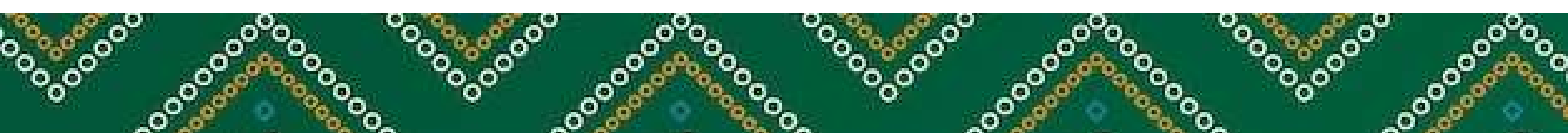


# U.S. GHG EMISSIONS ESTIMATES FOR ELECTRONICS MANUFACTURING

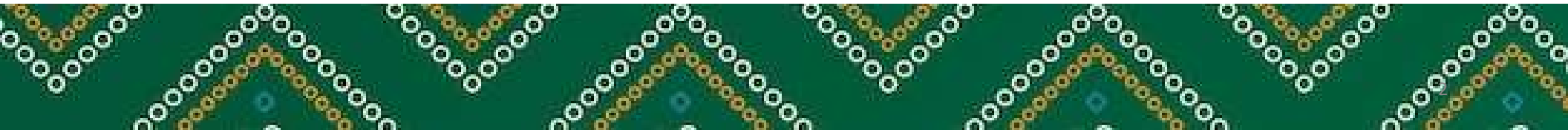
April/May 2024

U.S. Environmental Protection Agency

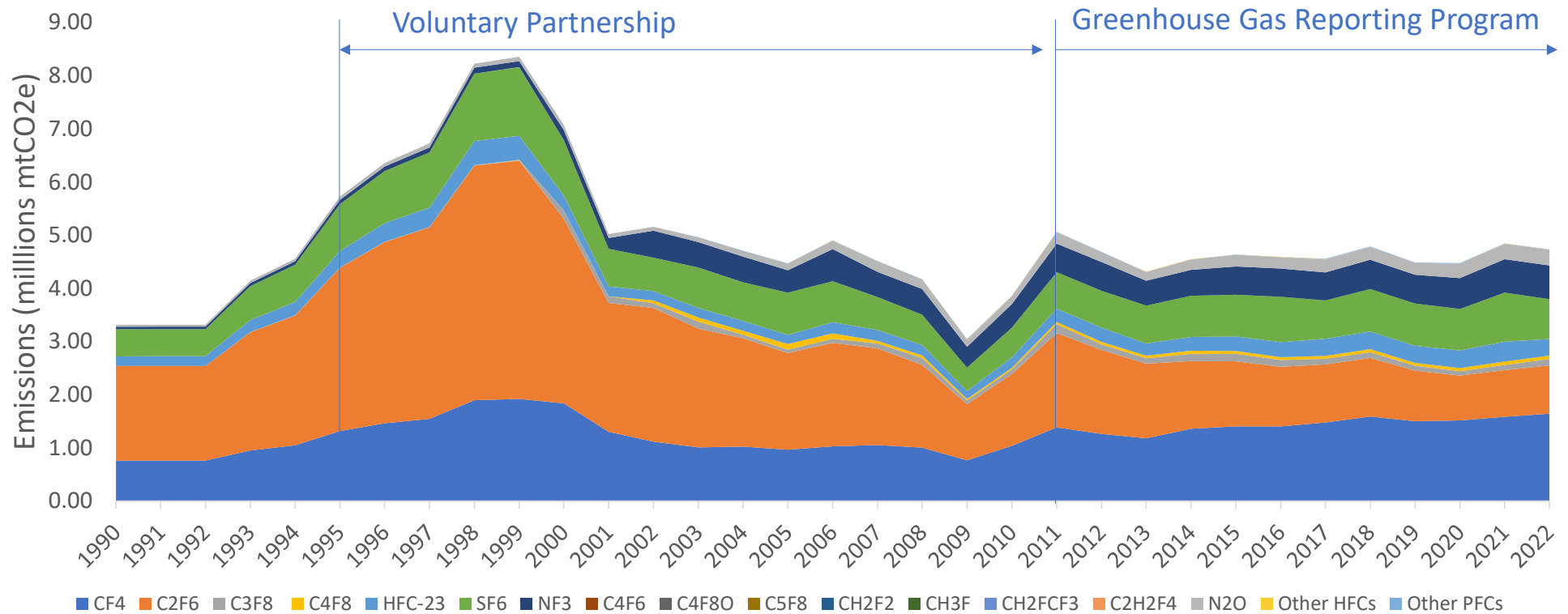


# OVERVIEW

- 1990-2021 GHG emissions from Electronics Manufacturing by Gas
- Methods
  - Trends
  - Data Sources
  - Extrapolation to the U.S.
  - Adjustments for Timeseries Consistency
- QA/QC
- Future improvements



# DIRECT GHG EMISSIONS FROM ELECTRONICS MANUFACTURING, 1990-2022 (U.S. GHG INVENTORY)<sup>a</sup>

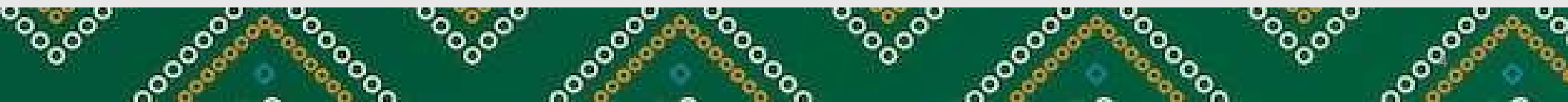


<sup>a</sup>Emissions reported using GWPs from the IPCC Fifth Assessment Report.



## SOURCES AND TYPES OF GHGs EMITTED DURING ELECTRONICS MANUFACTURING

Source	GHG(s) Emitted
Incompletely utilized FC gases fed into plasma etching, wafer cleaning, and chamber cleaning processes	Multiple FC gases
By-products formed from fluorine-containing gases (e.g., $\text{NF}_3$ , $\text{F}_2$ , $\text{COF}_2$ ) and carbon-containing fluorinated compounds fed into plasma etching, wafer, cleaning, and chamber cleaning processes that involve carbon-containing films	Multiple FC gases
By-product formed in some combustion-based FC abatement systems (newly identified in 2019 Refinement)	$\text{CF}_4$
Incompletely utilized $\text{N}_2\text{O}$ fed into thin film deposition and other (e.g., diffusion) processes	$\text{N}_2\text{O}$
Fluorinated liquids used for temperature control, device testing, cleaning substrate surfaces and other parts, and soldering	Multiple FC gases

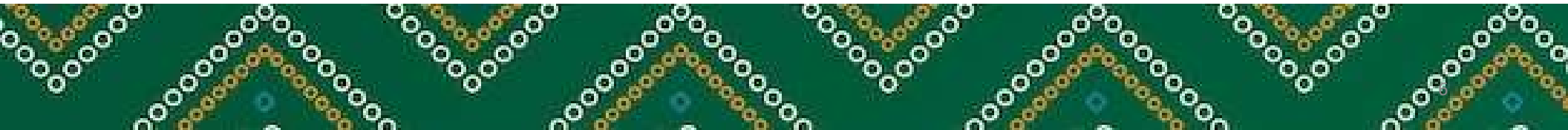


# ELECTRONICS - ESTIMATION METHODS

IPCC 2019 Refinement Tiers	2006 Guidelines Tiers	Emissions Calculation Method
Tier 1	Tier 1	Default emission factors x annual production [for PV, x fraction of production that uses F-GHGs]
Tier 2a	Tier 2a	Gas consumption x default emission factors x fraction of gas destroyed using emissions control technologies by gas
Tier 2b		Gas consumption by wafer size [200 or smaller vs 300 mm]x Default emission factors x gas consumption x fraction of gas destroyed using emissions control technologies by gas and wafer size
	Tier 2b	Gas consumption by process type x Default Emission Factors x fraction of gas destroyed using emissions control technologies by wafer size, gas and process type
Tier 2c		Gas consumption by wafer size and process type x Default Emission Factors x fraction of gas destroyed using emissions control technologies by wafer size, gas and process type <b>[US Inventory uses a Tier 2c approach with country specific emission factors]</b>
Tier 3a	Tier 3	Measure process specific parameters for each recipe or family of similar recipes
Tier 3b		Stack testing [Although an available option, no US facilities report stack testing]

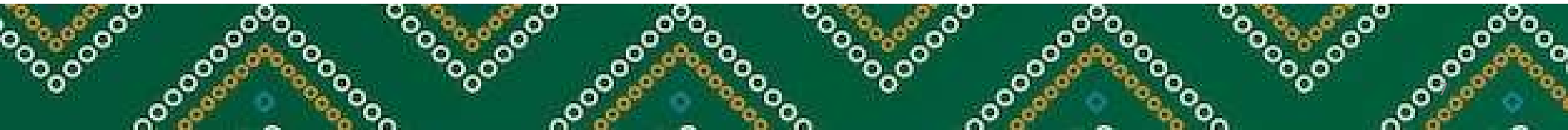
# METHODS – US DATA SOURCES

- GHG Reporting Program (GHGRP) data available from 2011-2022.
  - Required to be reported by Electronics Manufacturing facilities with estimated emissions (based on capacity) equivalent to 25,000 mtCO<sub>2</sub>e or higher.
  - Approximately ~93-96% of total estimated emissions are reported through the GHGRP for the electronics industry
  - EPA uses verified estimates from reporting facilities when estimating U.S. emissions.
- Voluntary Partnership data available for earlier years
  - For the electronics industry, emission estimates from partners available beginning from 1996. Voluntary reported data accounted for ~69-81% of emissions from the industry
  - Industry participants in EPA's emissions reduction partnerships ("partners") developed and submitted their emissions estimates based on EPA/IPCC methods.
  - In 2011, the electronics industry began reporting to the GHGRP instead of the voluntary partnership.
- Published Industry data – to estimate emissions for non-reporters, use published fab capacity data (e.g. World Fab Forecast), estimates of layers by technology and US capacity utilization data.



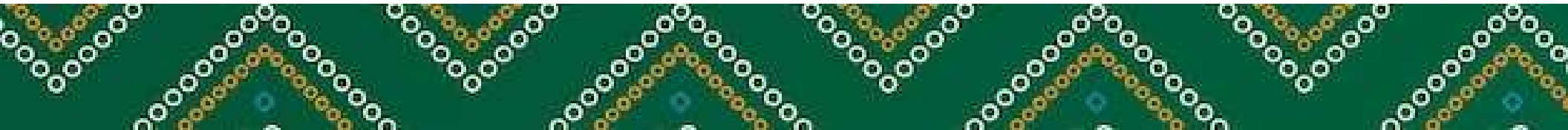
# SEMICONDUCTORS

- Fabs representing 65% - 98% of U.S. activity (layer-area) have reported emissions (to a third party or EPA) since 1995. Emissions from 95-98% of U.S. activity reported through GHGRP.
  - Reporters provide emissions by gas but not gas consumption. We estimate consumption based on reported emissions.
- 1990-1994 emissions estimated using a model (PEVM). PEVM uses an EF derived from 1995-1999 emissions reported by partners, and activity data based on Si area and layers per device (total manufactured layer-area or TMLA).
- 1995-2022 emissions for non-partner and non-reporter fabs estimated in three distinct ways:
  - 1995-1999: Estimates of partner fabs scaled to the U.S. level based on ratio of U.S. layer-weighted silicon capacity to the layer-weighted silicon capacity of reporting fabs.
  - 2000-2010: Estimates for non-partner fabs developed using PEVM, adjusting the emission factor. The average non-partner emission factor was determined by interpolating between the partner emission factor estimated for 1999 and the GHGRP reporter emission factor estimated for 2011.
  - 2011-Present: EPA's GHGRP program for semiconductor manufacturing began. Emissions were directly reported for this group. The emission factor for non-reporters was developed based on estimated TMLA and reported emissions from reporting facilities. (in units of mass of CO<sub>2</sub> Eq./TMLA [MSI], now estimated by gas)



## ESTIMATING EMISSIONS FROM NON-REPORTERS

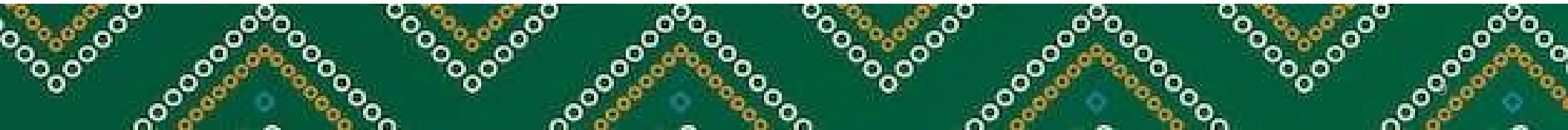
- Depending on the year, GHGRP or voluntary reporters represent 65% to 97% of the semiconductor manufacturing activity resulting in emissions.
- For non-reporters (do not meet the GHGRP reporting threshold or did not report to the voluntary partnership) need to identify and quantify
  - activity resulting in emissions; and
  - appropriate emission factors
- Assume that non-reporters emit at same rate as reporters (unabated). We develop emissions factors by gas (unabated) per TMLA (layer weighted area) of production to apply to non-reporter estimated TMLA (based on production capacity, capacity utilization and estimated layers) for semiconductors.





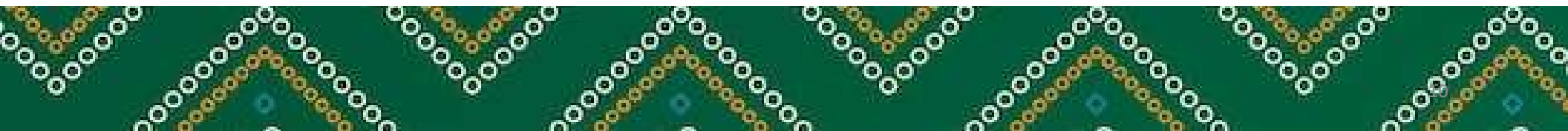
# SEMICONDUCTORS

- Emissions from Fluorinated Heat Transfer Fluids (F-HTFs) were also calculated and reported in the National Inventory Report.
  - Only F-HTF emissions that consist of HFCs or PFCs are included in the National Inventory totals.
    - HFCs or PFCs used as HTFs are less than 5% of total F-HTF emission.
    - Other F-HTFs consist of hydrofluoroethers and fully fluorinated GHGs (e.g., PFPMIE, perfluoroamines). Their emissions are provided in NIR for informational purposes.
  - F-HTF emissions account for 2%-23% of total annual GWP-weighted emissions from semiconductor manufacturing.
  - Emissions estimates for non-reporting facilities are calculated using the ratio of reported F-HTF emissions to F-GHG emissions from etch/clean processes. The ratio is then multiplied by estimated emissions from etch/clean processes of non-reporters to obtain their F-HTF emissions.



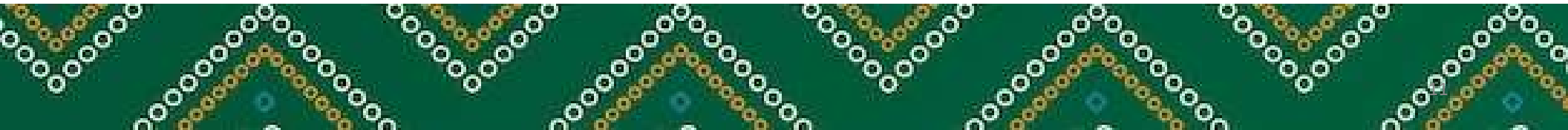
## RECENT UPDATES

- In 2014, the GHGRP updated reporting requirements for the electronics industry, which included updating the default EFs. For timeseries consistency, we updated the inventory estimates for 2011-2013 using the revised EFs, assuming that the updated emission factors reflected improved data and not a change in actual emission factors.
- In the 2024 Inventory, we updated our assumptions about which fabs should be included in the non-reporter population (i.e. use F-GHGs but do not report to the GHGRP). It is important to update these as technology changes.



# PHOTOVOLTAICS & MEMS

- Emissions from Photovoltaic (PV) manufacturing were also calculated and reported in the National Inventory Report.
  - The emission factor for non-reporters was developed based on data reported to the GHGRP and estimated production. This EF is applied to the estimated capacity of non-reporters. There currently are no PV reporters to the GHGRP; so, emission factors developed from historical data are used.
  - When estimating emissions from non-reporters, we currently assume that all silicon PV cell manufacturing uses F-GHGs and that non-silicon PV does not.
- Emissions from MEMS manufacturing were also calculated and reported in the National Inventory Report.
  - Only reported emissions are included in the National Inventory Report. Emissions estimates for non-reporting facilities are a planned improvement.



# REPORTING TABLE - ELECTRONICS

TABLE 2(II).B-H SECTORAL BACKGROUND DATA FOR INDUSTRIAL PROCESSES AND PRODUCT USE  
Sources of fluorinated substances  
(Sheet 1 of 2)

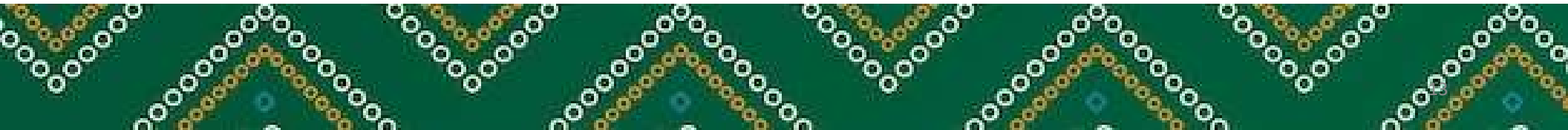
Inventory 2022  
Submission 2024 v1  
UNITED STATES OF AMERICA

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Gas (please specify) <i>One row per substance</i>	ACTIVITY DATA		IMPLIED EMISSION FACTORS <sup>(1)</sup> (kg/t)	EMISSIONS	
		Description	(t)		Emissions <sup>(2)</sup> (t)	Recovery <sup>(3)</sup> (t)
<b>E. Electronics industry<sup>(7)</sup></b>						
1. Integrated circuit or semiconductor						
		Consumption				
HFC-23	HFC-23	Consumption	60.72	415.34	25.22	NA
HFC-32	HFC-32	Consumption	60.72	17.08	1.04	NA
HFC-41	HFC-41	Consumption	5.90	414.51	2.45	NA
HFC-43-10mee	HFC-43-10mee	Consumption	NO	NO	NO	NO
HFC-125	HFC-125	Consumption	NO	NO	NO	NO
HFC-134	HFC-134	Consumption	NO	NO	NO	NO
CF4	CF4	Consumption	281.55	878.13	247.24	NA
C2F6	C2F6	Consumption	103.69	787.21	81.62	NA
C3F8	C3F8	Consumption	37.83	359.78	13.61	NA
C4F10	C4F10	Consumption	NO	NO	NO	NO
c-C4F8	c-C4F8	Consumption	55.27	110.75	6.12	NA
C5F12	C5F12	Consumption	NO	NO	NO	NO
C6F14	C6F14	Consumption	NO	NO	NO	NO
C10F18	C10F18	Consumption	NO	NO	NO	NO
c-C3F6	c-C3F6	Consumption	NO	NO	NO	NO
Unspecified mix of PFCs	Unspecified mix of PFCs	Consumption	10.20	83.38	0.85	NE
Unspecified mix of HFCs and PFCs	Unspecified mix of HFCs and PFCs	Consumption	NE	NE	NE	NE
SF6	SF6	Consumption	113.52	276.40	31.38	NA
NF3	NF3	Consumption	1312.64	30.00	39.38	NA

Consumption estimated based reported emissions

# QA/QC

- GHGRP Reports are submitted electronically and go through an annual multi-step verification process, including automatic checks during data-entry, statistical analyses on completed reports, and staff review of the reported data.
- Reports by semiconductor manufacturers kept by third parties were audited annually through 2008 by EPA or by EPA contractors.
- Inventory QA/QC is tracked and documented with designated QC checklists/ reporting forms each year.



# FUTURE IMPROVEMENTS

- The Greenhouse Gas Reporting Program recently revised reporting requirements, including updates to emission factors and DREs. We plan to consider how/if we need to update the inventory to reflect these updates.
  - E.g. Consider whether the revised DREs and/or revised EFs are reflective of entire timeseries or more appropriate for modern abatement equipment.
- We plan to estimate for non-reporter emissions from MEMS manufacturing
- We continue to assess our methodology for determining appropriate activity metric (e.g. TMLA, TMLA + turns)

