Supplementary Material for F-Gases at the Fenceline

Exposing the Fluorochemical Production Sector's Undisclosed Emissions

Full report here

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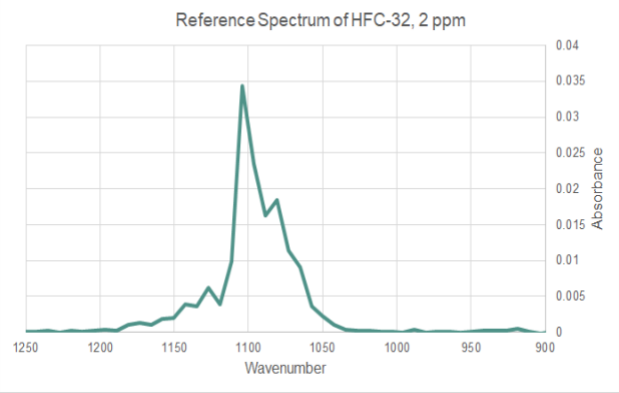
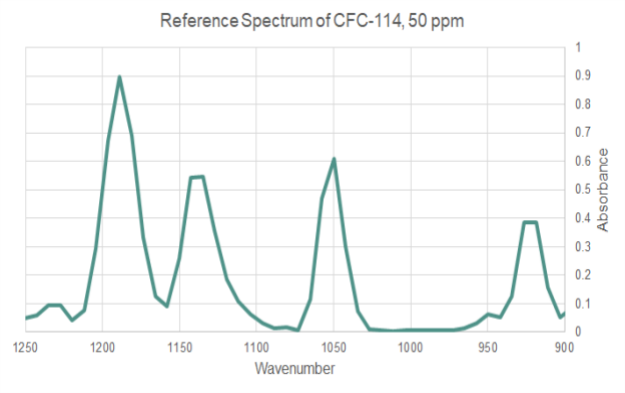
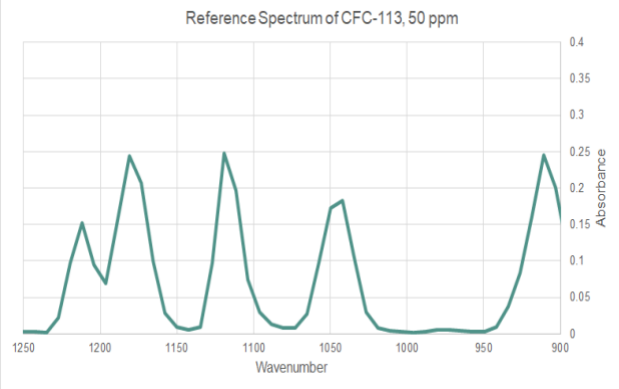
Annex 1: Reference Spectra of Compounds Identified in Samples

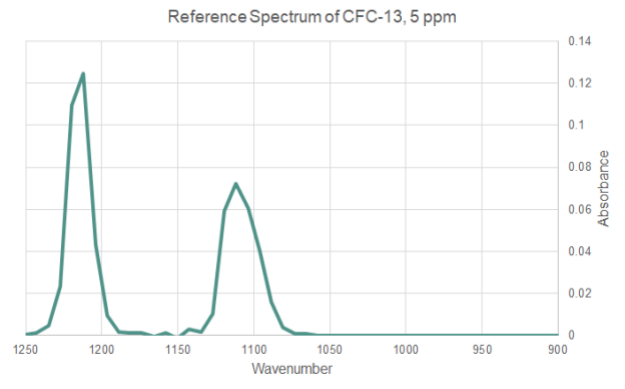
As described in the report's methodology overview, a library of reference spectra of 496 gases was used to compare with the infrared footprint of air samples collected at the production facilities. The reference spectra for all gases detected are shown below, along with their sources.

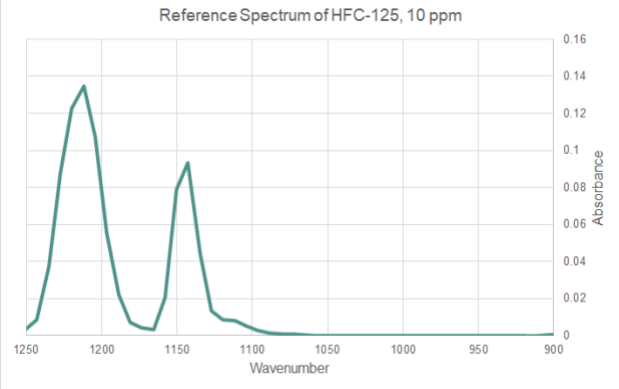
Reference Spectra from Gasmet Library

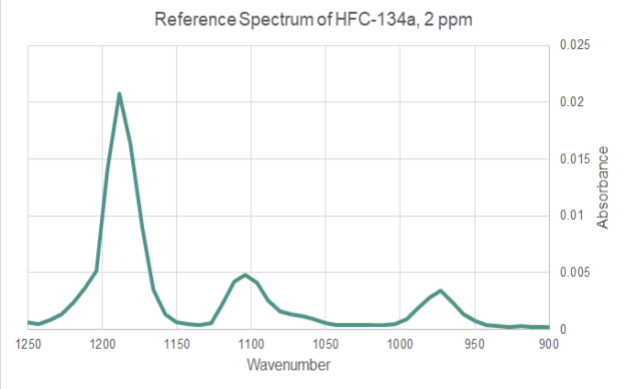


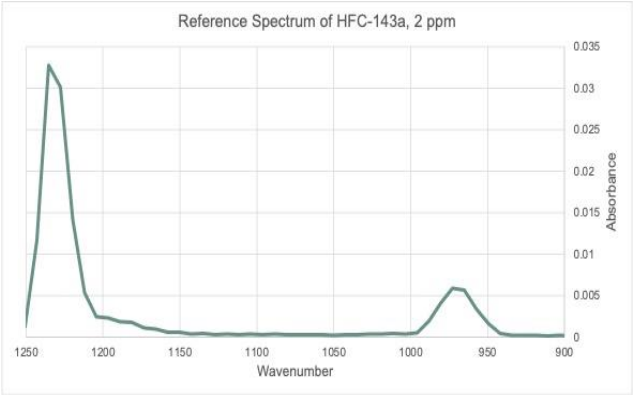


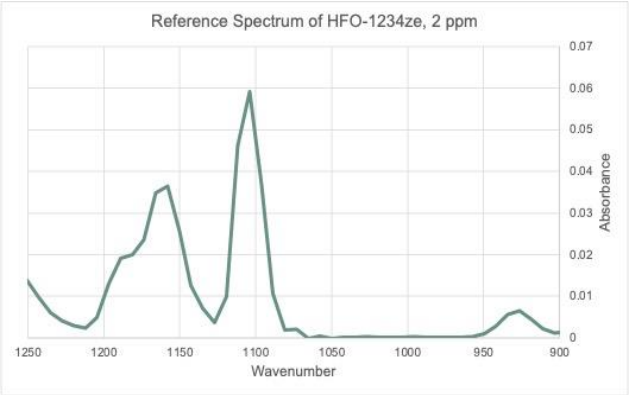






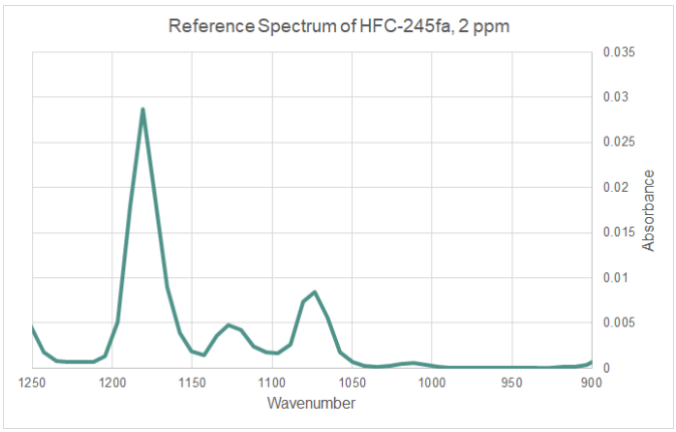




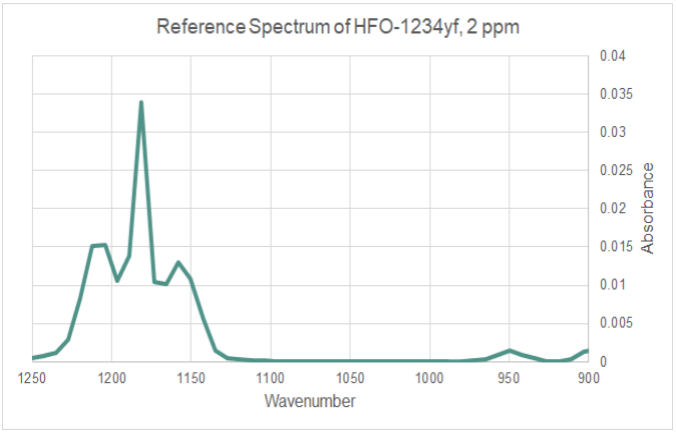


Reference Spectra from HITRAN

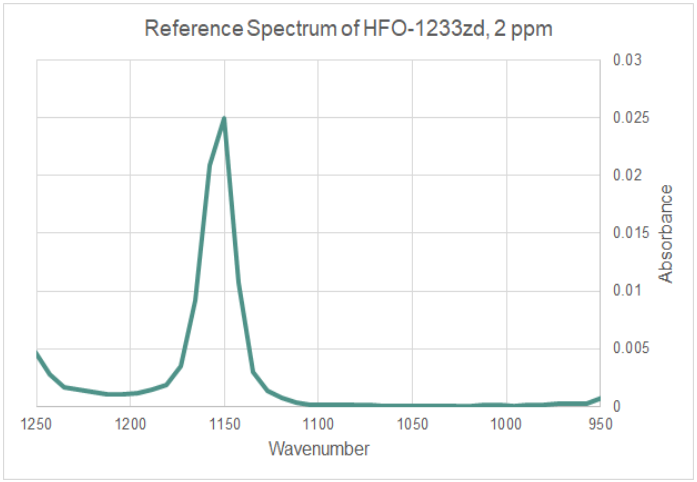
In cases where reference spectra were not available in the reference library provided by Gasmet, reference spectra were added to the library from the HITRAN Molecular Spectroscopic database (2020).[1] Infrared cross-section data from Hitran was scaled based on its relationship with the HITRAN cross-section for HFC-134a. This relationship is determined by comparing the peak values of both, and the data is adjusted accordingly to align with the measured reference from the Gasmet library for HFC-134a at 2 ppm.



Reference 1166: Sihra et al. (2001)[2]



Reference 1152: Nielsen et al. (2007)[3]



Reference 1135: Andersen et al. (2008)[4]

Annex 2: Summary of U.S. Fluorochemical Production Facilities Emissions Reporting

The report provides highlights from EIA's review and analysis of emissions reported under mandatory federal emissions reporting programs applicable to fluorinated gas (F-gas) production. Below is a more detailed overview of the reporting requirements under each program and analysis of publicly available data on emissions of F-gases and toxic substances reported by U.S. production facilities.

U.S. Greenhouse Gas Reporting Program

Under the Subpart L of the Greenhouse Gas Reporting Program (GHGRP) facilities report emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), nitrogen trifluoride (NF3), and hydrofluoroethers (HFEs).[5] Under Subpart O, Facilities are also required to separately report HFC-23, a by-product of producing the hydrochlorofluorocarbon HCFC-22 and other fluorochemicals.[6]

Facilities with F-gas production processes must report to the GHGRP if their emissions, in the absence of controls, would equal 25,000 metric tonnes CO_2 equivalent (CO_2e) per year or more. The only exception is that any facility that produces HCFC-22 must report if the production process generates HFC-23 as a byproduct.[7] In addition, facilities that operate devices to destroy more than 2.14 metric tonnes of HFC-23 annually must report.

Toxics Release Inventory (TRI)

Emissions of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and carbon tetrachloride (CTC) are not reported under the GHGRP, but are reported separately under the Toxics Release Inventory (TRI).

The TRI is a mandatory Federal reporting program for industrial and federal facilities tracking releases and disposal of toxic pollutants posing a threat to human health or the environment. TRI reporting covers 787 chemicals across 33 chemical categories and it is regularly updated through an EPA review and petition process.[8] In terms of F-gas releases, TRI reporting covers most CFCs and HCFCs, but does not currently cover industrial releases of any HFCs or their replacements, hyrdrofluoro-olefins (HFOs) or hydrochloro-olefins (HCFOs).[9] HFO and HCFO emissions are not required to be reported by either the GHGRP or the TRI programs.

Reported Fluorinated Greenhouse Gas Emissions

EIA conducted an analysis of combined reporting under the EPA's GHGRP and TRI programs for the most recent four years of reported data available (2018-2021) for the top 15 facilities in the chemical sector reporting fluorinated greenhouse gas emissions.[10] Although overall reported F-gas emissions are declining with the control of HFC-23, reported CFC emissions increased somewhat during this period.

Table 1: Chemical Sector Top 15 Facilities Reported Total Emissions (Tonnes CO_2e)*					
	2018	2019	2020	2021	Total
HFC-23	4,172,862	4,452,719	2,677,956	3,095,767	14,399,304
Other HFCs	1,380,071	1,288,591	899,030	831,573	4,399,265
HCFC	1,224,545	991,028	742,994	804,440	3,763,007
CFC	1,989,037	2,210,264	2,731,292	2,305,630	9,236,222
PFC	553,769	527,876	572,353	361,360	2,015,358
SF6	0	1,177	1,462	0	2,638

*Utilizes Assessment Report 6, 100-yr Global Warming Potentials

Table 2: Reported Emissions by Facility (2018-2021) (Tonnes CO_2e)						
Facility	**HFCs**	**CFCs**	**HCFCs**	**PFCs**	**SF6**	**Total**
Chemours - Louisville Works	11,744,289	0	2,196,752	0	0	13,941,041
Arkema Inc. - Calvert City	2,629,041	0	557,650	0	0	3,186,691
Honeywell - Geismar	1,671,355	83,283	79,153	0	0	1,833,791
Chemours - Washington Works	688,997	6,228	105,852	416,378	0	1,217,455
Chemours - El Dorado	328,809	0	9	16,336	0	345,153
Chemours - Corpus Christi	190,317	214,924	8,444	0	0	413,686
Chemours - Fayetteville	176,784	0	0	0	0	176,784
Daikin America Inc. - Decatur	173,519	0	364,264	20,346	0	558,129
Honeywell - Baton Rouge	147,682	5,359,336	219,849	0	0	5,726,867
Mexichem Fluor Inc. - Saint Gabriel	87,510	0	35,418	0	0	122,928
3M - Cordova	83,508	0	0	2,175,661	3,828	2,262,997
Chemours - Chamber Works	10,255	0	0	0	0	10,255
3M - Cottage Grove	1,070	0	248	1,370	0	2,689
3M - Decatur	296	0	195,368	0	0	195,664
Honeywell - Colonial Heights	0	3,572,451	0	0	0	3,572,451

*Utilizes Assessment Report 6, 100-yr Global Warming Potentials

Analysis of Toxic Releases Reporting

Facilities producing fluorochemicals, including HFCs and/or their newer substitutes HFOs for refrigerants and other uses are known to be releasing toxic chemicals with potential health impacts on plant workers and surrounding communities. A 2021 environmental justice analysis conducted by EPA identified 17 chemicals used or released as by-products in HFC production with a variety of harmful health effects.[11]

EIA analyzed EPA TRI reporting for the 15 facilities identified in Table 2. Our analysis covers the chemicals identified by EPA's analysis, and any additional chemicals appearing in the list of the top 15 TRI chemicals (other than CFCs and HCFCs) by volume of total releases reported between 2018-2021. The resulting list of chemicals and associated health impacts are summarized below in Table 3.

Table 3: Toxic Chemicals Used or Released from Fluorochemical Production Facilities

Chemical Name	Health Effects
Antimony Compounds*	Metabolic, Other Systemic
Butyraldehyde	Respiratory
Carbon Tetrachloride	Cancer, Developmental, Hepatic, Reproductive
Chlorine	Ocular, Respiratory
Chloroform	Cancer, Developmental, Hepatic, Renal, Respiratory
Chromium Compounds*	Cancer, Gastrointestinal, Hematological, Respiratory
Cobalt Compounds*	Cancer, Hematological, Respiratory
Ethylidene dichloride (1,1-Dichloroethane)	No information
Ethylene dichloride (1,2-Dichloroethane)	Cancer, Hepatic, Renal
Hydrochloric acid	Respiratory
Hydrogen fluoride	Ocular, Respiratory
Methylene chloride (Dichloromethane)	Cancer, Hematological, Hepatic, Neurological
Methanol	Birth Defects, Ocular
Methyl acrylate	Respiratory, Ocular
Nickel Compounds*	Body Weight, Cancer, Hematological, Immunological, Respiratory
Nitrate/Nitrite compounds	Reproductive, Cardiovascular, Developmental
Sulfuric acid	Respiratory
Tetrachloroethylene (Perchloroethylene)	Body Weight, Cancer, Developmental, Hepatic, Neurological, Ocular, Renal, Respiratory
Tetrafluoroethylene (TFE)	Potential Cancer
Toluene	Hepatic, Renal, Potential Cancer
Methyl chloroform (1,1,1-Trichloroethane)	Body Weight, Hepatic, Neurological
Trichloroethylene	Cancer, Cardiovascular, Developmental, Immunological, Neurological, Ocular

Vinyl chloride (chloroethene)	Cancer, Developmental, Hepatic, Neurological, Ocular, Respiratory
Vinylidene chloride (1,1-dichloroethylene)	Hepatic, Other Systemic
Xylene isomers	Respiratory, Neurological

Notes: * Denotes toxic chemicals that are used as a catalyst in HFC production.

Table 4: Reported Total Releases of Toxic Chemicals* by Facility (2018-2021) (pounds)	
Chemours - Chamber Works	2,115,369
3M - Cottage Grove	1,998,874
Chemours - Washington Works	1,714,721
Chemours - Fayetteville	316,378
3M - Decatur	274,157
Daikin America Inc. - Decatur	259,388
Arkema Inc. - Calvert City	243,901
Honeywell - Baton Rouge	205,479
Honeywell - Geismar	201,211
3M - Cordova	157,803
Chemours - Corpus Christi/Ingleside	108,326
Chemours - El Dorado	31,808
Chemours - Louisville Works	15,536
Mexichem Fluor Inc. - Saint Gabriel	12,500

*Total Releases of Toxic Chemicals listed in Table 3

Annex 3: Chemical Pathways Considered Likely to Have "Significant" Emissions

In 2023, responding to a request for information on gaps in global atmospheric monitoring of emissions and options to enhance that monitoring, the Montreal Protocol's Technical and Economic Assessment Panel (TEAP) conducted an assessment of chemical production pathways likely to produce "substantial emissions" of controlled substances.[12] TEAP only considered chemical pathways with a combination of high potential emissions rates and high global production to meet the threshold of "substantial emissions" equating to greater than around 1,000 tonnes of controlled substance emitted per year.

The TEAP assessment identified twenty-four production pathways considered likely to have "substantial emissions'' of controlled substances: CFC-113, CFC-113a, CFC-114, CFC-115, CTC, HCFC-22, HCFC-124, HCFC-141b, HCFC-142b, HFC-23, HFC-32, HFC-125, HFC-134a, HFC-125, HFC-143a, HFC-152a, HFC-245fa, HFC-227ea, and 1,1,1-trichloroethane (methyl chloroform). The information in TEAP's assessment for the 24 chemical pathways is summarized in Table 5 below. It should be noted that the TEAP assessment does not capture emissions of substances that are not controlled under the Montreal Protocol, but may be emitted as a result of production or feedstock uses of controlled substances, such as by-product emissions of PFC-318 from feedstock use of HCFC-22 in producing polytetrafluoroethylene (PTFE).

Table 5: Chemical Pathways Considered Likely to Have Significant Emissions in TEAP May 2023 Progress Report

Substance emitted	Chemical pathway	Reason for presence of controlled substance
CFC-113	Perchloroethylene to CFC-113	Product
CFC-113a	CFC-113 to CFC-113a	Product
CFC-114	Perchloroethylene to CFC-114	Product
CFC-115	Perchloroethylene to HFC-125	By-product
CTC	Methyl chloride to dichloromethane to chloroform to CTC	Product/By-product
HCFC-22	Chloroform to HCFC-22	Product
HCFC-22	HCFC-22 to TFE/HFP by pyrolysis	Feedstock
HCFC-124	Perchloroethylene to HCFC-124	Product
HCFC-141b	1,1-Trichloroethane or vinylidene chloride (VDC) to HCFC-141b	Product
HCFC-141b	1,1,1-Trichloroethane or VDC to HCFC-141b	Co-product
HCFC-142b	1,1,1-Trichloroethane or VDC to HCFC-142b	Product
HCFC-142b	HCFC-142b to VDF to PVDF	Feedstock
HCFC-142b	HFC-152a to HCFC-142b	Product
HFC-23	Chloroform to HCFC-22	By-product
HFC-23	Chloroform to HCFC-22 to TFE/HFP to HFC-227ea	By-product in HCFC-22 production step
HFC-32	Dichloromethane to HFC-32	Product
HFC-134a	Trichloroethylene to HFC-134a	Product
HFC-125	Perchloroethylene to HFC-125	Product
HFC-143a	1,1,1-Trichloroethane or VDC to HFC-143a	Product/Co-product
HFC-152a	Vinyl chloride to HFC-152a	Product
HFC-152a	Acetylene to HFC-152a	Product
HFC-245fa	Vinyl chloride and CTC to HFC-245fa	Product
HFC-227ea	HCFC-22 to HFP to HFC-227ea	Product
1,1,1-Trichloroethane	1,1-Dichloroethane to 1,1,1-trichloroethylene	Product

[1] The latest full release of the HITRAN database is described in: Gordon, I. E. et al., "The HITRAN2020 Molecular Spectroscopic Database", *Journal of Quantitative Spectroscopy and Radiative Transfer*, p. 277, 107949 (2022), DOI 10.1016/j.jqsrt.2021.107949, available here.

HITRAN cross-sections paper is described in: Kochanov, R. V. et al., "Infrared absorption cross-sections in HITRAN2016 and beyond: Expansion for climate, environment, and atmospheric applications", *Journal of Quantitative Spectroscopy and Radiative Transfer*, Volume 230, p. 172-221 (2019). DOI: 10.1016/j.jqsrt.2019.04.001, available here.

[2] HFC-245fa Reference 1166: Sihra, K. et al., "Updated radiative forcing estimates of 65 halocarbons and nonmethane hydrocarbons", Journal of Geophysical Research: Atmospheres 106(D17), 20493-20505 (2001), available here. ADS available here.

[3] HFO-1234yf Reference 1152: Nielson, O. J. et al., "Atmospheric chemistry of CF3CF=CH2: Kinetics and mechanisms of gas-phase reactions with Cl atoms, OH radicals, and O3", *Chemical Physics Letters* 439(1-3), p. 18-22 (2007), available here. ADS available here.

[4] HCFO-1233zd Reference 1135: Andersen, M. P. S. et al., "Atmospheric chemistry of trans-CF3CHCHCl: Kinetics of the gas-phase reactions with Cl atoms, OH radicals, and O3", Journal of Photochemistry and Photobiology A: Chemistry 199(1), p. 92-97 (2008), available here. ADS available here.

[5] EPA, Subpart L Information Sheet (2015), available here.

[6] EPA, Subpart O Information Sheet (2015), available here.

[7] EPA, Fluorinated Greenhouse Gas Emissions and Supplies Reported to the GHGRP (2022), available here.

[8] EPA, Toxics Release Inventory (TRI) Program (2023), available here.

[9] EPA, Chemical List (2023), available here.

[10] Using the EPA's FLIGHT (Facility Level Information on GHGs Tool), EIA's search selection filtered by Chemical sector facilities and emissions of Fluorinated Greenhouse Gases. EPA FLIGHT, available here.

[11] EPA, Draft regulatory Analysis for Phasing Down HFCs, Chapter 6: Environmental Justice Analysis (2021), See Table 6-3, available here.

[12] TEAP May 2023 Assessment Report (Volume 1), available here. See Table 5-5.