# Annex 4 - EFCTC technical paper on destruction technologies of HFCs and HFOs


## Summary

Destruction technologies for HFCs are approved under the Montreal Protocol following independent evaluation of performance criteria, including the efficiency of destruction. The performance of approved destruction technologies is well characterised and achieve a high efficiency of destruction (minimum 99.99% for concentrated HFCs[1]). Detailed reports on destruction technologies and applicable criteria have been published since 1992 initially for ozone depleting substances (ODS). It has been reported that there are 49 destruction facilities for ODS in Europe, although 17 are registered in 2021 for destruction of F-gas Annex I & II substances in the EU (HFCs, HCFCs, HFOs, and HCFOs), as required by the F-gas Regulation. The MCTOC report estimates that there are in total 169 or more facilities destroying ODS globally. Municipal solid waste and rotary kiln incineration are approved for destruction of foams containing HFCs. The HFOs and HCFOs, having double bonds, have reduced stability compared to HFCs and technologies approved for HFC destruction are expected to achieve the same efficiency of destruction, if operated under conditions that destroy HFCs.


## F-gas Regulation Registration for Destruction Facilities

Under the F-gas Regulation and its implementing acts, there is an obligation for EU destruction companies to register in the EU F-gas Portal & HFC Registry[2] and to report their destroyed quantities of HFCs (Annex I) and the HFOs listed in Annex II. Reporting has been a legal requirement since 2015. The reporting requirement threshold is 1 metric tonne or 1000 tonnes $CO_2e$. According to the EEA Fluorinated greenhouse gases 2022 Report (table 23)[3], 17 destruction companies reported data for the year 2021 in the EU (UK has already been excluded from the count).

## Destruction Technologies and Technical Requirements

The Technical and Economic Assessment Panel (TEAP) and its subsidiary bodies[4], under the Montreal Protocol has published detailed reports on destruction technologies and applicable criteria since

[1] Under Montreal Protocol, destruction technologies are approved separately for concentrated HFCs and dilute HFCs. Concentrated HFCs are typically refrigerants recovered from equipment; HFCs in foams are dilute sources.

[2] More information can be found on the Commission website

[3] European Environment Agency Report “Fluorinated greenhouse gases 2022”, ETC CM Report 2022/3, March 2022. Available here

[4] In 1990 the Technology and Economic Assessment Panel was established as the technology and economics advisory body to the Montreal Protocol Parties. The Technology and Economic Assessment Panel (TEAP) provides, at the request of Parties, technical information related to the alternative technologies that have been investigated and employed to make it possible to virtually eliminate use of Ozone Depleting Substances (such as CFCs and halons), that harm the ozone layer. More information can be found on the UN Environment Programme website.

EFCTC
Rue Belliard 40, Box 15, B-1040 Brussels
www.fluorocarbons.org | [redacted]@cefic.be
EU Transparency Register n° 64879142323-90

1992.[5,6,7,8,9] Initially these technologies were assessed for the destruction of ozone depleting substances (ODS), but since 2018[10,11,12] have been assessed and, if suitable, approved for the destruction of HFCs. HFOs and HCFOs have reduced stability compared to HFCs and technologies approved for HFCs destruction are expected to achieve the same Destruction and Removal Efficiency (DRE)[13], if operated under conditions that destroy HFCs. However, as HFOs and HCFOs are not controlled substances under the Montreal Protocol their destruction has not been assessed by the TEAP. Table 8.2 of the 2022 MCTOC Assessment Report[14], lists the approved destruction technologies for ODS and HFCs. In practice, for some technologies higher DREs are achieved than the minimum requirement. The table has been attached to this report as Appendix 1.

In its submission to the Destruction Task Force, the European Union[15] stated that HFC incineration systems operating at or above 1200°C, with residence times of at least two seconds, ensure decomposition of HFCs/HCFCs and minimize the formation of unwanted combustion products such as dioxins/furans, carbonyl halides ($COF_2$, $COCl_2$) and hydrocarbons. The suggestion that specific incineration facility operating conditions might be used as an assurance of meeting DRE and emissions limits highlights the importance of operating at conditions sufficient to meet those criteria.

The criteria used to assess the destruction technologies are listed in Table 8.3, also from the 2022 MCTOC Assessment Report. "*To undertake its assessment and provide its technical advice, and to provide advice that the technology has the minimum level of technical capability to destroy ODS/HFCs efficiently and safely, TEAP considers information for all these parameters.*"[16]

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[5] UNEP Report of the Ad Hoc Technical Advisory Committee on ODS Destruction Technologies. United Nations Environment Program, May 1992.

[6] UNEP Report of the Technology and Economic Assessment Panel ODS Disposal Subcommittee Workshop held in Montreal, Canada, May 2-3, 1995, June 1995.

[7] UNEP Report of the Technology and Economic Assessment Panel, Volume 3B, Report of the Task Force on Destruction Technologies, April 2002.

[8] UNEP Report of the Technology and Economic Assessment Panel, Progress Report, Response to Decision XVI/15, May 2005.

[9] UNEP Report of the Technology and Economic Assessment Panel, Volume 1, Progress Report, TEAP Task Force Response to Decision XXII/10, May 2011.

[10] Report of the UNEP Technology and Economic Assessment Panel, April 2018, Volume 2, Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances

[11] Report of the UNEP Technology and Economic Assessment Panel May 2018, Supplement to the April 2018 Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances

[12] Report of the UNEP Technology and Economic Assessment Panel September 2018, Volume 1, Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances (Addendum to the May 2018 Supplemental Report-Revision)

[13] Destruction and Removal Efficiency (DRE) has traditionally been determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical alone that is released in stack gases and expressing that difference as a percentage of the mass of that chemical fed into the system.

[14] United Nations Environment Programme (UNEP), Report of the Medical and Chemical Technical Options Committee (MCTOC) 2022 Assessment Report

[15] Report of the UNEP Technology and Economic Assessment Panel, April 2018, Volume 2, Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances see page 19 and Appendix 1: Summary of submissions received from parties in response to Decision XXIX/4.

[16] 2022 MCTOC Assessment Report, page 212.

**Table 1: Technical performance assessment and advisory criteria[17]**

| Performance Qualification | Units | Concentrated Sources | Diluted Sources (e.g., foams) |
|---|---|---|---|
| DRE | % | 99.99 | 95 |
| Dioxins/furans | ng-ITEQ/Nm$^3$ | 0.2 | 0.5 |
| $HCl/Cl_2$ | mg/Nm$^3$ | 100 | 100 |
| HF | mg/Nm$^3$ | 5 | 5 |
| $HBr/Br_2$ | mg/Nm$^3$ | 5 | 5 |
| Particulates (TSP) | mg/Nm$^3$ | 50 | 50 |
| CO | mg/Nm$^3$ | 100 | 100 |

*Notes to the table:*

- *All concentrations of pollutants in stack gases and stack gas flow rates are expressed on the basis of dry gas at normal conditions of 0°C and 101.3 kPa, and with the stack gas corrected to 11% $O_2$ (as referred to by normal cubic metre, Nm$^3$). NB. Different stack gas conditions may apply in different countries for different technologies.*
- *ITEQ: International Toxic Equivalents[18].*
- *Acid gases will be assessed based on the specific halogen species present in the waste stream.*
- *TSP – total suspended particles*

## Destruction Capacity

The 2022 MCTOC Assessment Report discusses the global destruction capacity and reports that there are 49 destruction facilities in Europe. An earlier 2010 study prepared by ICF International for the European Commission listed the European destruction facilities at that time; with 23 confirmed destruction facilities, including two in the UK[19]

***8.6.6 Global capacity for ODS/HFC destruction*** *(reproduced from 2022 MCTOC Assessment Report)*
MCTOC notes that the destruction of controlled substances is not fundamentally limited by the technologies themselves. Among the range of technologies that have already been approved for use for purposes of meeting obligations under Article 7 of the Montreal Protocol, many are installed and operational globally on a commercial basis. The scope of available destruction facilities covered by this menu of technologies includes:

- Commercial hazardous waste facilities destroying a wide range of halogenated chemical waste streams,
- Destruction facilities with similar capabilities integrated into chemical production plants,
- Speciality facilities intended specifically for controlled substances,
- Industrial facilities, such as cement kilns, mineral (ore) processing, electric arc furnace steelmaking etc., capable of accepting waste streams for destruction in production processes, and
- Energy from waste facilities processing solid waste containing controlled substances.

[17] Replicating Table 8.3 of the 2022 MCTOC Assessment Report, page 212.

[18] The International Toxic Equivalents (ITEQ) scheme was established by NATO in 1988. More recently the TEFs were re-evaluated by the World Health Organisation and the revised TEQ scheme is generally universally accepted, with the updated TEFs used in the TEQ calculation. Some of the data reviewed by the 2018 TFDT quotes TEQ values. A detailed discussion of ITEQ and TEQ is on page 13 of 2018 TEAP Report, Volume 2: Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances

[19] Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-Gases) Banked in Products and Equipment, Prepared by: ICF International Prepared for: The European Commission, March 2010. Table C-1, Appendix C.

Furthermore, this range of technology options and the facilities employing them provides substantial global capacity capable of destroying the amounts of EOL ODS/HFCs projected to becoming available from recoverable banks. A recent review by U.S. EPA[20] provides an estimate of available capacity both for the United States and globally. In the United States, over 70 facilities were identified as destroying controlled substances., Overall, the current amounts of controlled substances destroyed represents 0.1% of hazardous waste managed in the country, indicating no current capacity limitations. It also notes that this capacity could be significantly increased if co-disposal in cement kilns meeting regulatory requirements were utilized. The 2022 MCTOC Report also estimates globally there are 169 or more facilities destroying ODS globally, of which 80 are in Japan, 49 are in the European Union (and UK), and 11 are in the United States. Twenty or more facilities are identified in Article 5 parties (Algeria, Argentina, Brazil, China, Colombia, Cuba, Indonesia, Mexico, Nigeria, Venezuela) that should have the capability to destroy ODS in Article 5 parties.

## Destruction of Foams

Foams are categorised as a dilute source for the approvals listed in Table 8.2. The 2022 MCTOC Assessment Report[21] explains that the approved list of destruction technologies applicable to dilute EOL ODS/HFC is currently limited to municipal solid waste and rotary kiln incineration, noting that municipal solid waste incineration is unique to the destruction of dilute waste. Cement kilns are not an approved technology for the destruction of dilute waste, even though it is an approved technology for the destruction of concentrated EOL ODS/HFCs, except for Halons, methyl bromide and HFC-23. This option for foam waste streams is being utilized in some countries, such as Colombia, largely because of foam waste streams restrictions being placed on conventional disposal.

The 2018 TFDT[22] noted that, for Municipal Solid Waste Incineration, solid materials including foams are transferred to a bin that feeds the waste onto a moving grate. Combustion air is drawn through the refuse pit, preheated and introduced into the combustion zone through the moving grate. Hot gases from the combustion of the waste are typically cooled in a waste heat boiler and then cleaned, either by a spray drier and bag house or by a dry electrostatic precipitator. In order to obtain low dioxins/furans emissions, advanced air pollution control systems use spray-dry scrubbers with activated carbon injection, followed by bag houses. The combustors may be refractory lined or, as in many newer systems, the walls may be water-cooled to recover additional heat.

The required DRE of 95% does not necessarily reflect what can be achieved for the destruction of foams. It was originally set at this level by the 2002 TFDT[23], which defined a DRE for foam destruction based on what could be achieved for a recovery step for the foam blowing agent followed by destruction and concluded a DRE of 95% for foam destruction was appropriate. The 2002 TFDT determined that 95% of ODS could be recovered from foam. Once recovered, the ODS could be

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[20] ODS Destruction in the United States and Abroad, April 2021, EPA 430-R-21-006, Prepared for the U.S. Environmental Protection Agency by ICF

[21] United Nations Environment Programme (UNEP), Report of the Medical and Chemical Technical Options Committee (MCTOC) 2022 Assessment Report

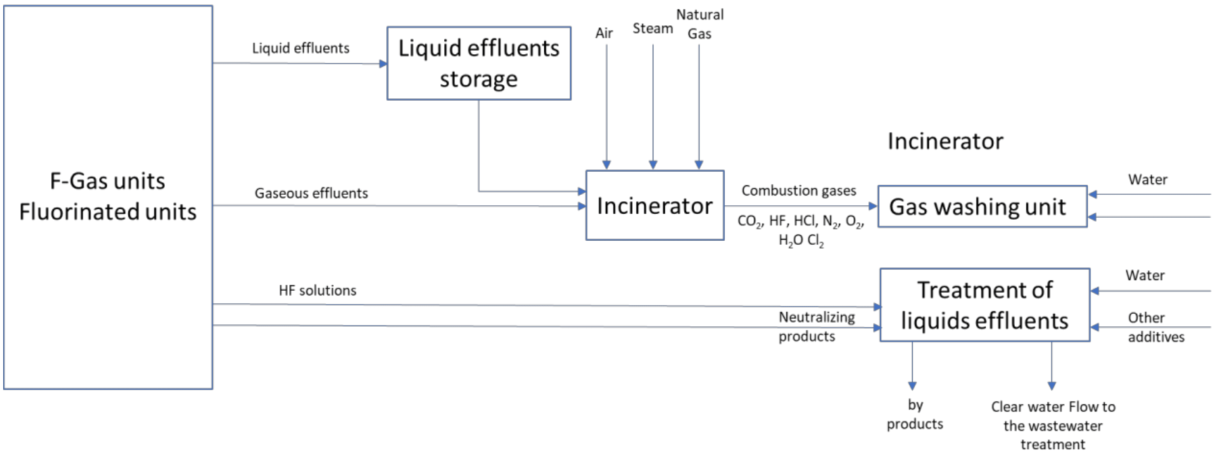
[22] Report of the UNEP Technology and Economic Assessment Panel May 2018, Supplement to the April 2018 Decision XXIX/4 TEAP Task Force on Destruction Technologies for Controlled Substances.

[23] UNEP Report of the Technology and Economic Assessment Panel, Volume 3B, Report of the Task Force on Destruction Technologies, April 2002.

destroyed at a DRE of 99.99%. However, waste foam can be destroyed without recovery of ODS or HFC which might be expected to result in higher DREs.

## Incineration/neutralization of HFC, HCFC and halogenated effluents

Plants manufacturing HFCs/HFOs/HCFOs in the EU include a unit for the incineration and thermal oxidation of gaseous and liquid fluorinated effluents and an associated unit for the neutralization of acidic aqueous effluents.




The gaseous effluents arrive directly in the incinerator from the various production units on the manufacturing plant. Liquid residues are stored in containers and then sent by pump to the incinerator. Gaseous effluents (several hundred kg/h) and liquid effluents (several hundred kg/h) are burned in the incinerator above 1100°C. Natural gas is also introduced into the furnace (10 to 100 $Nm^3/h$) to maintain the combustion temperature. Combustion air (1100 to 1500 $Nm^3/h$) is added to ensure an excess of oxygen in order to limit the production of $Cl_2$ and CO.

Operating permits dictate the operating limits of the incinerator and facilities including the thermal oxidizer in terms of maximum feed rate, minimum operating temperature, maximum emissions, etc.

The combustion gases mainly consist of HF, HCl, $CO_2$, $O_2$, $Cl_2$ and $N_2$ and are quickly cooled with demineralized water. These cooled gases are sent to successive washing columns with demineralized water then with a basic solution in order to eliminate the residual acidity. The neutralized gases are released into the atmosphere through a chimney. The incinerator is equipped with continuous and semi-continuous smoke analyzers to measure the concentration of certain compounds (CO, $O_2$, $NO_x$, HF, HCl, dioxins, etc.) in the discharge into the atmosphere. Some incinerators can be equipped with a wet electrostatic precipitator to remove trace metals.

The liquid and acid effluents resulting from the cooling of the combustion gases are neutralized using a basic solution (for example milk of lime). The pH is regulated to arrive at a neutral solution. The neutralized acidic waters are treated by flocculation and the CaF2 precipitates (spar, very slightly soluble in water). Clear water is sent to the plant's Effluent Treatment Station.

## Appendix 1

**Table 8.2 Based on Annex II, MOP-30 list of technologies subject to this review that are either not approved or not determined*** (from 2022 MCTOC Assessment Report)

| Technology | Applicability | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentrated Sources | | | | | | | | | Dilute Sources | |
| | Annex A | | Annex B | | | Annex C | Annex E | Annex F | | | Annex F |
| | Group 1 | Group 2 | Group 1 | Group 2 | Group 3 | Group 1 | Group 1 | Group 1 | Group 2 | | Group 1 |
| | Primary CFCs | Halons | Other CFCs | Carbon Tetrachloride | Methyl Chloroform | HCFCs | Methyl Bromide | HFCs | HFC-23 | ODS | HFCs |
| **DRE** | 99.99% | 99.99% | 99.99% | 99.99% | 99.99% | 99.99% | 99.99% | 99.99% | 99.99% | 95% | 95% |
| **Cement Kilns** | Approved | Not Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Not Determined | | |
| **Gaseous/Fume Oxidation** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Liquid Injection Incineration** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Municipal Solid Waste Incineration** | | | | | | | | | | Approved | Approved |
| **Porous Thermal Reactor** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Not Determined | | |
| **Reactor Cracking** | Approved | Not Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Rotary Kiln Incineration** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | Approved | Approved |
| **Thermal Decay of Methyl Bromide** | Not Determined | Not Determined | Not Determined | Not Determined | Not Determined | Not Determined | Approved | Not Determined | Not Determined | | |
| **Argon Plasma Arc** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Inductively coupled radio frequency plasma** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Not Determined | Not Determined | | |
| **Microwave Plasma** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Not Determined | Not Determined | | |



EFCTC
Rue Belliard 40, Box 15, B-1040 Brussels
www.fluorocarbons.org | [redacted]@cefic.be
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|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nitrogen Plasma Arc** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Portable Plasma Arc** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Not Determined | | |
| **Chemical Reaction with $H_2$ and $CO_2$** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Gas Phase Catalytic De-halogenation** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Not Determined | | |
| **Superheated steam reactor** | Approved | Not Determined | Approved | Approved | Approved | Approved | Not Determined | Approved | Approved | | |
| **Thermal Reaction with Methane** | Approved | Approved | Approved | Approved | Approved | Approved | Not Determined | Not Determined | Not Determined | | |

*Orange shaded cells indicated those destruction technologies subject to review under decision XXX/6, excluding any new technology for which information might become available.



**EFCTC**
Rue Belliard 40, Box 15, B-1040 Brussels
www.fluorocarbons.org | [redacted]@cefic.be
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