground coal mining. These emissions have two sources: ventilation systems and degasification systems. Emissions are estimated using mine-specific data, then summed to determine total CH_4 liberated. The CH_4 recovered and used is then subtracted from this total, resulting in an estimate of net emissions to the atmosphere. See Section 3.4 of the national *Inventory* (EPA 2023) for more detail.

To estimate CH_4 liberated from ventilation systems, EPA uses data collected through its GHGRP[20] (Subpart FF, "Underground Coal Mines"), data provided by the U.S. Mine Safety and Health Administration (MSHA) (MSHA

[20] In implementing improvements and integrating data from EPA's GHGRP, the EPA follows the latest guidance from the IPCC in its Technical Bulletin on the Use of Facility-Specific Data in National Greenhouse Gas Inventories (IPCC 2011).

2020), and occasionally data collected from other sources on a site-specific level (e.g., state gas production databases). Since 2011, the nation's "gassiest" underground coal mines—those that liberate more than 36,500,000 actual cubic feet of CH_4 per year (about 17,525 metric tons CO_2 equivalent)—have been required to report to EPA's GHGRP (EPA 2022).[21] Mines that report to EPA's GHGRP must report quarterly measurements of CH_4 emissions from ventilation systems; they have the option of recording and reporting their own measurements or using the measurements taken by MSHA as part of that agency's quarterly safety inspections of all mines in the United States with detectable CH_4 concentrations.[22] More information can be found in the national *Inventory* (Chapter 3, Section 3.4 and Annex 3.4) at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-3-Energy.pdf.

EPA estimates fugitive CO_2 emissions from underground mining using an IPCC Tier 1 method. Emission estimates are based on the IPCC Tier 1 emission factor (5.9 m^3/metric ton) and annual coal production from underground mines from EIA (IPCC 2019; EIA 2022 Table 1). The underground mining default emission factor accounts for all the fugitive CO_2 likely to be emitted from underground coal mining. Estimates of fugitive CO_2 emissions were included for the first time in the national Inventory for 1990–2020 (see Planned Improvements section below).

2.2.1.2.2. Surface Mining and Post-mining Activities

Mine-specific data are not available for estimating CH_4 emissions from surface coal mines or for post-mining activities. For surface mines, basin-specific coal production obtained from EIA's Annual Coal Report (EIA 2022 are multiplied by basin-specific CH_4 contents (EPA 1996, 2005) and a 150% emissions factor (to account for CH_4 from overburden and underburden) to estimate CH_4 emissions (King 1994, Saghafi 2013). For post-mining activities, basin-specific coal production is multiplied by basin-specific gas contents and a mid-range 32.5% emissions factor for CH_4 desorption during coal transportation and storage (Creedy 1993). Basin-specific in situ gas content data were compiled from the American Association of Petroleum Geologists (1984) and U.S. Bureau of Mines (1986).

To determine state-level CH_4 emissions estimates for surface coal mining and post-mining activities, emissions estimates are apportioned based on the coal production in each state, as reported in the EIA Annual Coal Report (i.e., using Approach 1 as defined in the Introduction of this report). The appropriate basin-specific CH_4 content for the coal produced in a state was assigned based on the coal basin within which the state is located. For post-mining activities, these emissions are assigned to the state where the coal was produced, even if a portion of such emissions may occur outside the state, such as during interstate transport and storage before use. More information can be found in the national *Inventory* (Chapter 3, Section 3.4 and Annex 3.4). EPA estimates fugitive CO_2 emissions from surface mining using an IPCC Tier 1 method. Emission estimates are based on the IPCC Tier 1 emission factor (0.44 m^3/metric ton) and annual coal production from surface mines (EIA 2021, Table 1). IPCC methods and data to estimate fugitive CO_2 emissions from post-mining activities (for both underground and surface coal mining) are currently not available. Estimates of fugitive CO_2 emissions were included for the first time in the national *Inventory* for 1990–2020 (see Planned Improvements section below).

2.2.1.3 Uncertainty

The overall uncertainty associated with the 2020 national estimates of CH_4 and CO_2 emissions from coal mining was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006), which is described further in Chapter 3 of the national *Inventory* (EPA 2023). The level of uncertainty in the 2021 national CH_4 estimate is −10%/+22%; for the national fugitive CO_2 estimate, the level of uncertainty is −68%/+76%. Because CH_4

[21] Underground coal mines report to the EPA under Subpart FF of the GHGRP (40 CFR Part 98). In 2020, 71 underground coal mines reported to the program.

[22] MSHA records coal mine CH_4 readings with concentrations of greater than 50 ppm (parts per million) of CH_4. Readings below this threshold are considered nondetectable.

emissions estimates from underground mine ventilation and degasification systems were based on actual measurement data from EPA's GHGRP and from MSHA, uncertainty is relatively low. Surface mining and post-mining CH_4 emissions, which are based on coal production and the application of emissions factors, are associated with considerably more uncertainty than underground mines because of the difficulty in developing accurate basin-level emissions factors from field measurements. However, because underground mine emissions constitute the majority of total coal mining emissions, the uncertainty associated with underground emissions is the primary factor that determines the overall uncertainty of the CH_4 emissions estimates. The major sources of uncertainty for estimates of fugitive CO_2 emissions are the Tier 1 IPCC default emission factors used for underground mining (−50%/+100%) and surface mining (−67%/+200%) (IPCC 2019).

National-level emissions estimates for underground mines were developed by aggregating mine-level estimates. Similarly, state-level emissions estimates for underground mines were developed by aggregating mine-level estimates for all the coal mines located within each state. The relatively low uncertainty associated with underground mine emissions at the national level is assumed to be the same for state-level underground mine emissions estimates. State-level emissions estimates for surface mining and post-mining emissions are associated with higher uncertainty than underground estimates because they are based on coal production within a state and the application of emissions factors. Because state-level estimates are based on the coal production within a state, the uncertainty associated with surface mining and post-mining emissions at the national level is assumed to be the same for state-level estimates. However, as with the national estimates, underground emissions account for the majority of state-level coal mining emissions, and the uncertainty associated with underground emissions is the primary factor that determines overall uncertainty for state-level emissions estimates.

2.2.1.4 Recalculations

No recalculations were applied for this current report.

2.2.1.5 Planned Improvements

Planned improvements for state level coal mining estimates are consistent with those EPA has planned for improving national estimates for coal mining which are discussed in Section 3.4 of the national *Inventory* report (EPA 2023). For more information, see Chapter 3, Section 3.4, of the national *Inventory*.

2.2.1.6 References

AAPG (1984) *Coalbed Methane Resources of the United States*. AAPG Studies in Geology Series #17.

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EPA (2022) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020*. EPA 430-R-22-003. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

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IPCC (2011) *Technical Bulletin on the Use of Facility-Specific Data in National Greenhouse Gas Inventories*. Available online at: https://www.ipcc-nggip.iges.or.jp/public/tb/TFI_Technical_Bulletin_1.pdf

IPCC (2019) *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. E.C. Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize A. Osako, Y. Pyrozhenko, P. Shermanau, and S. Federici (eds).

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MSHA (Mine Safety and Health Administration) (2020) *Data Transparency at MSHA*. Available online at: http://www.msha.gov/

Saghafi, A. (2013) *Estimation of Fugitive Emissions from Open Cut Coal Mining and Measurable Gas Content*. 13th Coal Operators' Conference, University of Wollongong, The Australian Institute of Mining and Metallurgy & Mine Managers Association of Australia. 306–313.

U.S. Bureau of Mines (1986) *Results of the Direct Method Determination of the Gas Contents of U.S. Coal Basins*. Circular 9067.

2.2.2 Abandoned Underground Coal Mines (NIR Section 3.5)

2.2.2.1 Background

Underground coal mines continue to release CH_4 after closure. As mines mature and coal seams are mined through, mines are closed and abandoned. Many are sealed, and some flood when groundwater or surface water intrudes into the mine void. Shafts or portals are generally filled with gravel and capped with a concrete seal, while vent pipes and boreholes are plugged in a manner similar to oil and gas wells. Some abandoned mines are vented to the atmosphere to prevent the buildup of CH_4 that may find its way to surface structures through overburden fractures. As work stops within the mines, CH_4 liberation decreases, but it does not stop completely. Following an initial decline, abandoned mines can liberate CH_4 at a near-steady rate over an extended period of time, or, if flooded, produce gas for only a few years. The gas can migrate to the surface through the conduits described above, particularly if they have not been sealed adequately. In addition, diffuse emissions can occur when CH_4 migrates to the surface through cracks and fissures in the strata overlying the coal mine.

2.2.2.2 Methods/Approach

For the national *Inventory*, EPA estimates national-level CH_4 emissions from abandoned underground coal mines using the Abandoned Mine Methane (AMM) model. The AMM model predicts mine-level CH_4 estimates from the time of abandonment through the inventory year of interest. The flow of CH_4 from the coal to the mine void is primarily dependent on the mine's emissions when active and the extent to which the mine is flooded, sealed, or vented. For each abandoned mine, the AMM model accounts for mine status, date of abandonment, and the reported average daily emission rate at the time of abandonment to estimate emissions using decline curves specific to mine status and coal basin. For the 1990–2019 time series, the model results by coal basin and mine status are then aggregated to the national level.[23] More information on the estimation methodology and model input data can be found in Chapter 3, Section 3.5, of the national *Inventory* (EPA 2023).

[23] The AMM model is run using @Risk software, which is a stochastic Monte Carlo simulation software.

For the 1990-2020 national *Inventory*, EPA updated the AMM model to include state-level estimates as a regular output. These state-level estimates apply for inventory year 2020 and future inventory years. Previously, the AMM model included only coal basin identifiers; EPA has added state identifiers. Under this approach, both national-level and state-level estimates are generated for an inventory year by the AMM model. The modified model output contains emissions subtotals by state, coal basin, and mine status. These subtotals are then aggregated to generate state-level estimates. The final model result (i.e., national-level estimates) is the average of 10,000 model iterations, but the calculated state estimates are not. Therefore, the sum of the state-level estimates may not exactly equal the final national-level estimate. The state-level estimates are normalized to the final national-level model result using the difference between the national-level total and the sum of state-level totals. This approach relies on model simulations using decline curves based on mine location (state and basin) and mine status, rather than using state allocation factors (as described above) to develop state-level estimates. Therefore, this approach provides more accurate state-level estimates.

The disaggregation method used to estimate state-level emission estimates for the 1990–2019 time series is described below. State-level emissions estimates for the 1990–2019 time series were developed from the national-level emissions estimates using Approach 2, as defined in the Introduction to this report. Specifically, estimates were disaggregated using mine-level average daily CH_4 emissions at the time of abandonment, mine status (i.e., flooded, sealed, vented, and unknown), date of abandonment, and mine location (basin and state), as follows.

2.2.2.2.1. Step 1: Develop state allocation factors by basin and mine status

For liberated CH_4, the estimated mine-level average daily emissions from the AMM model were totaled by state, mine status, and coal basin (Central Appalachia, Illinois, Northern Appalachia, Warrior, and Western basins) for each year in the 1990–2019 time series. Using these state-level totals of average daily emissions and the basin-level totals of average daily emissions by mine status, state allocation factors (percent) were developed by state, mine status, and coal basin such that allocation factors across all states within the same coal basin and same mine status total 100% for each year in the time series (see Appendix B, Tables B-1 through B-4, for these data).

State allocation factors for recovered CH_4 were calculated similarly to liberated CH_4 state allocation factors, with the exception that allocation factors were calculated by basin only (not mine status). There are very few CH_4 recovery projects for each year in the time series, so the breakdown by coal basin was sufficient to develop state allocation factors.

For pre-1972 emissions,[24] state allocation factors for mines abandoned before 1972 (referred to as "pre-1972 mines") were developed using 2019 emissions estimates. For these mines, 2019 emissions estimates serve as a good proxy for the entire time series because the pre-1972 mine estimates are developed using county-level default percentages built into the AMM model.

As an example, Table 2-5 presents the state allocation factors for liberated CH_4 for all states in the Illinois Basin with sealed abandoned mines for year 2019 in the time series.

Table 2-5. Example State Allocation Factors for the Illinois Coal Basin (Sealed Mines)

State	Basin	Status	Percent (%) of Emissions
IL	Illinois	Sealed	77%
IN	Illinois	Sealed	6%

[24] Because of limited data availability for mines abandoned before 1972, a different approach was used in the AMM model to estimate emissions from these mines (referred to as "pre-1972 mines") compared with mines abandoned in 1972 and later years. The AMM model estimates emissions for the pre-1972 mines at the county level and does not use mine-level average daily emissions at the time of abandonment. Refer to the national *Inventory* Chapter 3, Section 3.5, for further details.

State	Basin	Status	Percent (%) of Emissions
KY	Illinois	Sealed	17%

2.2.2.2.2. Step 2: Develop master table of basin and mine status-level emissions for 1990–2019

EPA compiled data from previous AMM models. The AMM model only estimates annual emissions for a single inventory year (i.e., for the 1990–2019 time series, there are 29 separate AMM models, each addressing a single year in the time series). EPA compiled into a master table the time series estimates of liberated CH_4, recovered CH_4, and CH_4 emissions from previous annual versions of the AMM model for the 1990–2019 time series.

Next, EPA normalized direct calculations to match model iterations. The master table contains the following AMM model outputs for each year in the time series (under separate categories for liberated emissions, recovered emissions, and emissions from pre-1972 mines):

1. Annual emissions subtotals by coal basin and by mine status (calculated using in-built decline curves in the AMM model and input data, such as average daily emissions at the time of abandonment, date of abandonment, and mine status indicator).
2. Annual national-level total emissions (based on an average of 10,000 stochastic iterations performed on the AMM model output #1 above and their associated uncertainty ranges).

The master table contains annual subtotals by coal basin and mine status; however, the aggregate of the annual subtotals by basin and mine status (i.e., sum of AMM model output #1 above) does not match the annual national-level total emissions estimate (AMM model output #2 above). Model output #2 above is the average value for 10,000 model iterations. Therefore, there is a very small difference between the two national-level totals for each year in the time series (typically less than 0.5% in any year of the time series). For this reason, the annual estimates in the master table (i.e., annual subtotals by coal basin and by mine status; AMM model output #1) must be normalized[25] to equal the national-level emissions estimate (AMM model output #2) that represents the national emissions estimates used in the national *Inventory*.

2.2.2.2.3. Step 3: Apply state allocation factors to basin- and mine status-level emissions

The emissions values from the master table generated in Step 2 were multiplied by the state allocation factors generated in Step 1 to develop 1990–2019 annual state-level CH_4 estimates.

For pre-1972 mines, 2019 state allocation factors were applied to the annual pre-1972 national estimates in the master table.

For mines abandoned after 1972, annual basin and mine status-level state allocation factors were applied to the normalized basin- and mine status-level emissions estimates in the master table.

2.2.2.3 Uncertainty

The overall uncertainty associated with the 2020 national estimates of CH_4 emissions from abandoned coal mines was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described in Chapter 3 of the national *Inventory* (EPA 2023), the level of uncertainty in the 2021 national CH_4 emission estimate is −22%/+21%.

National-level abandoned mine emissions estimates were developed by predicting the emissions of a mine since the time of abandonment using basin-level decline curves. Multiple aspects of the estimation method introduce uncertainty for the emissions estimates. In developing national estimates, because of a lack of mine-

[25] The difference between the national total and summed total of modeled emissions by coal basin and mine status was allocated to a coal basin and mine status grouping based on their share of the national total (before normalization).

specific data, abandoned mines are grouped by basin with the assumption that they will generally have the same initial pressures, permeability, and isotherm. Other sources of uncertainty in the national estimates are mine status (venting, flooded, or sealed) and CH_4 liberation rates at the time of abandonment. These data are not available for all the abandoned mines in the national *Inventory*. Abandoned mines with unknown status are assigned a status based on the known status of other mines located within the same basin. Mine-specific CH_4 liberation rates at the time of abandonment are not available for mines abandoned before 1972 ("pre-1972 mines"). It is assumed that pre-1972 mines are governed by the same physical, geologic, and hydrologic constraints that apply to post-1971 mines; thus, their emissions may be characterized by the same decline curves.

State-level estimates have a higher uncertainty because the national emissions estimates were apportioned to each state based on mine-specific CH_4 liberation rates, mine status, and basin information for all abandoned mines located within the state. Additionally, the number of mines with unknown status in each state affects the relative uncertainty of state-level estimates. Estimates for states with a greater number of mines with unknown status are expected to have relatively higher uncertainty compared with states with fewer abandoned mines with unknown status. Similarly, states with a greater number of pre-1972 abandoned mines are expected to have relatively higher uncertainty compared with states with fewer pre-1972 mines.

2.2.2.4 Recalculations

No recalculations were applied for this current report.

2.2.2.5 Planned Improvements

For the 1990–2020 national inventory, EPA updated the AMM model to include state-level estimates as a regular output, as described above, implementing planned improvements described in the previous report. These state-level estimates apply for RY 2020 and future years.

2.2.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. U.S. online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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2.2.3 Petroleum Systems (NIR Section 3.6)

2.2.3.1 Background

This section describes methods used to estimate state-level CO_2, CH_4, and N_2O emissions from petroleum systems. This category includes fugitive emissions from leaks, venting, and flaring. CH_4 emissions from petroleum systems are primarily associated with onshore and offshore crude oil production, transportation, and refining operations. During these activities, CH_4 is released to the atmosphere as emissions from leaks, venting (including emissions from operational upsets), and flaring. CO_2 emissions from petroleum systems are primarily associated with onshore and offshore crude oil production and refining operations. Note that CO_2 emissions in petroleum systems exclude all combustion emissions (e.g., engine combustion) except for flaring CO_2 emissions. All combustion CO_2 emissions (except for flaring) are accounted for in the FFC section. Emissions of N_2O from petroleum systems are primarily associated with flaring.

A recalculation was made in the final national *Inventory* to use basin-level data from GHGRP for certain onshore production sources (equipment leaks, tanks, pneumatic controllers, and chemical injection pumps) to develop basin-level emission estimates, which were then summed to the national level (EPA 2023). The methods used to develop the state-level estimates for petroleum systems follow the Hybrid approach (a combination of Approach 1 and Approach 2), as defined in the Introduction of this report. Most sources follow Approach 2 and rely on relative differences in basic state activity levels (e.g., petroleum production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Consistent with updated information available in the national *Inventory*, Approach 1 was used for the onshore production emission sources using a basin-level approach in the national *Inventory*, and also for petroleum refining. Petroleum refining emissions are allocated to states for years after 2010 using facility-level emissions reported to the GHGRP, Subpart Y. Future state-level inventory reports may incorporate additional state- or region-specific data to improve estimates and better reflect these differences.

2.2.3.2 Methods/Approach

To compile national *Inventory* estimates of GHG emissions (CH_4, CO_2, and N_2O) from petroleum, EPA compiles emissions estimates for emissions sources in each segment of a petroleum system (e.g., exploration, production, transport, refining) into a national total (EPA 2023, Section 3.6). Additional information on emissions estimates and data used to develop the national-level emissions estimates for petroleum systems is available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2021-ghg.

The state-level methodology for petroleum systems follows the Hybrid approach. The production sources that rely on Approach 1, consistent with incorporating more disaggregated data in the national-level 2023 GHGI, are discussed further in the following Exploration and Production section. For other industry segments and sources, national emissions from each segment are allocated to all U.S. states, territories, and federal offshore waters (for the production segment only) using activity data sets that have information broken out at a state level, such as the number of oil wells or volume of oil production in each state. Where possible, these data sets are chosen to align with current activity data sets used to develop national *Inventory* estimates. See Appendix B for information on the current state-level underlying proxy data sets (i.e., Tables B-5 to B-7). The specific data sets used to disaggregate national emissions to the state level vary by segment, as described in the following sections.

2.2.3.2.1. Exploration and Production

For the national *Inventory*, EPA uses emissions data collected by the GHGRP to quantify emissions for most exploration and production sources in recent years (i.e., 2010–2021). For sources where recent data are unavailable, and for earlier years of the time series, estimates are developed using emissions factors from the Gas Research Institute (GRI)/EPA (1996) and Radian (1999) studies. Other key data sources for the national estimates include oil well counts and production levels from Enverus, the Bureau of Ocean Energy Management, and total crude oil production from EIA.

Four onshore production emission sources used information available through the updated national *Inventory* (EPA 2023), to implement Approach 1 to develop state emissions: pneumatic controllers, storage tanks, equipment leaks (i.e., from separators, heater/treaters, headers, and wellheads), and chemical injection pumps. These sources relied on basin-specific emission factors and/or activity factors from GHGRP and basin-level activity data (i.e., well counts and oil production) to estimate basin emissions across the time series. The basin emissions were then directly allocated to each state using the same activity data. The state activity data are in Appendix B, Tables B-5 and B-6.

To develop state-level emissions for other petroleum exploration and production emission sources, national *Inventory* emissions were allocated to each state, primarily based on the fraction of oil wells in each state relative to national totals across each year in the time series (Appendix B, Tables B-5 and B-6). Other key state-level proxy data sets used to disaggregate national emissions include the number of oil well completions with and without hydraulic fracturing in each state, as well as the total volume of oil produced in each state. These state data were derived from time series of oil and gas well data from Enverus, consistent with the Enverus data set used as activity data to derive total national emissions. For offshore activities, emissions from state waters in the Gulf of Mexico were allocated based on relative state-level oil production levels, while emissions from activities in federal waters were retained as a separate category (i.e., not allocated to states). For both exploration and production segments, the data sets used for state allocation were consistent across the entire emissions time series.

2.2.3.2.2. Crude Oil Transport

For the national *Inventory*, EPA estimates emissions of CH_4, CO_2, and N_2O from crude oil transport for petroleum systems using a combination of crude oil transportation and pipeline and crude deliveries data from EIA, the American Petroleum Institute, and the *Oil and Gas Journal*.

To develop state-level emissions from crude oil transport, national *Inventory* emissions were allocated to each state based on three state proxy data sets. Vented emissions from marine loading were allocated to states based on oil production from offshore wells in state waters from the Enverus data set (Appendix B, Table B-6). Similarly, vented emissions from truck loading and rail loading were allocated based on onshore levels of oil well production in each state. All other transport emissions, including tanks, pump stations, and floating roof tanks, were allocated based on the relative state counts of oil refineries from GHGRP Subpart Y data after 2010 and EIA atmospheric crude oil distillation capacity for 1990–2009 (Appendix B, Table B-7), as described in the next section.

2.2.3.2.3. Refineries

For the national *Inventory*, EPA uses data from the GHGRP Subpart Y and national-level activity data. All U.S. refineries have been required to report CH_4, CO_2, and N_2O emissions for all major activities starting with emissions that occurred in 2010. The reported total CH_4, CO_2, and N_2O emissions are used for the emissions in each year from 2010 forward. Certain activities that are not reported to the GHGRP are estimated using data from Radian (1999). These sources account for a small fraction of refinery emissions. To estimate emissions for 1990–2009, the emissions data from the GHGRP, along with the refinery feed data, are used to derive emissions factors that are applied to the annual refinery feed in years 1990–2009.

To develop state-level estimates for refineries for 2010–2021, national *Inventory* emissions from refineries were apportioned to each state based on that state's share of refinery emissions of each gas, as reported to GHGRP Subpart Y. This method is consistent with national *Inventory* estimates for refineries over these years. For 1990–2009, national *Inventory* emissions from refineries were apportioned to each state based on that state's share of national operating atmospheric crude oil distillation capacity (barrels per calendar day), as shown in Appendix B, Table B-7 (EIA 2022).

2.2.3.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and CH_4 from petroleum systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). Uncertainty estimates for N_2O applied the same uncertainty bounds as calculated for CO_2. As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −13%/+19% for CO_2 and N_2O and −10%/+15% for CH_4.

The uncertainty estimates for the national *Inventory* largely account for uncertainties in the magnitude of emissions and activity factors used to develop the national estimates for the largest contributing sources. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates because of the additional step of apportioning national emissions to each state using spatial proxy data sets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying data set (e.g., number of oil wells in each state), as well as the ability of each proxy to accurately represent the point of emission from each source within the petroleum supply chain.

Where possible, this second source of uncertainty was minimized in the petroleum state-level analysis by selecting proxy data sets that are consistent with activity factors used in the national *Inventory*. For example, national CO_2 and CH_4 from vented emissions in the production segment largely relied on national counts of oil wells and production volumes as activity factors; therefore, additional uncertainty in the state-level estimates is largely associated with the uncertainty in oil well locations. The sources of uncertainty for this category, other than refinery emissions, are also consistent over time because the same proxy data sets were applied across the entire time series. This allocation method, however, cannot account for state-specific mitigation programs and reduction efforts or state-specific variations in emissions factors, which each introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty and underlying data sets and methodologies improve.

Given the variability of practices and technologies across oil and gas systems and the occurrence of episodic events, it is possible that EPA's estimates do not include all CH_4 emissions from abnormal events. For many equipment types and activities, EPA's emissions estimates include the full range of conditions, including "super-emitters." For other situations, where data are available, emissions estimates for abnormal events were calculated separately and included in the national *Inventory* (e.g., Aliso Canyon leak event). EPA continues to work through its stakeholder process to review new data from EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.3.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure the national emission trend is accurate. See section 3.6 of Chapter 3 in the national *Inventory* report for more details on recalculations in the latest national *Inventory* estimates.

Four onshore production emission sources used a new, basin-level methodology for this year's national *Inventory*. As such, changes in absolute state-level emissions between this version and the previous state report for these sources reflect, to some extent, state-specific practices and data.

As the state-level emissions are otherwise estimated using Approach 2 (national emissions are disaggregated to the state level), changes in absolute state-level emissions between this version and the previous state report will largely reflect recalculations and improvements implemented in the national *Inventory*. Similar to the national *Inventory*, the calculation of state-level estimates has been updated to incorporate updates to the underlying state-level proxy data sets. State-level proxy data sets have been updated across the entire time series, to ensure that the state emission trends are accurate.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.3.5 Planned Improvements

Potential refinements in future state-level inventories include refining state proxies used within each segment and incorporating additional GHGRP data.

2.2.3.6 References

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2.2.4 Natural Gas Systems (NIR Section 3.7)

2.2.4.1 Background

This section describes methods used to estimate state-level CO_2, CH_4, and N_2O emissions from natural gas systems. Similar to petroleum systems, this category includes fugitive emissions from leaks, venting, and flaring. The U.S. natural gas system encompasses hundreds of thousands of wells, hundreds of processing facilities, and over a million miles of gathering, transmission, and distribution pipelines. Methane and CO_2 emissions from natural gas systems include those resulting from normal operations, routine maintenance, and system upsets. Emissions from normal operations include natural gas engine and turbine uncombusted exhaust, flaring, and leak emissions from system components. Routine maintenance emissions originate from pipelines, equipment, and wells during repair and maintenance activities. Pressure surge relief systems and accidents can lead to system upset emissions. Emissions of N_2O from flaring activities are included in the national *Inventory*, with most of the emissions occurring in the processing and production segments. Note, CO_2 emissions exclude all combustion emissions (e.g., engine combustion) except for flaring CO_2 emissions. All combustion CO_2 emissions (except for flaring) are accounted for in the FFC section.

A recalculation was made in the national *Inventory* to use basin-level data from GHGRP for certain onshore production sources (liquids unloading, equipment leaks, tanks, pneumatic controllers, and chemical injection pumps), to develop basin-level emission estimates, which were then summed to the national level (EPA 2023).

The methods used to develop the state-level estimates for natural gas systems follow the Hybrid approach (a combination of Approach 1 and Approach 2), as defined in the Introduction of this report. Most sources follow Approach 2 and rely on relative differences in basic state activity levels (e.g., gas production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Consistent with updated information available from the national *Inventory* (EPA 2023), Approach 1 was used for the onshore production emission sources using a basin-level approach in the national *Inventory*. Future state-level inventory reports may incorporate additional state-specific or region-specific data to improve estimates and better reflect these differences.

2.2.4.2 Methods/Approach

To compile national estimates of CH_4, CO_2, and N_2O emissions from natural gas systems for the national *Inventory*, EPA compiles emissions estimates for emissions sources in each segment of natural gas systems (i.e., exploration, production, processing, transmission and storage, distribution, and post-meter sources) into a national total. Additional information on emissions estimates and data used to develop the national-level emissions estimates for natural gas systems is available online at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2021-ghg.

The state-level methodology for natural gas systems follows the Hybrid approach. The production sources that rely on Approach 1, consistent with incorporating more disaggregated data in the national-level 2023 GHGI, are discussed further in the following Exploration and Production section. For other industry segments and sources, national emissions from each segment are allocated to all U.S. states, territories, and federal offshore waters (production segment only) using activity data sets that have information broken out at a state level, such as the number of gas wells or volume of gas produced in each state. Where possible, these data sets are chosen to align with current activity data sets used to develop national *Inventory* estimates. See Appendix B for information underlying the estimates (Tables B-8 to B-12). The specific data sets used to disaggregate national emissions to the state level vary by segment, as described in the following sections.

2.2.4.2.1. Exploration and Production

For the national *Inventory*, EPA uses emissions data collected by the GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2021) and data from a GRI/EPA 1996 study for earlier years of the time series or for sources where recent data are unavailable. Other key data sources include data provided in Zimmerle et al. (2019), production and well count data from Enverus, and offshore production emissions data from the Bureau of Ocean Energy Management. Each emissions source for production in the national *Inventory* was generally scaled to the national level using either well counts, gas production, or condensate production.

Five onshore production emission sources used information available through the updated national *Inventory* to implement Approach 1 and develop state emissions: pneumatic controllers, storage tanks, equipment leaks (i.e., from separators, dehydrators, heaters, compressors, and meters/piping), liquids unloading, and chemical injection pumps (EPA 2023). These sources relied on basin-specific emission factors and/or activity factors from GHGRP and basin-level activity data (i.e., well counts, gas production) to estimate basin emissions across the time series. The basin emissions were then directly allocated to each state using the same activity data. The state activity data are in Appendix B, Tables B-8 and B-9.

To develop state-level emissions for other natural gas exploration and production emission sources, national *Inventory* emissions were generally allocated to states using state-level proxy data sets that align with the activity data used in the national *Inventory* (i.e., well counts, gas production, or condensate production). For example, state counts of gas wells were derived from time series of gas well data from Enverus, consistent with the Enverus data used as national-level activity data in the national *Inventory* (see Appendix B, Table B-8). In addition, state-level proxy data sets for natural gas production from Enverus (Appendix B, Table B-9) and state-level lease condensate production from EIA (2022) aligned with national activity data sources. Proxy data for exploration included the number of wells and well completions with and without hydraulic fracturing, as well as the total number of gas wells drilled in each state relative to the national total. Offshore emissions in the Gulf of Mexico and the state of Alaska were allocated based on natural gas production at each platform. Additional production emissions from offshore federal waters were not allocated to individual states but were included as a separate total, and emissions from gathering and boosting were allocated based on the relative emissions in each state of all other production sources. To account for updates to the national *Inventory* that incorporate CH_4 emission estimates from well blowout events in Ohio, Texas, and Louisiana, CH_4 emissions from these one-time events were allocated each state in the appropriate year (e.g., 60,000 metric tons in Ohio in 2018, 4,800 metric tons in Louisiana in 2019, and 49,000 metric tons in Texas in 2019). In addition, the allocation of national *Inventory* estimates from produced water has been updated to using produced water volumes from Enverus to align the activity data used in the national *Inventory*. The Enverus gas well counts and production levels were used to assign basin-level emissions estimates to the appropriate state. For both exploration and production segments, the sources of proxy data used for state allocation were consistent across the entire emissions time series.

2.2.4.2.2. Processing

For the national *Inventory*, EPA uses emissions data collected by GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2021) and data from GRI/EPA (1996) for earlier years of the time series or for sources where recent data are unavailable. Key activity data include processing plant counts from *Oil and Gas Journal*.

To develop state-level estimates for the processing segment for each year of the time series, EPA apportioned the total national processing segment emissions to each state based on the fraction of national onshore marketed natural gas production occurring in each state (EIA 2022), as shown in Appendix B, Table B-10.

2.2.4.2.3. Transmission and Storage

For the national *Inventory*, EPA uses emissions data collected by the GHGRP and data from a Zimmerle et al. (2015) study to quantify emissions from most sources in recent years (i.e., 2011–2021), and GRI/EPA (1996) data for earlier years of the time series and for sources for which recent data are unavailable. Key activity data include transmission stations (calculated using the GHGRP data and Zimmerle et al.), storage stations (calculated using Zimmerle et al. and EIA data), and transmission pipeline miles (PHMSA 2023).

To develop state-level estimates for the transmission and storage segment for each year of the time series, EPA apportioned the total national transmission and storage segment emissions to each state based on the fraction of national transmission pipeline mileage occurring in each state (Appendix B, Table B-11). In the national *Inventory,* CH_4 emissions from anomalous events are added to storage emission totals in several years. In the state-level estimates, these emissions are allocated to the state in which the event occurred, while remaining emissions from storage wells are allocated based on the relative transmission pipeline mileage in each state.

2.2.4.2.4. Distribution

For the national *Inventory*, EPA uses data collected by the GHGRP and data from a Lamb et al. (2015) study to quantify emissions from most sources in recent years (i.e., 2011–2021) and GRI/EPA (1996) data for earlier years of the time series or for sources for which recent data are unavailable. Key activity data include pipeline mileage by material from the PHMSA station counts from Subpart W of the GHGRP and number of natural gas residential, commercial, and industrial consumers from EIA.

To develop state-level estimates for the distribution segment for each year of the time series, the EPA national total emissions from pipeline leaks were allocated based on the relative pipeline mileage by material (cast iron, unprotected/protected steel, plastic) in each state, the relative number of natural gas residential, commercial, and industrial consumers in each state from EIA, and the number of above- and below-grade stations in each state as reported to the GHGRP (scaled up by the ratio of PHMSA to GHGRP pipeline mileage in each state to include non-reporters). Complete PHMSA data are available starting in 2003 and GHGRP data are available for all years starting in 2011. For all earlier years, national emissions were allocated using the same relative state contributions as those values in the earliest available years (e.g., relative state-level pipeline mileage amounts held constant before 2003), as shown in Appendix B, Table B-12.

2.2.4.2.5. Post-meter Sources

For the national *Inventory,* post-meter sources include leak emissions from residential and commercial appliances, industrial facilities and power plants, and natural gas–fueled vehicles. Leak emissions from residential appliances and industrial facilities and power plants account for the majority of post-meter CH_4 emissions. CO_2 emissions from residential appliances are included in the natural gas residential source within the energy sector and are not accounted for here. There are no N_2O emissions from the post-meter segment. Key activity data include the counts of homes in the United States with natural gas appliances from the American Housing Survey national data set, the number of commercial natural gas customers from EIA, natural gas consumption volumes for industrial and electric generating units from EIA, and counts of compressed natural gas vehicles from the EPA MOVES model. For more information on the post-meter emissions in the national *Inventory*, see Chapter 3 of the national *Inventory* report.

To develop state-level estimates for post-meter emissions for each year of the time series, the EPA national total emissions from residential and commercial appliances were allocated to states using the relative number of residential and commercial natural gas customers in each state from EIA. Industrial and electric generating unit emissions were allocated based on the relative consumption volumes from the EIA SEDS, and compressed natural gas vehicles were allocated to the number of compressed natural gas vehicles in each state, derived from the MOVES model. These proxy data sets are generally consistent with the activity data sets used in the national *Inventory*, except for residential emissions, which are allocated based on data from EIA rather than the American Housing Survey due to the limited state-level information in the survey data set. The same proxy data sets are used across the entire time series for this segment.

2.2.4.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and CH_4 from natural gas systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). Uncertainty estimates for N_2O applied the same uncertainty bounds as CO_2. As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −13%/+15% for CO_2 and N_2O and −17%/+17% for CH_4.

The uncertainty estimates for the national *Inventory* largely account for uncertainty in the magnitude of emissions and activity factors used to develop the national estimates for the largest contributing sources. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates due to the additional step of apportioning national (or basin-level as applicable) emissions to each state using spatial proxy data sets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying data set (e.g., number of non-associated gas wells in each state), as well as the ability of each proxy to accurately represent the point of emission from each source within the natural gas supply chain. Where possible, this second source of uncertainty is minimized in the natural gas state-level analysis by selecting proxy data sets that are consistent with activity factors used in the national *Inventory*. However, this is not always possible when activity factor data sets only include national aggregate statistics. For example, national CO_2 and CH_4 emissions from transmission and storage compressor stations largely rely on station counts developed from GHGRP station counts and scaled up to the national level with an adjustment factor. In the state-level estimates, these emissions are allocated based on share of national transmission pipeline mileage occurring in each state and will therefore include additional uncertainty associated with the accuracy of the state-specific data in the PHMSA data set, as well as the accuracy in which relative state-level pipeline mileage reflects the relative state-level emissions from compressor stations and other sources in transmission and storage. In contrast, the national *Inventory* estimates for sources within the natural gas production segment typically use national well counts and production volumes as activity factors. Therefore, additional uncertainty in the state-level estimates for these sources will largely be the spatial representation of gas wells in the activity factor data set. The sources of uncertainty for this category are also consistent over time because the same proxy data sets are applied across the entire time series. This allocation method, however, cannot account for state-specific mitigation programs and reduction efforts or state-specific variations in emissions factors, which each introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying data sets and methodologies improves.

Given the variability of practices and technologies across oil and gas systems and the occurrence of episodic events, it is possible that EPA's estimates do not include all methane emissions from abnormal events. For many equipment types and activities, EPA's emissions estimates include the full range of conditions, including "super-emitters." For other situations, where data are available, emission estimates for abnormal events were calculated separately and included in the national *Inventory* (e.g., Aliso Canyon leak event and the three well blowout events included for the first time in the 2022 national *Inventory*). EPA continues to work through its stakeholder process to review new data from EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.4.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure that the national emission trend is accurate. See Section 3.7 of Chapter 3 in the national *Inventory* report for more details on recalculations in the latest *Inventory* estimates.

Five onshore production emission sources used a new, basin-level methodology for this year's national *Inventory*. As such, changes in absolute state-level emissions between this version and the previous state report for these sources reflect to some extent state-specific practices and data.

As the state-level emissions are otherwise estimated using Approach 2 (national emissions are disaggregated to the state level), changes in absolute state-level emissions between this version and the previous state report largely reflect recalculations and improvements implemented in the national *Inventory*. See Chapter 3 in the national *Inventory* report for further details on these updates in the national *Inventory*.

To align with these methodological improvements in the national *Inventory*, methodological updates to the state estimates, relative to the previous version, include incorporating the use of the basin-level emissions estimates developed in the national *Inventory* for certain production sources as described above (Exploration and Production section). These new sources have been allocated to the state level following the approaches described in the segment-specific sections above.

For other sources, the calculation of state-level estimates has been updated to incorporate updates to the underlying state-level proxy data sets, following the same procedure as in the national *Inventory*. State-level proxy data sets have been updated across the entire time series to ensure that the state-emission trends are accurate.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.4.5 Planned Improvements

Potential refinements to exploration and production estimates in future state-level inventories include refining state proxies used for individual sources within each segment and the incorporating additional GHGRP data for allocating emissions within the production segment.

Potential refinements to processing estimates in future state-level inventories include using emissions levels reported to the GHGRP (along with other data) to apportion emissions to each state. In addition, information on processing plant locations from other data sets or use of *Oil and Gas Journal* or EIA data on gas processing volumes could be incorporated to improve estimates. Potential refinements to transmission and storage estimates in future state-level inventories include using emissions levels reported to the GHGRP (along with other data) to apportion emissions to each state. In addition, information on transmission and storage station locations from other data sets could be incorporated to improve estimates.

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2.2.5 Abandoned Oil and Gas Wells (NIR Section 3.8)

2.2.5.1 Background

This section describes methods used to estimate state-level CO_2 and CH_4 emissions from abandoned oil and gas wells. The term “abandoned wells” encompasses various types of wells, including orphaned wells and other nonproducing wells such as:

- Wells with no recent production, and that are not plugged. Common terms (such as those used in state databases) might include inactive, temporarily abandoned, shut-in, dormant, and idle.
- Wells with no recent production and no responsible operator. Common terms might include orphaned, deserted, long-term idle, and abandoned.
- Wells that have been plugged to prevent migration of gas or fluids.

The U.S. population of abandoned wells, including orphaned wells and other nonproducing wells, is around 3.7 million (with around 2.9 million abandoned oil wells and 0.8 million abandoned gas wells). The methods to calculate emissions from abandoned wells involved calculating the total populations of plugged and unplugged abandoned oil and gas wells in the United States. An estimate of the number of orphaned wells within this population is not developed as part of the methodology for the national- or state-level inventories. Other groups have developed estimates of the total national number of orphaned wells. The Interstate Oil and Gas Compact Commission, for example, estimates 92,198 orphaned wells in the United States (IOGCC 2021). State applications for grants to plug orphaned wells indicate over 130,000 orphaned wells in the United States (U.S. Department of the Interior 2022).

The state-level methodology for abandoned oil and gas wells follows Approach 1, as defined in the Introduction of this report, where emissions from this segment are calculated for each U.S. state in the methodology used to develop the national *Inventory* using activity data sets with information broken out at the state level, including well counts, type (e.g., oil, gas), and plugging status. See Appendix B, Table B-13, for the underlying data sets.

2.2.5.2 Methods/Approach

To compile national estimates of CH_4 and CO_2 emissions from abandoned oil and gas wells for the national *Inventory*, EPA develops emissions estimates for plugged and unplugged abandoned wells for each state and sums to the national level. Key data sources are two research studies—Kang et al. (2016) and Townsend-Small et al. (2016)—for emissions factors, as well as the Enverus database and historical state-level data sets for abandoned well counts.

To develop state-level estimates of GHG emissions from abandoned natural gas and oil wells when developing the national *Inventory*, an estimate of the number of abandoned wells in each state (developed using Enverus and historical data sets), as well as their type (oil versus gas) and plugging status (plugged versus unplugged) were estimated across the time series. Well type and plugging status were derived from Enverus. The applicable emission factor was then applied to the state activity data to estimate emissions for each state. State-level counts of abandoned oil and natural gas wells (which include all nonproducing wells, not only orphaned wells) are available in Appendix B, Table B-13.

2.2.5.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of both CO_2 and CH_4 from abandoned oil and gas wells were each calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 for both abandoned oil and gas wells were −83%/+204% for CO_2 and −83%/+204% for CH_4.

The uncertainty estimates for the national *Inventory* account for uncertainty in the magnitude of emissions and activity factors used to develop the national estimates. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates, for example, due to regional emission factors that may not reflect state-specific emissions. The sources of uncertainty for this category are generally consistent over time, and the same data sets were used across the entire time series. The uncertainty method cannot account for state-specific variations in emissions factors, which would introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying data sets and methodologies improves.

2.2.5.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure the national emission trend was accurate. See Chapter 3 in the national *Inventory* report for more details on recalculations in the latest national *Inventory* estimates.

The abandoned oil and natural gas wells calculation methodology was revised for the current national *Inventory*. Abandoned well counts and plugged and unplugged fractions were calculated at the state level and used to estimate emissions, instead of calculating these data at the national level as was done in previous national *Inventories*. Changes in absolute state-level emissions between this version and the previous state report will reflect these recalculations implemented in the national *Inventory*.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.5.5 Planned Improvements

Potential refinements include incorporating improved state-level abandoned well counts for each year of the time series.

2.2.5.6 References

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