# ELECTRONICS MANUFACTURING SECTOR, 2012

All emissions presented here are as of 9/1/2013 and exclude biogenic $CO_2$.

## Highlights

- Emissions reported by this sector decreased by nine percent from 5.6 million metric tons of $CO_2e$ in 2011 to 5.1 million metric tons of $CO_2e$ in 2012.
- The decrease is associated with a decrease in the emissions of perfluorocarbon (PFC) compounds. This reduction in emissions was associated with a similar sized reduction in total production from 2011 to 2012.

## 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 cells (PV). 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 with processes that use fluorinated GHGs as heat transfer fluids (HTF) to control temperature or clean surfaces.

## Who Reports?

In 2012, 53 facilities in the Electronics Manufacturing Sector submitted GHG reports. Total reported emissions were 5.1 million metric tons $CO_2e$ (MMT $CO_2e$), which represents less than one percent of total U.S. GHG emissions.[a]

**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 (2011–2012)**

| Source Category | Number of Reporters | |
|---|---|---|
| | 2011 | 2012 |
| Electronics Manufacturing Sector | 53 | 53 |

Of the 53 facilities that report in this sector, all 53 manufacture semiconductors and four also manufacture PV, MEMS, or LCDs in addition to semiconductors.

[a] The total U.S. GHG emissions are 6,525.6 MMT $CO_2e$ as reported in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012. U.S. Environmental Protection Agency. April 15, 2014. EPA 430-14-003. Available at: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

**Table 3: Electronics Manufacturing Sector – GHGRP Coverage**

| Source Category | 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] Estimate of size of the industry was based on 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., fabrication plants) are located together at a single facility. For additional information of the WFF produced by SEMI, please see http://www.semi.org/en/Store/marketinformation/fabdatabase/ctr_027238. The lower end of the percent of covered facilities (24%) includes R&D facilities in the denominator; the upper end of the range (56%) is based on just production facilities and excludes R&D facilities.

[b] Estimate of the quantity of industry emissions was based on actual emissions reported to the GHGRP plus estimated emissions for facilities that did not report to the GHGRP using the World Fab Forecast. The range reflects the uncertainty regarding the emission 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

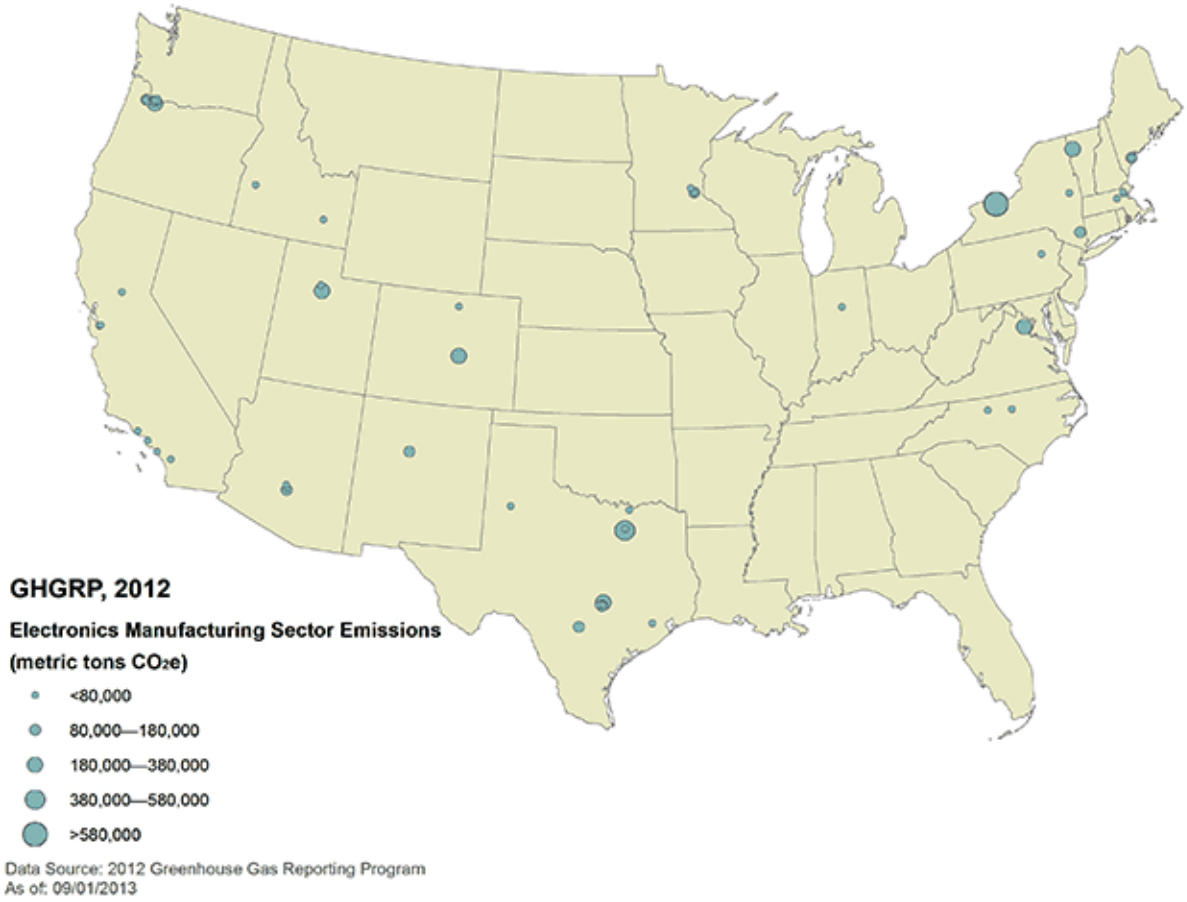
All GHG emissions data, displayed in units of carbon dioxide equivalent ($CO_2e$), reflect the global warming potential (GWP) values from the Intergovernmental Panel on Climate Change, "Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change," K.E. Trenberth, J.T. Houghton, L.G. Meira Filho, Cambridge University Press, Cambridge, United Kingdom. The GWP values also can be found in the version of Table A-1 in subpart A to 40 CFR part 98 that was published on October 30, 2009.

**Table 4: Electronics Manufacturing Sector Emissions Reported to the GHGRP (2011–2012)**

| Electronics Manufacturing Sector | Emissions (MMT $CO_2e$)[a] | |
|---|---|---|
| | 2011 | 2012 |
| Electronics Manufacturing | 5.6 | 5.1 |

[a] Represents total emissions reported to the GHGRP from this industry. Additional emissions occur at facilities that have not reported; for example, those below the reporting threshold.

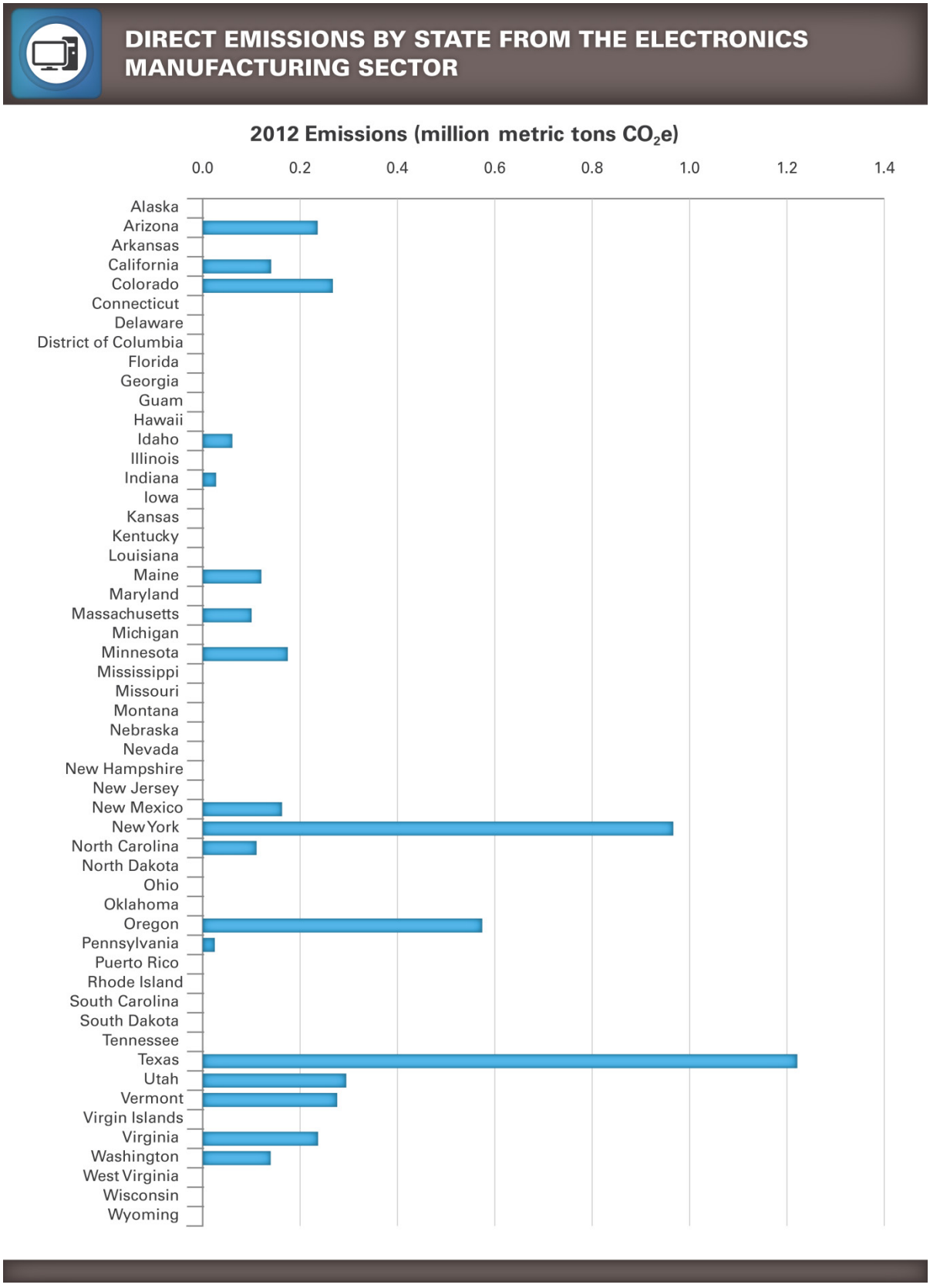
**Figure 1: Location and Emissions Range for Each Reporting Facility in the Electronics Manufacturing Sector (as of 9/1/13)**




This map 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 by visiting the Facility Level Information on Greenhouse Gases (FLIGHT) website (http://ghgdata.epa.gov).

**Figure 2: Electronics Manufacturing Sector: Emissions by State (2012)[a]**

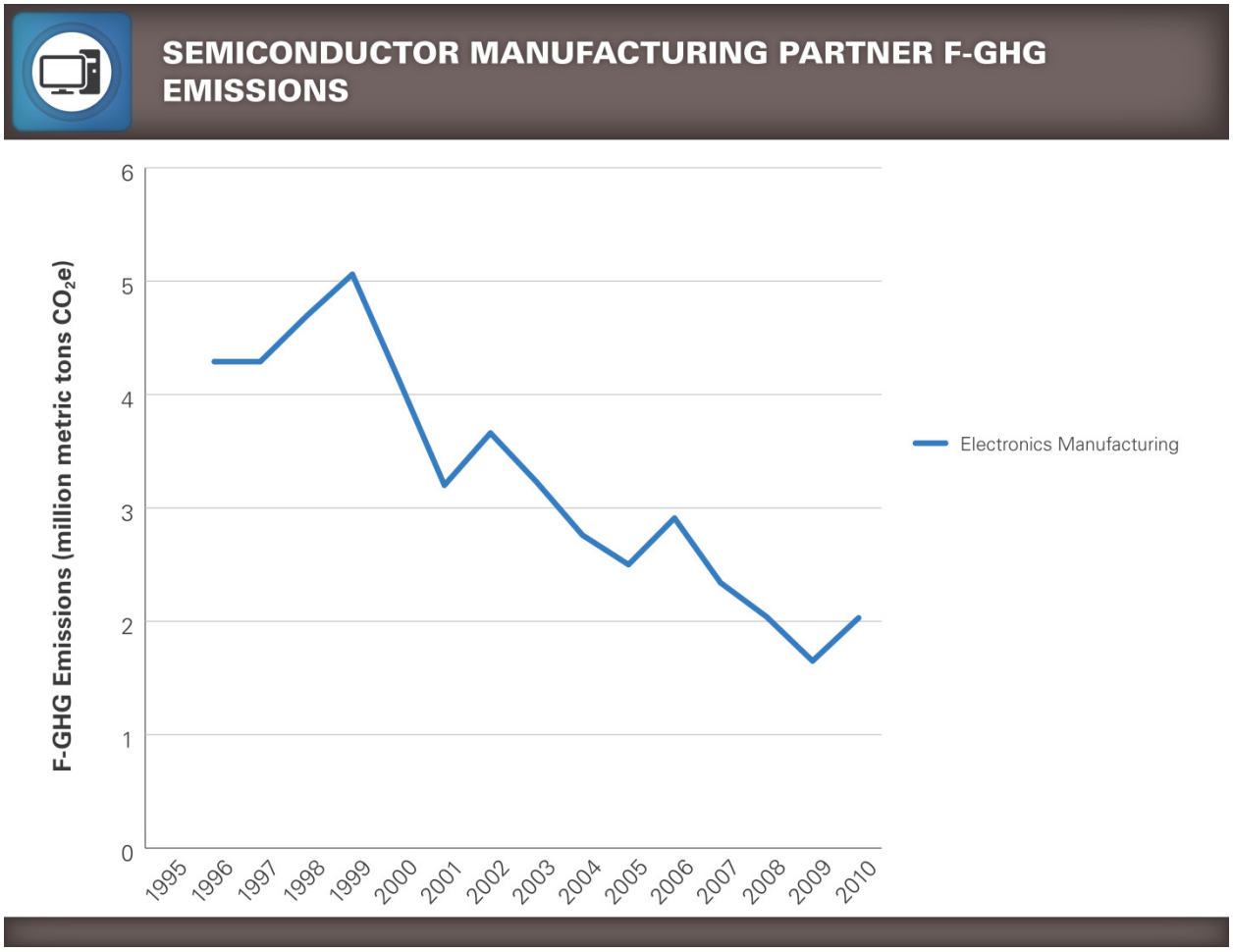



[a] Represents total emissions reported to the GHGRP from this industry. Additional emissions occur at facilities that have not reported; for example, those below the reporting threshold.

## 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 F-GHGs to EPA under the voluntary 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, 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[a]**

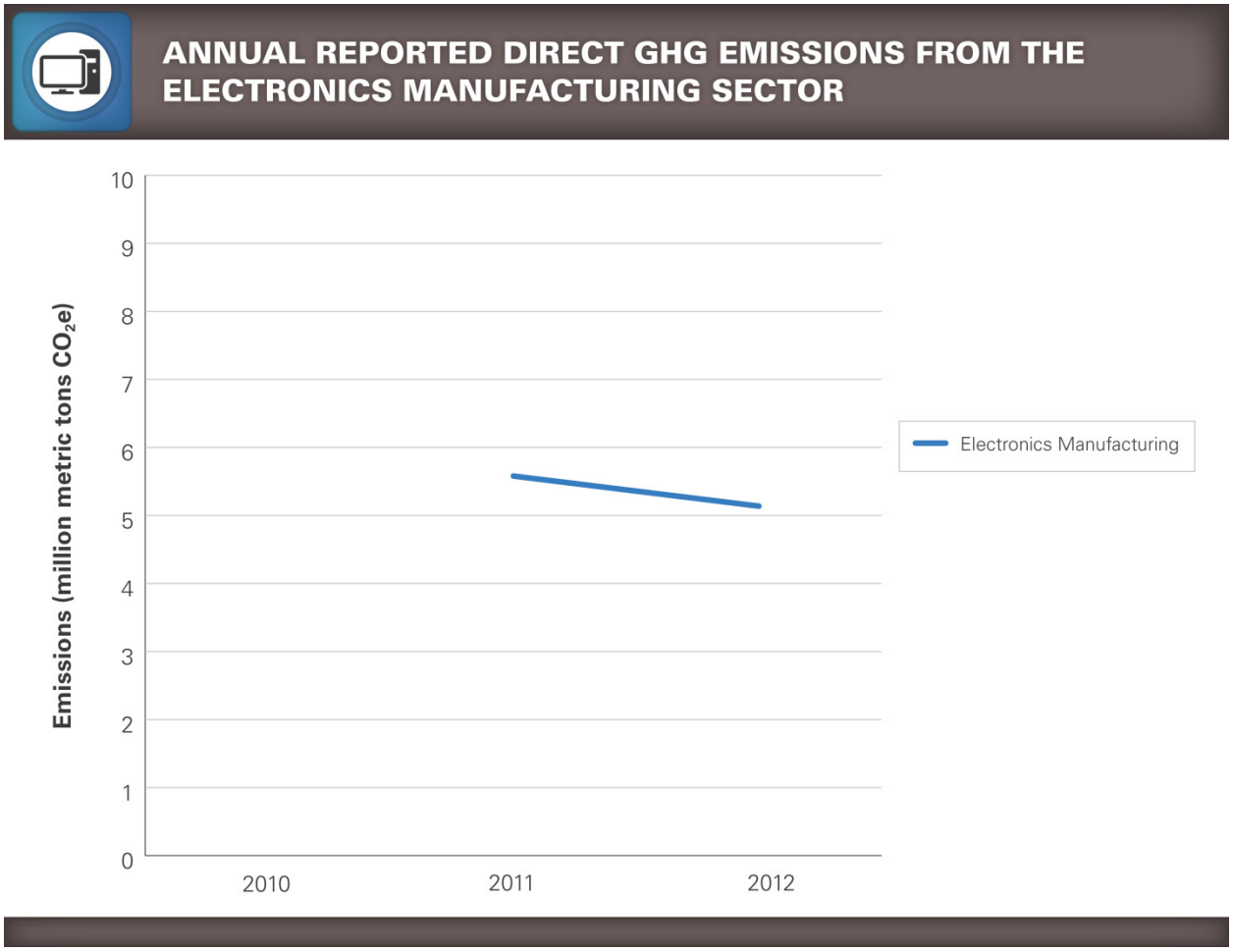



[a] The graph includes only semiconductor EPA partner F-GHG emissions, not the entire U.S. electronics manufacturing industry. Specifically, the following seven F-GHGs are represented in this graph: $CF_4$, $C_2F_6$, $C_3F_8$, $C_4F_8$, $CHF_3$, $SF_6$, and $NF_3$. Emissions of $CO_2$, $N_2O$ and HTF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

## Electronics Manufacturing Sector Emissions Trends 2011 to 2012

Emissions from the Electronics Manufacturing sector were lower in 2012 (5.1 MMT $CO_2e$) than 2011 (5.6 MMT $CO_2e$), a reduction of about 0.5 MMT $CO_2e$ (about eight percent). The decrease was not due to reductions at any specific facilities, but instead a general decrease across the industry commensurate with a similar reduction in total production. About 80% of the reduction was from decreased emissions of fluorinated GHGs. In 2012, emissions decreased at 32 facilities. Both production and emissions declined at 23 facilities; five facilities had no change in production, but a decrease in emissions; and four facilities increased production but decreased emissions.

**Figure 4: Electronics Manufacturing Sector – Emissions Trend (2011–2012)**




Click here to view the most current information using FLIGHT.

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

| Electronics Manufacturing Sector | Reporting Year | |
|---|---|---|
| | 2011 | 2012 |
| **Number of facilities** | 53 | 53 |
| **Total Reported Emissions (MMT $CO_2e$)[b]** | 5.6 | 5.1 |
| **Emissions by GHG[c]** | | |
| Carbon dioxide ($CO_2$)[d] | 1.6 | 1.5 |
| Methane ($CH_4$)[d] | ** | ** |
| Nitrous oxide ($N_2O$) | 0.2 | 0.2 |
| Sulfur hexafluoride ($SF_6$) | 0.4 | 0.3 |
| Nitrogen trifluoride ($NF_3$) | 0.7 | 0.7 |
| Hydrofluorocarbons (HFCs) | 0.1 | 0.2 |
| Perfluorocarbons (PFCs) | 2.5 | 2.3 |

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

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

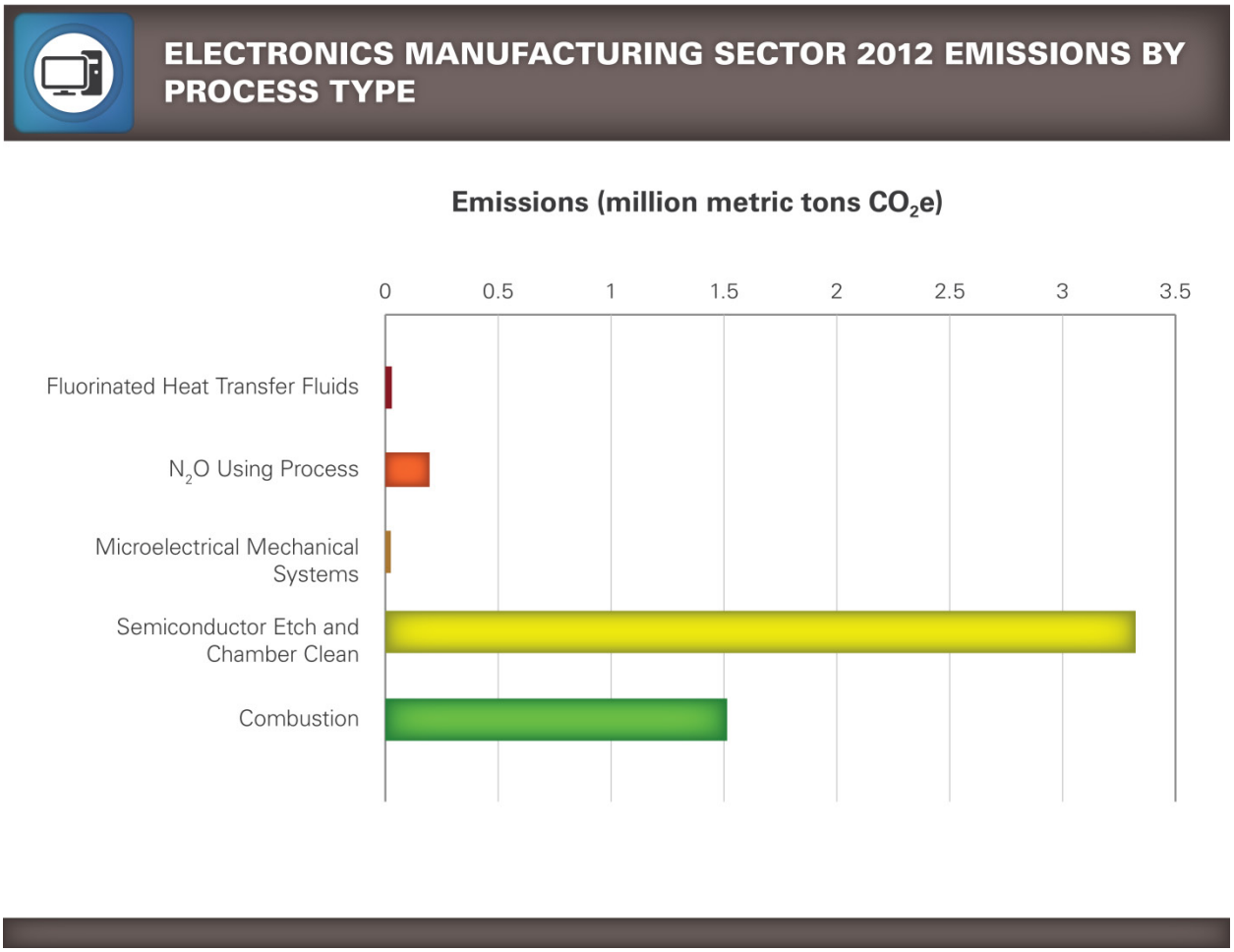
[c] Totals might not sum due to independent rounding.

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

** Total reported emissions are less than 0.05 MMT $CO_2e$.

In 2012, reporters in the Electronics Manufacturing Sector reported emissions of 112 metric tons from the use of fluorinated HTF; however, a majority of fluorinated HTF reported by facilities were not assigned a global warming potential (GWP) value for Reporting Year 2012, resulting in a disproportionate under-representation in Table 5. The total emissions in $CO_2e$ associated with these fluorinated HTF will change in future reports if GWP values are established for these compounds by the GHGRP.

**Figure 5: Electronics Manufacturing Sector 2012 Emissions by Process Type[a]**




[a] $CO_2e$ emissions from heat transfer fluids are underrepresented because the GHGRP has not assigned a GWP for most of these compounds for reporting year 2012. The EPA has proposed GWPs for heat transfer fluids, and so reported $CO_2e$ emissions from the use of heat transfer fluids is expected to increase in the future if the GWPs are adopted.

**Figure 6: Electronics Manufacturing Sector – Average Emissions per Reporter (2012)**

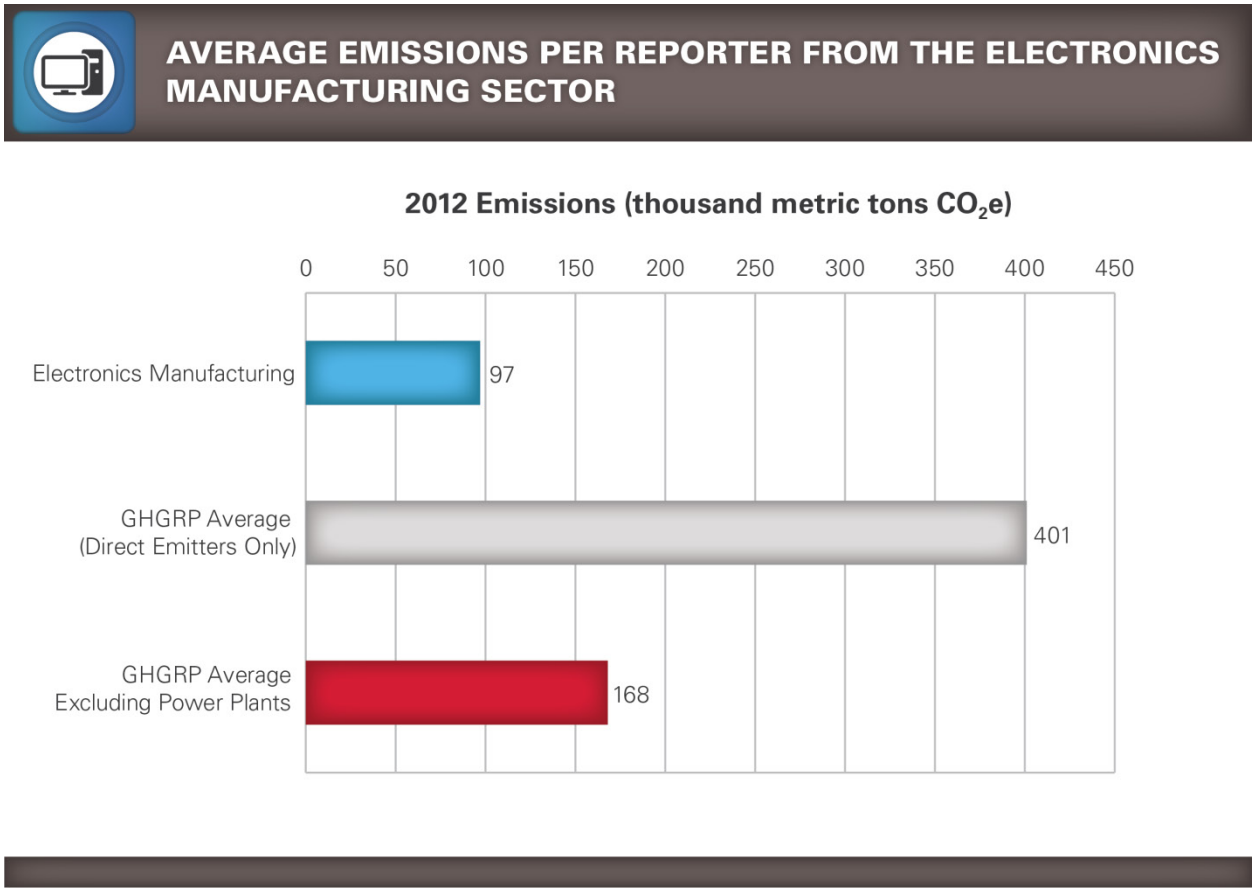
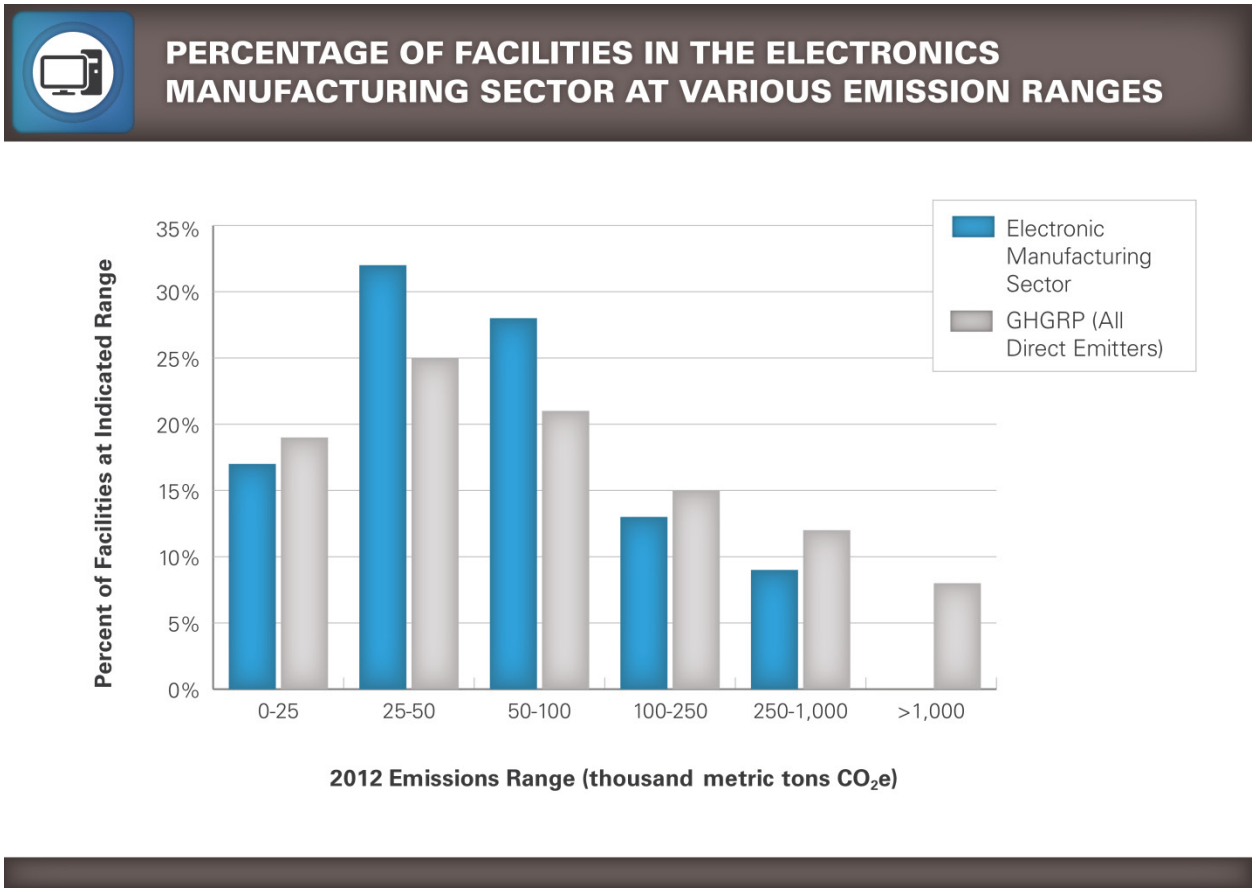



**Table 6: Electronics Manufacturing Sector – Number of Reporters by Range of Emissions (MMT $CO_2e$) (2012)**

| Electronics Manufacturing Sector | < 0.025 | 0.025 - 0.05 | 0.05 – 0.1 | 0.1 – 0.25 | 0.25 - 1 | >1 |
|---|---|---|---|---|---|---|
| Electronics Manufacturing | 9 | 17 | 15 | 7 | 5 | 0 |

**Figure 7: Percentage of Reporters by Range of Emissions (2012)**




## Calculation Methods Used

For 2011 and 2012, facilities in the Electronics Manufacturing Sector could select one of two different methodologies to report fluorinated GHG and $N_2O$ emissions. The two methodologies are default emission factors or facility-specific emission factors for different process and operating conditions. In reporting years 2011 and 2012, all reporting facilities used the default emission factors to report fluorinated GHG and $N_2O$ emissions.

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. Carbon dioxide emissions from stationary fuel combustion represent about 29% of the GHG emissions from the electronics sector.

**Table 7: Electronics Manufacturing - Methodologies**

| Type of Emissions | Methodology | Percentage of $CO_2$ Emissions Monitored by Method | |
|---|---|---|---|
| | | 2011 | 2012 |
| Combustion | Alternative Part 75 Methodology: CEMS per §98.33(a)(5)(iii) | 57.8%* | 55.9% |
| | Measured high heating values (HHVs) and default emission factors (Tier 2) | 22.7% | 22.1% |
| | Default HHVs and emission factors (Tier 1) | 19.5% | 21.8% |

* The high percentage of emissions monitored by CEMS is driven by one facility. This facility is a large business park that contains a small electronics manufacturing plant and a large centralized power plant to serve the park tenants.

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

Recently, EPA made three changes to the methodologies that electronics manufacturing facilities must use to determine their emissions. These changes will impact information reported 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 EPA 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 will 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 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 8: 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 electronics manufacturing 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 clean 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 process 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 production yield.

Various types of abatement are available to mitigate F-GHG emissions from electronics manufacturing. 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.[b] 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 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,[c] 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 emission chemical vapor deposition (CVD) tools, and
- Increasing wafer size and advanced process technology.

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

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[b] See the United Nations Framework Convention on Climate Change's Clean Development Mechanism project: https://cdm.unfccc.int/.

[c] See "Reduction of Perfluorocompound (PFC) Emissions: 2005 State-of-the-Technology Report," by Laurie S. Beu, Technology Transfer #05104693A-ENG, December 2, 2005, available: http://www.epa.gov/semiconductor-pfc/documents/final_tt_report.pdf.

## 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. Additional information describing EPA's verification process in more details is available here.

## 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 (http://ghgdata.epa.gov/ghgp).

**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. For more information, please see http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

**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.

**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.

**$SF_6$** 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.

**SEMI** means Semiconductor Equipment and Materials International.

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