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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Seventy-eighth Meeting
Montreal, 4-7 April 2017

KEY ASPECTS RELATED TO HFC-23 BY-PRODUCT CONTROL TECHNOLOGIES

Background

1. At the Twenty-eighth Meeting[1], the Parties to the Montreal Protocol adopted the Kigali Amendment[2], which inserted Article 2J on the control of consumption and production of the controlled substances listed in Annex F[3] to the Montreal Protocol. With regard to Annex F, Group II substances (i.e., HFC-23), the Kigali Amendment stipulated, *inter alia*, that:

(a) Each party manufacturing Annex C, Group I, or Annex F substances shall ensure that for the twelve-month period commencing on 1 January 2020, and in each twelve-month period thereafter, its emissions of Annex F, Group II substances generated in each production facility that manufactures Annex C, Group I, or Annex F substances are destroyed to the extent practicable using technology approved by the Parties in the same twelve-month period[4];

(b) Emissions of Annex F, Group II substances generated in each facility that generates Annex C, Group I, or Annex F substances by including, among other things, amounts emitted from equipment leaks, process vents, and destruction devices, but excluding amounts captured for use, destruction or storage[5];

(c) Each Party shall provide to the Secretariat statistical data of its annual emissions of Annex F, Group II controlled substances per facility in accordance with paragraph 1(d) of Article 3 of the Protocol[6]; and

[1] Kigali, Rwanda, 10 – 15 October 2016.
[2] Decision XXVIII/1, Annex I of document UNEP/OzL.Pro/28/12.
[3] Annex F consists of two groups: Group I consists of 17 HFCs and Group II of one HFC, namely HFC-23.
[4] Article 2J, paragraph 6 of the Protocol.
[5] Article 3, paragraph 1(d) of the Protocol.
[6] Article 7, paragraph 3ter. of the Protocol.

(d) For the purposes of Articles 2, 2A to 2J and 5, each Party shall, for each group of substances in Annex A, Annex B, Annex C, Annex E or Annex F, determine its calculated levels of emissions of Annex F, Group II substances generated in each facility that generates Annex C, Group I or Annex F substances by including, among other things, amounts emitted from equipment leaks, process vents, and destruction devices, but excluding amounts captured for use, destruction or storage.

2. Through decision XXVIII/2, the Parties requested the Executive Committee to develop guidelines for financing the phase-down of HFC consumption and production. With regard to the production sector, the costs of reducing emissions of HFC-23, a by-product from the production process of HCFC-22, by reducing its emission rate in the process, destroying it from the off-gas, or by collecting and converting it to other environmentally safe chemicals, should be funded by the Multilateral Fund to meet the obligations of Article 5 Parties[7].

3. At the 77th meeting[8], the Executive Committee discussed a note from the Secretariat in the context of agenda item 10 on Issues relevant to the Executive Committee arising from the Twenty-eighth Meeting of the Parties to the Montreal Protocol, which aimed to seek guidance from the Executive Committee on a way forward to address decision XXVIII/2.

4. Further to the discussion, the Executive Committee *inter alia* decided to hold a four-day special meeting early in 2017 to address matters related to the Kigali Amendment arising from decision XXVIII/2, and requested the Secretariat to prepare an agenda for the meeting based on a document to be prepared by the Secretariat containing preliminary information, *inter alia,* on HFC consumption and production, as well as on HFC-23 by-product; and key aspects related to HFC-23 by-product-control technologies (decision 77/59(b)(i) and (iii)).

5. The Executive Committee also invited Executive Committee members of the 77th meeting to share relevant information with the Secretariat, no later than 31 January 2017 on an exceptional basis owing to the limited time until the end of 2016 (decision 77/59(c)).

6. In response to the above elements of decision 77/59(b)(i) and (iii), the Secretariat has developed the present document. Information on HFC-23 by-product-control technologies received from Executive Committee members[9] in line with decision 77/59(c) has been included in this document.

<u>Scope of the document</u>

7. Control obligations related to destruction of a by-product that may be emitted during the production of a controlled substance have not been previously considered by the Executive Committee. In addition, there is limited experience on how HFC-23[10] emissions would be reported and monitored. Therefore, while there may be experience outside the Multilateral Fund, there is limited experience related to the technology for such controls and associated costs under the Multilateral Fund.

[7] Paragraph 15(b)(viii) of decision XXVIII/2.
[8] Montreal, Canada, 28 November – 2 December 2016.
[9] Information was received from the Governments of Argentina, Germany, Japan and the United States of America. Data on HFC-23 emissions and costs provided by the Governments of Argentina and Japan has been included in relevant sections of the document. All sources of information on HFC-23 provided by the Government of the United States of America have been included in relevant sections of the document. The full text of the relevant information received from Executive Committee members of the 77th meeting in accordance with decision 77/59(c) is contained in Annex II of document UNEP/OzL.Pro/ExCom/78/1/Add.1 (Annotated provisional agenda)."
[10] Trifluoromethane.

8. The present document provides preliminary information obtained from various sources on key aspects related to HFC-23 by-product-control technologies. It presents an overview of HFC-23 emissions in relation to the production of HCFC-22[11] in Article 5 countries; it describes potential opportunities for reducing HFC-23 emissions; potential technologies for destruction of HFC-23 and preliminary and limited information on associated costs. The document also describes enabling activities that could initiate the process of HFC-23 emission reduction.

9. In reviewing this document, the Executive Committee might wish to:

(a) Note that one of the earliest obligations of the Kigali Amendment is the HFC-23 control obligations, and the related reporting requirements, which commence on 1 January 2020. The Executive Committee may therefore wish to consider how it wishes to support Article 5 countries to meet this obligation; and

(b) Consider the following information provided by Executive Committee members in response to decision 77/59(c).

Argentina

10. With respect to HFC-23 emission control, the Government of Argentina suggested that:

(a) Approval of HFC funding guidelines should not preclude the approval of HFC phase-down activities, particularly for HFC-23 emissions that must be eliminated by 2020;

(b) The most important action would be to agree on the HCFC and HFC production guidelines and ensure that funding is swiftly provided to swing plants for production closure/conversion; and

(c) The most effective way to reduce HFC-23 by-product is to close HCFC-22 production and provide guidance and sufficient funding for that. The cost for HFC-23 emission reduction, by reducing its emission rate in the process, destroying it from the off-gas, or by collecting and converting to other environmentally safe chemicals, should be funded by the Multilateral Fund, to meet the obligations of Article 5 countries specified under the Kigali Amendment.

Germany

11. The Government of Germany suggested the following:

(a) In the evaluation of the HFC inventories, to describe the needs to integrate and include emission reporting under the Montreal Protocol;

(b) To invite other Governments to provide, on a voluntary basis, information on their experience in controlling HFC-23 by-product emissions; and

(c) In the evaluation of information on potential HFC-23 funding, to include:

(i) How independent verification of the information on HFC-23 emission will be warranted?

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[11] Other than for the production of HCFC-22, the Secretariat is not aware of any other production of Annex C, Group I or Annex F substances that would result in the generation of, and hence need to control, HFC-23.

(ii) What the lifetime of existing productions are and timeline for regulations to avoid emissions from production of HCFC-22?

(iii) If, and what incentives for early action are needed? What are the incremental costs of establishing HFC-23 destruction capacity?

12. With regard to the potential HFC-23 by-product-control technologies, the Government of Germany requested the following information:

(a) What is the state of art, what is the incremental cost of destruction?

(b) What is the mechanism influencing avoidance of new cases of HFC-23 by-production?

(c) How will HFC-23 mitigation become mandatory in the long-term?

(d) What will be the market demand for HCFC-22 feedstock in view of future products (polytetrafluoroethylene (PTFE), refrigerants)?

An overview of HFC-23 emissions

13. As reported in the U.S. Environmental Protection Agency (USEPA) global mitigation report of 2013[12], the production of HCFC-22 in non-Article 5 countries has decreased in the last decade, while it has substantially increased in Article 5 countries, driven primarily by the demand for its use as feedstock in fluoropolymer manufacture. Overall, global HCFC-22 production is expected to continue to grow at a modest rate to meet the demand of HCFC-22 use for feedstock, despite restrictions on HCFC-22 production for controlled uses in response to the control measures under the Montreal Protocol.

14. HFC-23 is formed at the reactor stage of the manufacture of HCFC-22 (chlorodifluoromethane) as a result of over-fluorination. Specifically, the most common process to produce HCFC-22 is via the reaction of chloroform (CHCl3) and anhydrous hydrogen fluoride (HF) in the presence of an antimony pentachloride ($SbCl_5$) catalyst. Two molecules of HF react with one molecule of chloroform to yield HCFC-22; however, HCFC-22 can further react with another molecule of HF to produce HFC-23 (i.e., overfluorination). Most of the HFC-23 produced is released from the reaction system at the control valve used to maintain the system pressure (the "condenser vent") and, unless separated for collection and/or destruction, is then emitted to the atmosphere[13].

15. The amount of HFC-23 generated per tonne of HCFC-22 (waste generation rate) depends largely on process optimization and plant operating conditions, and typically varies between 4.0 and 1.4 per cent[14]. The HCFC-22 production process can be optimized to minimize, but not eliminate[15], HFC-23 generation. In earlier versions of the approved baseline and monitoring methodology "Decomposition of fluoroform (HFC-23) waste streams"[16] under the Clean Development Mechanism (CDM)[17], the waste generation rate was capped at 3.0 per cent; however, the most updated version of the methodology uses a

[12] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).
[13] IPCC/TEAP special report on safeguard ozone layer, 2005, page 396.
[14] IPCC/TEAP special report on safeguard ozone layer, 2005, page 382.
[15] Incineration of HFC-23 waste streams for abatement of emissions from HCFC-22 production: A review of scientific, technical and economic aspect, McCulloch, 2004, available at http://cdm.unfccc.int/methodologies/Background_240305.pdf.
[16]CDM AM0001,https://cdm.unfccc.int/methodologies/DB/GAOZAY2DWIQHK71LJS027N6N4AV6SC.
[17] The CDM is one of the Flexible Mechanisms defined in the Kyoto Protocol that provides for emissions reduction projects which generate certified emission reduction units (CERs) which may be traded in emissions trading schemes.

waste generation rate of 1 per cent. Information provided by the Government of Japan in response to decision 77/59(c) indicated an HFC-23 waste generation ratio of 1.46 per cent. One producer in the United States of America has developed technology that could improve the yield of HCFC-22, reduce the HFC-23 by-product generation rate to as low as 1.0 percent, and improve the collection efficiency of HFC-23 that is generated.

16. Based on production data reported under Article 7 of the Montreal Protocol in 2015, six Article 5 countries, namely Argentina, China, Democratic People's Republic of Korea, India, Mexico, and Bolivarian Republic of Venezuela, manufactured 596,591 metric tonnes (mt) of HCFC-22 for controlled and feedstock uses. The total amount of HFC-23 generated from this HCFC-22 production was estimated[18] at 15,499 mt (7,357 mt and 8,142 mt for controlled and feedstock production, respectively), as shown in Table 1. It is unclear to the Secretariat whether there are additional lines that only manufacture HCFC-22 for feedstock use in an integrated plant. Moreover, the Secretariat has no information on HFC-23 generated from facilities that manufacture Annex F substances or any Annex C, Group I substances other than HCFC-22.

Table 1. Level of HFC-23 estimated in 2015 and destruction facilities in Article 5 countries

Country	**HCFC-22 production *(mt/year)**	**HFC-23 generation**		**HCFC-22 production lines**				
		(mt/year)	**Rate (%)**	**Number**	**With CDM project**	**With destruction facility**	**With recovery system**	**Without destruction facility**
Argentina	2,446	73	3.00	1	1	0	0	0
China	534,928	13,602	2.54	32	14	16	1**	1
Democratic People's Republic of Korea	498	15	3.00	1	0	0	0	1
India	53,314	1,674	3.14	5 (or 6)***	5	0	0	0
Mexico	4,729	115	2.44	2	1	0	0	1
Bolivarian Republic of Venezuela	677	20	3.00	1	0	0	0	1
Total	596,591	15,499		42	21	16	1	4

* Article 7 production data for 2015, including both controlled and feedstock use.

** HFC-23 in this line was recovered and used as feedstock for production of pesticides.

*** The Secretariat is unclear whether there are five or six production facilities that manufacture HCFC-22 in India. Five facilities had projects under the CDM, including an HCFC-22 manufacturing line owned by Gujarat Fluorochemicals Ltd. In addition, there may be a sixth facility in Dahej, which manufactures PTFE and, in so doing, may manufacture HCFC-22. That facility is owned by Gujarat Fluorochemicals Ltd. and appears to be a different facility than the facility that had a CDM project. In addition, for the five HCFC-22 production facilities in India that had CDM projects, some facilities might have more than one production line or have one line with two reactors.

17. The data on the HFC-23 generation rates used in Table 1 is explained below:

(a) The amount of HFC-23 generated by the only HCFC-22 production line in Argentina is approximately 3.0 per cent of the HCFC-22 produced[19];

(b) The independent verification under the HCFC production phase-out management plan (HPPMP) on HCFC-22 production lines that operated in 2015 in China, reported HFC-23 waste generation rates between 3.03 and 1.78 per cent for 29 production lines in 13 production facilities, with an average of 2.54 per cent;

[18] Using HCFC-22 production multiplying by HFC-23 waste generation rate.

[19] Information provided by the Government of Argentina in response to decision 77/59(c). The Ministry of Production carries out audits on a quarterly basis and monitors HCFC-22 production and HFC-23 generation under the coordination of the National Directorate of Sustainable Industry Development.

(c) The waste generation rate used in the production facilities in India is from CDM projects;

(d) The independent verification on HCFC-22 production in Mexico (Quimobásicos) conducted in 2015 reported a waste generation rate of 2.44 per cent; and

(e) For the Democratic People's Republic of Korea and the Bolivarian Republic of Venezuela, a waste generation rate of 3.00 per cent is used.

18. Of the six Article 5 countries that reported HCFC-22 production under Article 7, only China has an approved HPPMP. The issue of the eligibility of swing plants continues to be under discussion by the Production Sector Sub-group. Under the current guidelines, except for the Democratic People's Republic of Korea, other Article 5 producing countries are currently not eligible to receive funding from the Multilateral Fund for the closure of their HCFC-22 (swing) plants. The Sub-group continued its discussion of the HCFC production sector guidelines at the 77th meeting and, in light of the Kigali Amendment and the new obligations for HFC-23 emission control and reporting, recommended that the Executive Committee continue discussion of the eligibility of swing plants producing HCFC-22 at the next meeting of the Sub-group, and to consider this issue in the context of its discussions of by-product controls of HFC-23 arising from the Kigali Amendment. Members of the Sub-group have agreed to paragraphs (a) and (b) of the draft guidelines that set out the procedures for submitting the preliminary data and conducting technical audit of the production facilities that would seek funding.

Current HFC-23 management practices in Article 5 countries

19. HFC-23 generated in Article 5 countries has been emitted or destroyed, except for a small amount that was consumed in refrigeration, fire suppression, plasma-etching processes in semiconductor manufacturing[20], or as a feedstock[21] for producing other chemicals. The management practice varies by country as summarized below:

(a) In Argentina, HFC-23 is currently being vented although previously it was destroyed under the CDM[22];

(b) In China, through implementation of the HPPMP approved at the 69th meeting, the Government agreed that it would minimize environmental and climate impacts as much as possible, including by giving priority to HCFC production closure to achieve HCFC reduction targets (decision 69/28); and that coordination with stakeholders and authorities will be undertaken to make best efforts to manage HCFC production and associated by-product production in HCFC plants in accordance with best practices to minimize associated climate impacts[23]. With the support of the Government, the construction of 13 new destruction facilities at 15 HCFC-22 production lines[24] not covered by CDM was started in 2014. Once these new destruction facilities are completed, 30 out of 32 production lines[25] will be equipped with a destruction facility. As reported by the independent verification on HCFC production commissioned by the World Bank, the

[20] Information paper on feedstock uses of ozone-depleting substances, Melanie Miller, Touchdown Consulting, 2012. Available at https://ec.europa.eu/clima/sites/clima/files/ozone/docs/feedstock_en.pdf .

[21] It was reported in the verification report on HCFC production in China, HFC-23 was used as feedstock for producing pesticides in one plant.

[22] Information provided by the Government of Argentina in response to decision 77/59(c).

[23] Paragraph 10 of the Agreement between the Executive Committee and the Government of China for the phase-out of production of hydrochlorofluorocarbons required by the Montreal Protocol.

[24] Two destruction facilities each covered two production lines.

[25] Including the newly established feedstock plant Yinguang. One of the two lines without destruction facility recovers all HFC-23 and sells it as feedstock for pesticide production; another plant vented all HFC-23 generated as a by-product.

15 CDM lines were operating their respective HFC-23 destruction facility in 2015. For the non-CDM lines, some have completed the installation of the destruction facility during the year and incineration was conducted part of the year; others were still in the process of installation. As a result, 45 per cent of HFC-23 generated was destroyed in 2015; 10 per cent was collected, sold or stored for use; and 45 per cent was emitted. The percentage of HFC-23 that was destroyed increased from 28 per cent in 2014 to 45 per cent in 2015. The Government also provides funding to subsidize operating costs from 2014 to 2019 to encourage the operation of destruction facilities;

(c) In Mexico, HFC-23 by-product from HCFC-22 production is emitted, separated for a specific use (rare), or destroyed. The 2015 production verification report submitted by the Government of Mexico to the 77th meeting indicated that an argon plasma arc destruction facility attached to Plant No. 1 as part of the CDM project registered in 2006 at the Quimobásicos HCFC-22 manufacturing facility continued to be operated in 2015. The Secretariat is not aware of specific data on the extent to which the destruction facility is operated, and whether there were any HFC-23 emissions, from that line. The survey on ozone-depleting substances (ODS) alternatives for Mexico indicated that future activities will be developed in the country to calculate HFC-23 emissions that will be reported to the United Nations Framework Convention on Climate Change (UNFCCC);

(d) In India, the Government issued orders directing manufacturers of HCFC-22 not to emit or vent HFC-23 in the atmosphere on 13 October 2016[26]. Five HCFC-22 production facilities have implemented a CDM project. Two of the CDM projects are still on-going, namely Navin Fluorine International Limited (NFIL)[27] which will expire in April 2017, and Hindustan Fluorocarbon Limited (HFL Ltd)[28], which will expire in November 2018. For the three facilities with expired CDM projects, the newly issued order would suggest that the destruction facilities at the other three lines continue to be operated; however, the Secretariat is not clear whether this is the case. In addition to the five HCFC-22 production facilities that had a CDM project, there may be a sixth facility in Dahej owned by Gujarat Fluorochemicals Ltd. that manufactures PTFE and, in so doing, may manufacture HCFC-22. It is not clear to the Secretariat whether that facility generates HFC-23 and, if so, whether it has an operating destruction facility; and

(e) The HCFC-22 production facilities in the Democratic People's Republic of Korea and the Bolivarian Republic of Venezuela (one each) have neither implemented a CDM project nor (to the Secretariat's knowledge) built a destruction facility. It is therefore anticipated that HFC-23 is vented at those two facilities.

HFC-23 process optimization

20. Process optimization can be used to minimize the generation of HFC-23. As reported by Irving and Branscombe (2002)[29], a number of factors affect halogen exchange of chlorine to fluorine and thus affect the generation of HFC-23 in the reactor. These factors include temperature, pressure, feed rates, catalyst concentration and catalyst deactivation (associated with catalyst life). The reflux rate and the composition of the reflux also affect the concentrations of compounds in the reactor. In general, higher

[26] The Indian Express, http://indianexpress.com/article/india/government-bans-some-manufacturers-from-emitting-greenhouse-gas-4411938.
[27] CDM project database: http://cdm.unfccc.int/Projects/DB/DNV-CUK1167824240.14/view.
[28] CDM project database: http://cdm.unfccc.int/Projects/DB/DNV-CUK1212826580.92/view.
[29] HFC-23 emissions from HCFC-22 production, Irving, W. N. and M. Branscombe, Background Papers–IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2002, available at http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_8_HFC-23_HCFC-22_Production.pdf

catalyst concentrations and higher pressure will increase the amount of HFC-23 produced. Catalyst life is one of the most important factors affecting the generation of HFC-23.

21. The USEPA global mitigation report of 2013[30] indicated that all HCFC-22 producers in non-Article 5 countries have implemented either process optimization and/or thermal destruction to reduce HFC-23 emissions. Similarly, the Intergovernmental Panel on Climate Change (IPCC) report of 2014[31] indicated that: nearly all HCFC-22 production plants in non-Article 5 countries have optimized systems; the technology for optimization of the HCFC-22 production process to minimize HFC-23 emissions is readily transferable to Article 5 countries; and process optimization is relatively inexpensive and is demonstrated to reduce emissions of fully optimized plants to below 2.0 per cent of HCFC-22 production. In contrast, McCulloch (2004)[32] indicated that optimisation may require technical resources, modifications to the existing equipment and capital expenditure, and may lead to additional operating costs. The Secretariat has not evaluated the potential costs (or any potential savings) of optimization.

22. Implementation of the HPPMP for China includes technical assistance related to HFC-23 by-product control, and in particular an investigation on the mechanisms and technical feasibility of reducing the HFC-23 production ratio in HCFC-22 production through best practices. This technical assistance intends to reduce the HFC-23 by-product ratio through policy and technical measures. A consultant firm is to be employed to review the current policy framework and recommend regulatory measures to support emission reduction through best practices. The consultant will also collect data and review current by-product yield, raw material losses, and intermediate and final products, to identify opportunities to improve the process efficiency. In addition, the consultant will provide technical advice for specific production lines to reduce the HFC-23 by-product ratio, and assess the economic feasibility of the technical measures, and estimate their costs. Under current implementation of the HPPMP, the project is to be completed by the end of 2017.

HFC-23 by-product destruction

23. Further reduction of HFC-23 emissions beyond the extent achievable through process optimization would need to be realized through destruction, conversion, or capturing HFC-23 for a controlled use or as a feedstock to manufacture other chemicals. The Kigali Amendment stipulates that each party shall ensure that HFC-23 emissions generated from production facilities producing HCFCs or HFCs are destroyed to the extent possible using technology approved by the Parties[33].

24. The Parties have not assessed and approved destruction technologies for HFC-23. However, according to the IPCC report of 2014[34], thermal destruction technologies available today can achieve emissions reductions of HFC-23 as high as 99 per cent, or more than 99 per cent under optimal conditions (i.e., a relatively concentrated HFC-23 vent stream with a low flow rate)[35]. From the design documents for CDM projects, destruction technologies usually have an efficiency of destruction greater than 99.9 per cent. In practice, however, actual reductions will be determined by the fraction of production time that the destruction device is actually operating. Units may experience some downtime because of the extreme

[30] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).
[31] Climate Change 2014: Mitigation of Climate Change, IPCC Working Group III, available at http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=111#3544.
[32] Incineration of HFC-23 waste streams for abatement of emissions from HCFC-22 production: A review of scientific, technical and economic aspect, McCulloch, 2004, available at http://cdm.unfccc.int/methodologies/Background_240305.pdf.
[33] Paragraphs 6 and 7 of Article 2J.
[34] Climate Change 2014: Mitigation of Climate Change, IPCC Working Group III, available at http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=111#3544.
[35] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).

corrosivity of hydrogen fluoride and the high temperatures required for complete destruction, resulting in reduction efficiency of 95 per cent[36]. Information provided by the Government of Japan in response to decision 77/59(c) notes the emissions of HFC-23 from the liquid injection incineration destruction facility were estimated at approximately 2 mt, suggesting a destruction efficiency of approximately 99.7 per cent[37].

25. The list of destruction technologies for ODS was first approved by the Fourth Meeting of the Parties (decision IV/11). In approving the destruction technologies, the Parties call on each Party that operates, or plans to operate, facilities for the destruction of ODS to ensure that its destruction facilities are operated in accordance with the Suggested Regulatory Standards for Destruction Facilities[38] unless similar procedures currently exist domestically. The Parties requested that each Party, for the purposes of paragraph 5 of Article 1 of the Protocol, to provide each year, in its report under Article 7 of the Protocol, statistical data on the actual quantities of ODS destroyed, calculated on the basis of the destruction efficiency[39] of the facility employed. The list of destruction technologies was subsequently modified and updated by decisions V/26, VII/35 and XXIV/6. Parties called on each Party that operates, or plans to operate, the approved technologies to ensure that its destruction facilities are operated in accordance with the Code of Good Housekeeping Procedures[40], and adhered to relevant international or national standards addressing hazardous substances taking into account cross-media emissions and discharges, including those identified in the Suggested Substances for Monitoring and Declaration when Using Destruction Technologies[41].

26. The Technology and Economic Assessment Panel (TEAP) Task Force on destruction technologies reported in April 2002 that a number of technologies were suitable for destruction of different types of ODS in bulk or in foams. It established criteria for destruction and removal efficiency (DRE) for dilute and concentrated ODS, for dioxin/furan emissions, and a number of other practical matters associated with the operation of destruction facilities. The Task Force, in response to decision XXII/10, undertook a review of the destruction technologies adopted at the Fourteenth Meeting and recommended additional technologies that could be approved for ODS destruction. The updated list of destruction technologies was adopted at the Twenty-third Meeting of the Parties (decision XXIII/12[42]) as shown in Table 2. These technologies would need to be assessed for suitability in destroying HFC-23 and the Parties would have to take a corresponding decision approving such technologies for this use.

[36] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).
[37] It is unclear to the Secretariat if the emission of HFC-23 relates to the input and output of the destruction process itself, or to the destruction facility as a whole.
[38] Annex VII to the report of the Fourth Meeting of the Parties.
[39] According to decision IV/11, the definition of destruction efficiency relates to the input and output of the destruction process itself, not to the destruction facility as a whole.
[40] Annex III to the report of the Fifteenth Meeting of the Parties, it sets out the procedures for handling ODS prior to destruction, monitoring emissions, testing, verification and record keeping.
[41] Annex IV to the report of the Fifteenth Meeting of the Parties, it listed substances for testing and monitoring when operating an approved destruction facility.
[42] To approve the highlighted destruction processes in the present decision for the purposes of paragraph 5 of Article 1 of the Montreal Protocol, as additions to the technologies listed in Annex VI to the report of the Fourth Meeting of the Parties and modified by decisions V/26, VII/35 and XIV/6.

Table 2. Approved destruction processes (Annex to decision XXIII/12)*

Technology**	CFC	Halons	Other CFC	CTC	TCA	HCFC
Argon plasma arc	X	X	X	X	X	X
Cement kilns	X	n/a	X	X	X	X
Chemical reaction with H_2 and CO_2	X	X	X	X	X	X
Gas phase catalytic de-halogenation	X	n/d	X	X	X	X
Gaseous/fume oxidation	X	n/d	X	X	X	X
Inductively coupled radio frequency plasma	X	X	X	X	X	X
Liquid injection incineration	X	X	X	X	X	X
Microwave plasma	X	n/d	X	X	X	X
Municipal solid waste incineration						
Nitrogen plasma arc	X	n/d	X	X	X	X
Porous thermal reactor	X	n/d	X	X	X	X
Portable plasma arc	X	n/d	X	X	X	X
Reactor cracking	X	n/a	X	X	X	X
Rotary kiln incineration	X	X	X	X	X	X
Superheated steam reactor	X	n/d	X	X	X	X
Thermal reaction with methane	X	X	X	X	X	X

* It also includes technologies for the destruction of methyl bromide.
** The DRE of all the technologies is 99.99 per cent.
X Approved
n/a Not approved
n/d Not determined

27. Among the destruction technologies approved at the Twenty-third Meeting, the technology proposed by Midwest Refrigerants[43](Chemical reaction with H_2 and CO_2) and University of Newcastle (Gas phase catalytic de-halogenation) were considered as irreversible transformation of ODS to other compounds that have a specific use (anhydrous hydrogen fluoride in the former and vinylidene fluoride in the latter). The Task Force believed that this represented a significant additional technology option[44].

28. Information provided by the Government of the United States of America in response to decision 77/59(c) also noted that the Midwest Refrigerants destruction technology is chemical reaction with hydrogen and carbon dioxide. In contrast to many other destruction technologies, this technology is strictly an irreversible transformation process that converts fluorocarbon into anhydrous hydrogen fluoride and small amounts of anhydrous hydrogen chloride. The Government of the United States of America noted that those outputs can either be put back into the production cycle or sold as high purity chemicals, and that there are other possible products with commercial value that can also be produced in this process with commercial value that can help offset capital and operating costs of the technology.

29. For the HCFC-22 manufacturing lines that have no access to a destruction facility, new destruction facilities[45] would need to be installed or the HFC-23 can be captured, stored and transported to an off-site destruction facility. The Secretariat understands that facilities in the United States of America use both approaches. Alternatively, HFC-23 could be used for feedstock or consumed for controlled uses. It is expected that controlled uses of HFC-23 would eventually result in the emission of the HFC-23.

Cost of destruction of HFC-23 emission

30. The reported costs of destruction of HFC-23 vary. The USEPA global mitigation report of 2013[46]

[43] According to the technology proponent, the Midwest Refrigerants technology can also be used for removal of HFCs.
[44] TEAP progress report, Volume 1, May 2011.
[45] The Secretariat is using the term “destruction” in line with the TEAP, thus also including (irreversible) transformation of HFC-23 to other chemicals.
[46] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).

provided an analysis for evaluating the cost of reducing HFC-23 emissions from HCFC-22 production, based on a typical HCFC-22 production facility, with a production capacity of approximately 22,400 mt, operating at 82 per cent of that production capacity. The analysis also considered several possibilities for the level of abatement technology used at the typical HCFC-22 production facility, reflecting different levels of emissions. The report considered different categories of facilities, including:

(a) Facilities with abatement controls in place already. This would apply for production facilities that have CDM projects. Since the start of CDM there have been 19 CDM projects at HCFC-22 production facilities in China (11 in total), India (5), Argentina (1), Mexico (1), and the Republic of Korea (1)[47];

(b) Facilities with no abatement technology controls installed. Such facilities currently exist in China (2), the Democratic People's Republic of Korea (1), Mexico (1) and the Bolivarian Republic of Venezuela (1). Depending on national regulations and other factors, new facilities entering the market may or may not be built with control technology;

(c) Facilities having previously participated in a CDM project, but not currently destroying HFC-23 through incineration. When the CDM project is completed, the USEPA report assumed that the incineration device installed as a result of the CDM project will not be kept in operation, such as the case noted in Argentina's submission in response to decision 77/59(c). The cost assumptions for these facilities differ from those of a new uncontrolled facility in that no capital costs will be needed to install the incinerator. The report assumed that all facilities participating in CDM have completed their crediting periods by 2020; and

(d) New facilities entering the market. To meet future global demand of HCFC-22, the report projected that new capacities would be developed when Article 5 countries have such demand. New facilities were characterized as being built without control technology.

31. The USEPA global mitigation report of 2013[48] estimated the costs for installing and operating a thermal oxidizer with a technical lifetime of 20 years which are summarized below (based on communication with industry and best available industry assessments; actual costs of some systems could differ from these estimates[49]):

(a) The capital cost is estimated to be approximately US $4.8 million to install at an existing plant and US $3.7 million to install as part of constructing a new plant;

(b) Operating and maintenance costs are approximately 2.0 to 3.0 per cent of total capital costs. The analysis assumes an annual cost that is 2.5 per cent of total capital costs for facilities with no abatement technology control installed and just over 3.0 per cent of total capital costs for new facilities that are entering the market. Based on these assumptions, operating costs would be approximately US $0.22/kg; and

(c) No annual savings or revenues are associated with the thermal oxidation abatement option.

[47] Not received funding from the Multilateral Fund.
[48] Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030, United States Environmental Protection Agency September 2013 (EPA-430-R-13-011).
[49] It is not clear to the Secretariat if such communication and assessment is solely based on information from the United States of America or also included data from Article 5 countries.

32. Preliminary information provided by a producer from the United States of America indicates incremental operating costs of approximately €0.30-0.40/kg of HFC-23 (US $0.32-0.42/kg of HFC-23) for its production facility based in Europe. Production facilities may opt to collect, store and transport HFC-23 that is generated to an off-site destruction facility, rather than destroy on-site. The Secretariat has not evaluated the costs of such destruction.

33. Based on information from a workshop held in Sanya City (China), Schneider reported in 2005[50] that HFC-23 destruction costs amount to about US $4-6/kg of HFC-23, including amortization of the required investments. Based on information from the China production sector technical audit report, the capital cost of incineration facilities under CDM projects ranges from US $3.8 million to US $8.0 million, including the costs of incinerator and associated auxiliary facilities. The IPCC/TEAP report[51] indicated US $2.0 million to US $8.0 million total installed capital costs and US $189,000 to US $350,000 annual operating cost; it further quoted a study by Harnisch and Hendriks[52] in 2000, indicating the cost of a typical unit is about US $4 million to destroy 200 mt of HFC-23 per year, with US $250,000 operating costs (i.e., US $1.25/kg).

34. The Government of Argentina in its response to decision 77/59(c) reported that under CDM[53], a destruction facility was set up to destroy HFC-23 by-product. However the producer (Frio Industrias Argentinas S.A. (FIASA)), is not currently operating the destruction facility and all the HFC-23 that is generated is vented. Since the destruction facility has not been in use for a while, the producer believes that to start up the operation again, funding would be needed to replace a damaged absorption tower, valves, and to purchase zeolite for the oxygen generator. The operating cost of destruction was estimated by the Government at approximately US $5.68/kg of HFC-23.

35. The Secretariat is not aware of detailed information on the costs of conversion technology. According to information extracted from the website of Midwest Refrigerants[54], the conversion process results in the formation of anhydrous hydrogen fluoride, with small amounts of anhydrous hydrogen chloride, that are of high purity (over 99.99 per cent), with trace-metals in parts per billion, and can either be returned to the production cycle or possibly sold for greater value for electronics and semi-conductor manufacturing. The technology developer further indicated that the capital cost for the conversion technology would be slightly more than a thermal oxidizer; however, that the value created would eliminate that disadvantage within the first year and make a profit for future operation of the conversion process. The technology developer stated that the operating cost of a thermal oxidizer in the United States of America and the conversion technology is about the same; patents have been granted in Australia, Canada, China (Hong Kong, Macau), the European Union, Japan, Mexico, Russian Federation, South Africa, and the United States of America (India is pending). To date, the Secretariat has been unable to verify these claims nor collect similar information on the other conversion technology (e.g. by University of Newcastle) approved by the Parties.

36. In addition, other conversion technologies may either be developed or under development that could be applicable to HFC-23. In particular, implementation of the HPPMP for China includes a research study on HFC-23 conversion/pyrolysis technologies. This technical assistance is intended to support research and development on HFC-23 conversion technology in order to find a more cost-effective solution for HFC-23 disposal. Co-funding will be provided to one enterprise to explore the feasibility to recycle and reuse the HFC-23 generated from the HCFC-22 production. Under current implementation,

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[50] Implications of the CDM on other Conventions. The case of HFC-23 destruction. Lambert Schneider, Oko-Institute e.V, www.oeko.de/oekodoc/248/2005-006-en.pdf.

[51] IPCC/TEAP special report on safeguard ozone layer, 2005, page 81, Table TS-27.

[52] Economic evaluation of emission reductions of HFCs, PFCs and SF6 in Europe, Harnisch and Hendriks, 2000.

[53] According to the information on CDM database, the crediting period was from 15 October 2007 to 14 October 2014, http://cdm.unfccc.int/Projects/DB/DNV-CUK1166182519.48/view.

[54] How the Midwest chemical conversion technology is superior to thermal oxidation for eliminating HFC-23 produced during HCFC -22 manufactures (www.midwestrefrigerants.com).

the project is to be completed by the end of 2017. It is unclear to the Secretariat whether the conversion technology studied in this research is similar or different to the two conversion technologies approved by the Parties for ODS destruction

37. The Secretariat notes that hydrofluoric and hydrochloric acid were also by-products of the thermal oxidation process for HFC-23 destruction used in some CDM projects. In addition, there may be potentially other outputs from the thermal oxidation destruction process that can be recovered. It is unclear to the Secretariat whether such outputs from the thermal oxidation process could be recovered cost-effectively to help offset the destruction cost in those destruction technologies.

Other means of reducing HFC-23 emissions

38. Reducing fugitive emissions (equipment leaks, process venting or losses during collection, storage and transportation) through good industrial practices would help reduce HFC-23 emitted to the atmosphere. It should be noted that not all HFC-23 that is generated can be captured. Capturing and storing HFC-23 for subsequent feedstock use would provide an alternative option to destruction. As reported by McCulloch[55], historically, some HFC-23 was recovered and used as a feedstock to produce halon-1301 (bromotrifluoromethane). However, when production of halon-1301 ceased in the developed countries in 1994 in accordance with the Montreal Protocol, this requirement for HFC-23 also ceased. Using HFC-23 as feedstock in chemical reactions is becoming an active area of research and will continue to be so for some time[56].

39. Data collected from the reports of ODS alternatives surveys from 30 countries has shown that very small amounts (i.e., less than 2.5 mt in 2015) of HFC-23 were reported to be used in five Article 5 countries for the refrigeration and firefighting sectors[57]. In addition, the verification report for HPPMP in China indicated that 887.23 mt of HFC-23 was collected and sold in 2015. Controlled uses are expected to eventually result in the release of emissions of HFC-23, thus delaying rather than avoiding such emissions.

Enabling activities

40. The Kigali Amendment added the reporting of annual emissions of HFC-23 per facility to Parties' reporting obligations under Article 7 of the Protocol and requested each Party to ensure HFC-23 emissions are destroyed to the extent practical using the approved technologies by the Parties.

41. To meet compliance obligation, policies and regulations would need to be developed to ensure that an HFC-23 destruction facility is put in place and continues operation at each HCFC-22 manufacturing line. The methodology for data collection and reporting would need to be developed. Routine monitoring and annual verification would also need to be implemented to ensure that HFC-23 emissions at each line that manufactures Annex C, Group I and Annex F substances that generates such emissions are destroyed. For any HFC-23 that is collected for controlled or feedstock uses, monitoring and verification would need to ensure that those are properly measured, stored and verified, and fugitive emissions in the process are minimized. Monitoring, data collection and reporting could be facilitated by lessons learned from such activities under the CDM.

42. Document UNEP/OzL.Pro/ExCom/78/10 has proposed for the consideration by the Executive Committee the Procedures for Article 5 countries that have HFC consumption baseline years from 2020

[55] Incineration of HFC-23 waste streams for abatement of emissions from HCFC-22 production: A review of scientific, technical and economic aspect, McCulloch, 2004, available at http://cdm.unfccc.int/methodologies/Background_240305.pdf.
[56] Fluoroform (CF_3H): An industrial waste or a useful raw material? Journal of Postdoctoral Research, September 2013, Loker Hydrocarbon Research Institute, University of Southern California.
[57] UNEP/OzL.Pro/ExCom/78/4.

to 2022 in accessing additional contribution for enabling activities. Enabling activities that would help initiate the process of HFC-23 emission reduction in HCFC-22 producing Article 5 (Group I) countries, noting the 1 January 2020 compliance obligation, *inter alia:*

(a) Development of policy and regulations to ban the venting of HFC-23 and mandatory reporting on HFC-23 emissions;

(b) Technical assistance for process optimization and leakage control;

(c) Establishing a framework for HFC-23 emission monitoring, data collection and reporting; and

(d) Awareness-raising and information dissemination activities on HFC-23 emission control.

43. Should the Executive Committee decide to include such activities amongst the activities to be funded under the US $27 million in voluntary contributions, the procedure for Article 5 countries (Group I) to access such funding has been presented in document UNEP/OzL.Pro/ExCom/78/10.

44. Funding enabling activities for Article 5 countries that have production facilities that generate HFC-23 could facilitate the ability of those countries to meet the HFC-23 control measures and related reporting requirements under the Kigali Amendment.

Recommendation

45. The Executive Committee may wish to note document UNEP/OzL.Pro/ExCom/78/9 on Key aspects related to HFC-23 by-product-control technologies.