Yale Carbon Containment Lab

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Draft Methodology

Recovery and Destruction of Hydrofluorocarbon Refrigerant Gases in Article 5 Countries

Revised May 23, 2023

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Developed as a set of revisions to Verra Methodology VM0016, Recovery and Destruction of Ozone-Depleting Substances (ODS) from Products, v1.1.

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Disclaimer

This draft methodology for the recovery and destruction of HFC refrigerants in Article 5 countries was written as a set of revisions to the existing Verra Carbon Standard methodology VM0016 v1.1, developed by USG Umweltservice GmbH and Energy Changes Projektentwicklung GmbH, assessed by TÜV SÜD Industrie Service GmbH and Bureau Veritas Certification Holdings SAS, and approved for project development on November 30, 2017.

The development of this set of revisions was carried out by the Yale Carbon Containment Lab, independently from Verra Carbon Standard or the original authors and assessors of VM0016 v1.1 (or v1.0). This draft methodology cannot be used to certify carbon credits for the Verra registry, or any other registry named within.

This draft methodology has been through one round of peer review. Prior to publishing, this methodology will go through a second round of peer review, followed by a formal assessment by a verification body to ensure that the process can be verified. The Yale Carbon Containment Lab welcomes all comment on this document, from project developers, certification bodies, regulators, and any other stakeholders.

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1 SOURCES

This methodology refers to the latest version of the following approved methodologies and standards:

- Verra (VCS) methodology *VM0016 Recovery and Destruction of Ozone-Depleting Substances*
- *VCS Standard*
- Climate Action Reserve (CAR) methodology *U.S. Ozone Depleting Substances Project Protocol, Destruction of U.S. Ozone Depleting Substances Banks*
- Climate Action Reserve (CAR) methodology *Article 5 Ozone Depleting Substances Project Protocol, Destruction of Article 5 Ozone Depleting Substances Banks*

This methodology refers to the latest version of the following approved tools and modules:

- CDM tool *Tool for the demonstration and assessment of additionality*
- CDM tool *Tool to calculate the emission factor for an electricity system*
- VCS module *VMD0048 Activity method for the determination of additionality for recovered and stockpiled ODS refrigerant projects*

The following have also informed the development of the methodology:

- American Carbon Registry (ACR) methodology *Destruction of Ozone Depleting Substances from International Sources*
- CDM tool *Tool to calculate project or leakage* CO_2 *emissions from fossil fuel combustion*
- CDM tool *Tool to calculate baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation*
- *UNEP Technology and Economic Assessment Panel (TEAP) Report of the Task Force on Destruction Technologies*, UNEP, 2002.
- *UNEP TEAP, April 2018 Report, Vol. 2: Decision XXIX/4 Task Force Report on Destruction Technologies for Controlled Substances*, UNEP, 2018.

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Project
Crediting Baseline	Project

Building upon previous ODS destruction methodologies, this methodology quantifies the GHG emission reductions from activities that recover and destroy hydrofluorocarbons (HFC) from products where a partial or total atmospheric release of HFCs occurs in the baseline scenario. This methodology is applicable to HFCs recovered from equipment within Montreal Protocol Article 5 countries. While not explicitly stated throughout, all project activities are relevant and applicable to eligible ODS refrigerants, inclusive of HCFCs.

3 DEFINITIONS

In addition to the definitions set out in VCS document *Program Definitions*, the following definitions and acronyms apply to this methodology.

Hydrofluorocarbon (HFC)

A family of man-made compounds that contain carbon, fluorine, and hydrogen. Although HFCs do not deplete stratospheric ozone, many are Greenhouse Gases (GHGs) with high Global Warming Potentials (GWPs). The Kigali Amendment to the Montreal Protocol governs a global phasedown of HFC production.

HFC refrigerant

A chemical (being an HFC) used or intended for use in a cooling mechanism, such as an air conditioner or refrigerator, as the heat carrier which changes from gas to liquid and then back to gas in the refrigeration cycle.

Article 5 Country

Any party to the Montreal Protocol that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A (of the Montreal Protocol) is less than 0.3 kilograms per capita. Article 5 countries are separated into two groups. Group 1 is the majority of Article 5 countries, while Group 2 is composed of Bahrain, India, Iran, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates. Group 2 countries have a delayed freeze (2028 compared with 2024) and phasedown schedule.

Non-Article 5 Country

Any party to the Montreal Protocol which is not an Article 5 country.

Product

Any of the following: refrigeration, air conditioning or fire suppression equipment, systems or appliances.

Recovery

To remove refrigerant in any condition from a product and store it in an external container.

Recovery Site

The location where the project proponent recovers HFCs from appliances, including stationary equipment such as a chiller, or obtains appliances from which HFCs are to be recovered.

Aggregation

The collection of HFC refrigerant in any condition in a centralized holding location. Aggregation can include the combining of HFC refrigerants in a single container or refer to the storage of multiple containers in a single location.

Aggregation Facility

Any facility in which HFC refrigerant or products containing HFC refrigerant are aggregated or stored for the purposes of the project activity, additional to the recovery site. Aggregation facilities are not a requirement of the full system (i.e., recovered HFC refrigerant can be transported directly to the destruction facility).

Destruction Facility

The facility where the destruction of the HFC refrigerant takes place and which meets the screening criteria for destruction technologies set out in the report, as may be updated from time to time, by the UNEP Technology and Economic Assessment Panel (TEAP) Task Force on Destruction Technologies. *UNEP Technology and Economic Assessment Panel (TEAP) Report of the Task Force on Destruction Technologies*, UNEP, 2002.

Recycle

To extract refrigerants from an appliance and clean them using oil separation and single or multiple passes through filter-driers, which reduce moisture, acidity, and particulate matter.

Reclaim

To reprocess used HFC refrigerants, typically by distillation, to specifications that meet or exceed virgin product specifications with the objective of reusing the refrigerant.

Venting

To directly release a chemical to the atmosphere. In the case of HFC refrigerants, venting refers to the process whereby HFC is directly released to the atmosphere during the servicing of or at the end-of-life of a product.

Leakage

A scenario that arises when efforts to reduce fossil fuel or other emissions in one place simply shift emissions to another sector or location where they remain uncontrolled or uncounted.

Leak Rate

The rate at which HFC refrigerant escapes from the product through normal operation.

4 APPLICABILITY CONDITIONS

This methodology applies to project activities that recover and destroy HFCs where the baseline scenario is their total atmospheric release, such as routine venting before servicing or at equipment end-of-life. This methodology does not apply to HFC refrigerant that is manufactured for the sole purpose of their subsequent destruction, or to HFC refrigerant that would remain in equipment in the baseline scenario.

Applicable HFC refrigerant must be recovered from Article 5 countries which have ratified the Kigali Amendment and where regulatory prohibitions against refrigerant venting do not exist or are not enforced (see Appendix I for country-level inclusion criteria and additionality check). The remainder of project activities (e.g., aggregation, destruction, or reclaim) can be implemented in Article 5 as well as in Non-Article 5 countries.[2]

In addition to all eligible refrigerant gases in VM0016, the following HFC species and blends, with their associated GWPs (100-year values taken from the IPCC's Fifth Assessment Report), are eligible under this methodology:

Table 1. HFC Refrigerants and their GWPs

HFC Refrigerant	GWP
HFC-23	12,400
HFC-32	677
HFC-125	3,169
HFC-134a	1,301
HFC-152a	137
HFC-227ea	3,348
R-404A	3,945
R-407A	1,923
R-407C	1,301
R-410A	1,923
R-417C	1,643
R-422B	2,289
R-422C	2,794
R-422D	2,473
R-507A	3,987
R-508B	11,710

All HFCs must be collected, stored, and transported in cylinders or other hermetically sealed containers.

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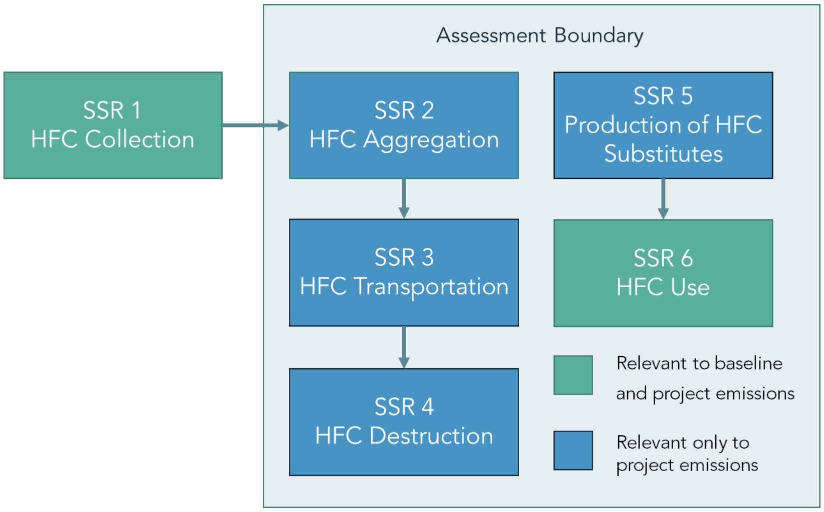
[2] For the avoidance of doubt: Recovery and destruction activities can take place in separate countries.

5 PROJECT BOUNDARY

The spatial extent of the project boundary encompasses the following sources, sinks, and reservoirs (SSRs):

- The recovery site or sites
- The aggregation facility or facilities
- The destruction facility
- Transportation between recovery sites, aggregation facilities, and the destruction facility
- Leakage from production of substitute gas and use of HFC or substitute refrigerant



SSR 1 HFC Collection	Fossil fuel emissions from collection of HFCs; Excluded; No difference from baseline
SSR 2 HFC Aggregation	HFC and fossil fuel emissions from recovery of HFC at servicing or end of life; Included; Venting assumed 100% in baseline, complete capture assumed in project scenario
SSR 3 HFC Transportation	Fossil fuel emissions associated with transport of HFC from collection to aggregation and from aggregation to destruction facility; Included; Estimated based on distance and weight
SSR 4 HFC Destruction	Emissions of incomplete HFC destruction, emissions from oxidation of carbon contained in destroyed HFC, fossil fuel emissions from destruction facility operation, indirect emissions from use of grid- delivered electricity; Included; Based on HFC destroyed or included in default deduction
SSR 5 Production of HFC Substitutes	Fossil fuel and substitute refrigerant emissions from production of substitute refrigerant; Included; Based on reclamation rate in project location; expected to be negligible in Article 5 countries
SSR 6 HFC Use	HFC or substitute gas emissions from leaks resulting from continued operation; Included; Project emissions based on market-weighted emission rates and reclamation rates

6 BASELINE SCENARIO

The project proponent must use Step 1 of the latest version of the CDM *Tool for the demonstration and assessment of additionality*, to identify all realistic and credible baseline alternatives. In doing so, relevant policies and regulations related to the management of installed refrigerant banks should be considered. Such policies or regulations may include mandatory HFC capture or destruction requirements because of regional or local environmental regulations. In addition, the assessment of alternative scenarios should account for regional economic and technological circumstances.

For HFC refrigerants the realistic and credible alternative(s) may include, *inter alia*

R1 Project activity not performed as emission reduction project

R2 Products are disposed of into an incineration facility and thereby HFC refrigerants are destroyed

R3 Atmospheric release of the HFC refrigerant or partial capture and destruction

R4 Atmospheric release of the HFC refrigerant or partial capture and reuse in existing products or continued storage in stockpile

R5 Products partially or entirely remain installed in existing equipment

The methodology is only applicable for HFC refrigerants if the most plausible baseline scenario for the HFC refrigerant is either R3 or R4 or a combination of both.

7 ADDITIONALITY

The project proponent should use the two-step process set out below for the demonstration of additionality for projects that destroy HFC refrigerant. A third country-level check should be completed annually to ensure that destruction is not enabling production or import of controlled substances above set limits (Appendix I).

Step 1: Regulatory surplus

The project proponent must demonstrate regulatory surplus in accordance with the following requirement, adapted from those regarding regulatory surplus set out in the January 2022 version of the *VCS Standard*:

> The project shall not occur within a host country in which HFC refrigerant recovery is mandated by any law, statute or other regulatory framework, or the compliance rate of any such law, statute or other regulatory framework during (part of) the project crediting period shall be below 50 percent.

All Article 5 countries are assumed to meet the regulatory surplus requirement and are therefore eligible for host country status. As changing conditions continue to be monitored, eligibility conditions may be updated accordingly.

Step 2: Positive list

The positive list for this methodology is adapted from the applicability conditions of VCS activity method module VMD0048, *Activity method for the determination of additionality for recovered and stockpiled ODS refrigerant projects.* VMD0048 was established using the revenue streams option (Option C in the *VCS Standard*) only for the destruction of CFCs and other ozone-depleting substances. However, the justification of this option in Appendix II of VMD0048 was found to apply equally to HFCs. Specifically, there is a comparable lack of revenue streams for the collection, aggregation, and destruction of HFCs, and the venting of HFCs during servicing or at end-of-life is common practice across the world, especially in Article 5 countries.

Projects that meet all the applicability conditions in Section 4 of this methodology, as well as the following requirements, are deemed additional.

1) The project activity consists of the collection, aggregation, and destruction of HFC refrigerants recovered at equipment end-of-life or during servicing in which venting would otherwise occur. Government seizures of illegal shipments are also an approved source insofar as seized refrigerants are turned over to project developers for the express purpose of destruction. When refrigerant is recovered from equipment, the project proponent must distinguish between refrigerant recovered at equipment end-of-life and during equipment servicing. In the latter case, the project proponent must provide documentation regarding the service call, and demonstrate the following:

   a) Evacuation of refrigerant from the equipment was required or is common practice before such servicing; and

   b) Onsite recycling of the recovered refrigerant and refilling of the serviced equipment was not feasible.

2) The project activity does not consist of the destruction of HFCs from, or as part of, a product stewardship scheme or other program incentivizing HFC recovery as an industry common practice. At validation, the project proponent must provide a description of any schemes or programs designed to incentivize HFC recovery, reclamation, or destruction in the jurisdictions in which the refrigerant is collected.

The project proponent must provide appropriate documentation to demonstrate that the project activity meets all applicability conditions. Documentation may include but is not limited to: bills of landing, invoices, receipts, chains of custody, inventory records, contracts, or other signed statements or agreements.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

Baseline emissions from HFC refrigerants are determined as follows:

$$BE_{HFC\_ref,y} = \sum_{i=1}^{n} ((M_{DESTR,eHFC,i,y} \times VR_{HFC,i} \times EF_{VR}) + \left(M_{DESTR,eHFC,i,y} \times RR_{HFC,i} \times EF_{RR,HFC,i}\right) + (M_{DESTR,eHFC,i,y} \times DR_{HFC,i} \times EF_{DR})) \times GWP_{HFC,i} \tag{1}$$

$$1 = VR_{HFC,i} + RR_{HFC,i} + DR_{HFC,i} \tag{2}$$

Where:

$BE_{HFC\_ref,y}$ = Baseline emissions from HFC refrigerants which would be released into the atmosphere in the absence of the project activity in year y [tCO$_2$e]

$M_{DESTR,eHFC,i,y}$ = Eligible quantity HFC refrigerant i sent for destruction by the project activity in year y [tHFC$_i$]

$VR_{HFC,i}$ = Rate of HFC refrigerant i which would be vented into the atmosphere in the baseline [0-1]

EF_{VR} = Emission factor for HFC refrigerant i which would be vented into the atmosphere [1]

$RR_{HFC,i}$ = Rate of HFC refrigerant i which would be used, reused or remain in storage in the baseline [0-1]

$EF_{RR,HFC,i}$ = Emission factor for HFC refrigerant i which would be reused in the baseline [0-1]

$DR_{HFC,i}$ = Rate of HFC refrigerant i destroyed by the project activity which would also be destroyed in the baseline [0-1]

EF_{DR} = Emission factor for HFC refrigerant i which would also be destroyed in the baseline [0]

$GWP_{HFC,i}$ = Global warming potential of HFC refrigerant i [tCO$_2$e/tHFC$_i$]

$$EF_{VR} = 1 \tag{3}$$

$$EF_{DR} = 0$$

(4)

$$EF_{RR,HFC,i} = 1 - (1 - LR_{HFC,i,y})^{\mathrm{tcp}} \tag{5}$$

Where:

$EF_{RR,HFC,i}$ = Emission factor for HFC refrigerant i which would be reused in the baseline [0-1]

$LR_{HFC,i,y}$ = Leak rate of HFC refrigerant i which would be used as refrigerant for existing equipment or remain in storage in the baseline in year y [0-1]

tcp = Project crediting period in years [10]

When recovery of the HFC refrigerants by the project activity is mandated by law, statute or other regulatory framework applying in the host country, and this mandate is demonstrably enforced, the baseline shall be the gradually increasing compliance with such law, statute or other regulatory framework, and the baseline GHG emissions shall be calculated as follows:

$$BE_{HFC\_ref,y,a} = BE_{HFC\_ref,y} \times (1 - CR_y) \tag{6}$$

Where:

$BE_{\mathrm{HFC}\_ref,y,a}$ = Adjusted baseline emissions to be used for the calculation of emission reductions in year y [tCO_2e]

$BE_{HFC\_ref,y}$ = Baseline emissions from HFC refrigerants which would be released into the atmosphere in the absence of the project activity in year y [tCO_2e]

CR_y = Host country-level compliance rate of the law, statute or other regulatory framework in the year y. Calculation of the compliance rate shall exclude other projects implemented under GHG programs. If the compliance rate exceeds 50% (or 0.50), the project shall receive no further credit [0-1]

8.2 Project Emissions

Project emissions in year y are:

- Emissions that are caused by the project activity due to energy consumption at aggregation facilities
- Emissions that are caused by the project activity due to transportation of HFC refrigerant between recovery sites, aggregation facilities, and the destruction facility
- Emissions that are caused by the project activity due to HFC destruction (including energy consumption due to project activity at the destruction facility)

Project emissions are determined as follows:

$$PE_y = PE_{Energy\_Consump,y} + PE_{HFC\_Transport,y} + PE_{HFC\_Destruct,y} \tag{7}$$

Where:

PE_y = Project emissions during year y [tCO_2e]

$PE_{Energy\_Consump,y}$ = Project emissions from energy consumption due to project activity at aggregation facilities during year y [tCO_2e]

$PE_{HFC\_Transport,y}$ = Project emission from HFC transportation during year y [tCO_2e]

$PE_{HFC\_Destruct,y}$ = Project emission from HFC destruction during year y [tCO_2e]

Determination of $PE_{Energy\_Consump,y}$:

$$PE_{Energy\_Consump,y} = PE_{EC,y} + PE_{FC,j,y} \tag{8}$$

Where:

$PE_{Energy\_Consump,y}$ = Project emissions from energy consumption attributable to the project activity at aggregation facilities during year y [tCO_2e]

$PE_{EC,y}$ = Project emissions from electricity consumption from the grid attributable to the project activity at aggregation facilities during year y [tCO_2e]

$PE_{FC,j,y}$ = Project emissions from fossil fuel consumption attributable to the project activity, including third party used fossil fuel to generate energy, at aggregation facilities during year y [tCO_2e]

Determination of $PE_{EC,y}$:

$$PE_{EC,y} = EC_{PJ,y} \times EF_{grid,y} \times (1 + TDL_y) \tag{9}$$

Where:

$PE_{EC,y}$ = Project emissions from electricity consumption from the grid due to project activity at the HFC aggregation facilities during year y [tCO_2e]

$EC_{PJ,y}$ = Amount of electricity consumed due to project activity at the HFC aggregation facilities from the grid during year y [MWh]

$EF_{grid,y}$ = Grid emission factor during the monitoring period y [tCO_2e /MWh]

TDL_y = Average technical transmission and distribution losses in the grid for the voltage level at which electricity is obtained from the grid at the aggregation facilities during year y [0-1]

For determination of $EF_{grid,y}$ the project proponent shall choose one of the following options:

- Calculate the combined margin emission factor, using the procedures in the latest approved version of the CDM “Tool to calculate the emission factor for an electricity system”; or
- Use a conservative default value of 1.3 tCO_2/MWh

For determination of TDL_y the project proponent shall choose one of the following options:

- Use recent, accurate and reliable data available within the country; or
- Use a conservative default value of 20%

Determination of $PE_{FC,j,y}$:

$$PE_{FC,j,y} = \sum_{i=1}^{n} FC_{i,j,y} \times COEF_{i,y} \tag{10}$$

Where:

$PE_{FC,j,y}$ = Project emissions from fossil fuel consumption attributable to the project activity at aggregation facilities, including third party used fossil fuel to generate energy, during year y [tCO_2e]

$FC_{i,j,y}$ = Amount of fuel type i combusted in process j at an aggregation facility or at any third party generating energy for an aggregation facility during year y [mass or volume unit]

$COEF_{i,y}$ = CO_2 emission coefficient of fuel type i in year y [tCO_2e / mass or volume unit] i are the fuel types combusted in process j

The CO_2 emission coefficient $COEF_{i,y}$ can be calculated according to two different procedures, depending on the available data about the fossil fuel type i,:

Option A: The CO_2 emission coefficient $COEF_{i,y}$ is calculated based on the chemical composition of the fossil fuel type i, using the following approach:

If $FC_{i,j,y}$ is measured in a mass unit: $COEF_{i,y} = w_{C,i,y} \times 44/12$

If $FC_{i,j,y}$ is measured in a volume unit: $COEF_{i,y} = w_{C,i,y} \times \rho_{i,y} \times 44/12$

Where:

$COEF_{i,y}$	=	CO_2 emission coefficient of fuel type i during year y [tCO_2e / mass or volume unit]
$w_{C,i,y}$	=	Weighted average mass fraction of carbon C in fuel type i during year y [tC / mass unit of the fuel]
$\rho_{i,y}$	=	Weighted average density of fuel type i during year y [mass unit / volume unit of the fuel]

Option B: The CO_2 emission coefficient $COEF_{i,y}$ is calculated based on net calorific value and CO_2 emission factor of the fuel type i, as follows:

$$COEF_{i,y} = NCV_{i,y} \times EF_{CO_2,i,y} \tag{11}$$

Where:

$COEF_{i,y}$	=	CO_2 emission coefficient of fuel type i during year y [tCO_2e / mass or volume unit]
$NCV_{i,y}$	=	Weighted average net calorific value of the fuel type i during year y [GJ/mass or volume unit]
$EF_{CO_2,i,y}$	=	Weighted average CO_2 emission factor of fuel type i during year y [tCO_2e /GJ]

Where necessary data is available option A should be used.

Determination of $PE_{HFC\_Transport,y}$ and $PE_{HFC\_Destruct,y}$:

For project emissions due to HFC transportation and destruction, the project proponent shall apply a default factor of 9 tCO_2/tHFC. This was calculated using the methods and conservative default values found in Appendix D of the *CAR Article 5 Ozone Depleting Substances Project Protocol*, v2.0, with the exception of the electricity grid emissions factor, which was increased from 0.889 tCO_2/MWh to 1.3 tCO_2/MWh, to reflect that destruction activities may occur outside the United States. This emissions factor may be periodically re-assessed and updated.

$$PE_{HFC\_Transport,y} + PE_{HFC\_Destruct,y} = M_{DESTR,\mathrm{HFC},i,y} \times EF_{HFC\_Transport+Destruct,y} \tag{12}$$

Where:

$PE_{HFC\_Transport,y}$ = Project emission from HFC transportation during year y [tCO_2e]

$PE_{HFC\_Destruct,y}$ = Project emission from HFC destruction during year y [tCO_2e]

$M_{DESTR,HFC,i,y}$ = Quantity of HFC refrigerant i sent for destruction, including eligible and ineligible material by the project activity during year y [$tHFC_i$]

$EF_{HFC\_Transport+Destruct,y}$ = Default emission factor aggregating both transportation and destruction emissions [9 tCO_2/tHFC]

8.3 Leakage

Leakage emissions occur where in the baseline HFC refrigerant would have been re-used or reclaimed, and in the project scenario, must be substituted by other chemicals. Leakage is considered in cases where the reclamation rate, $RR_{HFC,i}$, is greater than 5%. Leakage is assumed to be 0 in cases where the venting rate of the destroyed gas, $VR_{HFC,i}$, is 100%.

When refrigerant HFCs are destroyed instead of reclaimed, continued demand for refrigeration will lead to the production and consumption of other refrigerant chemicals whose production is still legally allowed. Emissions associated with the production of new refrigerants, $PE_{Sub,i}$, are considered leakage and are included below in Equation 13.

Whether HFCs are destroyed or reclaimed, the resulting case will likely result in a gradual release, or leak, of HFCs or substitute gases over the project crediting period. The leakage calculation therefore additionally includes the difference between the leaked refrigerant GWP in the reclamation versus destruction case. To be conservative, the GWP of the substitute gas is always assumed to be greater than or equal to the GWP of the destroyed gas, such that project developers are not credited for decreased leakage due to a lower GWP substitute gas.

Leakage emissions are calculated as follows:

$$LE_{Total} = \sum_{i=1}^{n} RR_{HFC,i} \times (PE_{Sub,i} + \left(M_{DESTR,HFC,i,y} \times TLR\right) \times \max\,[0, \left(GWP_{Sub,i} - GWP_{HFC,i}\right)]) \tag{13}$$

Where:

LE_{Total} = Total leakage emissions by the project activity over project crediting period [tCO_2e]

$RR_{HFC,i}$ = Rate of HFC refrigerant i which would be used, reused or remain in storage in the baseline [0-1]

$PE_{Sub,i}$ = Emissions associated with production of substitute refrigerant for HFC refrigerant i [tCO$_2$e]

$M_{DESTR,HFC,i,y}$ = Quantity of HFC refrigerant i which is sent to destruction by the project activity in year y [tHFC$_i$]

$GWP_{HFC,i}$ = Global warming potential of destroyed HFC refrigerant i [tCO$_2$e/tHFC$_i$]

$GWP_{Sub,i}$ = Global warming potential of substitute refrigerant for HFC refrigerant i [tCO$_2$e/tSubstitute]

$$TLR = 1 - (1 - LR_{HFC,i,y})^{tcp} \qquad (14)$$

Where:

TLR = Total leakage rate over the project crediting period [0-1]

$LR_{HFC,i,y}$ = Leak rate of HFC refrigerant i or substitute chemical in year y [0-1]

tcp = Project crediting period [10]

The project proponent shall apply a substitute chemical derived from either official published data, research, industry studies, or default values provided in the latest version of the *CAR Article 5 Ozone Depleting Substances Project Protocol*. The leak rate $LR_{HCF,i,y}$ shall be obtained from either official published data, research, industry studies, or default values provided in the latest version of the *CAR Article 5 Ozone Depleting Substances Project Protocol*.

8.4 Net GHG Emission Reduction and Removals

Emission reductions are calculated as follows:

$$ER_{HFC,y} = BE_{HFC\_ref,y,a} - PE_y - (LE_{total} / tcp) \qquad (15)$$

Where:

$ER_{HFC,y}$ = Total emission reductions during year y [tCO$_2$e]

$BE_{HFC\_ref,y,a}$ = Adjusted baseline emissions from HFC refrigerants which would be released into the atmosphere in the absence of the project activity during year y [tCO$_2$e]

PE_y = Project emissions by the project activity during year y [tCO$_2$e]

LE_{Total} = Total leakage emissions by the project activity over project crediting period [tCO$_2$e]

tcp = Project crediting period [10]

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter:	$GWP_{HFC,i}$
Data unit:	$tCO2e/tHFC_i$
Description:	Global warming potential of HFC refrigerant i
Source of data:	IPCC
Description of measurement methods and procedures to be applied:	See Table 1 above for values. Shall be updated according to any future COP/MOP decisions or Assessment Reports.
Comments:	

Data / Parameter:	$GWP_{Sub,\ i}$
Data unit:	tCO2e/tSubstitute
Description:	Global warming potential of substitute refrigerant for HFC refrigerant i
Source of data:	IPCC
Description of measurement methods and procedures to be applied:	See Table 1 above for values. Shall be updated according to any future COP/MOP decisions or Assessment Reports. The project proponent shall apply a substitute chemical derived from either official published data, research, industry studies, or assume destroyed refrigerants to be replaced by HFC-134a (as per the latest version of the Climate Action Reserve's *Article 5 ODS Project Protocol*). This will be periodically re-assessed and updated.
Comments:	

Data / Parameter:	$VR_{HFC,i}$
Data unit:	%; expressed as a proportion [0-1]
Description:	Rate of HFC refrigerant i which would be vented in the baseline
Source of data:	Default value given below or project-specific rate(s) sourced from officially published data, research studies, industry data, etc. The default rate is 0% unless the project proponent demonstrates that all or a portion of the refrigerant destroyed meets the requirements of Section 7 above. For refrigerant from such sources, the venting rate is assumed to be 100%.

Description of measurement methods and procedures to be applied:	For default rate, see documentation as outlined in Section 7. For project-specific rate, consult officially published country data, research studies, industry data, etc.
Comments:	Calculated as a cumulative rate over the 10-year period following HFC destruction.

Data / Parameter:	$RR_{HFC,i}$
Data unit:	%; expressed as a proportion [0-1]
Description:	Rate of HFC refrigerant i which would be used, reused or remain in storage in the baseline
Source of data:	Default value given below or project-specific rate(s) sourced from officially published data, research studies, industry data, etc. The default rate is 100% unless the project proponent demonstrates that all or a portion of the refrigerant destroyed meets the requirements of Section 7 above. For refrigerant destroyed from such sources, the recovery rate is assumed to be 0%.
Description of measurement methods and procedures to be applied:	For default rate, see documentation as outlined in Section 7. For project-specific rate, consult officially published data, research studies, industry data, etc.
Comments:	Calculated as a cumulative rate over the 10-year period following HFC destruction.

Data / Parameter:	$DR_{HFC,i}$
Data unit:	%; expressed as a proportion [0-1]
Description:	Rate of HFC refrigerant i which would be destroyed in the baseline
Source of data:	Default value given below or project-specific rate(s) sourced from officially published data, research studies, industry data, etc. In the absence of a government mandate, product stewardship scheme, or other program that creates an incentive or mechanism for HFC refrigerant destruction in the country(ies) where the project activity occurs, the default rate is 0%.
Description of measurement methods and procedures to be applied:	
Comments:	Calculated as a cumulative rate over the 10-year period following HFC destruction.

Data / Parameter:	$LR_{HFC,i,y}$
Data unit:	%; expressed as a proportion [0-1]
Description:	Leak rate of HFC refrigerant i or substitute chemical in year y [0-1]
Source of data:	Default values given below or project-specific rate(s) sourced from officially published data, research studies, industry data, etc. Default values for HFC refrigerant used or reused in existing equipment are the applicable annual emission rates given in the latest version of the Climate Action Reserve's *Article 5 ODS Project Protocol*.
Description of measurement methods and procedures to be applied:	
Comments:	

Data / Parameter:	$EF_{HFC\_Transport+Destruct,y}$
Data unit:	$tCO_2e/tHFC$
Description:	Default emission factor aggregating both transportation and destruction emissions
Source of data:	Default value is 9 tCO2e/tHFC, calculated using the method found in Appendix D of *CAR Article 5 ODS Project Protocol.*
Description of measurement methods and procedures to be applied:	
Comments:	

Data / Parameter:	$PE_{Sub,i}$
Data unit:	tCO_2e
Description:	Emissions associated with production of substitute refrigerant for HFC refrigerant i [tCO_2e]
Source of data:	Officially published data, research studies, LCA, or industry data.
Description of measurement methods and procedures to be applied:	
Comments:	Shall be updated to reflect the results of a refrigerant production LCA in a later version. In scenarios where $RR_{HFC,i} = 0$, estimation of $PE_{Sub,i}$ may be omitted.

9.2 Data and Parameters Monitored

Data / Parameter:	$M_{DESTR,HFC,i,y}$
Data unit:	$tHFC_i$
Description:	Quantity of HFC refrigerant i sent for destruction by the project activity, including eligible and ineligible material, during year y
Source of data:	• Operation logbook of recovery facility • Identification note for each individual HFC container by a bill of lading • Certificate of Destruction for each individual HFC container (refer to Section 9.3 of this methodology "Monitoring Methodology")
Description of measurement methods and procedures to be applied:	Refer to Section 9.3 of this methodology "Monitoring Methodology"
Frequency of monitoring/recording:	Each container with HFC sent for destruction
QA/QC procedures to be applied:	All measurements should be conducted with calibrated measurement equipment according to relevant industry standards (refer to Section 9.3 of this methodology "Monitoring Methodology")
Comments:	

Data / Parameter:	$M_{DESTR,eHFC,i,y}$
Data unit:	$tHFC_i$
Description:	Eligible quantity of HFC refrigerant i sent for destruction by the project activity, including eligible and ineligible material, during year y
Source of data:	• Operation logbook of recovery facility • Identification note for each individual HFC container by a bill of lading • Certificate of Destruction for each individual HFC container (refer to Section 9.3 of this methodology "Monitoring Methodology")
Description of measurement methods and procedures to be applied:	Refer to Section 4 of this methodology "Applicability Conditions"

Frequency of monitoring/recording:	Each container with HFC sent for destruction
QA/QC procedures to be applied:	All measurements should be conducted with calibrated measurement equipment according to relevant industry standards (refer to Section 9.3 of this methodology "Monitoring Methodology")
Comments:	

Data / Parameter:	CR_y
Data unit:	%; expressed as a proportion [0-1]
Description:	Host country-level compliance rate of the law, statute or other regulatory framework in the year y. Calculation of the compliance rate shall exclude other projects implemented under GHG programs. If the compliance rate exceeds 50% (or 0.50), the project shall receive no further credit.
Source of data:	Default rate given below or officially published data, inventories, research studies, industry data etc. In countries eligible under this methodology, the default compliance rate is assumed to be 0%.
Description of measurement methods and procedures to be applied:	
Frequency of monitoring/recording:	Annually
QA/QC procedures to be applied:	
Comments:	Should baseline rates begin to increase due to increased enforcement of venting prohibitions or for any other reason, the methodology will be revised and further guidance will be provided on the calculation protocols.

Data / Parameter:	$FC_{i,j,y}$
Data unit:	Mass or volume unit per year (e.g. ton/y or m^3/y)
Description:	Quantity of fuel type i combusted in process j in year y
Source of data:	Onsite measurements

Description of measurement methods and procedures to be applied:	Use utility bills or invoices for purchased fuel, or alternatively, either mass or volume meters onsite. In cases where fuel is supplied from small daily tanks, rulers can be used to determine mass or volume of the fuel consumed, with the following conditions: The ruler gauge must be part of the daily tank and calibrated at least once a year and have a book of control for recording the measurements (on a daily basis or per shift); Accessories such as transducers, sonar and piezoelectronic devices are accepted if they are properly calibrated with the ruler gauge and receiving a reasonable maintenance; In case of daily tanks with pre-heaters for heavy oil, the calibration will be made with the system at typical operational conditions.
Frequency of monitoring/recording:	Continuously
QA/QC procedures to be applied:	If onsite measurements are used, the consistency of metered fuel consumption quantities should be cross-checked by an annual energy balance that is based on purchased quantities and stock changes. Where the purchased fuel invoices can be identified specifically for the project activity, the metered fuel consumption quantities should also be cross-checked with available purchase invoices from the financial records.
Comments:	

<table>
<tr><td>Data / Parameter:</td><td>$w_{C,i,y}$</td></tr>
<tr><td>Data unit:</td><td>tC/mass unit of the fuel</td></tr>
<tr><td>Description:</td><td>Weighted average mass fraction of carbon C in fuel type i in year y</td></tr>
<tr><td>Source of data:</td><td>The following data sources may be used if the relevant conditions apply:
<table>
<tr><th>Data source</th><th>Conditions for using the data source</th></tr>
<tr><td>a) Values provided by the fuel supplier in invoices</td><td>Where relevant information is available use option a)</td></tr>
<tr><td>b) Measurements by the project proponent</td><td>If a) is not available</td></tr>
</table></td></tr>
<tr><td>Description of measurement methods and procedures to be applied:</td><td>Measurements should be undertaken in line with national or international fuel standards.</td></tr>
<tr><td>Frequency of monitoring/recording:</td><td>The mass fraction of carbon should be obtained for each fuel delivery, from which weighted average annual values should be calculated.</td></tr>
<tr><td>QA/QC procedures to be applied:</td><td>Verify if the values under a) and b) are within the uncertainty range of the IPCC default values as provided in Table 1.2, Vol. 2 of the 2006 IPCC Guidelines. If the values fall below this range collect additional information from the testing laboratory to justify the outcome or conduct additional measurements. The laboratories in b) should have ISO17025 accreditation or justify that they can comply with similar quality standards.</td></tr>
<tr><td>Comments:</td><td>Applicable where option A is used</td></tr>
</table>

<table>
<tr><td>Data / Parameter:</td><td>$\rho_{i,y}$</td></tr>
<tr><td>Data unit:</td><td>Mass unit/volume unit of the fuel</td></tr>
<tr><td>Description:</td><td>Weighted average density of fuel type i in year y</td></tr>
<tr><td>Source of data:</td><td>The following data sources may be used if the relevant conditions apply:
<table>
<tr><th>Data source</th><th>Conditions for using the data source</th></tr>
<tr><td>a) Values provided by the fuel supplier in invoices</td><td>Where relevant information is available use option a)</td></tr>
</table></td></tr>
</table>

	b) Measurements by the project proponent	If a) is not available
	c) Regional or national default values	If a) is not available These sources can only be used for liquid fuels and should be based on well documented, reliable sources (such as national energy balances).

Description of measurement methods and procedures to be applied:	Measurements should be undertaken in line with national or international fuel standards.
Frequency of monitoring/recording:	The density of the fuel should be obtained for each fuel delivery, from which weighted average annual values should be calculated.
QA/QC procedures to be applied:	
Comments:	Applicable where option A is used and where $FC_{i,j,y}$ is measured in a volume unit. Preferably the same data source should be used for $W_{C,i,y}$ and $\rho_{i,y}$.

Data / Parameter:	$NCV_{i,y}$
Data unit:	GJ per mass or volume unit (e.g., GJ/m^3, GJ/ton)
Description:	Weighted average net calorific value of fuel type i in year y
Source of data:	The following data sources may be used if the relevant conditions apply:

Data source	**Conditions for using the data source**
a) Values provided by the fuel supplier in invoices	Where relevant information is available use option a)
b) Measurements by the project proponent	If a) is not available
c) Regional or national default values	If a) is not available. These sources can only be used for liquid fuels and should be based on well documented,

<table>
<tr><td rowspan="2"></td><td></td><td>reliable sources (such as national energy balances).</td></tr>
<tr><td>d) IPCC default values at the upper limit of the uncertainty at a 95% confidence interval as provided in Table 1.2 of Chapter 1 of Vol. 2 (Energy) of the 2006 IPCC Guidelines on National GHG Inventories</td><td>If a) is not available</td></tr>
<tr><td>Description of measurement methods and procedures to be applied:</td><td colspan="2">For a) and b): Measurements should be undertaken in line with national or international fuel standards</td></tr>
<tr><td>Frequency of monitoring/recording:</td><td colspan="2">For a) and b): The NCV should be obtained for each fuel delivery, from which weighted average annual values should be calculated For c): Review appropriateness of the values annually
For d): Any future revision of the IPCC Guidelines should be taken into account</td></tr>
<tr><td>QA/QC procedures to be applied:</td><td colspan="2">Verify if the values under a), b) and c) are within the uncertainty range of the IPCC default values as provided in Table 1.2, Vol. 2 of the 2006 IPCC Guidelines. If the values fall below this range collect additional information from the testing laboratory to justify the outcome or conduct additional measurements. The laboratories in a), b) or c) should have ISO17025 accreditation or justify that they can comply with similar quality standards.</td></tr>
<tr><td>Comments:</td><td colspan="2">Applicable where option B of this methodology is used</td></tr>
</table>

<table>
<tr><td>Data / Parameter:</td><td colspan="2">$EF_{CO2,i,y}$</td></tr>
<tr><td>Data unit:</td><td colspan="2">tCO_2e/GJ</td></tr>
<tr><td>Description:</td><td colspan="2">Weighted average CO_2 emission factor of fuel type i in year y</td></tr>
<tr><td rowspan="3">Source of data:</td><td colspan="2">The following data sources may be used if the relevant conditions apply:</td></tr>
<tr><td>Data source</td><td>Conditions for using the data source</td></tr>
<tr><td>a) Values provided by the fuel supplier in invoices</td><td>Where relevant information is available use option a).</td></tr>
</table>

<table>
<tr><td></td><td><table>
<tr><td>b) Measurements by the project proponents</td><td>If a) is not available</td></tr>
<tr><td>c) Regional or national default values</td><td>If a) is not available
These sources can only be used for liquid fuels and should be based on well documented, reliable sources (such as national energy balances).</td></tr>
<tr><td>d) IPCC default values at the upper limit of the uncertainty at a 95% confidence interval as provided in table 1.4 of Chapter1 of Vol. 2 (Energy) of the 2006 IPCC Guidelines on National GHG Inventories</td><td>If a) is not available</td></tr>
</table></td></tr>
<tr><td>Description of measurement methods and procedures to be applied:</td><td>For a) and b): Measurements should be undertaken in line with national or international fuel standards.</td></tr>
<tr><td>Frequency of monitoring/recording:</td><td>For a) and b): The CO_2 emission factor should be obtained for each fuel delivery, from which weighted average annual values should be calculated
For c): Review appropriateness of the values per monitoring interval y
For d): Any future revision of the IPCC Guidelines should be considered</td></tr>
<tr><td>QA/QC procedures to be applied:</td><td></td></tr>
<tr><td>Comments:</td><td>Applicable where option B is used.
For a): If the fuel supplier does provide the NCV value and the CO_2 emission factor on the invoice and these two values are based on measurements for this specific fuel, this CO_2 factor should be used. If another source for the CO_2 emission factor is used or no CO_2 emission factor is provided, options b), c) or d) should be used</td></tr>
</table>

Data / Parameter:	$EC_{PJ,y}$
Data unit:	MWh
Description:	Amount of electricity consumed at the HFC aggregation facility from the grid during year y
Source of data:	Onsite measurements and recorded by a computer system and/or by printed journals; or, alternatively, utility bills or invoices for purchased electricity
Description of measurement methods and procedures to be applied:	Directly measured by calibrated electricity meter installed at the project site.
Frequency of monitoring/recording:	Continuously, aggregated at least annually
QA/QC procedures to be applied:	If onsite measurements are used, cross check measurement results with invoices for purchased electricity if relevant
Comments:	

Data / Parameter:	$EF_{grid,y}$
Data unit:	tCO_2/MWh
Description:	Grid emission factor during the monitoring period y
Source of data:	Choose one of the following options: • Calculate the combined margin emission factor, using the procedures in the latest approved version of the CDM "Tool to calculate the emission factor for an electricity system"; or • Use a conservative default value of 1.3 tCO_2/MWh.
Description of measurement methods and procedures to be applied:	
Frequency of monitoring/recording:	
QA/QC procedures to be applied:	If the "Tool to calculate the emission factor for an electricity system" will be used the source and/or the calculation shall be available by printed journals.
Comments:	

Data / Parameter:	TDL_y
Data unit:	%, expressed as proportion [0-1]
Description:	Average technical transmission and distribution losses in the grid for the voltage level at which electricity is obtained from the grid at the project site during year y
Source of data:	Choose one of the following options: a) Use recent, accurate and reliable data available within the country; or b) Use a conservative default value of 20%
Description of measurement methods and procedures to be applied:	For a) TDL_y should be estimated for the distribution and transmission networks of the electricity grid of the same voltage as the connection where the proposed project activity is connected to. The technical distribution losses should not contain other types of grid losses (e.g. commercial losses/theft). The distribution losses can either be calculated by the project proponent or be based on references from utilities, network operators or other official documentation.
Frequency of monitoring/recording:	
QA/QC procedures to be applied:	In the absence of data from the relevant year, most recent figures should be used, but not older than 5 years.
Comments:	

9.3 Description of the Monitoring Plan[3]

Composition and Quantity Analysis Requirements

The requirements of this section must be followed to determine the quantities of HFC refrigerants. Prior to destruction, the precise mass and composition of HFCs to be destroyed must be determined. The following analysis must be conducted:

Mass shall be determined by individually measuring the weight of each container of HFCs:

1. When it is full prior to destruction; and
2. After it has been emptied and the contents have been fully purged and destroyed. The mass of HFCs and any contaminants is equal to the difference between the full and empty weight, as measured.

The following requirements must be met when weighing the containers of HFCs:

1. A single scale must be used for generating both the full and empty weight tickets at the destruction facility;
2. Weighing instruments must comply with the relevant national requirements and/or international standards – such as EC Directive 2009/23/EC or International Organization for Legal Metrology OIML R 76-1 – and be subject to regular calibration, as set out in the relevant national requirements and/or international standards to accuracy appropriate to its accuracy class. These instruments shall have a measuring range corresponding to the capacity of containers and tanks weighed. If a scale is found to be out of tolerance, it must be recalibrated;
3. The full weight must be measured no more than two days prior to commencement of destruction per the Certificate of Destruction; and
4. The empty weight must be measured no more than two days after the conclusion of destruction per the Certificate of Destruction.

Composition and concentration of HFCs shall be established for each individual container by taking a sample from each container of HFCs and having it analyzed for composition and concentration at a lab accredited to perform analyses in compliance with the applicable International Organization for Standardization (ISO) standard or equivalent standards. Further, where national standards exist, they may be used in lieu of ISO standards provided that they have been the subject of a verification or validation process addressing their accuracy and representativeness. In the case where no such standards exist, the US Air-Conditioning, Heating and Refrigeration Institute *700-2006* standard shall be applied.

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[3] This section is mainly based on Climate Action Reserve (CAR): U.S. Ozone Depleting Substances Project Protocol Version 2 February 27 2012 and on RAL Quality Assurance and Test Specifications for the Demanufacture of Refrigeration Equipment version: 2007/09

The laboratory performing the composition analysis must not be affiliated with the project proponent or the project activities beyond performing these services.

The following requirements must be met for each sample:

1. The sample must be taken while the HFC is in the possession of the company that will destroy the HFC;
2. Samples must be taken by a technician unaffiliated with the project developer;
3. Samples must be taken with a clean, fully evacuated sample bottle that meets applicable U.S. DOT requirements or an equivalent national (host country) or ISO standard;
4. The technician must ensure that the sample is representative of the contents of the container;
5. Each sample must be taken in liquid state;
6. A minimum sample size of 0.453592 kg (1 pound) must be drawn for each sample;
7. Each sample must be individually labeled and tracked according to the container from which it was taken, and the following information recorded:
    - Time and date of sample
    - Name of project developer
    - Name of technician taking sample
    - Employer of technician taking sample
    - Volume of container from which sample was extracted
    - Ambient air temperature at time of sampling
8. Chain of custody for each sample from the point of sampling lab must be documented by paper bills of lading or electronic, third-party tracking that includes proof of delivery.

All project samples shall be analyzed using the International Organization for Standardization (ISO) standard applicable. Further, where national standards exist, they may be used in lieu of ISO standards provided that they have been the subject of a verification or validation process addressing their accuracy and representativeness. In the case where no such standards exist, the US Air-Conditioning, Heating and Refrigeration Institute *700-2006* standard shall be applied. The analysis shall provide:

1. Identification of the refrigerant
2. Purity (%) of the HFC mixture by weight using gas chromatography
3. Moisture level in parts per million. The moisture content of each sample must be less than 75% of the saturation point for the HFC based on the temperature recorded at the time the sample was taken. For containers that hold mixed HFC, the sample's saturation point shall be assumed to be that of the HFC species in the mixture with the lowest saturation point that is at least 10 percent of the mixture by mass.

4. Analysis of high boiling residue, which must be less than 10% by mass
5. Analysis of other HFCs in the case of mixtures of HFCs, and their percentage by mass

If any of the requirements above are not met, no GHG reductions may be verified for HFC destruction associated with that container. If a sample is tested and does not meet one of the requirements as defined above, the project proponent may elect to have the material re-sampled and re-analyzed. The project proponent may sample for moisture content and perform any necessary de-watering prior to the required sampling and laboratory analysis.

If the container holds non-mixed HFC (defined as greater than 90% composition of a single HFC species), no further information or sampling is required to determine the mass and composition of the HFC. If the container holds mixed HFCs, which is defined as less than 90% composition of a single HFC species, the project proponent must meet additional requirements as provided below.

Composition and Quantity Analysis Requirements for Mixed HFCs

If a container holds mixed HFCs, its contents must also be processed and measured for composition and concentration according to the requirements of this section. The sampling required under this section may be conducted at the final destruction facility or at an aggregation facility. However, the circulation and sampling activities must be conducted by a third-party organization (i.e., not the project proponent), and by individuals who have been properly trained for the functions they perform. Circulation and sampling may be conducted at the project proponent's facility, but all activities must be directed by a properly trained and contracted third-party. The project description must specify the procedures by which mixed HFCs are analyzed.

The composition and concentration of HFCs on a mass basis must be determined using the results of the analysis of this section for each container. The results of the composition analysis in the section above shall be used by verifiers to confirm that the destroyed HFC refrigerant is in fact the same HFC refrigerant that is sampled under these requirements. Prior to sampling, the HFC mixture must be circulated in a container that meets all the following criteria:

1. The container has no solid interior obstructions; mesh baffles or other interior structures that do not impede the flow of HFCs are acceptable;
2. The container was fully evacuated prior to filling;
3. The container must have sampling ports to sample liquid and gas phase HFC;
4. The liquid port intake must be at the bottom of the container, and the vapor port intake must be at the top of the container. For horizontally oriented mixing containers, the intakes must be located in the middle third of the container; and
5. The container and associated equipment can circulate the mixture via a closed loop system from the bottom to top.

If the original mixed HFC container does not meet these requirements, the mixed HFC must be transferred into a temporary holding tank or container that meets all the above criteria. The weight of the contents placed into the temporary container shall be calculated and recorded.

During transfer of refrigerant into and out of the temporary container, refrigerant shall be recovered to the vacuum levels required by the U.S. EPA for that refrigerant (see 40 CFR 82.156) or any national (host country) or ISO standard.

Once the mixed HFCs are in a container or temporary storage unit that meets the criteria above, circulation of mixed HFCs must be conducted as follows:

1. Liquid mixture shall be circulated from the liquid port to the vapor port;
2. A volume of the mixture equal to two times the volume in the container shall be circulated;
3. Circulation must occur at a rate of at least 113.6l/minute; and
4. Start and end times shall be recorded.

Within 30 minutes of the completion of circulation, a minimum of two samples shall be taken from the bottom liquid port and analyzed according to the procedures above. The mass composition and concentration of the mixed HFCs shall be equal to the lesser of the two GWP-weighted concentrations.

Destruction Facility Requirements

Destruction of HFCs must occur at a facility that has a valid host country permit for refrigerant destruction and meets the screening criteria for destruction technologies set out in the report, as may be updated from time to time, by the UNEP Technology and Economic Assessment Panel (TEAP) Task Force on Destruction Technologies.

The UNEP TEAP Task Force on Destruction Technologies has reviewed HFC destruction and concluded “that no additional performance criteria [beyond ODS protocols] are necessary for assessing destruction technologies for the destruction of HFCs." ICF International, in a report commissioned by US EPA, similarly advises that "the best installation, handling, recovery, reclamation, and disposal practices are identical between ODS and HFCs.” Thus operating parameters of the destruction unit while destroying HFC material shall be monitored and recorded as described in the Code of Good Housekeeping[4] (as reproduced in full in Appendix II) approved by the Montreal Protocol, with only the substitution of “HFC” for “ODS” where applicable. Likewise, the Technology Screening Process for ODS destruction technologies (reproduced in full in Appendix III from TEAP *Report of the Task Force on Destruction Technologies*, Chapter 2 (2002)) is equally valid for HFCs, and should be followed with only the substitution of “HFC” for “ODS” where applicable.

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[4] TEAP, Code of Good Housekeeping in *Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer - 7th Edition* (2006).

10 REFERENCES

TEAP, Code of Good Housekeeping in *Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer - 7th Edition* (2006)

UNEP Technology and Economic Assessment Panel (TEAP) Report of the Task Force on Destruction Technologies, UNEP, 2002.

APPENDIX I: COUNTRY-LEVEL INCLUSION CRITERIA AND ADDITIONALITY CHECK

The Kigali Amendment to the Montreal Protocol assigns each signatory country to one of four possible HFC phasedown schedules, summarized in the table below.[5]

Table AI-1. *HFC Phasedown Schedules*

	Article/Group HFC Phasedown Schedules Pursuant to Kigali Amendment			
Country Group	Countries Included	Baseline Calculation Years	Freeze Year	First Stepdown Year
Non-Article 5 (Main)	Most of the developed world	2011, 2012, 2013	--	2019
Non-Article 5 (Other)	Belarus, Russia, Kazakhstan, Turkmenistan, Uzbekistan	2011, 2012, 2013	--	2020
Article 5 (Group 1)	Most of the developing world (includes China)	2020, 2021, 2022	2024	2029
Article 5 (Group 2)	The Middle East (also includes India)	2024, 2025, 2026	2028	2032

The Kigali Amendment to the Montreal Protocol requires the determination of baseline production and consumption, from which HFC phasedown schedules are calculated:

$$Production = CS_{Produced} - CS_{Destroyed} - CS_{Feedstock} \qquad \text{(Equation AI-1)}$$

$$Consumption = Production + Imports - Exports \qquad \text{(Equation AI-2)}$$

where CS or "controlled substance" refers to a substance in Annex A, B, C, E or F to the Montreal Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance.

Substituting Equation AI-1 into Equation AI-2 yields the following equation for consumption:

$$Consumption = CS_{Produced} - \boldsymbol{CS_{Destroyed}} - CS_{Feedstock} + Imports - Exports \qquad \text{(Equation AI-3)}$$

The interaction between the Montreal Protocol and carbon crediting for HFC destruction depends on a country's phasedown stage because destroyed refrigerant ($\boldsymbol{CS_{Destroyed}}$, Equation AI-3) is subtracted from both the baseline and stepdown consumption values. Specifically, if destruction occurs during baseline setting years, it will decrease the baseline consumption calculation and all subsequent stepdown year values will follow. As a result, destruction in Article 5 Group 2 countries is especially effective if completed in 2024-2026 (Table AI-1).

When a country is already in phasedown, however, subtracting destroyed refrigerant from the calculated consumption level may increase allowable production or imports. Such manipulations would be highly improbable and have never been exploited, despite the existence of destruction credits for controlled substances such as ODS (Office of the Ozone Secretariat, *unpublished data*[6]).

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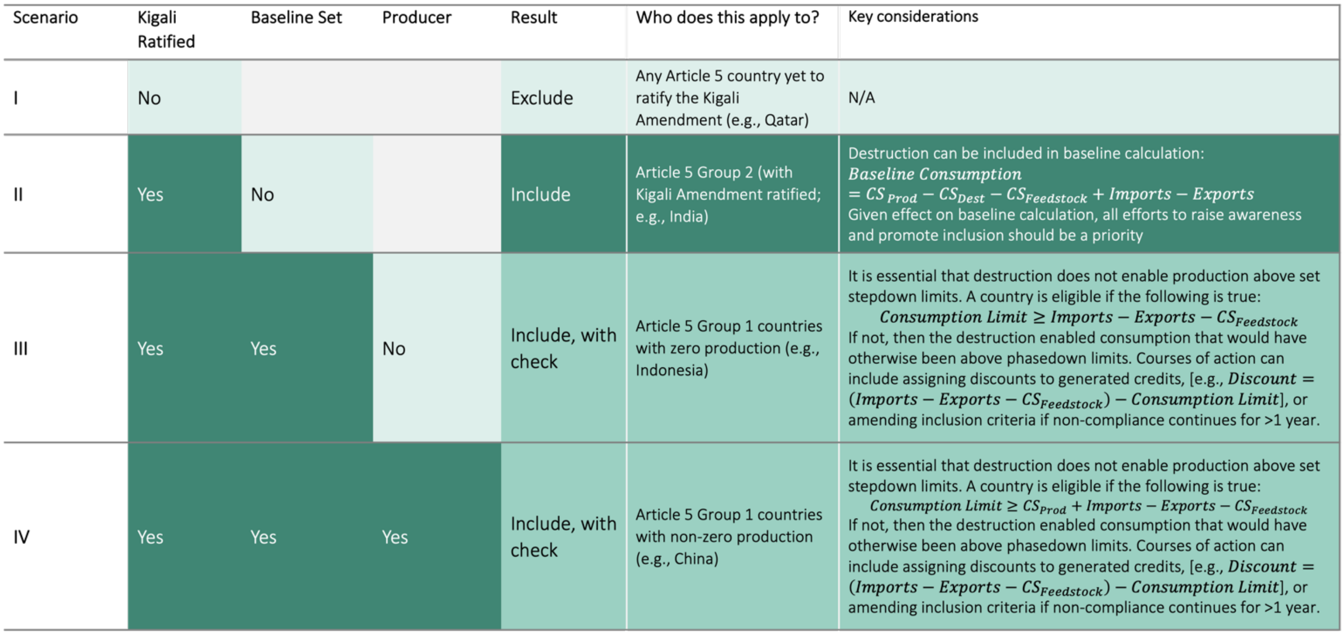
[5] Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction (link).

[6] Mr. Gerald Mutisya, Office of the Ozone Secretariat, analyzed past reported data to assess if destruction was among the uses allowing the party to stay in compliance by any Article 5 party from 1986-2022, inclusive of all controlled substances. Results indicated only one A5 country with one year in which a small amount of destruction was the basis for compliance. The amount destroyed is considered small because it was approximately 0.1% of the total production reported by that country in that year.

Nevertheless, to safeguard against this issue, eligibility requirements for countries that use destruction to comply with their consumption limits may be updated to reflect this (Table A1-2). Specifically, Ozone Secretariat data can be monitored annually to ensure that destruction, as described in this methodology, is not enabling additional production of refrigerant gas.

If a country does increase its production or imports due to destruction, pathways for addressing this could include discounting total credits (by the excess over the cap) or removing them from the list of eligible countries. With these safeguards in place, this methodology can safely apply to all A5 countries which have ratified the Kigali Amendment.

Table A1-2. Proposed criteria for inclusion and exclusion



Scenario	Kigali Ratified	Baseline Set	Producer	Result	Who does this apply to?	Key considerations
I	No			Exclude	Any Article 5 country yet to ratify the Kigali Amendment (e.g., Qatar)	N/A
II	Yes	No		Include	Article 5 Group 2 (with Kigali Amendment ratified; e.g., India)	Destruction can be included in baseline calculation: $Baseline\ Consumption = CS_{Prod} - CS_{Dest} - CS_{Feedstock} + Imports - Exports$ Given effect on baseline calculation, all efforts to raise awareness and promote inclusion should be a priority
III	Yes	Yes	No	Include, with check	Article 5 Group 1 countries with zero production (e.g., Indonesia)	It is essential that destruction does not enable production above set stepdown limits. A country is eligible if the following is true: $Consumption\ Limit \geq Imports - Exports - CS_{Feedstock}$ If not, then the destruction enabled consumption that would have otherwise been above phasedown limits. Courses of action can include assigning discounts to generated credits, [e.g., $Discount = (Imports - Exports - CS_{Feedstock}) - Consumption\ Limit$], or amending inclusion criteria if non-compliance continues for >1 year.
IV	Yes	Yes	Yes	Include, with check	Article 5 Group 1 countries with non-zero production (e.g., China)	It is essential that destruction does not enable production above set stepdown limits. A country is eligible if the following is true: $Consumption\ Limit \geq CS_{Prod} + Imports - Exports - CS_{Feedstock}$ If not, then the destruction enabled consumption that would have otherwise been above phasedown limits. Courses of action can include assigning discounts to generated credits, [e.g., $Discount = (Imports - Exports - CS_{Feedstock}) - Consumption\ Limit$], or amending inclusion criteria if non-compliance continues for >1 year.

APPENDIX II: CODE OF GOOD HOUSEKEEPING[7]

To provide additional guidance to facility operators, in May 1992 the Technical Advisory Committee prepared a "Code of Good Housekeeping" as a brief outline of measures that should be considered to ensure that environmental releases of ozone-depleting substances (ODS) through all media are minimized. This Code, updated by the Task Force on Destruction Technologies and amended by the Parties at their Fifteenth Meeting, in 2003, is also intended to provide a framework of practices and measures that should normally be adopted at facilities undertaking the destruction of ODS.

Not all measures will be appropriate to all situations and circumstances and, as with any code, nothing specified should be regarded as a barrier to the adoption of better or more effective measures if these can be identified.

Pre-delivery

This refers to measures that may be appropriate prior to any delivery of ODS to a facility.

The facility operator should generate written guidelines on ODS packaging and containment criteria, together with labelling and transportation requirements. These guidelines should be provided to all suppliers and senders of ODS prior to agreement to accept such substances.

The facility operator should seek to visit and inspect the proposed sender's stocks and arrangements prior to movement of the first consignment. This is to ensure awareness on the part of the sender of proper practices and compliance with standards.

Arrival at the facility

This refers to measures that should be taken at the time ODS are received at the facility gate. These include an immediate check of documentation prior to admittance to the facility site, coupled with a preliminary inspection of the general condition of the consignment. Where necessary, special or "fast- track" processing and repackaging facilities may be needed to mitigate risk of leakage or loss of ODS. Arrangements should exist to measure the gross weight of the consignment at the time of delivery.

Unloading from delivery vehicle

This refers to measures to be taken at the facility in connection with the unloading of ODS. It is generally assumed that ODS will normally be delivered in some form of container, drum or other vessel that is removed from the delivery vehicle in total. Such containers may be returnable.

All unloading activities should be carried out in properly designated areas, to which restricted access of personnel applies. Areas should be free of extraneous activities likely to lead to, or increase the risk of, collision, accidental dropping, spillage, etc. Materials should be placed in designated quarantine areas for subsequent detailed checking and evaluation.

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[7] Reproduced in full from: TEAP, Code of Good Housekeeping in *Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer - 7th Edition* (2006)

Testing and verification

This refers to the arrangements made for detailed checking of the ODS consignments prior to destruction.

Detailed checking of delivery documentation should be carried out, along with a complete inventory, to establish that delivery is as advised and appears to comply with expectations.

Detailed checks of containers should be made both in respect of accuracy of identification labels, etc, and of physical condition and integrity. Arrangements must be in place to permit repackaging or “fast-track” processing of any items identified as defective. Sampling and analysis of representative quantities of ODS consignments should be carried out to verify material type and characteristics. All sampling and analysis should be conducted using approved procedures and techniques.

Storage and stock control

This refers to matters concerning the storage and stock control of ODS.

ODS materials should be stored in specially designated areas, subject to the regulations of the relevant local authorities. Arrangements should be put in place as soon as possible to minimize, to the extent practicable, stock emissions prior to destruction.

Locations of stock items should be identified through a system of control that should also provide a continuous update of quantities and locations as stock is destroyed and new stock delivered. In regard to storage vessels for concentrated sources of ODS, these arrangements should include a system for regular monitoring and leak detection, as well as arrangements to permit repackaging of leaking stock as soon as possible.

Measuring quantities destroyed

It is important to be aware of the quantities of ODS processed through the destruction equipment. Where possible, flow meters or continuously recording weighing equipment for individual containers should be employed. As a minimum, containers should be weighed “full” and “empty” to establish quantities by difference.

Residual quantities of ODS in containers that can be sealed and are intended to be returned for further use, may be allowed. Otherwise, containers should be purged of residues or destroyed as part of the process.

Facility design

This refers to basic features and requirements of plant, equipment and services deployed in the facility.

In general, any destruction facility should be properly designed and constructed in accordance with the best standards of engineering and technology and with particular regard to the need to minimize, if not eliminate, fugitive losses.

Particular care should be taken when designing plants to deal with dilute sources such as foams. These may be contained in refrigeration cabinets or may be part of more general demolition waste. The area in which foam is first separated from other substrates should be fully enclosed wherever possible and any significant emissions captured at that stage.

Pumps: Magnetic drive, sealers or double mechanical seal pumps should be installed to eliminate environmental releases resulting from seal leakage.

Valves: Valves with reduced leakage potential should be used. These include quarter-turn valves or valves with extended packing glands.

Tank vents (including loading vents): Filling and breathing discharges from tanks and vessels should be recovered or vented to a destruction process.

Piping joints: Screwed connections should not be used and the number of flanged joints should be kept to the minimum that is consistent with safety and the ability to dismantle for maintenance and repair.

Drainage systems: Areas of the facility where ODS are stored or handled should be provided with sloped concrete paving and a properly designed collection system. Water that is collected should, if contaminated, be treated prior to authorized discharge.

Maintenance

In general, all maintenance work should be performed according to properly planned programmes and should be executed within the framework of a permit system to ensure proper consideration of all aspects of the work.

ODS should be purged from all vessels, mechanical units and pipework prior to the opening of these items to the atmosphere. The contaminated purge should be routed to the destruction process or treated to recover the ODS.

All flanges, seals, gaskets and other sources of minor losses should be checked routinely to identify developing problems before containment is lost. Leaks should be repaired as soon as possible.

Consumable or short-life items, such as flexible hoses and couplings, must be monitored closely and replaced at a frequency that renders the risk of rupture negligible.

Quality control and quality assurance

All sampling and analytical work connected with ODS, the process and the monitoring of its overall performance should be subject to quality assessment and quality control measures in line with current recognized practices. This should include at least occasional independent verification and confirmation of data produced by the facility operators.

Consideration should also be given to the adoption of quality management systems and environment quality practices covering the entire facility.

Training

All personnel concerned with the operation of the facility (with "operation" being interpreted in its widest sense) should have training appropriate to their task. Of particular relevance to the ODS destruction objectives is training in the consequences of unnecessary losses and in the use, handling and maintenance of all equipment in the facility. All training should be carried out by suitably qualified and experienced personnel and the details of such training should be maintained in written records. Refresher training should be conducted at appropriate intervals.

Code of transportation

In the interest of protecting the stratospheric ozone layer, it is essential that used ODS and products containing ODS are collected and moved efficiently to facilities practising approved destruction technologies. For transportation purposes, used ODS should receive the same hazard classification as the original substances or products. In practice, this may introduce restrictions on hazardous waste shipment under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and this should be consulted separately. In the absence of such specific restrictions, the following proposed code of transportation for ODS from customer to destruction facilities is provided as a guide to help minimize damage caused to the ozone layer as a result of ODS transfers. Additional guidance is contained in the United Nations Transport of Dangerous Goods Model Regulations.

It is important to supervise and control all shipments of used ODS and products containing ODS according to national and international requirements to protect the environment and human health. To ensure that ODS and products containing ODS do not constitute an unnecessary risk, they must be properly packaged and labelled. Instructions to be followed in the event of danger or accident must accompany each shipment to protect human beings and the environment from any danger that might arise during the operation.

Notification of the following information should be provided at any intermediate stage of the shipment from the place of dispatch until its final destination. When making notification, the notifier should supply the information requested on the consignment note, with particular regard to:

a. The source and composition of the ODS and products containing ODS, including the customer's identity;
b. Arrangements for routing and for insurance against damage to third parties;
c. Measures to be taken to ensure safe transport and, in particular, compliance by the carrier with the conditions laid down for transport by the States concerned;
d. The identity of the consignee, who should possess an authorized centre with adequate technical capacity for the destruction;
e. The existence of a contractual agreement with the consignee concerning the destruction of ODS and products containing ODS.

This code of transportation does not necessarily apply to the disposal of ODS-containing rigid insulation foams. The most appropriate way to dispose of such products may be by direct incineration in municipal waste incinerators or rotary kiln incinerators.

Monitoring

The objectives of monitoring should be to provide assurance that input materials are being destroyed with an acceptable efficiency generally consistent with the destruction and removal efficiency (DRE) recommendations listed in annex II to the present report and that the substances resulting from destruction yield environmentally acceptable emission levels consistent with, or better than, those required under national standards or other international protocols or treaties.

As there are as yet no International Organization for Standardization (ISO) standards applicable for the sampling and analysis of ODS or the majority of the other pollutants listed in annex IV to the present report, where national standards exist they should be employed. Further, where national standards exist they may be used in lieu of ISO standards provided that they have been the subject of a verification or validation process addressing their accuracy and representativeness.

As ISO develops international standards for pollutants listed in annex IV to the present report, the technical bodies charged with developing such standards should take note of the existing national standards including those identified in appendix F to the report of the Technology and Economic Assessment Panel (TEAP) of April 2002 (volume 3, report of the Task Force on Destruction Technologies) and strive to ensure consistency between any new ISO standards and the existing standard test methods, provided that there is no finding that those existing methods are inaccurate or unrepresentative.

Where national standards do not exist, the Technical Advisory Committee recommends adoption of the following guidelines for monitoring of destruction processes operating using an approved technology.

Recognizing that the Unites States of America Environmental Protection Agency (EPA) methods have been the subject of verification procedures to ensure that they are reasonably accurate and representative, that they cover all of the pollutants of interest (although not all ODS compounds have been the specific subject of verification activities), that they provide a comprehensive level of detail that should lead to replicability of the methods by trained personnel in other jurisdictions and that they are readily available for reference and downloading from the Internet without the payment of a fee, applicable EPA methods as described in appendix F to the 2002 report of TEAP may be employed.

In the interest of ensuring a common international basis of comparison for those pollutants or parameters where ISO standards exist (currently particulates, carbon monoxide, carbon dioxide and oxygen), use of those standards is encouraged and jurisdictions are encouraged to adopt them as national standards or acceptable alternatives to existing national standards.

The use of EPA or other national standards described in appendix F is also considered acceptable, however. The precedence given to the EPA methods in the present code is based on the relative comprehensiveness of the methods available (both in scope and content), and the relative ease of access to those methods.

Measurement of ODS

Operators of destruction facilities should take all necessary precautions concerning the storage and inventory control of ODS-containing material received for destruction. Prior to feeding the ODS to the approved destruction process, the following procedures are recommended:

a. The mass of the ODS-containing material should be determined, where practicable;

b. Representative samples should be taken, where appropriate, to verify that the concentration of ODS matches the description given on the delivery documentation;

c. Samples should be analysed by an approved method. If no approved methods are available, the adoption of United States EPA methods 5030 and 8240 is recommended;

d. All records from these mass and ODS-concentration measurements should be documented and kept in accordance with ISO 9000 or equivalent.

Control systems

Operators should ensure that destruction processes are operated efficiently to ensure complete destruction of ODS to the extent that it is technically feasible for the approved process. This will normally include the use of appropriate measurement devices and sampling techniques to monitor the operating parameters, burn conditions and mass concentrations of the pollutants that are generated by the process.

Gaseous emissions from the process need to be monitored and analysed using appropriate instrumentation. This should be supplemented by regular spot checks using manual stack-sampling methods. Other environmental releases, such as liquid effluents and solid residues, require laboratory analysis on a regular basis.

The continuous monitoring recommended for ongoing process control, including off-gas cleaning systems, is as follows:

a. Measurement of appropriate reaction and process temperatures;

b. Measurement of flue gas temperatures before and after the gas cleaning system;

c. Measurement of flue gas concentrations for oxygen and carbon monoxide.

Any additional continuous monitoring requirements are subject to the national regulatory authority that has jurisdiction. The performance of online monitors and instrumentation systems must be periodically checked and validated. When measuring detection limits, error values at the 95 per cent confidence level should not exceed 20 per cent.

Approved processes must be equipped with automatic cut-off control systems on the ODS feed system, or be able to go into standby mode whenever:

a. The temperature in the reaction chamber falls below the minimum temperature required to achieve destruction;

b. Other minimum destruction conditions stated in the performance specifications cannot be maintained.

Performance measurements

The approval of technologies recommended by TEAP is based on the destruction capability of the technology in question. It is recognized that the parameters may fluctuate during day-to-day operation from this generic capability. In practice, however, it is not possible to measure against performance criteria on a daily basis. This is particularly the case for situations where ODS only represents a small fraction of the substances being destroyed, thereby requiring specialist equipment to achieve detection of the very low concentrations present in the stack gas. It is therefore not uncommon for validation processes to take place annually at a given facility.

With this in mind, TEAP is aware that the measured performance of a facility may not always meet the criteria established for the technology. Nonetheless, TEAP sees no justification for reducing the minimum recommendations for a given technology. Regulators, however, may need to take these practical variations into account when setting minimum standards.

The ODS destruction and removal efficiency[8] for a facility operating an approved technology should be validated at least once every three years. The validation process should also include an assessment of other relevant stack gas concentrations identified in annex II to decision XV/[…] and a comparison with maximum levels stipulated in relevant national standards or international protocols/treaties.

Determination of the ODS destruction and removal efficiency and other relevant substances identified in annex IV to the present report should also be followed when commissioning a new or rebuilt facility or when any other significant change is made to the destruction procedures in a facility to ensure that all facility characteristics are completely documented and assessed against the approved technology criteria.

Tests shall be done with known feed rates of a given ODS compound or with well-known ODS mixtures. In cases where a destruction process incinerates halogen-containing wastes together with ODS, the total halogen load should be calculated and controlled. The number and duration of test runs should be carefully selected to reflect the characteristics of the technology.

In summary, the destruction and removal efficiency recommended for concentrated sources means that less than 0.1 gram of total ODS should normally enter the environment from stack-gas emissions when 1,000 grams of ODS are fed into the process. A detailed analysis of stack test results should be made available to verify emissions of halogen acids and polychlorinated dibenzodioxin and dibenzofuran (PCDD/PCDF). In addition, a site-specific test protocol should be prepared and made available for inspection by the appropriate regulatory authorities. The sampling protocol shall report the following data from each test:

a. ODS feed rate;
b. Total halogen load in the waste stream;
c. Residence time for ODS in the reaction zone;
d. Oxygen content in flue gas;
e. Gas temperature in the reaction zone;
f. Flue gas and effluent flow rate;
g. Carbon monoxide in flue gas;

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[8] Destruction and removal efficiency 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

h. ODS content in flue gas;

i. Effluent volumes and quantities of solid residues discharged;

j. ODS concentrations in the effluent and solid residues;

k. Concentration of PCDD/PCDF, particulates, HCl, HF and HBr in the flue gases;

l. Concentration of PCDD/PCDF in effluent and solids.

APPENDIX III: TECHNOLOGY SCREENING PROCESS[9]

Criteria for Technology Screening

The following screening criteria were developed by the UNEP TFDT. Technologies for use by the signatories to the Montreal Protocol to dispose of surplus inventories of ODS were assessed on the basis of:

1. Destruction and Removal Efficiency (DRE)
2. Emissions of dioxins/furans
3. Emissions of other pollutants (acid gases, particulate matter, & carbon monoxide)
4. Technical capability

The first three refer to technical performance criteria selected as measures of potential impacts of the technology on human health and the environment. The technical capability criterion indicates the extent to which the technology has been demonstrated to be able to dispose of ODS (or a comparable recalcitrant halogenated organic substance such as PCB) effectively and on a commercial scale.

For convenience, the technical performance criteria are summarized in Table 3-1. These represent the minimum destruction and removal efficiencies and maximum emission of pollutants to the atmosphere permitted by technologies that qualify for consideration by the TFDT for recommendation to the Parties of the Montreal Protocol for approval as ODS destruction technologies. The technologies must also satisfy the criteria for technical capability as defined below.

Table A3-1: Summary of Technical Performance Qualifications[10]

Performance Qualification	Units	Diluted Sources	Concentrated Sources
DRE	%	95	99.99
PCDDs/PCDFs	ng-ITEQ/NM^3	0.5	0.2
HCL/CL_2	mg/NM^3	100	100
HF	mg/NM^3	5	5
HBr/Br_2	mg/NM^3	5	5
Particulates	mg/NM^3	50	50
CO	mg/NM^3	100	100

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[9] Reproduced in full from: *UNEP Technology and Economic Assessment Panel (TEAP) Report of the Task Force on Destruction Technologies*, UNEP, 2002. Available at: http://ozone.unep.org/teap/Reports/Other_Task_Force/TEAP02V3b.pdf

[10] All concentrations of pollutants in stack gases and stack gas flow rates are expressed on the basis of dry gas at normal conditions of 0ºC and 101.3 kPa, and with the stack gas corrected to 11% O2.

Destruction and Removal Efficiency

Destruction Efficiency (DE)[11] is a measure of how completely a particular technology destroys a contaminant of interest – in this case the transformation of ODS material into non-ODS by-products. There are two commonly used but different ways of measuring the extent of destruction – DE and Destruction and Removal Efficiency (DRE)[12]. For a more detailed explanation of how DRE is calculated, see section 4.2.1. The terms are sometimes interchanged or used inappropriately. DE is a more comprehensive measure of destruction than DRE, because DE considers the amount of the chemical of interest that escapes destruction by being removed from the process in the stack gases and in all other residue streams. Most references citing performance of ODS destruction processes only provide data for stack emissions and thus, generally, data is only available for DRE and not DE.

Because of the relatively volatile nature of ODS and because, with the exception of foams, they are generally introduced as relatively clean fluids, one would not expect a very significant difference between DRE and DE. For these reasons this update of ODS destruction technologies uses DRE as the measure of destruction efficiency. For the purposes of screening destruction technologies, the minimum acceptable DRE is:

- 95% for foams; and,
- 99.99% for concentrated sources.

It should be noted that measurements of the by-products of destruction of CFCs, HCFCs and halons in a plasma destruction process have indicated that interconversion of ODS can occur during the process. For example, under some conditions, the DRE of CFC-12 (CCl_2F_2) was measured as 99.9998%, but this was accompanied by a conversion of 25% of the input CFC-12 to CFC-13 ($CClF_3$), which has the same ozone-depleting potential. The interconversion is less severe when hydrogen is present in the process, but can nonetheless be significant.[13] For this reason, it is important to take into account all types of ODS in the stack gas in defining the DRE.

For the reasons described in the previous paragraph, the Task Force recommends that future calculations of DRE use the approach described below[14].

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[11] Destruction Efficiency (DE) is 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 that is released in stack gases, fly ash, scrubber water, bottom ash, and any other system residues and expressing that difference as a percentage of the mass of the chemical fed into the system.

[12] 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

[13] R. T. Deam, A. R. Dayal, T. McAllister, A. E. Mundy, R. J. Western, L. M. Besley, A. J. D. Farmer, E. C. Horrigan, and A. B. Murphy, Interconversion of chlorofluorocarbons in plasmas, *J. Chem. Soc.: Chem. Commun.* No. 3 (1995) 347-348; A. B. Murphy, A. J. D. Farmer, E. C. Horrigan, and T. McAllister, Plasma destruction of ozone depleting substances, *Plasma Chem. Plasma Process.* **22** (2002) 371-385.

[14] Since different ODS have different ODP, consideration should be given to taking into account the ODP of each type of ODS present in the stack gas in calculating the DRE. An appropriate definition that takes into account the differences in ODP is: *DRE of an ODS is determined by subtracting from the number of moles of the ODS fed into a destruction system during a specific period of time, the total number of moles of all types of ODS that are released in stack gases, weighted by their ODP relative to that of the feed ODS, and expressing that difference as a percentage of the number of moles of the ODS fed into the system.*

DRE of an ODS should be determined by subtracting from the number of moles of the ODS fed into a destruction system during a specific period of time, the total number of moles of all types of ODS that are released in stack gases, and expressing that difference as a percentage of the number of moles of the ODS fed into the system.

In mathematical terms, $DRE = \frac{N_I^{in} - \sum_i N_i^{out}}{N_I^{in}}$ where N_I^{in} is the number of moles of ODS fed into the destruction system and N_I^{in} is the number of moles of the *i*th type of ODS that is released in the stack gases.

Emissions of Dioxins and Furans

Any high temperature process used to destroy ODS has associated with it the potential formation (as by-products) of polychlorinated dibenzo-paradioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). These substances are among the products of incomplete combustion (or PICs) of greatest concern for potential adverse effects on public health and the environment. The internationally recognized measure of the toxicity of these compounds is the toxic equivalency factor (ITEQ),[15] which is a weighted measure of the toxicity for all the members of the families of these toxic compounds that are determined to be present.

The task force members note that the World Health Organization has developed a new system for calculating TEQs, however, most of the existing data on emissions is expressed in the former ITEQ system established in 1988.

For purposes of screening destruction technologies, the maximum concentration of dioxins and furans in the stack gas from destruction technologies is:

- 0.5 ng-ITEQ/Nm^3 for foams; and,
- 0.2 ng-ITEQ/Nm^3 for concentrated sources.

These criteria were determined to represent a reasonable compromise between more stringent standards already in place in some industrialized countries [for example, the Canada-Wide Standard of 0.08 ng/m^3 (ITEQ)], and the situation in developing countries where standards may be less stringent or non-existent. Although a previous standard of 1.0 ng/m^3 (ITEQ) had been suggested in the UNEP 1992 report, advances in technology in recent years, and the level of concern for emissions of these highly toxic substances justified a significantly more stringent level.

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[15] There are 75 chlorinated dibenzo-p-dioxins and 135 chlorinated dibenzofurans that share a similar chemical structure but that have a wide range in degree of chlorination and a corresponding wide range in toxicity. Of these, one specific dioxin [2,3,7,8- Tetrachlorodibenzo-p-dioxin, or (TCDD)] is the most toxic and best characterized of this family of compounds. Since PCDDs and PCDFs are generally released to the environment as mixtures of these compounds, the scientific community has developed a system of toxic equivalency factors (TEFs) which relate the biological potency of compounds in the dioxin/furan family to the reference TCDD compound. The concentration of each specific compound is multiplied by its corresponding TEF value, and the resulting potency-weighted concentration values are summed to form an expression of the mixture's overall toxic equivalence (TEQ). The result of this exercise is a standardized expression of toxicity of a given mixture in terms of an equivalent amount of TCDD (the reference compound). The internationally accepted protocol for determining TEQ – *i.e.,* ITEQ – was established by NATO in 1988. [*Scientific Basis for the Development of International Toxicity Equivalency Factor (I-TEF), Method of Risk Assessment for Risk Assessment of Complex Mixtures of Dioxins and Related Compounds*. North Atlantic Treaty Organization/Committee on the Challenge of Modern Society. Report No. 176, Washington, D.C. 1988.]

Emissions of Acid Gases, Particulate Matter and Carbon Monoxide

Acid gases are generally formed when ODS are destroyed and these must be removed from the stack gases before the gases are released to the atmosphere. The following criteria for acid gases have been set for purposes of screening destruction technologies:

- A maximum concentration in stack gases of 100 mg/Nm^3 HCl/Cl$_2$
- A maximum concentration in stack gases of 5 mg/Nm^3 HF; and,
- A maximum concentration in stack gases of 5 mg/Nm^3 HBr/Br$_2$.

Particulate matter is generally emitted in the stack gases of incinerators for a variety of reasons and can also be emitted in the stack gases of facilities using non-incineration technologies. For the purposes of screening technologies, the criterion for particulate matter is established as:

- A maximum concentration of total suspended particulate (TSP) of 50 mg/Nm^3.

Carbon monoxide (CO) is generally released from incinerators resulting from incomplete combustion and may be released from some ODS destruction facilities because it is one form by which the carbon content of the ODS can exit the process. Carbon monoxide is a good measure of how well the destruction process is being controlled. For the purposes of screening technologies, the following criterion has been established:

- A maximum CO concentration in the stack gas of 100 mg/Nm^3.

These maximum concentrations apply to both foams and concentrated sources. They were set to be achievable by a variety of available technologies while ensuring adequate protection of human health and the environment.

Technical Capability

As well as meeting the above performance requirements it is necessary that the destruction technologies have been demonstrated to be technically capable at an appropriate scale of operation. In practical terms, this means that the technology should be demonstrated to achieve the required DRE while satisfying the emissions criteria established above. Demonstration of destruction of ODS is preferred but not necessarily required. Destruction of halogenated compounds that are refractory, *i.e.,* resistant to destruction, is acceptable. For example, demonstrated destruction of polychlorinated biphenyls (PCBs) was often accepted as an adequate surrogate for demonstrated ODS destruction.

For this evaluation, an ODS destruction technology is considered technically capable if it meets the following minimum criteria:

- It has been demonstrated to have destroyed ODS to the technical performance standards, on at least a pilot scale or demonstration scale (designated in Table 2-2 as “Yes”).
- *It has been demonstrated to have destroyed a refractory chlorinated* organic compound other than an ODS, to the technical performance standards, on at least a pilot scale or demonstration scale (designated in Table 2-2 as “P,” which indicates that the technology is considered to have a high potential for application with ODS, but has not actually been demonstrated with ODS).

- The processing capacity of an acceptable pilot plant or demonstration plant must be no less than 1.0 kg/hr of the substance to be destroyed, whether ODS or a suitable surrogate.

These criteria of technical capability will minimize the risk associated with technical performance and ensure that destruction of ODS will be performed in a predictable manner consistent with protecting the environment.