2011–2017 Greenhouse Gas Reporting Program Industrial Profile: Electronics Manufacturing Sector

October 2018

CONTENTS

ELECTRONICS MANUFACTURING SECTOR

All emissions presented here are as of 8/19/2018 and exclude biogenic carbon dioxide (CO_2). Greenhouse gas (GHG) data displayed in units of CO_2e reflect the global warming potential (GWP) values from Table A-1, which is generally based on the IPCC AR4, with the addition of GWPs from the IPCC AR5 for fluorinated GHGs that did not have GWPs in the AR4.

Highlights

- Emissions reported by this sector decreased by one-and-a-half percent from 6.2 million metric tons of carbon dioxide equivalent (MMT CO_2e) in 2016 to 6.1 MMT CO_2e in 2017.
- This decrease is associated with a decrease in the emissions of sulfur hexafluoride (SF_6) and other fully fluorinated compounds.

About this Sector

The Electronics Manufacturing sector includes, but is not limited to, facilities that manufacture semiconductors (including light-emitting diodes), micro-electromechanical systems (MEMS), liquid crystal displays (LCDs), and photovoltaic (PV) cells. Specifically, this sector consists of electronics manufacturing facilities with production processes that use plasma-generated fluorine atoms and other reactive fluorine-containing fragments to etch thin films, clean chambers for depositing thin films, clean wafers, or remove residual material. The sector also includes electronics manufacturing facilities with chemical vapor deposition processes or other production processes that use nitrous oxide (N_2O), and processes that use fluorinated greenhouse gases (GHGs) as heat transfer fluids (HTFs) to control temperature or clean surfaces.

Who Reports?

In 2017, 51 facilities in the Electronics Manufacturing sector submitted GHG reports. Total reported emissions were 6.1 MMT CO_2e, which represents less than one percent of total U.S. GHG emissions.[1] Tables 1, 2, and 3 show the reporting schedule, number of reporters, and coverage, respectively.

Table 1: Electronics Manufacturing Sector – Reporting Schedule by Subpart

Subpart	Source Category	Applicability	First Reporting Year
I	Electronics Manufacturing	Facilities that would emit ≥ 25,000 metric tons of CO_2e/year in the absence of emission controls.	2011

Table 2: Electronics Manufacturing Sector – Number of Reporters (2011–2017)

Sector	Number of Reporters						
	2011	2012	2013	2014	2015	2016	2017
Electronics Manufacturing	56	56	58	59	58	53	51

Of the 53 facilities that reported in 2016 in this sector, 52 manufacture semiconductors, 3 of which also manufacture PV cells, MEMS, or LCDs in addition to semiconductors. One facility was a PV cell manufacturer. These facilities represented 24–56% of total facilities and 75–90% of total emissions in the sector.

[1] The total U.S. GHG emissions are 6,511.3 MMT CO_2e, as reported in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016. U.S. Environmental Protection Agency. April 15, 2018. EPA 430-R-18-003.

Table 3: Electronics Manufacturing Sector – GHGRP Coverage in 2016

Sector	GHGRP Coverage of Industry	Estimated Percent of Industry Facilities Covered by GHGRP	Estimated Percent of Industry Emissions Covered by GHGRP
Electronics Manufacturing	Facilities that would emit ≥ 25,000 metric tons of CO_2e/year in the absence of emission controls	24–56%[a]	75%–90%[b]

[a] The estimate of the size of the industry was based on the total number of U.S. facilities determined from the World Fab Forecast (WFF) produced by Semiconductor Equipment and Materials International (SEMI), and by determining which fabs (i.e., semiconductor fabrication plants) are located together at a single facility. Access additional information on the WFF. The lower end of the percent of covered facilities (24%) includes Research and Development (R&D) facilities in the denominator, and the upper end of the range (56%) is based on just production facilities and excludes R&D facilities.

[b] The estimate of the quantity of industry emissions was based on actual emissions reported to the Greenhouse Gas Reporting Program (GHGRP) plus estimated emissions for facilities that did not report to the GHGRP using the WFF. The range reflects the uncertainty regarding the emissions rates of non-reporting facilities as well as the impact of including vs. excluding the emissions of R&D facilities in the denominator.

Reported Emissions

Table 4 shows emissions reported to the GHGRP for the Electronics Manufacturing Sector from 2011 to 2017.

Table 4: Electronics Manufacturing Sector Emissions Reported to the GHGRP (2011–2017)

Sector	Emissions (MMT CO_2e)[a]						
	2011	2012	2013	2014	2015	2016	2017
Electronics Manufacturing	7.0	6.4	5.2	6.2	6.3	6.2	6.1

[a] Represents total emissions reported to the GHGRP from this sector. Additional emissions occur at facilities that have not reported (e.g., those below the reporting threshold).

Figure 1: Location and Emissions Range for Each Reporting Facility in the Electronics Manufacturing Sector: 2017

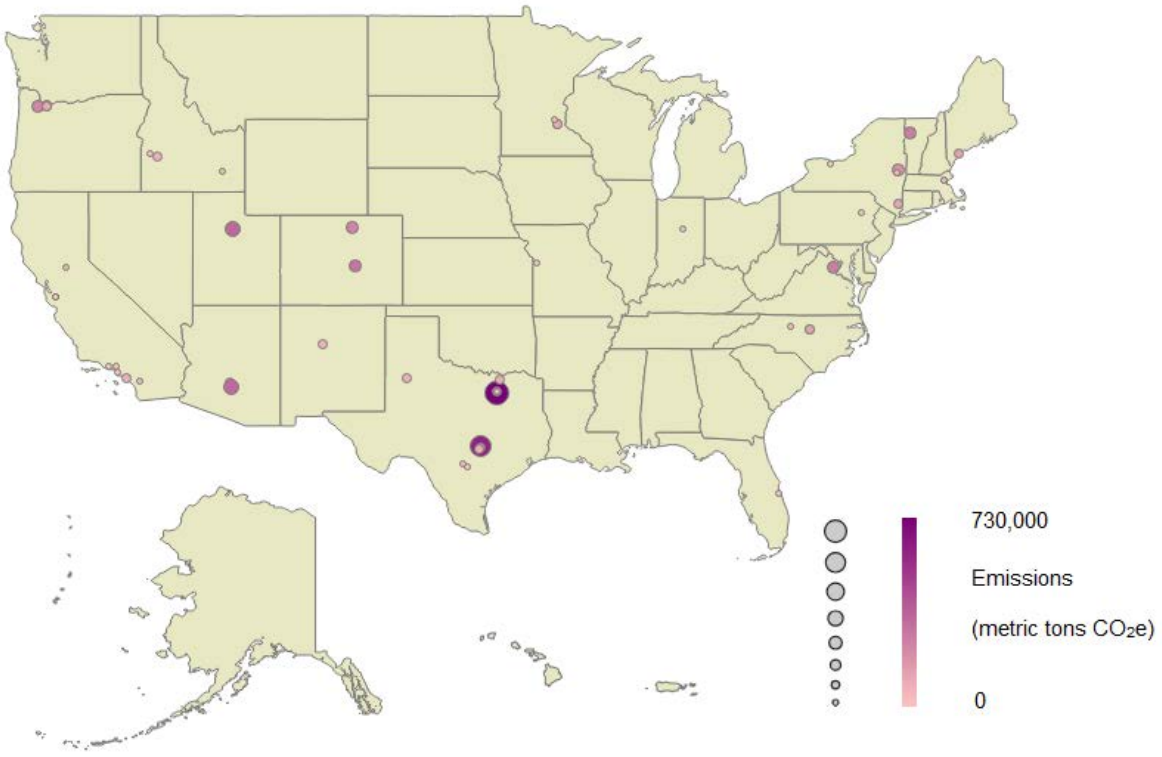
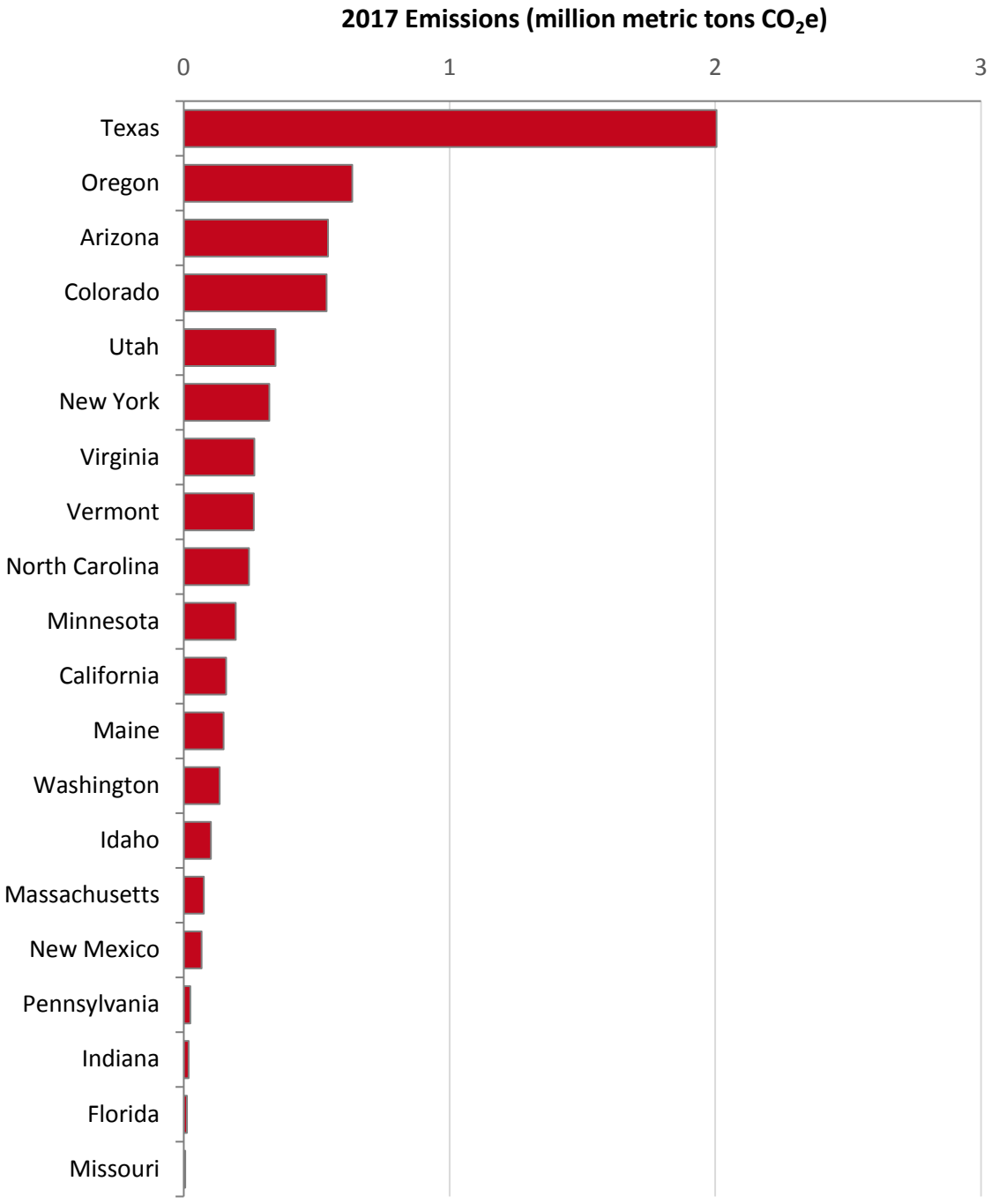


Figure 1 shows the locations of direct-emitting facilities. The size of a circle corresponds to the quantity of emissions reported by that facility. All reporting facilities were located in the lower 48 contiguous states.

Readers can identify the largest emitting facilities with the Facility Level Information on Greenhouse Gases Tool (FLIGHT). Figure 2 shows the GHG emissions for the Electronics Manufacturing sector for 2017 by state.

Figure 2: Electronics Manufacturing Sector: Emissions by State (2017)[a]

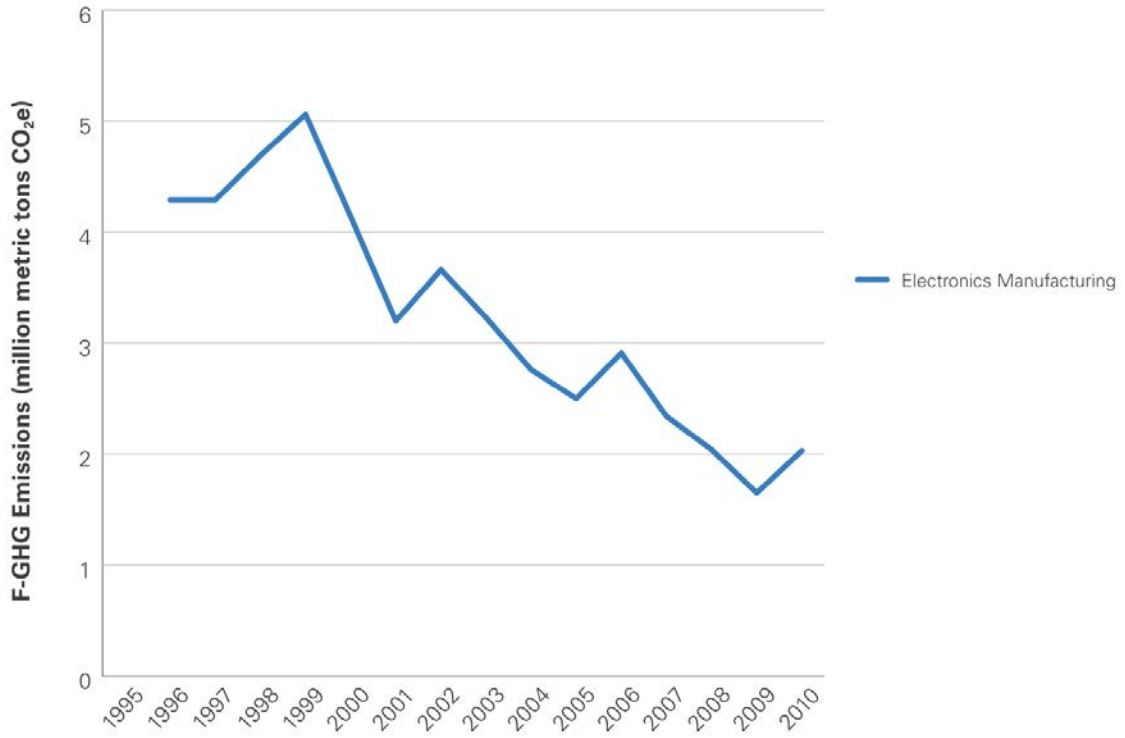


[a] Represents total emissions reported to the GHGRP from this sector. Additional emissions occur at facilities that have not reported (e.g., those below the reporting threshold). States not shown had no electronics manufacturing sector emissions reported to the GHGRP in 2017.

Electronics Manufacturing Sector Emissions Trends Prior to 2011

From 1995 through 2010, a segment of the U.S. semiconductor manufacturing industry reported their aggregate emissions from the use of fluorinated greenhouse gases (F-GHGs) to the U.S. Environmental Protection Agency (EPA) under the voluntary Perfluorocarbon (PFC) Reduction/Climate Partnership. These manufacturers, representing about 80% of U.S. semiconductor manufacturing capacity, significantly reduced their emissions from etching and chamber cleaning between 1995 and 2010 (Figure 3), even though overall production increased during this period. The methods used by facilities to monitor their emissions under the partnership are believed to have been roughly comparable to those used to date under the GHGRP. However, the partnership reports did not include emissions from HTF, fuel combustion, and sources of N_2O; were sometimes based on less facility-specific data than required under the GHGRP; and sometimes did not include documentation of the method and data used.

Figure 3: Semiconductor Manufacturing Partner F-GHG Emissions (1995–2010)[a]

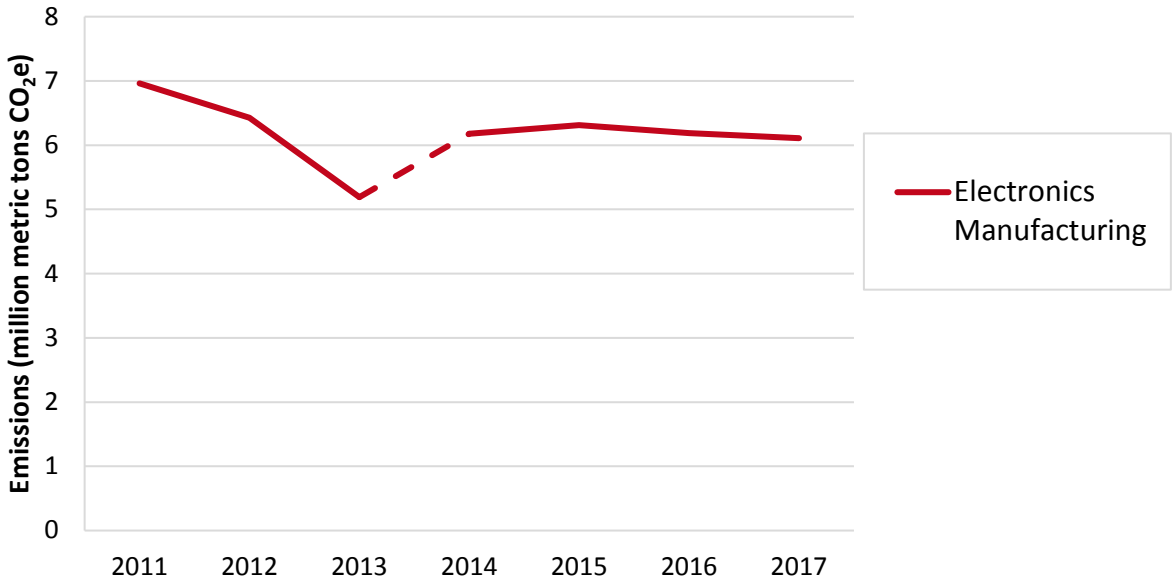


[a] The graph includes only semiconductor EPA partner F-GHG emissions, not the entire U.S. electronics manufacturing sector. Specifically, the following seven F-GHGs are represented in this graph: tetrafluoromethane (CF_4), hexafluoroethane (C_2F_6), perfluoropropane (C_3F_8), octafluorocyclobutane (C_4F_8), fluoroform (CHF_3), SF_6, and nitrogen trifluoride (NF_3). Emissions of CO_2, N_2O, and HTF are not included in these emissions estimates because they were not reported under the partnership.

Electronics Manufacturing Sector Emissions Trends from 2011 to 2017

Figure 4 shows GHG emissions reported to the GHGRP for the Electronics Manufacturing sector from 2011 to 2017. Reported emissions from the Electronics Manufacturing sector decreased from 7 MMT CO_2e in 2011 to 5.2 MMT CO_2e in 2013, a decrease of 25.7 percent. This decrease was primarily due to a large reduction in combustion emissions at one facility. Emissions increased by 19.2 percent between 2013 and 2014, due in part to a rule revision that changed the emission factors used by facilities to estimate emissions, resulting in higher estimated emissions. Emissions decreased from 2014 (6.2 MMT CO_2e) to 2017 (6.1 MMT CO_2e), a reduction of about 0.1 MMT CO_2e (about one-and-a-half percent). The decrease was not due to reductions at any specific facilities, but instead a general decrease across the industry. Most of the reductions were from decreased emissions of PFCs and other fully fluorinated GHGs. Tables 5 and 6 show Electronics Manufacturing sector emissions by GHG from 2011 to 2017. Figure 5 shows Electronics Manufacturing sector emissions by process type. Figure 6 shows the average emissions per reporter in the Electronics Manufacturing Sector compared to average emissions per reporter across the GHGRP, both including and excluding emissions from power plants. Table 7 and Figure 7 show the number and percentage of reporters by emission range, respectively.

Figure 4: Electronics Manufacturing Sector – Emissions Trend (2011–2017)[a]



[a] A rule revision in 2013 changed the default emission factors used to calculate emissions. Thus, emission reported in 2011–2013 are not directly comparable to those reported in 2014 or later.

Access the most current information using FLIGHT.

Table 5: Electronics Manufacturing Sector 2011–2013 – Emissions by GHG (MMT CO_2e)[a]

Electronics Manufacturing Sector	Reporting Year		
	2011	2012	2013
Number of Facilities	56	56	58
Total Reported Emissions (MMT CO_2e)[b]	7.0	6.4	5.2
Emissions by GHG[c]			
Carbon Dioxide (CO_2)[d]	1.6	1.5	0.69
Methane (CH_4)[d]	e	e	e
Nitrous Oxide	0.24	0.19	0.18
Sulfur Hexafluoride	0.34	0.33	0.35
Nitrogen Trifluoride	0.62	0.61	0.54
Hydrofluorocarbons (HFCs)	0.17	0.20	0.16
Perfluorocarbons	3.2	2.8	2.7
Other Fully Fluorinated Hydrofluoroethers	0.73	0.75	0.57
(HFEs)	e	e	e
Other	e	e	e

[a] Represents total emissions reported to the GHGRP in this industry sector. Additional emissions occur at facilities that have not reported (e.g., those below the 25,000 metric ton CO_2e reporting threshold).

[b] Total emissions do not include F-GHGs without GWP. These compounds made up about 14% of mass emissions from this sector.

[c] Totals might not sum due to rounding.

[d] Emissions of CO_2 and CH_4 are from stationary fuel combustion sources.

[e] Total reported emissions are less than 0.05 MMT CO_2e.

Table 6: Electronics Manufacturing Sector 2014–2017 – Emissions by GHG (MMT CO_2e)[a]

Electronics Manufacturing Sector	Reporting Year			
	2014	2015	2016	2017
Number of Facilities	59	58	53	51
Total Reported Emissions (MMT CO_2e)[b]	6.2	6.3	6.2	6.1
Emissions by GHG[c]				
Carbon Dioxide[d]	0.73	0.75	0.74	0.72
Methane[d]	e	e	e	e
Nitrous Oxide	0.21	0.23	0.23	0.27
Sulfur Hexafluoride	0.71	0.73	0.82	0.72
Nitrogen Trifluoride	0.50	0.56	0.56	0.59
Hydrofluorocarbons	0.30	0.32	0.34	0.36
Perfluorocarbons	3.0	3.0	2.9	2.9
Other Fully Fluorinated	0.76	0.70	0.63	0.56
HFEs	e	e	e	e
Other	e	e	e	e

[a] Represents total emissions reported to the GHGRP in this industry sector. Additional emissions occur at facilities that have not reported (e.g., those below the 25,000 metric ton CO_2e reporting threshold).

[b] Total emissions do not include F-GHGs without GWP. These compounds made up about 14% of mass emissions from this sector.

[c] Totals might not sum due to rounding.

[d] Emissions of CO_2 and CH_4 are from stationary fuel combustion sources.

[e] Total reported emissions are less than 0.05 MMT CO_2e.

Figure 5: Electronics Manufacturing Sector 2017 Emissions by Process Type

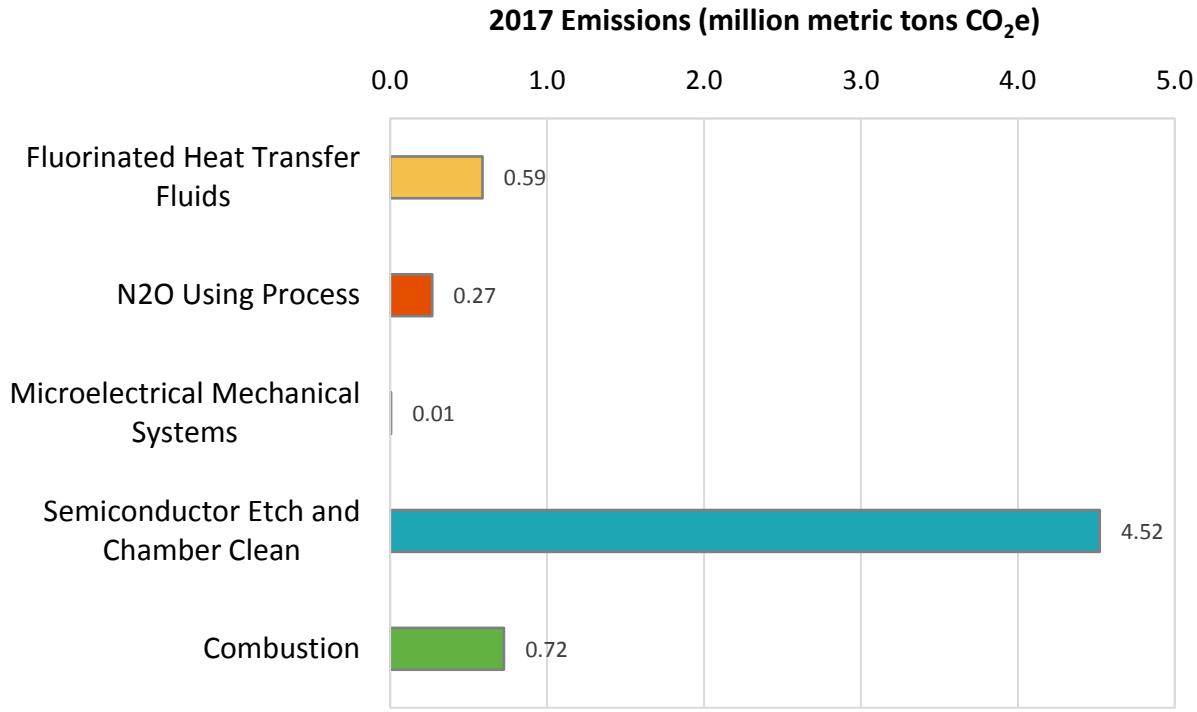


Figure 6: Electronics Manufacturing Sector – Average Emissions per Reporter (2017)

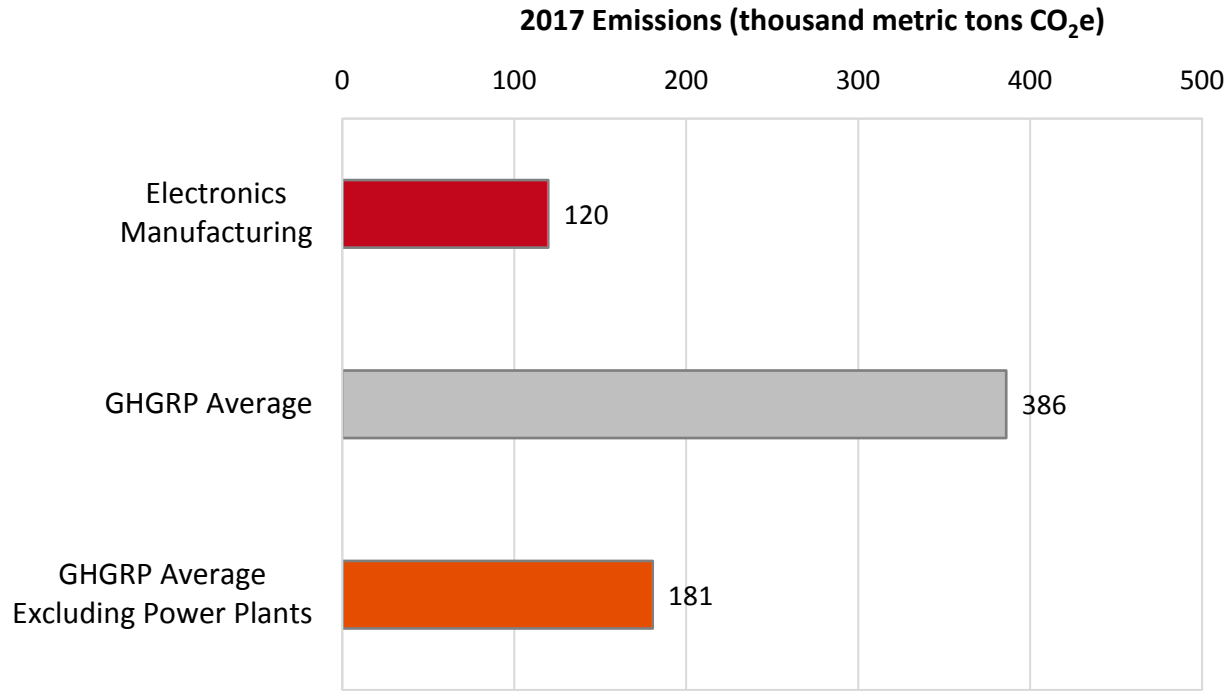
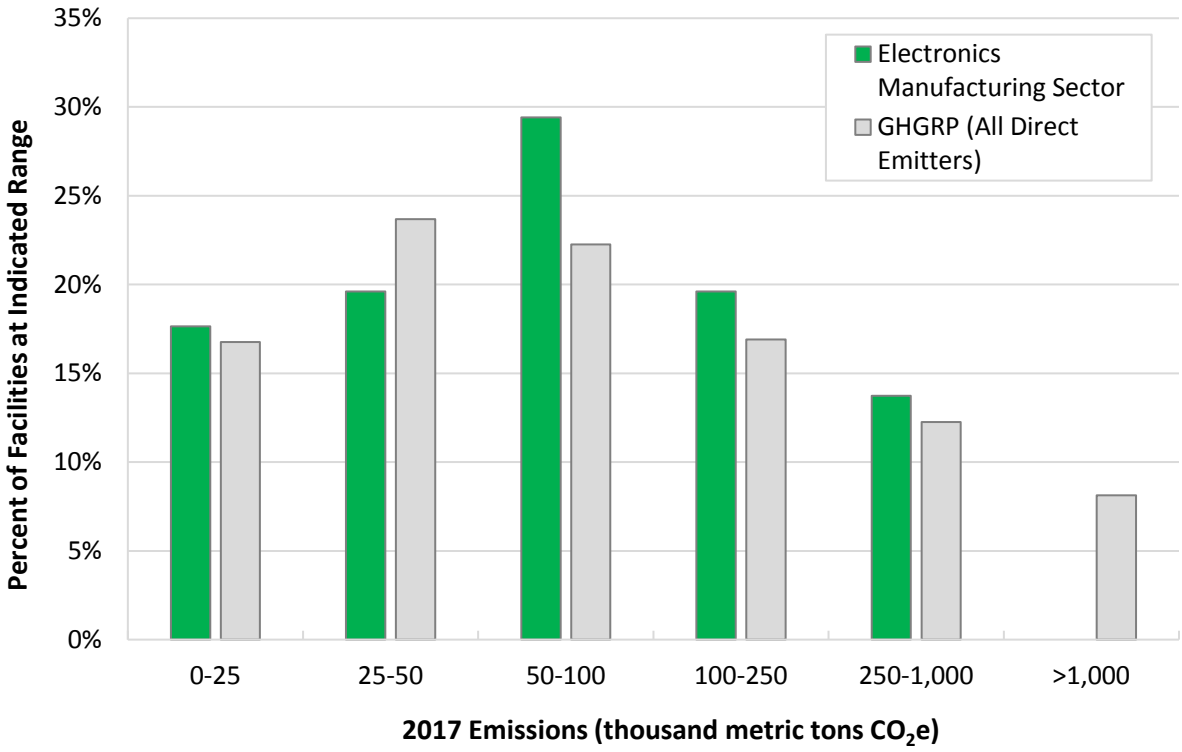


Table 7: Electronics Manufacturing Sector – Number of Reporters by Range of Emissions (2017)

Sector	Emissions Range (MMT CO2e)					
	< 0.025	0.025–0.05	0.05–0.1	0.1–0.25	0.25–1	> 1
Electronics Manufacturing	9	10	15	10	7	0

Figure 7: Percentage of Reporters by Range of Emissions (2017)



Calculation Methods Used

Starting in 2014, facilities in the Electronics Manufacturing sector could select one of two different methodologies to report F-GHGs. The methodologies for F-GHG reporting are default emission factors or the use of stack testing. Default factors are also used to calculate N_2O emissions from the chemical vapor deposition process and all other N_2O-using process types. Facilities may use site-specific or default destruction and removal efficiencies for abatement systems.

To report emissions of HTF, all facilities in the Electronics Manufacturing sector must use a mass balance approach based on purchase records and inventory.

Facilities with stationary fuel combustion equipment must report combustion emissions by following the calculation methods in Subpart C. CO_2 emissions from stationary fuel combustion represented approximately 12 percent of the GHG emissions from the Electronics Manufacturing sector in 2017.

Table 8: Electronics Manufacturing Sector – Methodologies (2014–2017)

Type of Emissions	Methodology	Percentage of CO_2 Emissions Monitored by Method			
		2014	2015	2016	2017
Process Emissions – F-GHGs	Default emission factors and default destruction and removal efficiencies (DREs)	99.9%	99.9%	99.7%	99.2%
	Default emission factors and site-specific DREs[a]	0.1%	0.1%	0.3%	0.8%
	Stack testing	0%	0%	0%	0%
HTFs	Mass balance	100%	100%	100%	100%
Combustion	Alternative Part 75 Methodology: Continuous Emissions Monitoring Systems (CEMS) per §98.33(a)(5)(iii)	0	0	0	0
	Measured high heating values (HHVs) and default emission factors (Tier 2)	49.3%	47.6%	42.9%	43.9%
	Default HHVs and emission factors (Tier 1)	50.7%	52.4%	57.1%	56.1%

[a] Includes facilities that used a combination of default and site-specific DREs.

Recent Changes to the Calculation Methods that Impact Reporting Year 2014 and Beyond

In 2013, EPA made three changes to the methodologies that electronics manufacturing facilities must use to determine their emissions. These changes were implemented beginning with the 2014 reporting year.

EPA removed the facility-specific emission factor calculation methodology as an option for fluorinated GHGs from the etch and chamber clean process types, and added a stack testing method for determining emissions of fluorinated GHGs. Therefore, starting in 2014, reporters have two options for calculating their emissions of fluorinated GHGs from the etch and chamber clean process types: using default emission factors or conducting stack measurements.

EPA also removed the facility-specific emission factor method for determining N_2O emissions. Starting in 2014, reporters will use only default factors to calculate their N_2O emissions from the chemical vapor deposition process and all other N_2O-using process types.

EPA also updated the default emission factors and the default factors for the abatement system destruction efficiency to reflect more current data collected by industry members.

Facilities continue to use the mass balance equation approach to report emissions of HTF.

Best Available Monitoring Methods (BAMM)

For 2011, facilities in the Electronics Manufacturing sector were allowed to use BAMM for any parameter that could not reasonably be measured according to the monitoring and quality assurance/quality control (QA/QC) requirements of Subpart I. The facilities were required to use the emissions calculation methodologies and equations in Subpart I, but were allowed to use a different monitoring approach than specified in Subpart I (i.e., BAMM) to determine the inputs to those equations. BAMM was allowed for any parameter for which they could not reasonably acquire, install, or operate a required piece of monitoring equipment; or procure necessary measurement services by January 1, 2011. EPA approved a number of requests for extensions of the

use of BAMM in 2012 and 2013. BAMM use is not approved for any Subpart I reporters beyond 2013.

Table 9: Electronics Manufacturing Sector – Percent of Facilities using BAMM (2011–2012)

BAMM Use	2011	2012
Electronics Manufacturing Facilities	64%	47%

Opportunities for Emissions Reductions

Emissions from the Electronics Manufacturing sector can be reduced through a variety of measures that target F-GHG, N_2O, and HTF emissions. To target F-GHG emissions, mitigation options currently used include the NF_3 remote chamber cleaning process, gas replacement, process optimization, and installation and use of abatement systems.

As compared to in-situ chamber cleaning processes, the remote cleaning process utilizes a larger portion of the F-GHG being used to clean chemical vapor deposition chambers, resulting in less unreacted gas being emitted. For gas replacement, some F-GHGs used in particular processes may be replaced with more efficient and/or lower GWP gases. Process optimization involves re-engineering a process to more efficiently use F-GHGs. Both gas replacement and process optimization are generally used provided that these changes do not negatively impact the production yield.

Various types of abatement are available to mitigate F-GHG emissions from the Electronics Manufacturing sector. These include thermal abatement, catalytic abatement, or plasma abatement. Typically, these are point-of-use abatement systems; however, recent developments through Clean Development Mechanism projects in Asia have shown that centralized abatement has worked for reducing emissions from flat panel display manufacturing.[2] In addition to being used on new facilities, abatement systems for F-GHGs can be retrofitted on existing facilities as well. Abatement systems also are available for N_2O emissions. Information submitted through the GHGRP indicates that approximately 35% of U.S. electronics facilities that reported to the GHGRP are using F-GHG and N_2O abatement, indicating there are further opportunities for the use of abatement to reduce Electronics Manufacturing sector emissions.

HTF emissions occur mainly from leakage. To reduce HTF emissions, proper handling and equipment maintenance techniques can be implemented to mitigate equipment leaks.

According to the International SEMATECH Manufacturing Initiative,[3] as of 2005 the semiconductor manufacturing industry was taking the following steps to reduce PFC emissions:

- Decommissioning fabrication plants manufacturing 150 millimeter or smaller wafers,
- Installation of abatement equipment,
- Process optimization,
- Installation of endpoint detection for processes to minimize gas consumption,
- Use of new and alternative clean chemistries,
- Integration of low emissions chemical vapor deposition (CVD) tools, and

[2] United Nations Framework Convention on Climate Change's Clean Development Mechanism project.

[3] Reduction of Perfluorocompound (PFC) Emissions: 2005 State-of-the-Technology Report, by Laurie S. Beu, Technology Transfer #05104693A-ENG, December 2, 2005

- Increasing wafer size and advanced process technology.

Additional opportunities for emissions reductions include PFC replacement and capture and recovery before emissions are released to the atmosphere.

Data Verification and Analysis

All reports submitted to EPA are evaluated by electronic validation and verification checks. If potential errors are identified, EPA will notify the reporter, who can resolve the issue either by providing an acceptable response describing why the flagged issue is not an error or by correcting the flagged issue and resubmitting their annual GHG report. Access additional information describing EPA's verification process in more detail.

Glossary

CO_2e means carbon dioxide equivalent, which is a metric used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). The carbon dioxide equivalent for a gas is calculated by multiplying the tons of the gas by the associated GWP.

F-GHG means fluorinated greenhouse gas.

FLIGHT refers to EPA's GHG data publication tool, named Facility Level Information on Greenhouse Gases Tool.

Fluorinated greenhouse gas means sulfur hexafluoride (SF_6), nitrogen trifluoride (NF_3), and any fluorocarbon except for controlled substances as defined at 40 CFR part 82, subpart A and substances with vapor pressures of less than 1 mm of Hg absolute at 25 degrees C. With these exceptions, "fluorinated GHG" includes but is not limited to any hydrofluorocarbon, any perfluorocarbon, any fully fluorinated linear, branched or cyclic alkane, ether, tertiary amine or aminoether, any perfluoropolyether, and any hydrofluoropolyether.

GHG means greenhouse gas.

GHGRP means greenhouse gas reporting program (40 CFR part 98).

GHGRP vs. GHG Inventory: EPA's Greenhouse Gas Reporting Program (GHGRP) collects and disseminates annual greenhouse gas data from individual facilities and suppliers across the U.S. economy. EPA also develops the annual Inventory of U.S. Greenhouse Gas Emissions and Sinks (GHG Inventory) to track total national emissions of greenhouse gases to meet U.S. government commitments to the United Nations Framework Convention on Climate Change. The GHGRP and Inventory datasets are complementary and may inform each other over time. However, there are also important differences in the data and approach. Access Greenhouse Gas Reporting Program and the US Inventory of Greenhouse Gas Emissions and Sinks for more information.

GWP means global warming potential, which is a measure of the total energy that a gas absorbs over a particular period of time (usually 100 years), compared to carbon dioxide. The GWP for carbon dioxide is one.

HFC means hydrofluorocarbon, which refers to compounds containing only hydrogen, fluorine, and carbon atoms. HFCs were introduced as alternatives to ozone depleting substances. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not significantly deplete the stratospheric ozone layer, but they are powerful greenhouse gases.

HTF means heat transfer fluid.

IPCC AR4 refers to the Fourth Assessment Report by the Intergovernmental Panel on Climate Change. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 2007. The AR4 values also can be found in the current version of Table A-1 in Subpart A of 40 CFR Part 98.

IPCC AR5 refers to the Fifth Assessment Report by the Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

LCD means liquid crystal display.

MEMS means micro-electromechanical systems.

MMT means million metric tons.

N_2O means nitrous oxide, which is a powerful greenhouse gas with a global warming potential of 298 times that of CO_2.

NF_3 means nitrogen trifluoride. Nitrogen trifluoride is a colorless, toxic, odorless, nonflammable gas that can be used as etchant in manufacturing microelectronics.

PFC means perfluorocarbon. Perfluorocarbon refers to a group of chemicals composed of carbon and fluorine only. These chemicals (predominantly CF_4 and C_2F_6) were introduced as alternatives, along with hydrofluorocarbons, to the ozone depleting substances. In addition, PFCs are emitted as by-products of industrial processes and are also used in manufacturing. PFCs do not harm the stratospheric ozone layer, but they are powerful greenhouse gases

PV means photovoltaic cell.

SEMI means Semiconductor Equipment and Materials International.

SF_6 means sulfur hexafluoride. Sulfur hexafluoride is a colorless gas soluble in alcohol and ether, slightly soluble in water. It is a very powerful greenhouse gas used primarily as an electrical insulator in electrical transmission and distribution systems and as a dielectric in electronics.

WWF means World Fab Forecast, a publication by Semiconductor Equipment and Materials International. **Fab** refers to a semiconductor fabrication plant.