Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020: Updates for Post-Meter Emissions

This memorandum discusses the updates implemented in EPA's 2022 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) to include emission estimates for natural gas post-meter sources. Additional considerations for post-meter were previously discussed in a memorandum released in September 2021 (Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020: Updates Under Consideration for Post-Meter Emissions).[1]

1 2021 (Previous) GHGI Methodology

Leak emissions beyond gas meters (e.g., such as from home heating, water heating, and stoves) and from natural gas-fueled vehicles were not included in the GHGI. EPA included emission estimates for natural gas post-meter sources in the current Inventory (2022 GHGI).

2 Background

Post-meter emissions are included in the 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories under natural gas systems (IPCC 2019 refinements). Post-meter emission sources include certain leak emissions from residential and commercial appliances, industrial facilities and power plants, and natural gas fueled vehicles. The IPCC post-meter sub-segments are as follows:

- Appliances in residential and commercial sectors - Leakage from house piping and natural gas appliances such as furnaces, water heaters, stoves and ovens, and barbecues/grills.
- Leakage at industrial plants and power stations – Leakage from internal piping.
- Natural gas fueled vehicles - Emissions from vehicles with alternative fuels produced from natural gas e.g., LNG, CNG, propane. Emissions for natural gas-fueled vehicles include releases from dead volumes during fueling, emptying of gas cylinders of high-pressure interim storage units, for execution of pressure tests and relaxation of residual pressure from vehicles' gas tanks, or decommissioning.

3 Available Data

EPA reviewed multiple data sources to identify relevant emission factors (EF) and activity data. Each of the data sources are identified here and a brief summary is provided.

3.1 Emission Factor Sources

EPA reviewed post-meter emissions data from the following sources:

- IPCC 2019 – IPCC 2019 refinements contain emission factors for CH_4 and CO_2 for post-meter emissions from residential and commercial sector appliances, industrial plants and EGUs, and natural gas fueled vehicles.[2] The IPCC EFs for the residential and commercial sectors are appliance-based EFs (i.e., emissions per appliance). The industrial plants and EGUs EFs are based on consumption of natural gas in the industrial and electricity generation sectors (i.e., emissions per volume of gas consumption). Finally, the EFs for natural gas fueled vehicles are based on the number of natural gas vehicles (i.e., emissions per natural gas vehicle).

[1] Stakeholder materials including draft and final memoranda for the current 1990-2020 Inventory and previous Inventories are available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems.
[2] 2019 IPCC Refinements, Vol 2, Chap 4, Table 4.2.4k.

- Research Studies – EPA reviewed four research studies on post-meter emissions that were recently published in peer-reviewed scientific journals. All the studies focused on leak emissions from residential natural gas appliances and households.
    - An Estimate of Natural Gas Methane Emissions from California Homes (Fischer et al. 2018)[3] – This study measured CH_4 leak emissions from 75 homes in California that use natural gas. The measurements captured passive house leak emissions, which included interior leaks and quiescent appliances (with only pilot lights burning), and steady-state operation of natural gas appliances.
    - Unburned Methane Emissions From Residential Natural Gas Appliances (Merrin and Francisco 2019)[4] – This study measured CH_4 leak emissions from residential natural gas appliances in Boston and Indianapolis. Natural gas space heating, water heating, and cooking appliances were measured in over 100 homes. The methane measurements were conducted during ignition, steady-state operation, and extinguishment phases of appliance operation.
    - Quantifying Methane Emissions from Natural Gas Water Heaters (Lebel et al. 2020)[5] – This study measured CH_4 leak emissions from natural gas water heaters in California. Water heaters from 64 northern California homes were measured during ignition, steady-state operation, and extinguishment phases of water heater operation.
    - Beyond-the-Meter: Unaccounted Sources of Methane Emissions in the Natural Gas Distribution Sector (Saint-Vincent and Pekney 2020)[6] – The authors performed a literature review on residential post-meter emissions data, which included assessing some of the above studies.
- California Air Resource Board (CARB) GHG Inventory – California's GHG Inventory includes CH_4 estimates from residential post-meter natural gas leaks. CARB uses CH_4 emissions data from the Fischer et al. 2018 study to estimate residential post-meter emissions.[7]
- International GHG Inventories – EPA reviewed national GHG Inventory reports and found several that included post-meter estimates.
    - The Australian GHG Inventory uses appliance-based CH_4 EFs from the Merrin and Francisco 2019 study to estimate residential appliance post-meter emissions.
    - The German GHG Inventory includes leak estimates from natural gas meters and fittings in the residential, commercial, and industrial sectors, and leak estimates from natural gas fueled vehicles. The CH_4 EFs used by Germany are based on local data and studies.
    - The UK GHG inventory includes residential and commercial leak emissions that are based on country-specific EFs for natural gas consumption (i.e., kg CH_4/TJ).

3.2 Activity Data Sources

EPA reviewed the following sources of activity data:

[3] Marc L. Fischer, Wanyu R. Chan, Woody Delp, Seongeun Jeong, Vi Rapp, Zhimin Zhu. An Estimate of Natural Gas Methane Emissions from California Homes. *Environmental Science & Technology* 2018, *52 (17)*, 10205–10213. https://pubs.acs.org/doi/10.1021/acs.est.8b03217.

[4] Zachary Merrin, Paul W. Francisco. Unburned Methane Emissions from Residential Natural Gas Appliances. Environmental Science & Technology 2019, 53 (9) , 5473-5482. https://doi.org/10.1021/acs.est.8b05323.

[5] Eric D. Lebel, Harmony S. Lu, Simone A. Speizer, Colin J. Finnegan, Robert B. Jackson. Quantifying Methane Emissions from Natural Gas Water Heaters. *Environmental Science & Technology* 2020, 54 (9) , 5737-5745. https://doi.org/10.1021/acs.est.9b07189.

[6] Patricia M. B. Saint-Vincent, Natalie J. Pekney. Beyond-the-Meter: Unaccounted Sources of Methane Emissions in the Natural Gas Distribution Sector. *Environmental Science & Technology* 2020, *54 (1)*, 39-49. https://doi.org/10.1021/acs.est.9b04657.

[7] CARB GHG Inventory Updates Documentation, 2019 Edition. Available online at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_00-17_method_update_document.pdf.

- Residential sector – Data available to estimate post-meter emissions from residential natural gas appliances are national counts of natural gas households. National data on housing counts, by fuel type and by specific end uses such as heating and cooking, are available from the U.S. Census Bureau's *American Housing Survey* (AHS) and Energy Information Administration's *Residential Energy Consumption Survey* (RECS).[8,9] Both the datasets include national counts on number of housing units using natural gas for specific end uses such as space heating, water heating, cooking, clothes drying, pools and spa heating, and outdoor grills. The data do not include natural gas appliance counts.
    - Housing Counts:
        - AHS. National data on housing counts, by fuel type, are available from the U.S. Census Bureau's AHS.[10] National summary data are reported biennially by AHS starting with 1973.
        - RECS. In addition to the U.S. Census Bureau, national data on housing counts by fuel type are also available from the Energy Information Administration (EIA). The EIA periodically conducts the nationwide *Residential Energy Consumption Survey* (RECS). The RECS data are only available for 7 years in the 1990-2020 time-series (i.e., 1990, 1993, 1997, 2001, 2005, 2006, and 2015).
- Commercial sector – Data available to estimate post-meter emissions from commercial natural gas appliances are national data on commercial buildings, by fuel types and end uses such as heating and cooking from EIA's *Commercial Buildings Energy Consumption Survey* (CBECS)[11]and commercial meter counts available from EIA. Natural gas appliance counts are unavailable.
    - Commercial building counts: The CBECS contains national data on commercial buildings by type of fuel and energy end use (i.e., space heating, water heating, and cooking). The CBECS does not contain information on number of natural gas appliances used in commercial buildings; however, the survey indicates the number of commercial buildings that use natural gas for a particular end use. The CBECS is only available for 1992, 1995, 1999, 2003, and 2012 (i.e., 5 years in the 1990-2020 time-series). Data for 2018 CBECS are not publicly released yet.
    - Commercial meter counts: National commercial appliance counts can be estimated by multiplying a default value of appliances per commercial natural gas meter by the number of commercial natural gas meters from EIA.[12] Time-series data for commercial natural gas meters from EIA is used in the GHGI for estimating emissions from meters in the distribution segment.
- Industrial plants and EGUs – Annual national natural gas consumption data for industrial and electricity generation sectors are available from the *Monthly Energy Review* publications of the EIA.[13]
- Natural gas fueled vehicles – National vehicle population estimates are available from EPA's Motor Vehicle Emission Simulator model (MOVES).[14] The latest version of the MOVES model, MOVES3, contains natural gas vehicle fleet population estimates for 1990 and 1999-2020 and incorporates updated data on vehicle population, travel activity, and fuel supply information. Additionally, EIA's

[8] U.S. Census Bureau's *American Housing Survey* (AHS). https://www.census.gov/programs-surveys/ahs.html.
[9] Energy Information Administration's *Residential Energy Consumption Survey* (RECS). https://www.eia.gov/consumption/residential/.
[10] The U.S. Census also publishes the *American Community Survey* (ACS), which contains national housing counts by type of house heating fuel. Unlike the AHS, ACS data are only available for natural gas space heating end use and don't include other end uses such as water heating, cooking, and clothes drying, and ACS data are only available from 2010 forward. EPA did not consider this data source for the update under consideration.
[11] EIA's Commercial Buildings Energy Consumption Survey - https://www.eia.gov/consumption/commercial/.
[12] U.S. Energy Information Administration. Number of Natural Gas Consumers. https://www.eia.gov/dnav/ng/ng_cons_num_dcu_nus_a.htm.
[13] U.S. Energy Information Administration. April 2021 Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/archive/00352104.pdf.
[14] U.S. EPA's Latest MOVES Model: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

Alternate Fuel Data Center (AFDC) contains the Alternate Fuel Vehicle Inventory.[15] This inventory contains natural gas fueled vehicle counts for 2004-2019 for cities participating in the U.S. Department of Energy's Clean Cities Coalition Network.[16]

4 Analysis of Available Data

This section presents the available emission factor data and activity data for the post-meter sub-segments – Appliances in residential and commercial sectors; Leakage at industrial plants and power stations; and Natural gas fueled vehicles.

4.1 Emission Factors

The following sections summarize EFs from various sources reviewed by EPA and identify the EFs used in the update for each sector.

4.1.1 Residential Sector

Residential sector CH_4 EFs for natural gas leak emissions from house piping and appliances are shown in Table 1. All the residential sector EFs presented in Table 1 include leaks from natural gas appliances (e.g., during steady state operations); however, only a single source (Fischer et al. 2018) also accounts for passive leaks from residential natural gas piping (i.e., quiescent house leakage).

Table 1. CH_4 Emission Factors – Post-Meter Leaks in Residential Sector.

Data Source	CH_4 EF	EF Units	EF Includes Appliance Leaks?	EF Includes Passive House Leaks?
IPCC	4.0	Kg/appliance	Yes	Unspecified
CARB/Fischer et al. (2018)	2.54	Kg/NG House	Yes	Yes
Merrin and Francisco (2019)	0.43	Kg/NG House	Yes	No
Lebel et al. (2020)	1.42	Kg/NG Water Heater	Yes	No
2021 Australia GHGI (1990-2019)	0.06 – 1.2	Appliance based[a]	Yes	No
2021 UK GHGI (1990-2019)	1.9	Kg/TJ natural gas	Yes	No

[a] The EFs were derived from the Merrin and Francisco 2019 study (CH_4 EFs for ovens, stoves, furnaces, and water heaters). The appliance-based emission factors range from 0.06 kg/stove to 1.2 kg/tankless water heater.

Another study (Saint-Vincent and Pekney, 2020), not listed in Table 1 above, estimated national emissions using emissions data from other studies. This study combined passive house leak emissions data from the Fischer et al. study and appliance emissions from the Merrin and Francisco study. The implied CH_4 EF developed by this study is 2.41 kg/natural gas household (i.e., national emissions estimated by study divided by national number of households using natural gas).

The California Air Resources Board (CARB) GHG Inventory developed an estimate for post-meter emissions using the Fischer et al. study. The EF calculated from the Fischer et al. study accounts for passive house leak emissions and appliance leak emissions.

[15] Clean Cities Alternate Fuel Vehicle Inventory: https://afdc.energy.gov/data/10581.
[16] Clean Cities Coalition Network: https://cleancities.energy.gov/coalitions/.

The Australian GHGI (1990-2019) uses residential appliance CH_4 EFs from the Merrin and Francisco study to estimate residential post-meter emissions.[17]

The UK GHGI (1990-2019) estimates post-meter emissions in the residential and commercial sectors.[18] Leakages are estimated for a range of different appliances that use gas, combined with national statistics on natural gas consumption in the domestic and commercial sectors. The UK GHGI includes appliances used for space heating, water heating, and cooking in the residential sector and appliances (ovens and boilers) used in commercial catering and other service sectors.

IPCC 2019 also provided a residential sector post-meter CO_2 EF of 0.033 kg/appliance. None of the other data sources provided CO_2 emissions data.

In the final 2022 GHGI methodology, EPA used the CH_4 EF from the Fischer et al. 2018 study to estimate emissions from residential post-meter sources. EPA deducted CH_4 emissions from the residential natural gas fuel combustion source (Fossil Fuel Combustion source in GHGI)[19] from the Fischer-derived estimate to avoid double-counting. EPA did not include CO_2 estimates for residential post-meter sources in the final 2022 GHGI methodology as these are captured under residential natural gas fuel combustion in the GHGI.

4.1.2 Commercial Sector

Commercial sector CH_4 EFs for natural gas appliance leak emissions are shown in Table 2.

Table 2. Emission Factors – Post-Meter Leaks in Commercial Sector.

Data Source	CH_4 EF	CO_2 EF	EF Units
IPCC	4.0	0.033	Kg/appliance

EPA used the IPCC CH_4 and CO_2 EFs (Table 2) to estimate emissions from commercial post-meter sources in the 2022 GHGI.

4.1.3 Industrial Plants and EGUs

CH_4 EFs for natural gas leak emissions at industrial plants and EGUs are shown in Table 3.

Table 3. Emission Factors – Post-Meter Leaks from Industrial Plants and EGUs.

Data Source	CH_4 EF[a]	EF Units
IPCC	11,326.7	Kg/billion cubic feet gas consumed
2021 Germany GHGI (1990-2019)	7,702.2[b]	Kg/billion cubic feet gas consumed

[a] Converted CH_4 EFs from kg/million cubic meters gas consumed to kg/billion cubic feet gas consumed using a conversion factor of 35.3147 cubic feet/cubic meter.

[b] The original CH_4 EF from the German National Inventory Report (NIR) is 0.4 m^3 CH_4/1,000 m^3 natural gas consumption. The conversion assumed density of CH_4 to be 19.26 g/ft^3 (0.68 kg/m^3).

IPCC 2019 also provided a CO_2 EF of 3.3 Kg/million cubic meters gas consumed for post-meter leaks at industrial plants and EGUs. EPA used the IPCC CH_4 and CO_2 EFs to estimate emissions from industrial post-meter sources in the 2022 GHGI.

[17] Australia. 2021 National Inventory Report (1990-2019), Volume 1, Table 3.49b. April 2021. Available online at: https://unfccc.int/documents/273478.

[18] United Kingdom. 2021 National Inventory Report (1990-2019), Section 3, MS 19. April 2021. Available online at: https://unfccc.int/documents/273439.

[19] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

4.1.4 Natural Gas Fueled Vehicles

IPCC 2019 default EFs for CH_4 and CO_2 are shown in Table 4. The IPCC EFs were derived from a German study and are also used in the German GHGI.

Table 4. Emission Factors – Post-Meter Leaks from Natural Gas Fueled Vehicles.

Data Source	CH_4 EF	CO_2 EF	EF Units
IPCC	0.33	0.0023	Kg/vehicle

EPA used the IPCC CH_4 and CO_2 EFs (Table 4) to estimate post-meter emissions from natural gas fueled vehicles in the 2022 GHGI.

4.2 Activity Data

4.2.1 Residential Sector

Activity data available for the residential sector post-meter estimates are the national number of households using natural gas as fuel. Table 5 contains a summary of available RECS and AHS housing units data (both total houses and houses using natural gas as a fuel) for the seven years for which RECS data are available and the most recent year (2019) that AHS data are available. National data in Table 5 represent occupied housing units.

Table 5. Summary of National Housing Data (millions of housing units).

Year	EIA/RECS		Census/AHS		% Difference NG Housing Units
	Total Housing Units	NG Housing Units	Total Housing Units	NG Housing Units	
1990	94.0	57.7	Not Available	Not Available	--
1993	96.6	58.4	94.7	65.6	-0.3%
1997	101.5	61.9	99.5	60.5	-2%
2001	107.0	66.9	106.3	83.1	-3%
2005	111.1	69.5	108.9	86.6	-4%
2009	113.6	69.2	111.8	86.2	-2%
2015	118.2	68.6	118.3	80.3	17%
2019	Not Available	Not Available	124.1	84.7	--

The AHS and RECS datasets also contain the number of housing units using natural gas for specific end use purposes such as space heating, water heating, cooking, clothes drying, outdoor grilling, and spa/pool heating. Natural gas appliance counts are not available in the AHS and RECS data. In Table 6 below, national appliance counts were estimated by assuming one appliance of each type per housing unit using natural gas for that appliance type. For example, if the data indicate 60,000 housing units that use natural gas for water heating, then the number of natural gas water heaters is assumed to be 60,000. Table 6 contains a summary of residential natural gas appliance counts from RECS and AHS for the seven years for which RECS data are available and the most recent year (2019) that AHS data are available.

Table 6. Summary of Estimated National Residential Appliance Data (millions of units).

Year	Based on EIA/RECS	Based on Census/AHS
1990	157	NA
1993	156	149
1997	164	159
2001	179	170
2005	185	176
2009	185	174

Year	Based on EIA/RECS	Based on Census/AHS
2015	189	176
2019	NA	181

EPA used the national count of natural gas households from the AHS data for the final 2022 GHGI methodology for residential post-meter sources.

4.2.2 Commercial Sector

EIA's CBECS contains data on the number of commercial buildings that use natural gas for specific end uses such as space heating, water heating, and cooking but does not indicate the number of appliances at commercial buildings. The commercial buildings included in the CBECS are categorized by their primary business activity. The commercial building categories covered by the CBECS include education, food service, health care, lodging, mercantile, offices, religious worship, public services, and others (e.g., laboratories, manufacturing with retail space, data centers, and crematoriums).

The CBECS data are only available for 1992, 1995, 1999, 2003, and 2012. Data from the 2018 CBECS are yet to be published.[20] Table 7 presents the national summary for the available years of CBECS data. The CBECS data do not contain commercial appliance counts. National appliance counts can be estimated by assuming one appliance of each type per commercial building using natural gas for that appliance type. For example, if the data indicate 100,000 commercial building use natural gas for water heating, then the number of natural gas water heaters is assumed to be 100,000. The estimated natural gas appliance counts are also shown in Table 7, below. In addition, the number of commercial natural gas meters are also shown in Table 7 for the years CBECS data are available. Using the derived appliance counts and the commercial meter counts, EPA developed estimates for appliances per commercial meter.

Table 7. Summary of CBECS Data (1000s).

	1992	1995	1999	2003	2012
All commercial buildings	4,806	4,579	4,657	4,645	5,557
Commercial buildings using natural gas as fuel for the following end uses:					
Primary space-heating energy source	2,276	2,106	2,189	1,999	2,322
Water-heating energy source	1,647	1,577	1,520	1,445	1,758
Cooking energy source	431	448	505	457	740
Cooling energy source	106	65	142	17	12
Estimated Appliance Count	4,460	4,196	4,356	3,918	4,832
Commercial Meter Count – 2022 GHGI	4,409	4,636	5,010	5,152	5,356
Estimated Appliances/Commercial Meter[a]	1	1	1	1	1

[a] All values rounded to the closest integer. The actual values range from 0.76 to 1.01 appliances/meter.

To estimate the number of commercial appliances, EPA used the number of commercial natural gas meters from EIA and the estimate of one appliance per commercial meter for the final 2022 GHGI methodology for commercial post-meter sources.

4.2.3 Industrial Plants and EGUs

Activity data used to estimate post-meter leak emissions from industrial plants and EGUs are national natural gas consumption for the industrial and electric power sectors. EIA provides national data on consumption of natural gas by the industrial and electric power sectors for the entire time-series (1990-2020); see Table 8.

[20] Preliminary 2018 CBECS data are not yet published. Website indicates detailed tables will be available in spring/summer 2021.

Table 8. Summary of Natural Gas Consumption By Industrial and Electric Power Sectors (BCF).

Year	Industrial Sector	Electric Power Sector
1990	8,255	3,245
1991	8,360	3,316
1992	8,698	3,448
1993	8,872	3,473
1994	8,913	3,903
1995	9,384	4,237
1996	9,685	3,807
1997	9,714	4,065
1998	9,493	4,588
1999	9,158	4,820
2000	9,293	5,206
2001	8,463	5,342
2002	8,640	5,672
2003	8,273	5,135
2004	8,354	5,464
2005	7,713	5,869
2006	7,669	6,222
2007	7,881	6,841
2008	7,890	6,668
2009	7,443	6,873
2010	8,112	7,387
2011	8,317	7,574
2012	8,622	9,111
2013	8,909	8,191
2014	9,158	8,146
2015	9,098	9,613
2016	9,274	9,985
2017	9,533	9,266
2018	10,112	10,590
2019	10,268	11,288
2020	10,086	11,616

EPA used EIA natural gas consumption data in the final 2022 GHGI methodology for industrial and EGU post-meter sources.

4.2.4 Natural Gas Fueled Vehicles

Activity data required to estimate post-meter leak emissions for natural gas fueled vehicles are the national population of natural gas fueled vehicles. EPA evaluated data from MOVES3 and AFDC. MOVES3 includes the annual compressed natural gas (CNG) vehicle population for 1990 and 1999 through 2020. The population of vehicles running on liquefied natural gas (LNG) or renewable natural gas (RNG) are not available in MOVES3. CNG vehicle counts from MOVES3 include buses (transit and school buses), refuse trucks, single-unit trucks, and combination trucks (i.e., heavy-duty vehicles). Currently, there is only a single OEM that offers a factory

built CNG light-duty vehicle in the U.S. market.[21] However, there are options for after-market CNG conversions for passenger automobiles. Converted passenger automobile counts are not included in MOVES3.[22]

The AFDC provides an annual alternate fuel vehicle inventory for 2004-2019 compiled from the Clean Cities Coalition. The AFDC data is not available at the national-level. The alternate fuel vehicle inventory only includes the cities that are part of the Clean Cities Coalition. An estimated 79 percent of the national population lives inside the boundaries of the Clean Cities Coalition Network. Table 9 summarizes the MOVES3 and AFDC data.

Table 9. Summary of Vehicle Populations from MOVES3 and Clean Cities Alternate Fuel Vehicle Inventory.

Year	MOVES3 CNG Vehicles	Clean Cities Alternate Fuel Vehicle Inventory			
		CNG Vehicles	LNG Vehicles	RNG Vehicles	All Natural Gas Vehicles
1990	6	NA	NA	NA	NA
1999	10,139	NA	NA	NA	NA
2000	13,063	NA	NA	NA	NA
2001	15,787	NA	NA	NA	NA
2002	19,229	NA	NA	NA	NA
2003	20,963	NA	NA	NA	NA
2004	22,364	76,257	0	0	76,257
2005	23,695	49,271	1,873	0	51,144
2006	24,093	57,458	2,271	0	59,729
2007	25,028	55,021	1,731	0	56,752
2008	26,959	51,121	2,053	0	53,174
2009	30,289	44,317	2,038	0	46,355
2010	30,708	42,911	3,410	0	46,321
2011	33,557	48,157	4,315	0	52,472
2012	37,925	59,521	3,411	0	62,932
2013	42,311	79,616	3,645	0	83,261
2014	50,317	68,479	2,992	313	71,784
2015	60,132	107,283	3,974	366	111,623
2016	69,897	98,388	4,924	1,157	104,469
2017	80,021	97,271	5,070	1,734	104,075
2018	89,033	82,266	5,100	1,677	89,043
2019	98,535	100,938	4,917	4,922	110,777
2020	107,519	NA	NA	NA	NA

NA = not available

EPA used CNG vehicle counts from MOVES3 for the final 2022 GHGI methodology for natural gas vehicle post-meter sources.

5 Time Series Considerations

- Emission Factors: Currently, there is no time series information on emission factors available for post-meter emissions. The emission factors in the update were held constant over the time series.
- Residential Activity Data:

[21] https://ngvamerica.org/vehicles/.
[22] MOVES population and activity technical report is available online at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1011TF8.pdf.

- U.S. Census Bureau's *American Housing Survey* (AHS) – National housing data by type of fuel and fuel end use purpose are available from AHS. National summary data from the AHS are published biennially (published every odd year). For the 2022 GHGI, natural gas households counts for missing years were gap filled as the average value of the two most recent years for which data are available (i.e., years immediately before and after the missing year).

- Commercial Activity Data – EPA estimated the number of appliances per commercial meter using data from the CBECS and the commercial meter counts data from EIA (see Table 7). The data indicate 1 appliance/commercial meter for all years with CBECS data. In the final 2022 GHGI methodology, EPA applied the same value (1 appliance/commercial meter) for all time-series years.
- Industrial and Power Plants Activity Data –EIA's natural gas consumption data for the industrial and electric power sectors are available for the entire time series.
- Natural Gas Vehicles Activity Data - MOVES3 National Vehicle Population – National vehicle counts are available from MOVES3 for 1990 and 1999-2020. In the final 2022 GHGI methodology, EPA used EIA's data on annual natural gas vehicular fuel consumption for 1990-1999 to gap fill MOVES3 vehicle counts for 1991-1998. EPA calculated the ratio of natural gas vehicle fuel consumption in each of the missing years (i.e., 1991-1998) to natural gas vehicle fuel consumption in 1999. The 1999 vehicle count from MOVES3 was then multiplied by the year specific ratio to gap fill MOVES3 vehicle counts for 1991-1998.

6 National Emissions Estimates for Post-Meter in the 2022 GHGI

Table 10 presents a summary of the 2020 national estimates for post-meter sources developed using the final 2022 GHGI methodology. The EFs and activity data incorporated into the final 2022 GHGI methodology are presented in sections 3 and 4, above.

Table 10. 2020 National Estimates From Post-Meter Sources (2022 GHGI).

Post-Meter Source	Activity	CH_4 EF	CO_2 EF	2020 Emissions (2022 GHGI)	
				CH_4 (metric tons)	CO_2 (metric tons)
Residential	84,726,000 NG houses	2.54 kg/NG House	NA	192,199[a]	NA
Commercial	5,626,925 appliances	4 kg/appliance	0.033 kg/appliance	22,508	186
Industrial & EGUs	21,571 Bcf	11,326.7 kg/bcf	3.3 kg/million cubic meters	244,333	2,016
Natural Gas Vehicles	107,519 vehicles	0.33 kg/vehicle	0.0023 kg/vehicle	32	0.2
Total				**459,072**	**2,202**

a. Incorporates a deduction of 23,005 mt CH_4 for residential natural gas combustion.

7 Requests for Stakeholder Feedback

EPA sought stakeholder feedback on the approaches under consideration through two 2021 webinars, in the September 2021 memo, and in the public review draft of the GHGI. EPA received comments on the September 2021 version of the Post-Meter Memo and through the public review draft of the Inventory. These comments included recommendations to delay inclusion of post-meter estimates to the GHGI until further research studies have been conducted. The comments cautioned against the use of residential post-meter EFs developed from a research study conducted in California, asserting that it is not representative at the national-

level. EPA also received comment on appliance pilot light phase-out and potential implications on time-series estimates.

The questions below were not updated for this memorandum and are copied from the September 2021 memo.

1. EPA seeks additional data sources to be considered for post-meter emissions (emission factor and activity data sources).

2. EPA seeks stakeholder feedback on time series data for post-meter emission sources. Are data available that would allow the GHGI to reflect changes over time in average emissions per emission source for post-meter?

Appendix A – Measurement Methodologies from Data Sources Considered for Updates

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
An Estimate of Natural Gas Methane Emissions from California Homes (Fischer et al. 2018)				
Quiescent whole-house emissions	Mass balance approach - Controlled flow of outdoor air was used to ventilate the house, while measuring both the indoor and outdoor air CH_4 concentrations over time. Once indoor CH_4 concentration reached steady state, the enhancement of indoor CH_4 relative to outdoor air combined with the known volumetric flow rate of air was used to estimate indoor CH_4 emissions. CH_4 was measured with a portable gas analyzer.	75 owner-occupied, single-family detached homes that use NG for at least two of the following purposes: space heating, water heating, cooking, and clothes drying.	30 homes were located in Northern California and Central Valley and 45 homes were located in Southern California.	Study estimated state-level emissions from whole-house and NG appliances using measurement results and Bayesian Markov chain Monte Carlo sampling combined with California housing statistics and gas use information. EFs were derived by using state-level estimates from the study and the number of natural gas homes in CA.
Appliance emissions	Methane emissions were measured during steady operation for two NG appliances in each home. Measurements were made using the same portable gas analyzer used for whole-house measurements. Each appliance was operated for 10−15 min before the measurement.			
Unburned Methane Emissions From Residential Natural Gas Appliances (Merrin and Francisco 2019)				
Appliance emissions	Gas concentrations were measured during appliance ignition, operation, extinguishment, and cool down. Appliances were tested using a Picarro portable gas concentration analyzer (ppm of CH_4, CO_2, and water vapor; sample temperature and pressure). Cooktop burners were tested using "CO Hot Pot" (device mimics cooking vessel and has sampling port for measurements).	Space heating, water heating, and cooking appliances were tested (furnaces, boilers, stoves, ovens, water heaters, outdoor grills, and space heaters from 100 residential sites in MA, IN, IL, and NY were tested.	72 sites in Boston, MA and Indianapolis, IN. 28 Additional sites in IL and NY.	Annual CH_4 emissions from an appliance type were calculated by combining average measured concentration, calculated exhaust flow, and appliance usage assumptions (days used per year, activations per day, average operational duration in mins, etc.).
Quantifying Methane Emissions from Natural Gas Water Heaters (Lebel et al. 2020)				
NG water heaters	Developed a high-flow sampling system to capture and measure the emissions from the water heaters. A local background measurement was taken 30 or more feet upwind from the WH exhaust each hour. The concentrations of CH_4 and CO_2 were measured using a Cavity Ring-Down Spectrometer G2210-i (Picarro Inc.). Emissions were measured: (1) before the appliance was turned on; (2) as the appliance was turning on, producing a pulse of CH_4; (3) until the concentration profile reached a steady concentration to measure incomplete combustion for a minimum of 2 min and multiple replicates; and (4) as the water heater turned off which typically created a second pulse of CH_4.	Emissions data were collected from 35 residential water heaters. Usage data were collected from 46 residential water heaters.	64 single-family homes with natural gas water heaters in Northern California. Water heaters included both storage and tankless type.	The measured emissions data were combined with the usage data to estimate annual emissions.