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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
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**KEY ASPECTS RELATED TO HFC-23 BY-PRODUCT CONTROL TECHNOLOGIES
(DECISION 78/5)****Background**

1. The Parties requested the Executive Committee to develop guidelines for financing the phase-down of HFC consumption and production (paragraph 10 of decision XXVIII/2). Pursuant to paragraph 15 (b)(viii) of decision XXVIII/2, 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.
2. At the 77th meeting,¹ the Executive Committee discussed the issues in decision XXVIII/2 and requested the Secretariat to prepare a document containing preliminary information, *inter alia*, on key aspects related to HFC-23 by-product-control technologies (decision 77/59(b)(i) and (iii)).
3. In response to decision 77/59(b)(i) and (iii), the Secretariat developed document UNEP/OzL.Pro/ExCom/78/9, which provides preliminary information on key aspects related to HFC-23 by-product control technologies.
4. At the 78th meeting, the Executive Committee discussed document UNEP/OzL.Pro/ExCom/78/9 and took decision 78/5 (Annex I).
5. In response to decision 78/5, the Secretariat sent letters to countries producing HCFC-22 inviting them to provide, on a voluntary basis, information on quantities of HFC-23 in facilities producing HCFC-22 as well as their experience in controlling and monitoring HFC-23 by-product emissions, including relevant policies and regulations and the related costs. Information that was kindly provided by Parties at the time of writing of this document has been included in the present document.

¹ Montreal, Canada, 28 November – 2 December 2016.

6. The Secretariat also contacted the Secretariat of the United Framework Convention on Climate Change (UNFCCC) and the Clean Development Mechanism (CDM) to request information on: the HFC-23 destruction projects under the CDM, including whether those projects were still generating credits that are being purchased and the longer-term outlook for those projects; costs to destroy HFC-23; approved monitoring methodologies, including the costs of such monitoring; and whether they are aware of any production facilities other than HCFC-22 production facilities that may generate HFC-23. Information that was kindly provided at the time of writing this document has been included in the present document.

7. Furthermore, detailed analysis was conducted on data extracted from the monitoring reports² of CDM projects. Information was also sought from the Ozone Secretariat and other sources available to the Fund Secretariat.

Scope of the document

8. The present document contains the information requested in decision 78/5(f), including information from document UNEP/OzL.Pro/ExCom/78/9 that was extracted and referenced in this updated document, organized in five parts:

Part I addresses the requested information in decision 78/5(f)(iv) on the current levels of HCFC-22 production and HFC-23 emissions, and information on management practices, per line (paragraphs 10 to 14).

Part II addresses the requested information in 78/5 (f)(i) on the cost of closure of HCFC-22 production swing plants (paragraphs 15 to 19).

Part III addresses the requested information in decision 78/5(f)(ii) on policies and regulations supporting the control and monitoring of HFC-23 emissions and requirements for sustaining those measures in Article 5 countries (paragraphs 20 to 26).

Part IV addresses the requested information in decision 78/5(f)(iii) providing further analysis of methods to control HFC-23 emissions (paragraphs 27 to 41).

Part V addresses the requested information in decision 78/5(f)(iv) and (v) on options for monitoring HFC-23 emissions including on approved monitoring methodologies under the UNFCCC (paragraphs 42 to 57).

9. As per decision 78/5(c), a brief report has been received by the Secretariat on the two technical assistance activities funded by the Multilateral Fund under the HCFC production phase-out management plan (HPPMP) for China. This information has been presented under Agenda item 7(b).

Part I A: HCFC-22 level of production and HFC-23 by-product generation

10. According to the Article 7 reporting, 12 countries (seven Article 7 and five non-Article 5 countries) produced HCFC-22 in 2015. The global HCFC-22 production in 2015 amounted to 828,952 metric tonnes (mt), including 307,580 mt for controlled uses, 517,886 mt for feedstock use. The detailed HCFC-22 production from 2009 to 2015 is shown in Table 1.

² Available at the CDM project data base website, for example the project information at India HFL Ltd can be found at: <http://cdm.unfccc.int/Projects/DB/DNV-CUK1212826580.92/view>.

Table 1. Global HCFC-22 production for the period of 2009 to 2015 (mt) (Article 7 data)

Country	2009	2010	2011	2012	2013	2014	2015
Argentina	3,914	4,251	4,018	4,190	1,951	2,286	2,446
China	483,982	549,265	596,984	644,485	615,901	623,899	534,930
Democratic People's Republic of Korea (the)	504	498	480	521	579	526	498
India	47,657	47,613	48,477	48,178	40,651	54,938	53,314
Mexico	12,725	12,619	11,813	7,872	7,378	9,214	4,752
Venezuela (Bolivarian Republic of)	6,913	7,634	7,262	5,704	6,673	6,833	7,180
Republic of Korea	2,307	2,167	2,443	2,914	2,204	1,566	677
Sub-total Article 5 countries	558,002	624,047	671,475	713,864	675,336	699,262	603,796
Non-Article 5 countries	195,796	229,863	241,783	219,909	193,519	210,042	225,155
Total	753,798	853,910	913,258	933,773	868,856	909,304	828,952

11. Based on HCFC-22 production reported under Article 7, and information on the HFC-23 by-product generation rate (w rate³), the amounts of HFC-23 are estimated and presented in Table 2.

Table 2. Amounts of HFC-23 generated from HCFC-22 production (mt)

Country	No of line	w (%)	2012	2013	2014	2015
Argentina	1	3.00	125.70	58.52	68.58	73.38
China	32	2.54-2.78	17,923.77	17,128.82	17,351.25	13,603.55
Democratic People's Republic of Korea (the)	1	0.70-2.30	8.44	10.59	7.84	7.42
India	5	2.97	1,417.10	1,195.69	1,615.94	1,568.16
Mexico	2	2.12-2.44	192.30	176.00	202.80	100.80
Republic of Korea	1	2.40-3.00	171.12	200.20	205.00	204.00
Venezuela (Bolivarian Republic of)	1	3.00	87.42	66.12	46.97	20.30
Sub-total Article 5 countries	43		19,925.84	18,835.94	19,498.38	15,577.61
Non-Article 5 countries		2.00	4,398.18	3,870.39	4,200.85	4,503.10
Total			24,324.03	22,706.32	23,699.22	20,080.71

12. The information on HFC-23 by-product presented in Table 2 is explained below, noting that the most recent information submitted by governments was used; in the absence of such information, data from the CDM was used:

- (a) For Argentina, the amounts of HFC-23 by-product generated were estimated using the w rate of 3.00 per cent as reported by the Government;
- (b) For China, the amounts of HFC-23 by-product generated in 2014 and 2015 were reported by the Government; the amounts of HFC-23 generated in 2012 and 2013 were calculated using a w rate of 2.78 per cent;
- (c) For the Democratic People's Republic of Korea, the amounts of HFC-23 by-product generated were reported by the Government;
- (d) For India, the amounts of HFC-23 by-product generated were estimated using an average w rate of 2.97 per cent based on the data from the CDM monitoring reports (weighted average from each of the five production facilities using 2015 HCFC-22 production data in the verification report);
- (e) For Mexico, the amounts of HFC-23 by-product generated were reported by the Government;

³ The generation rate w is the mass of HFC-23 generated per metric tonne of HCFC-22 produced, expressed as a percentage.

- (f) For the Republic of Korea, the amounts of HFC-23 by-product generated in 2014 and 2015 were reported by the Government while the amounts generated in 2012 and 2013 were calculated using a *w* rate of 3.00 per cent;
- (g) For Venezuela (Bolivarian Republic of), the amounts of HFC-23 by-product generated were estimated using a *w* rate of 3.00 per cent in the absence of data; and
- (h) For all non-Article 5 countries, the aggregated amounts of HFC-23 by-product generated were calculated using a *w* rate of 2.00 per cent in the absence of data.

13. Information on HCFC-22 production and HFC-23 by-production per line (as requested in decision 78/5(f)(iv)) are available for China and India; this information is considered confidential by the relevant governments and therefore was not included in the document. Information by line and facility in India is available from the CDM for certain monitoring periods. Disaggregated information was not provided by other countries.

Part I B: Current management practices for HFC-23 by-product control

14. The current management practice for HFC-23 emission control varies by country as shown below:⁴

- (a) HFC-23 by-product is collected and destroyed by a designated onsite or off-site destruction facility in Japan, the United States of America, and the United Kingdom of Great Britain and Northern Ireland, though the facility in the latter country has now closed;
- (b) In the Russian Federation, approximately half of the HFC-23 by-product that is generated is vented; the other half is captured and used in the HCFC-22 production facilities for unspecified uses;
- (c) In the Republic of Korea, HFC-23 by-product was destroyed by an incineration facility supported by CDM until the 1 May 2013 ban on the use of HFC-23 certified emission reduction (CER) credits in the European Union Emissions Trading System was enacted; HFC-23 CER credits are also not accepted in the Republic of Korea. While there are yet no policies and regulations for controlling and monitoring HFC-23 by-product emissions, the HFC-23 generated is collected and used as an etching gas for semiconductor, an extinguishing agent and for other purposes;
- (d) In Argentina and Mexico, HFC-23 by-product was destroyed with the support of CDM, but now it is vented. The plant in Mexico makes efforts to reduce the generation of HFC-23 through process optimization by controlling operating parameters, raw material ratio and catalyst;
- (e) The production facility in the Democratic People's Republic of Korea vents HFC-23 by-product that is generated, and seeks to reduce the quantity of HFC-23 generated by adjusting process variables such as the pressure and temperature in the HCFC-22 reactor;

⁴ In response to decision 78/5(d) China, the Democratic People's Republic of Korea, Japan, the Republic of Korea, Mexico, the Russian Federation, the United Kingdom of Great Britain and Northern Ireland and the United States of America provided information on HFC-23 by-product quantities generated, and/or their experience in controlling and monitoring HFC-23 emissions, including relevant regulations and policies. In addition, the Government of Argentina provided information in response to decision 77/59(c). The Secretariat notes the submissions with appreciation. Information on HFC-23 management practices was not received from other countries that produced HCFC-22 in 2015.

- (f) According to an order issued by the Government of India on 13 October 2016, producers of HCFC-22 are required, *inter alia*, to destroy HFC-23 by-product through incineration using an efficient and proven technology such as thermal oxidation; and
- (g) In China, HFC-23 by-product is destroyed, sold, collected and stored or vented to the atmosphere. In 2015, out of the total amount of 13,604 mt of HFC-23 generated, approximately 45 per cent were destroyed, as shown in Table 3 below.

Table 3. HCFC-22 production and HFC-23 emission control in China

Year	HCFC-22 (mt)	HFC-23 (mt)	HFC-23 (percentage)			
		Generated	Destroyed	Sold	Stored	Vented
2013	615,889	16,678.50	35	3	0	62
2014	623,899	17,351.25	28	5	2	65
2015	534,930	13,603.55	45	7	4	45

Part II: Information relevant to the cost of closure of HCFC-22 production swing plants

15. During CFC phase-out, the Executive Committee approved six projects to phase out the production of Group I Annex A and B substances in six Article 5 countries, several of which were amended to accelerate the phase-out with additional funding provided for that acceleration. The total production phase-out achieved amounts to 82,626 mt. The overall cost-effectiveness (CE) of these closure projects, including the additional funding provided for the accelerated phase-out, ranges from US \$2.88/kg to US \$3.86/kg with an average CE of US \$3.45/kg as shown in Table 4.

Table 4. Cost effectiveness of CFC production phase-out projects

Country	Baseline (mt)	Funding (US \$)	CE (US \$/kg)	No of swing production lines	No of non-swing production lines
Argentina	2,745.30	10,600,000	3.86	1	0
China	47,003.90	160,000,000	3.40	0*	18
India	22,632.40	85,170,000	3.76	4	1
Mexico	11,042.30	31,850,000	2.88	2	0
Venezuela (Bolivarian Republic of)	4,786.90	16,500,000	3.45	1	0
Democratic People's Republic of Korea (the)	414.99	1,421,400	3.43	0	1
Total	88,625.79	305,541,400	3.45	8	20

* Based on the Agreement between the Government of China and the Executive Committee on the phase-out of CFC production contained in Annex IV of document UNEP/OzL.Pro/ExCom/27/48.

16. Based on the Agreements between the governments and the Executive Committee, 28 CFC production lines ceased producing CFCs. Of these, eight were swing production lines which can produce both CFC-11/12 and HCFC-22. A condition was added to each of the Agreements for the Governments of Argentina, Mexico and Venezuela (Bolivarian Republic of), specifying that the country agreed that the funds approved for complete closure of its CFC production capacity is the total funding that will be available to it to enable its full compliance with the CFC production phase-out requirements of the Montreal Protocol, and that no additional Multilateral Fund resources will be forthcoming for related activities including the development of infrastructure for the production of alternatives, the import of alternatives, or the eventual closure of any HCFC facilities that use existing CFC infrastructure.

17. For the phase-out of CFC production in India, the Agreement stated: “This is the total funding that would be available to India from the Multilateral Fund for the cessation of production of Group I Annex A CFCs, Group I Annex B CFCs, and eventual cessation of production of Group I Annex C HCFCs as per Montreal Protocol phase-out schedule (including future amendments in schedule, if any) and dismantling of the plants following within 18 months of the cessation of production of ODS unless the plants are otherwise put to use producing substances other than ODS.”

18. Although the HCFC production guidelines are still under discussion by the production sector sub-group, the Executive Committee has approved stage I of the HCFC production phase-out management plan (HPPMP) for China at the 69th meeting. The compensation was calculated based on the technical audit report taking into consideration the status of the plant, production rates, number of employees to be compensated operation, and other factors. Total funding up to US \$385 million was approved in principle including all project costs (cost for compensation of closure, technical assistance activities and project management and coordination). The implementation of the HPPMP for China will phase out 445,888 mt of HCFC productions and retire an additional 24 per cent of idle production capacity. The overall CE is calculated as US \$0.86 per kg of HCFC-22. The CE of stage I as implemented is US \$1.35/kg, as the enterprises that closed their production capacity early lost more profit.

19. Given the above, HCFC production swing plants are not eligible for funding under the current production sector guidelines. However, funding for closure could be provided to enable those facilities to comply with the HFC-23 obligations under the Kigali Amendment once the Article 5 countries concerned ratified the Amendment. The CE from the previous approved projects could provide a reference for the Executive Committee while considering the level of compensation for the closure of HCFC-22 production swing plants. In light of the information on the level of HCFC-22 production provided in Table 1, the HFC-23 by-product generated during this production, and the CE in approved projects for CFC and HCFC production phase-out, the cost of closure of the HCFC-22 production swing plants can be estimated, accordingly.

Part III: A summary of the existing policies and regulations in Article 5 countries

Regulations related to HFC-23 controlling and monitoring

20. The Government of China has issued three policy documents to support the control of HFC-23 emission:

- (a) A Government notice⁵ issued by the Ministry of Environment (MEP) on 27 April 2015 forbids the direct discharge and requires complete and environmental disposal of HFC-23 as a by-product of HCFC-22 production for feedstock use at new, reconstructed or expanded HCFC-22 production facilities. New HCFC-22 production facilities for feedstock uses approved after 27 April 2015 are required to build and operate HFC-23 destruction facilities, the cost of which will be covered by the enterprises;
- (b) A Government notice⁶ issued by the National Development and Reform Commission (NDRC) in November 2014 applicable to production facilities established prior to 27 April 2015 provides a subsidy of up to 40 per cent (or CNY 15 and 10 million for capacity of 1,200 tonnes and 600 tonnes, respectively) of the capital costs to support the construction of new HFC-23 destruction facilities; and

⁵ Supplemental Notice on Strict Control over New Construction, Reconstruction and Expansion of HCFC-22 Production Facilities (Huanban[2015]644).

⁶ 2014 Central Budget Investment Plan for Important Demonstration Projects of HFC-23 Reduction (Fagaitouzi[2014]2533).

- (c) A Government notice⁷ issued by NDRC on 13 May 2015 provides a financial subsidy to operate HFC-23 destruction facilities until 31 December 2019, with the subsidy decreasing annually (the subsidy in the period 2014-2019 is CNY 4.0, 3.5, 3.0, 2.5, 2.0, and 1.0 per ton CO₂ equivalent reduction for the respective fiscal year). The policy defines an HFC-23 generation ratio of 2.0 per cent for the period of 2014-2017 and 1.5 per cent for the period 2018-2019; the GWP of HFC-23 is set to 11,700 by the notice. On this basis, the subsidy varies between CNY 46.8 and 23.4 per kg of HFC-23 (or US \$6.88-3.44/kg of HFC-23 converted on 1 June 2017).

21. Destruction of HFC-23 generated as by-product is voluntary in Japan, and emission data of fluorocarbons including HFC-23 has been reported annually under Industrial Voluntary Action plans. The Act on Rational Use and Proper Management of Fluorocarbons requires destruction of fluorocarbon refrigerants, including HFC-23, collected from designated products such as commercial refrigerators or air-conditioners.

22. In the United States of America under the mandatory reporting of greenhouse gas (GHG) rule, owners or operators of facilities producing HCFC-22 or destroying HFC-23 are required to report on emissions of HFC-23 from HCFC-22 production and HFC-23 destruction processes located either at the HCFC-22 production facilities or (for destruction of more than 2.14 mt of HFC-23 annually) elsewhere. To calculate emissions from HCFC-22 production processes that do not use or have a thermal oxidizer not connected to the production equipment, the annual HFC-23 emissions should be calculated using mass of HFC-23 generated, sent off-site for sale or destruction, destroyed on site and increase in the HFC-23 inventory. For HCFC-22 production processes with a thermal oxidizer connected to the production equipment, annual HFC-23 emissions should be calculated using mass of HFC-23 emissions from equipment leaks, process vents (emission tests to be conducted every five years, or after significant changes to the process) and the thermal oxidizer. For HFC-23 destruction processes, HFC-23 emissions should be calculated based on the mass of HFC-23 fed into the destruction device and the destruction efficiency. For the destruction efficiency, the fluorinated GHG concentration must be measured at the outlet to the destruction device annually. While monitoring of HFC-23 emissions is mandatory, destruction is voluntary.

23. According to the updated European Union (EU) regulation on fluorinated GHGs from 16 April 2014,⁸ producers of fluorinated compounds shall take all necessary precautions to limit emissions of fluorinated GHGs (including those produced as by-products) to the greatest extent possible during production, transport, and storage. In addition, intentional release of fluorinated GHGs into the atmosphere shall be prohibited where the release is not technically necessary for the intended use; and operators of equipment that contains fluorinated GHGs shall take precautions to prevent the unintentional leakage of those gases and take all measures to minimize their leakage.

24. Sites producing fluorinated gases in the United Kingdom of Great Britain and Northern Ireland⁹ are required to obtain a permit and set up emissions control measures. Site visits and audits are performed and criminal prosecution and sanctions are foreseen for offenders.

25. In India the order from 13 October 2016¹⁰ establishes a requirement for all HCFC-22 producing enterprises to destroy HFC-23 as by-product of HCFC-22 production using thermal oxidation. The plants are also required to ensure the down time of incinerators under 10 per cent, create sufficient capacity to store HFC-23 during shutdown of the destruction facility and report on the status of HFC-23 production to the Ozone Secretariat. The order forbids venting of HFC-23 and allows feedstock use of HFC-23.

⁷ Notice on Implementing HFC-23 Disposal Activities (Fagaibanqihou[2015]1189)

⁸ http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.150.01.0195.01.ENG

⁹ The EU regulation applies to the country.

¹⁰ <http://cseindia.org/userfiles/govt-order.pdf>

26. HFC-23 emissions are currently not regulated in Mexico, the Republic of Korea, and the Russian Federation; a new regulation on emission of GHGs including HFCs is underway in the Russian Federation.

Part IV: Further analysis of methods to control HFC-23 by-product emissions

Part IV A: Further analysis of methods to control HFC-23 by-product emissions from the CDM and other sources

27. Nineteen HFC-23 destruction projects have been approved by the CDM Executive Board. Based on the most recent data available, it appears that the projects are currently not generating CERs that are being purchased by Annex I parties to the UNFCCC.¹¹

28. Under the CDM, each facility that requests to receive CER credits is required to provide a monitoring report containing detailed information that allows the credits generated by the project in that reporting period to be calculated. While the monitoring reports provide detailed information on the operation of the destruction facility, they do not provide information on the incremental costs to operate the destruction facility.

29. The Secretariat reviewed monitoring reports of the 19 HFC-23 destruction projects registered under CDM between 2005 and 2009. Each monitoring report provides information on the amount of HCFC-22 produced, the amount of HFC-23 generated, the amount of HFC-23 supplied to and emitted from the destruction process, the amount of fuel (i.e., hydrogen, natural gas, liquefied petroleum gas (LPG), or diesel oil), and the quantity of oxygen, nitrogen and steam, where relevant, used for destruction, and electricity used to power the destruction device.¹² Reports for some of the projects contain the quantity of chemicals (e.g., sodium or calcium hydroxide) used to neutralize waste products, while for the rest of the projects it was not reported as the quantities were negligible, impossible to separate from the quantities used for treatment of waste other than from HFC-23 destruction, were not required to be monitored, or for other reasons. Some projects also include information on hydrogen fluoride (HF) generated during the destruction process¹³ that is recovered, either for re-use or for sale,¹⁴ and on the sludge (waste) that is generated, which may be transported off-site for disposal.

30. The Secretariat collected the data from the ten¹⁵ most recent monitoring reports (for which request for issuance of credits was issued) of the 19 HFC-23 CDM projects¹⁶ in order to estimate the incremental cost of the consumables and waste generated. By normalizing the use of the consumables and waste by the amount of HFC-23 that was destroyed, and using average, nominal costs of the consumables and waste, the Secretariat was able to estimate the incremental costs of the reported consumables and waste per kilogram of HFC-23 destroyed. For six projects, the Secretariat collected data from all the monitoring reports to assess whether using only data from the ten most recent reports affected the results.

¹¹ The 43 annex I Parties to the UNFCCC comprise the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition, including the Russian Federation, the Baltic States, and several Central and Eastern European States (http://unfccc.int/parties_and_observers/items/2704.php).

¹² Electricity was also used for heating the incinerator in three projects.

¹³ For each molecule of HFC-23 that is incinerated, three molecules of hydrogen fluoride are generated.

¹⁴ As a raw material used for the production of HCFC-22, hydrogen fluoride can be re-used in the production facility for that purpose. One facility (Dongyang Chemical) used the generated hydrogen fluoride to manufacture other products. A number of enterprises indicate that they sell the hydrogen fluoride rather than re-use it.

¹⁵ The number of monitoring reports varied (see Table 5), with an average of 25 and a maximum of 47 reports.

¹⁶ Except for the project at Hindustan Fluorocarbons Limited, where only three monitoring reports (covering November 2008 through November 2011) are available.

With few exceptions, the average values calculated using all versus only ten monitoring reports were within 5 per cent.

31. Table 5 summarizes the key characteristics and the calculated incremental cost of the reported consumables and waste by project. With one exception,¹⁷ the incremental cost of consumables and waste was below US \$1/kg of HFC-23 destroyed. Where fuel, electricity, waste and chemicals used to neutralize are all reported, the calculated incremental cost is between US \$0.58 and US \$0.94/kg of HFC-23 destroyed. For those cases where data on the quantity of chemicals used for neutralization and waste generated are not provided, the Secretariat assumed the associated costs to be zero; therefore, the calculated incremental cost of consumables and waste for those projects are not representative of the incremental operating costs (IOCs) for destruction. Annex II to the present document provides additional details of the analysis, including the normalized use of each consumable reported, and the average costs used for the analysis. Annex II also includes information on the quantity of HF recovered for sale or re-use; however, the Secretariat did not account for this possible revenue stream in its analysis as such possible revenue is likely to be small.

¹⁷ The calculated incremental cost of consumables and waste at Chemplast Sanmar was US \$1.98/kg of HFC-23.

Table 5. Key characteristics and calculated incremental costs of the reported consumables and waste from HFC-23 destruction projects under the CDM

Plant	Number of		Fuel	HF recovered	w (%)		Incremental cost of consumables and waste (US \$/kg of HFC-23)
	Reports	Line(s) in project			Weighted Average	Minimum	
Zhejiang Juhua Fluor-Chemistry	32	1	Air, steam and electricity (electric heater)	no*	3.17	3.11	0.89 ¹⁸
Zhejiang Juhua Fluor-Chemistry	24	2	Compressed air, steam and hydrogen	no*	3.26	3.12	0.94 ¹⁹
Jiangsu Meilan Chemical	27	2	Combustion air and hydrogen	yes*	3.06	2.97	0.17
Changshu 3F Zhonghao	25	2	Combustion air, steam and natural gas	yes	2.89	2.88	0.17
Limin Chemical	25	2	Air, steam and LPG	yes	3.13	3.09	0.16
Quimobásicos**	32	1	Argon/electricity and steam	no	2.54	2.37	0.53
Foosung***	26	1	Air, steam and natural gas	no	2.69	2.38	0.44
Chemplast Sanmar	26	1	Compressed air and hydrogen	yes*	3.03	1.58	1.98
Navin Fluorine International	23	1	Air, steam and natural gas	yes*	3.32	3.11	0.87
SRF	28	1	Hydrogen and oxygen	yes*	2.95	1.50	0.45
Zhonghao Chenguang Research Institute **	27	1	Compressed air, nitrogen/electricity	yes	3.03	3.01	0.29
Zhejiang Dongyang Chemical	23	1	Air, steam and LPG	yes	3.24	3.24	0.30
China Fluoro Technology	25	1	Air, steam and natural gas	no	3.09	2.96	0.67
Changshu Haike	12	1	Air, steam and natural gas	yes	1.78	1.11	0.25
Yingpeng Chemical	17	1	Air, steam and LPG	no*	3.05	2.99	0.58
Hindustan Fluorocarbons Limited	3	1	Hydrogen and oxygen	yes	3.20	3.13	n/a ²⁰
Gujarat Fluorochemicals Limited	47	1	Air, steam and natural gas	yes*	2.83	1.62	0.47
Shandong Dongyue Chemical	26	1	Air, steam, coal gas and diesel oil	no*	2.40	2.14 ²¹	0.81 ²²
Frio Industrias Argentinas	20	1	Oxygen and natural gas	yes	3.30	1.89	0.31

* Use of chemicals for neutralization is included in monitoring reports

** Plasma arc technology

*** Formerly Ulsan Chemical

¹⁸ Incremental cost includes cost of chemicals used for neutralization; however, data on the quantity of chemicals used for neutralization is only provided for 5 monitoring reports (out of 32 included in the analysis). The average quantity of chemicals for those five monitoring reports was assumed constant and added as a cost for all monitoring periods.

¹⁹ Incremental cost includes cost of chemicals used for neutralization and waste; however, data provided is for the entire plant, not just for the HFC-23 destruction facility. Therefore, calculated incremental cost represents an upper limit of the cost of chemicals for neutralization and for waste.

²⁰ The project at Hindustan Fluorocarbons Limited (HFL) only has three monitoring reports. Based on that limited data, the reported electricity consumption was between one and two orders higher than that reported in any other project, including those projects that use plasma arc technology (which are expected to have higher electricity consumption than projects using a thermal incinerator, such as in HFL). The Secretariat therefore excluded this data point from its analysis.

²¹ One monitoring report indicated a generation rate of 0.82 per cent. The Secretariat excluded this data point from its analysis as it deviated significantly from the generation rate reported in other monitoring periods.

²² The cost associated with sludge disposal is excluded for this project; data was provided but not evaluated by the Secretariat due to time constraints.

32. The cost of neutralization can constitute a significant proportion of the incremental cost of the reported consumables and waste if the HF generated through the destruction of HFC-23 is not recovered. Of the 19 CDM projects, 12 recovered HF and nine projects reported on the quantities of chemicals used to neutralize waste, though in one case such reported use reflected the chemicals used to neutralize all waste from the HCFC-22 production facility rather than only due the waste generated by the destruction of HFC-23. Of those nine projects, four did not recover HF but instead neutralized all the HF generated; the estimated cost of the chemicals needed to neutralize HF in those cases accounted for approximately one third of the incremental cost of the reported consumables and waste. In contrast, those projects that recovered HF had incremental cost of neutralization that were approximately an order of magnitude or more smaller.

33. The incremental cost of the reported consumables and waste does not include maintenance, labour, costs associated with monitoring, or other expenses that may affect the IOC of destruction, and therefore likely represents a lower bound on the IOC. The Secretariat considers that maintenance costs are likely to be significant as incinerators typically operate at 1,200°C and contain corrosive chemicals; e.g., re-bricking of the incinerator approximately every six years is a common industrial practice. Costs associated with labour are likely to be small given that an incinerator can be controlled from the same control room used to control the rest of the HCFC-22 production facility; however, the Secretariat has not analysed such costs. Monitoring costs, depending on the monitoring requirements, are likely to be present but small relative to the cost of consumables such as fuel and electricity.

34. When the fuel, electricity, waste and chemicals used to neutralize are all included, the incremental cost of consumables and waste calculated by the Secretariat is comparable to the analysis conducted by the Öko Institute for Applied Ecology,²³ which found that the typical marginal technical abatement costs of HFC-23 destruction (i.e., the IOCs) was 0.07 €/tCO_{2e} (approximately US \$1.17/kg of HFC-23, converted on 4 June 2017),²⁴ including the cost of maintenance, labour, monitoring, and other expenses.

35. Table 5 includes the minimum generation rate w achieved in the monitoring periods analysed. For some facilities, the generation rate is fairly constant across monitoring periods, while for others there is significant variation. Five facilities were able to achieve generation rates below 2 per cent, with the lowest at 1.11 per cent. These lower generation rates may reflect a recent change of the catalyst or other process improvements based on existing technology at the facility. This is consistent with research conducted by the Öko Institute for Applied Ecology, which found that while the w rate depends on how the process is operated and the degree of process optimization, a registered CDM plant had a value as low as 0.88 per cent for a period of one month and a value of 1.06 per cent for a period of six months.²⁵ A joint implementation project in the Russian Federation achieved an average annual rate of 1.06 per cent in 2004. These lower values were achieved through process optimization, which also increases the HCFC-22 yield.²⁶ The Government of Japan reported a decrease in the w rate from 2.34 per cent in 2009 to 1.46 per cent in 2015 based on improved process optimization, the costs of which are not known.

36. In addition to reducing the generation rate, emissions of HFC-23 by-product can be mitigated by capturing and destroying more of the HFC-23 that is generated. For example, the destruction rate at a production facility in the United Kingdom of Great Britain and Ireland increased from 94 per cent in 1999 to 96-97 per cent in 2003, due to installation of capture and storage mechanism to prevent emission during shutdown of the thermal oxidizer; further increased to 99 per cent in 2005-2006 as a result of

²³ European independent research and consultancy organization working for a sustainable future.

²⁴ “Options for continuing GHG abatement from CDM and JI industrial gas projects”, 2014, <https://www.oeko.de/oekodoc/2030/2014-614-en.pdf>

²⁵ Ibid.

²⁶ Ibid.

installation of a carbon bed storage unit (with a design life of 15 years, but expected over 20 years) to capture and destroy HFC-23 from the HCFC-22 plant's aqueous effluent streams; and reached 99.9 per cent in 2013 by diverting vents from hydrogen chloride (HCl) stock tanks to the thermal oxidizer. The level of investment costs related to those improved capture systems are not available. In addition, process optimization measures were undertaken, such as catalyst control (i.e., frequent partial changes to the catalyst which kept the impurity levels in the reactor more consistent and hence reduced the variability of the reactor operating parameters, allowing optimized control), and synchronizing the operation time of HCFC-22 with that of thermal oxidizer.

37. A producer based in the United States of America emphasized that for facilities that collect HFC-23 for off-site destruction, depending on the plant set-up, not all the HFC-23 that is generated can be destroyed given limitations in the ability to separate and capture HFC-23 from other streams in the process. In particular, the gas mixture exiting the HCFC-22 reactor typically contains HCFC-22, HCFC-21, HFC-23, HCl and HF. The HFC-23 tends to travel with the HCl stream and is difficult to separate without a liquid absorption system.

38. Several HCFC-22 production facilities use their destruction facility to not only destroy HFC-23 but also other fluorinated waste gases. Such co-destruction may help lower the destruction costs of those enterprises.

39. The estimated cost of off-site destruction of fluorochemicals varies, with one estimate of approximately US \$3.00/kg in the United States of America (plus shipping). Proposals for demonstration projects for the disposal of ozone-depleting substances in accordance with decision 58/19 provided varying costs of off-site destruction, as submitted. For example, the project in Mexico²⁷ estimated a cost of US \$3.00/kg for CFC-11 and US \$5.50/kg for CFC-12 for off-site destruction in Mexico and in the United States of America, respectively, as submitted; the project in Ghana²⁸ estimated a cost of US \$4.19/kg of CFC-12 for destruction at a facility in the EU, as submitted; the regional project in Europe and Central Asia²⁹ and the project in Lebanon³⁰ estimated a cost of US \$5.00/kg of ODS at a facility in the EU, as submitted; the project in Georgia³¹ estimated a cost of US \$8.00/kg for CFC-12 and HCFCs, including transportation, at a facility in the EU, as submitted.

40. Information was provided on one conversion technology (Midwest Refrigerants). To date, the technology has only been used at a pilot scale (with a capacity of 61 mt/year if operated continuously); a facility with capacity of 450 mt/year is planned. The information provided suggests that for every kg of HFC-23 converted, 0.86 kg of anhydrous HF (99.99 per cent purity) and 0.80 kg of technical grade carbon monoxide (99.98 per cent purity) will be generated. While the technology provider indicated that the value of the chemicals produced through the transformation process would compensate for the higher initial capital costs, detailed information on the costs of the technology was not provided.

Part IV B: Information provided by Parties in response to decision 78/5(d)

41. The Governments of China, Japan, Republic of Korea, and the United Kingdom of Great Britain and Northern Ireland provided information in response to decision 78/5(d). In addition, one producer provided information on a facility in Europe and two facilities in the United States of America; and the Government of Argentina provided information in response to decision 77/57(c). This information is summarized in Table 6 below; detailed information is contained in Annex III to the present document.

²⁷ UNEP/OzL.Pro/ExCom/63/42

²⁸ UNEP/OzL.Pro/ExCom/63/31

²⁹ UNEP/OzL.Pro/ExCom/69/32

³⁰ UNEP/OzL.Pro/ExCom/73/41

³¹ UNEP/OzL.Pro/ExCom/69/26

Table 6: Summary of information provided in response to decision 78/5(d)

Country	Capital cost (US \$ million)	Operating cost (US \$/kg)	Remarks
Argentina	n/a	5.68	IOC based on annual generation of 72 mt of HFC-23 by-product. Additional investments needed to start up the destruction facility which is currently in disuse
China	3.67-7.35	5.14-8.82	Capital costs for capacity between 500-1,500 mt/y. IOCs include maintenance, labor and depreciation but not revenue from recovered HF
Japan	5.00	2.00-3.00	Capital costs for capacity of 2,000 mt/y. IOCs including neutralization of HF and HCl waste, noting that HF is recovered
Republic of Korea	n/a	4.20	Annual operating costs amount to US \$800,000. As the destruction facility is currently not in use, an estimated additional US \$400,000 are needed to start the facility up again
EU country	n/a	0.28	IOC does not include neutralization as facility sells some of recovered HF; otherwise, additional neutralization costs of approximately US \$0.33/kg of HFC-23 destroyed
United Kingdom of Great Britain and Northern Ireland	n/a	1.53	Capital investments improved capture of HFC-23 by-product. For IOCs, note that HF is not recovered

Part V: Monitoring methodologies for HFC-23

42. The International Panel on Climate Change (IPCC) under the UNFCCC has developed guidelines for reporting emissions of GHGs. Those guidelines provide methodologies for making estimates of national anthropogenic emissions and removals of GHGs, including methodologies for reporting of HFC-23 emissions both at the individual facility level and the nationally aggregated level. These methodologies can be used to assist Parties to the UNFCCC in fulfilling their commitments to develop GHG emission inventories. The guidelines, which were last revised in 2006, are to be used by Parties included in Annex I of the UNFCCC, and can be used on a voluntary basis for non-Annex I Parties.

43. There is ongoing work within the IPCC on a supplement that will update the 2006 IPCC guidelines, which is expected to be ready around 2019. In addition, there are ongoing negotiations within the UNFCCC related to the implementation of the Paris Agreement, including on requirements on reporting using the IPCC guidelines. The outcomes from those negotiations are not yet known.

Methods to estimate HFC-23 emissions following IPCC Guidelines for National Greenhouse Gas Inventories

44. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides three approaches to estimate HFC-23 emissions from plants producing HCFC-22: Tier 1, Tier 2 and Tier 3. Tier 3 is considered the most accurate; Tier 1 is the least accurate and could be used where limited or no plant-level measurements for HFC-23 are available. Tier 2 and Tier 3 methodologies can only be used when monitoring data are available from HCFC-22 producing plants.

45. Tier 2 and Tier 3 were developed based on the two broad measurement approaches described in the following publications: IPCC (2000)³², DEFRA (2002a and 2002b)³³, EFCTC (2003)³⁴ and UN³⁵ (2004) (which is the CDM methodology presented below in paragraphs 49 to 51 and in Annex IV). Tier 1 method applies a default emission factor to the quantity of HCFC-22 produced and assumes that there is no destruction of HFC-23. Further details on the monitoring methods are provided in Annex IV to the present document.

46. Irrespective of which tier is used, the quantity of HFC-23 recovered for use as chemical feedstock, thus destroyed, should be discounted from the estimated emissions. Material recovered for uses where it may potentially be emitted may be discounted if the emissions are included in the calculations elsewhere.

47. The guidelines note that it is good practice to estimate emissions by summing measured parameters from all HCFC-22 plants in a country, and to subtract abated HFC-23 emissions from national estimates where the abatement has been verified by process records on every plant.

48. The UNFCCC does not have estimates of the likely costs of monitoring HFC-23 emissions in accordance with the guidelines.

Method to monitor HFC-23 emissions from the Clean Development Mechanism

49. The CDM first developed a facility-level methodology for monitoring HFC-23, termed AM0001, in 2003, based on the proposal from the HFC-23 decomposition project in Ulsan, Republic of Korea. It is applicable to CDM projects that capture and decompose HFC-23 formed in the production of HCFC-22. That AM0001 methodology was revised several times, with the latest (sixth) version prepared in 2011.³⁶ While AM0001 includes a useful method to allow HFC-23 emissions to be monitored, it was not developed for that purpose. Rather, AM0001 was developed to allow for the accurate and transparent accounting of the carbon credits generated from HFC-23 destruction in the relevant reporting period.

50. AM0001 requires measurements of the following parameters: quantity of HFC-23 generated; quantity of HFC-23 sent to the inlet of HFC-23 decomposition facility; quantity of HFC-23 emitted due to incomplete decomposition; the stock of HFC-23 stored at the beginning of the monitoring period; HFC-23 added to or taken from the stock; and HFC-23 sold. All monitoring procedures must be described and specified, including the type of measurement instrumentation used, and the responsibilities for monitoring and quality assurance/quality control procedures that will be applied. Meters should be installed, maintained and calibrated according to equipment manufacturer instructions and be in line with national standards or, if these are not available, international standards (e.g. IEC, ISO). Further details of the requirements of AM0001 are provided in Annex IV.

51. The CDM does not have estimates of the costs of monitoring under AM0001.

³² IPCC (2000). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., Tanabe K. (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA/IGES, Hayama, Japan.

³³ Defra (2002a). Protocol C1: Measurement of HFCs and PFCs from the Manufacture of HF, CTF, HCFC-22, HFC-125 and HFC-134a, in *Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme*, UK Department for Environment, Food and Rural Affairs, Report No. UKETS(01)05rev1, Defra, London, 2002.
Defra (2002b). Protocol C9: Measurement of HFCs and PFCs from Chemical Process Operations, UK Department for Environment, Food and Rural Affairs, *as above*, London, 2002.

³⁴ EFCTC (2003). *Protocol for the Measurement of HFC and PFC Greenhouse Gas Emissions from Chemical Process Operations*, Standard Methodology, European Fluorocarbon Technical Committee, Cefic, Brussels, 2003.

³⁵ UN (2004). Approved baseline methodology, 'Incineration of HFC 23 waste streams', AM0001/Version 02, CDM – Executive Board, United Nations Framework Convention on Climate Change, 7 April 2004

³⁶ AM0001/Version 06.0.0 is available at https://cdm.unfccc.int/filestorage/5/0/K/50KH2J9V6O1IQNBSPALXYU GRCZFED7.1/EB65_repan10_AM0001_ver06.0.0_v02.pdf?t=Vkn8b3B0Mjk3fDDPcXbfFKfk6t0T8nlLBbGP

Current practices for monitoring HFC-23 under the implementation of HPPMP for China

52. As per the Agreement between the Government of China and the Executive Committee for stage I of the HPPMP, the Government agrees to coordinate with its stakeholders and authorities 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. In order to monitor the impact of the implementation of the above activities, the Executive Committee decided (decision 72/44 (b)) that the World Bank's verification report should provide estimates of inadvertent emissions of HFC-23 and other by-products. The verifications conducted for 2013, 2014 and 2015 have included the relevant information on HFC-23 emission in the 16 HCFC-22 producers covered by the HPPMP and one feedstock producers outside of the HPPMP.

53. The verification included the technical verification on HCFC plant operation which is conducted on a line-to-line basis and the financial verification of the accounting system. Those verifications are conducted in parallel. The outputs of the technical and financial verification are cross checked to ensure consistency of the verified results.

54. During the verification, data on HFC-23 by-production from HCFC-22 production and the handling of HFC-23 is reviewed for each producer. The practice in managing HFC-23 in each line is investigated and recorded. The data on the amounts of HFC-23 generated, destroyed, vented, sold and stored are collected, verified and presented in the yearly production verification report for each facility. Total by-production of HFC-23 from HCFC-22 process is determined based on the verifiable records, by the amounts transferred to the on-site CDM incinerator or HFC-23 recovery system; the amounts sold are verified from financial records. Where specific measurement records are not available, an assumption of HFC-23 ratio of 3 per cent is used for estimating the overall generation of HFC-23.

55. In its response to decision 78/5(c), the Government of China included the HFC-23 monitoring methodology for domestic carbon emission reduction (CCER) projects CM-010-V01 'HFC-23 Gaseous Effluents Incineration Version I' and a revised HFC-23 monitoring methodology based on CM-010-V01 to support the implementation of the HFC-23 decomposition policy³⁷ issued on 13 May 2015. The revised HFC-23 monitoring methodology has the following components:

- (a) One HFC-23 flow meter should be installed at the outlet for each HCFC-22 production line. In case that a meter cannot be installed for each line at the outlet, one flow meter should be installed at the outlet of each separation facility to measure the individual HFC-23 generation;
- (b) All meters installed should be calibrated at least once a year; and
- (c) In order to meet relevant national environment standards, dioxin in the flue gas should be measured at least once a year. Other gaseous effluents (CO, HCl, HF, Cl₂ and NO_x), liquid effluents, suspended solids, phenol and metal substances (Cu, Zn, Mn and Cr) should be measured at least once every half year.

56. The relevant HFC-23 data collected through verification depends on the plant operation records (e.g., daily logs, monitoring records, and raw material movements) obtained from routine operation and monitoring system established in the individual plants.

³⁷ As previously noted, NDRC issued a policy to subsidize operational costs of incineration. The subsidy is to cover the 2014-2019 period on a sliding scale in order to entice the producers to start HFC-23 incineration as early as possible.

57. The Secretariat notes that the revised CM-010-V01 provides data on HFC-23 based on actual measurements, which is similar to the Tier 3a method used to estimate HFC-23 emissions in the IPCC Guidelines for National Greenhouse Gas Inventories. That method is considered as the most accurate method of monitoring HFC-23 emissions and should be considered sufficient for monitoring under the Kigali Amendment.

Recommendation

58. The Executive Committee may wish to:

- (a) Note document UNEP/OzL.Pro/ExCom/79/48 on Key aspects related to HFC-23 by-product-control technologies;
- (b) Note with appreciation the information related to HFC-23 by-product provided by the Governments of Argentina, China, the Democratic People's Republic of Korea, Japan, the Republic of Korea, Mexico, the Russian Federation, the United Kingdom of Great Britain and Northern Ireland, and the United States of America; the European Union; the Secretariat of the United Nations Framework Convention on Climate Change; a fluorochemical producer; and an independent research and consulting organization; and
- (c) Consider whether or not:
 - (i) To consider eligible for funding the closure of the HCFC-22 production swing plants in those countries that wish to do so to enable compliance with the control measures under the Kigali Amendment once the country concerned ratified the Amendment;
 - (ii) To request the Governments wishing to close their production swing plants to submit preliminary data as per decision 36/19; and
 - (iii) To request the Secretariat to contract an independent consultant to undertake a desk study on the cost of HFC-23 destruction and allocate the necessary budget, accordingly.

Annex I

Decision 78/5

The Executive Committee decided:

- (a) To take note of the key aspects related to HFC-23 by-product-control technologies contained in documents UNEP/OzL.Pro/ExCom/78/9 and Corr.1;
- (b) To note the urgency of taking action to enable Article 5 countries to meet the HFC-23 reporting and control obligations by 1 January 2020;
- (c) To reiterate, through the World Bank, its request to the Government of China that it provide to the 79th meeting reports on the status of the studies on “HFC-23 conversion/pyrolysis technologies” and on “investigation on reducing HFC-23 by-product ratio using best practices” that had been funded through the HCFC production phase-out management plan;
- (d) To invite all relevant HCFC-22 producing parties to provide to the Secretariat, on a voluntary basis, information on quantities of HFC-23 in facilities producing HCFC-22 as well as their experience in controlling and monitoring HFC-23 by-product emissions, including relevant policies and regulations and the related costs, no later than 15 May 2017;
- (e) To request the Secretariat to continue to explore whether there were HFC- or other HCFC-producing facilities in any party that generated HFC-23 emissions and to report back to the Executive Committee by 31 May 2018;
- (f) To request the Secretariat to submit an updated document of key aspects related to HFC-23 by-product control technologies to the 79th meeting, including:
 - (i) Information relevant to the cost of closure of HCFC-22 production swing plants;
 - (ii) A description of existing policies and regulations supporting the control and monitoring of HFC-23 emissions and requirements for sustaining those measures in Article 5 countries;
 - (iii) Further analysis of methods to control HFC-23 emissions based on the additional information provided by Executive Committee members and any other available information to the Secretariat, including information from the Clean Development Mechanism;
 - (iv) The current levels of HCFC-22 production and HFC-23 emissions, and information on management practices, per line, in each facility in Article 5 and non-Article 5 countries, including information on approved monitoring methodologies under the United Nations Framework Convention on Climate Change (UNFCCC); and
 - (v) Exploration of possible options for monitoring HFC-23 emissions, such as those approved for continuous monitoring under the UNFCCC, including the associated costs; and
- (g) To consider the need for a desk and field study at the 79th meeting (decision 78/5).

Annex II

Use and cost of consumables and waste at 19 HFC-23 facilities under the Clean Development Mechanism

1. Table 1 provides the data used to determine the cost of consumables and waste at 19 HFC-23 facilities under the Clean Development Mechanism (CDM), including the normalized use of each consumable reported, and the normalized sludge (waste) where that is reported; the table also provides the incremental cost of reported consumables and waste (ICRCW), US \$/kg of HFC-23. The nominal, average costs of consumables and waste used in the analysis are provided in Table 2. The Secretariat notes that the cost of consumables and waste disposal may vary by country. Where available, country-specific values could be used to better estimate the incremental costs of the consumables and waste.

Table 1. Use and cost of consumables and waste at 19 HFC-23 facilities under the CDM

Plant	Fuel 1				Fuel 2				Electricity		Sludge		Neutralizing agent 1			Neutralizing agent 2			ICRCW (US \$/kg HFC-23)	Other ¹		
	Type	Unit	Use (unit/kg HFC-23)	Cost (US \$/ kg HFC-23)	Type	Unit	Use (unit/kg HFC-23)	Cost (US \$/kg HFC-23)	Electricity (kWh/kg HFC-23)	Cost (US \$/ kg HFC-23)	Sludge (mt/kg HFC-23)	Cost (US \$/ kg HFC-23)	Type	Use (kg/kg HFC-23)	Cost (US \$/kg HFC-23)	Type	Use (kg/kg HFC-23)	Cost (US \$/kg HFC-23)		Other	Units	Value
Zhejiang Juhua Fluor-Chemistry (1 line)	Steam	kg	0.77	0.03	n/a	n/a	n/a	-	2.60	0.26	0.007	0.33	Ca(OH) ₂ ²	2.69	0.27	n/a	n/a	-	0.89	n/a	n/a	-
Zhejiang Juhua Fluor-Chemistry (2 lines)	Hydrogen	Nm ³	1.68	0.07	Steam	kg	1.00	0.04	0.73	0.07	0.009	0.43	Ca(OH) ₂ ³	3.27	0.33	n/a	n/a	-	0.94	n/a	n/a	-
Jiangsu Meilan Chemical	Hydrogen	kg	0.09	0.05	n/a	n/a	n/a	-	0.68	0.07	n/a	-	NaOH	0.15	0.06	n/a	n/a	-	0.17	Recovered HF	kg/kg of HFC-23	2.20
Changshu 3F Zhonghao	Natural gas	kg	0.20	0.15	Steam	kg	0.08	0.00	0.21	0.02	n/a	-	n/a	n/a	-	n/a	n/a	-	0.17	n/a	n/a	-
Limin Chemical	LPG ⁴	kg	0.13	0.14	Steam	kg	0.08	0.00	0.19	0.02	n/a	-	n/a	n/a	-	n/a	n/a	-	0.16	n/a	n/a	-
Quimobásicos ⁵	Steam	kg	0.87	0.03	n/a	n/a	n/a	-	5.00	0.50	n/a	-	n/a	n/a	-	n/a	n/a	-	0.53	n/a	n/a	-
Foosung ⁶	Natural gas	Nm ³	0.77	0.39	Steam	kg	0.35	0.01	0.36	0.04	n/a	-	n/a	n/a	-	n/a	n/a	-	0.44	n/a	n/a	-
Chemplast Sanmar	Hydrogen	Nm ³	3.77	1.88	C.air ⁷	m ³	8.00	0.04	0.51	0.05	n/a	-	NaOH	0.004	0.002	Na ₂ SO ₃	0.002	0.000	1.98	n/a	n/a	-

¹ The potential revenue from selling HF was not accounted in the ICRWC calculation.

² The quantity of neutralizing agent used is reported only in five monitoring periods.

³ Data provided is for the entire plant, not just for the HFC-23 destruction facility. Therefore, calculated incremental cost represents an upper limit of the cost of chemicals for neutralization and for waste.

⁴ Liquefied petroleum gas.

⁵ Plasma arc technology.

⁶ Formerly Ulsan Chemical.

⁷ Compressed air.

Plant	Fuel 1				Fuel 2				Electricity		Sludge		Neutralizing agent 1			Neutralizing agent 2			ICRCW (US \$/kg HFC-23)	Other ¹		
	Type	Unit	Use (unit/kg HFC-23)	Cost (US \$/ kg HFC-23)	Type	Unit	Use (unit/kg HFC-23)	Cost (US \$/kg HFC-23)	Electricity (kWh/kg HFC-23)	Cost (US \$/ kg HFC-23)	Sludge (mt/kg HFC-23)	Cost (US \$/ kg HFC-23)	Type	Use (kg/kg HFC-23)	Cost (US \$/kg HFC-23)	Type	Use (kg/kg HFC-23)	Cost (US \$/kg HFC-23)		Other	Units	Value
Navin Fluorine International	Natural gas	Nm ³	0.69	0.35	Steam	kg	0.85	0.03	3.44	0.34	0.0016	0.08	Ca(OH) ₂	0.64	0.06	NaOH	0.02	0.01	0.87	Recovered HF	kg/kg of HFC-23	0.55
SRF	Hydrogen	Nm ³	0.74	0.03	Oxygen	Nm ³	0.48	0.32	0.98	0.10	n/a	-	Ca(OH) ₂	0.03	0.003	n/a	n/a	-	0.45	Recovered HF	kg/kg of HFC-23	5.54
Zhonghao Chenguang Research Institute ⁸	n/a	n/a	n/a	-	n/a	n/a	n/a	-	2.90	0.29	0.00002	0.001	n/a	n/a	-	n/a	n/a	-	0.29	n/a	n/a	-
Zhejiang Dongyang Chemical	LPG	kg	0.21	0.23	Steam	kg	0.04	0.00	0.70	0.07	n/a	-	n/a	n/a	-	n/a	n/a	-	0.30	n/a	n/a	-
China Fluoro Technology	Natural gas	Nm ³	0.57	0.29	Steam	kg	0.26	0.01	0.99	0.10	0.01	0.27	n/a	n/a	-	n/a	n/a	-	0.67	n/a	n/a	-
Changshu Haike	Natural gas	Nm ³	0.40	0.20	Steam	kg	0.28	0.01	0.41	0.04	n/a	-	n/a	n/a	-	n/a	n/a	-	0.25	n/a	n/a	-
Yingpeng Chemical	LPG	Nm ³	0.16	0.33	Steam	kg	0.19	0.01	0.86	0.09	0.00	0.03	NaOH	0.24	0.10	Ca(OH) ₂	0.35	0.03	0.58	Wastewater	mt/kg of HFC-23	0.03
Hindustan Fluorocarbons Limited ⁹	Hydrogen	kg	0.16	0.08	Oxygen	kg	1.55	0.77	36.95 ¹⁰	3.69	n/a	-	n/a	n/a	-	n/a	n/a	-	n/a	Nitrogen	kg/kg of HFC-23	0.24
Gujarat Fluorochemicals Limited	Natural gas	kg	0.15	0.11	Steam	kg	2.94	0.12	1.82	0.18	n/a	-	NaOH	0.15	0.06	n/a	n/a	-	0.47	Recovered HF	kg/kg of HFC-23	3.32
Shandong Dongyue Chemical	Diesel	kg	0.42	0.42	Steam	kg	3.05	0.12	0.97	0.10	n/a ¹¹	-	Ca(OH) ₂	1.72	0.17	n/a	n/a	-	0.81	n/a	n/a	-
Frio Industrias Argentinas	Natural gas	Nm ³	0.54	0.27	n/a	n/a	n/a	-	0.40	0.04	n/a	-	n/a	n/a	-	n/a	n/a	-	0.31	Recovered HF	kg/kg of HFC-23	1.75

⁸ Plasma arc technology.

⁹ Only three monitoring reports (covering November 2008 through November 2011) were available.

¹⁰ Based on limited data, the reported electricity consumption was between one and two orders higher than that reported in any other project, including those projects that use plasma arc technology (which are expected to have higher electricity consumption than projects using a thermal incinerator, such as in Hindustan Fluorocarbons Limited). The Secretariat therefore excluded this data point from its analysis.

¹¹ The figures were provided, but not reviewed by the Secretariat due to time constraints.

Table 2. Indicative cost of consumables and waste

Consumable/Waste	Unit	Cost (US \$/unit)	Unit	Cost (US \$/unit)	Comments
Hydrogen	kg	0.50	Nm ³	0.04	Cylinders available for about US \$0.50-0.60/kg ¹²
Oxygen	kg	0.50	Nm ³	0.66	Secretariat's estimate
Nitrogen	kg	0.02			Secretariat's estimate
Diesel	kg	1.00			About US \$1/kg in China in 2017 ¹³
Electricity	kWh	0.10			Cost of electricity is US \$0.05-0.18/kWh in Republic of Korea (2013) ¹⁴ , US \$0.07-0.11/kWh in Mexico (2017) ¹⁵ , US \$0.04/kWh in Argentina (2017) ¹⁶ , US \$0.08/kWh in China and India (2011) ¹⁷
Natural gas	kg	0.75	Nm ³	0.50	Average price in China (city gate price) as of 2015 is about US \$ 0.4/m ³ . ¹⁸ In India compressed natural gas was about US \$0.7/kg and piped natural gas was US \$0.4/standard m ³ (2016) ¹⁹
LPG	kg	1.08	Nm ³	2.04	Based on global prices ²⁰
Steam	kg	0.04			US \$0.03/kg in China (2014) ²¹
Calcium hydroxide	kg	0.10			Around US \$0.07/kg in China ²²
Sludge disposal	mt	50.00			Secretariat's estimate
Sodium hydroxide	kg	0.40			In China varies between US \$0.08 and US \$0.15/kg depending on concentration and region (2014) ²³ ; in India is around US \$0.50/kg ²⁴ or US \$0.7-0.8/kg (2017) ²⁵
Sodium sulfate	kg	0.20			US \$0.2 US/kg (2017) in India ²⁶
Compressed air	m ³	0.01			Secretariat's estimate

¹² https://www.alibaba.com/product-detail/hot-selling-liquid-hydrogen-price_1029441347.html

¹³ http://www.globalpetrolprices.com/China/diesel_prices/

¹⁴ <https://home.kepco.co.kr/kepco/EN/F/htmlView/ENFBHP00103.do?menuCd=EN060201>

¹⁵ <http://sie.energia.gob.mx/bdiController.do?action=cuadro&cveca=IIIBC01>

¹⁶ <http://www.telesurtv.net/english/news/Argentina-Raises-Electricity-Prices-Again-Now-up-to-148-20170201-0008.html>

¹⁷ <https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html>

¹⁸ https://globalchange.mit.edu/sites/default/files/DanweiZhang_MS_2016.pdf

¹⁹ <http://timesofindia.indiatimes.com/business/india-business/Gujarat-Gas-cuts-natural-gas-prices/articleshow/51655633.cms>

²⁰ http://www.globalpetrolprices.com/lpg_prices/

²¹ <https://hub.globalccsinstitute.com/publications/adb-technical-assistance-project-aspen-simulation-and-evaluation-economic-feasibility-co2-capture-gaojing-gas-fired-power-plant/53-operating-costs>

²² http://www.made-in-china.com/products-search/hot-china-products/Hydrated_Lime_Price.html

²³ <http://www.tiankaichem.com/a/INDUSTYNEWS/22.htm>

²⁴ <https://dir.indiamart.com/impcat/caustic-soda-flakes.html>

²⁵ <http://www.adinathpetro.com/productlist1.asp>

²⁶ *ibid*

Annex III

Information provided by Parties in response to decision 78/5(d)

1. The Government of China indicated capital costs of the destruction facility with annual capacity of 500 to 600 tonnes at CNY 25 to 28 million (US \$3.67 to 4.11 million, converted on 1 June 2017) and with annual capacity of 1,200 to 1,500 tonnes at CNY 40 to 50 million (US \$5.88 to 7.35 million, converted on 1 June 2017). The operating costs were indicated at CNY 35-60/kg of HFC-23 (US \$5.14 to US \$8.82/kg of HFC-23, converted on 1 June 2017), which includes maintenance, labour and depreciation, but does not account for revenue from recovered hydrogen fluoride as it is considered negligible.
2. The Government of Japan indicated capital cost of a destruction facility with annual capacity up to 2,000 tonnes at US \$5 million, excluding the equipment to treat waste from the facility. The operating costs were indicated at US \$2-3/kg of HFC-23 destroyed, which includes neutralization of hydrogen fluoride (HF) and HCl waste, noting that HF is recovered for feedstock uses. The w rate in Japan decreased from 2.34 per cent in 2009 to 1.46 per cent in 2015.
3. The production facility in the Republic of Korea had participated in the CDM but stopped decomposition and started selling HFC-23 when trading of HFC-23 certified emissions reductions in the European Union market was banned. According to the enterprise, destruction of HFC-23 using the existing decomposition incineration facility is estimated to cost approximately US \$400,000 for facility renovation with annual operating costs at US \$800,000. Using w rate of 2.7 per cent and average 2014-2016 HCFC-22 production, the operating costs would be approximately US \$4.20/kg of HFC-23 destroyed.
4. The last HCFC-22 producing facility in the United Kingdom of Great Britain and Northern Ireland closed in 2016; it generated around 110 mt of HFC-23 in 2016 (170 mt in 2015 and 175 mt in 2014). The estimated w rate for that facility in the United Kingdom of Great Britain and Northern Ireland for the years 2014-2016 is about 2.5 per cent. The operating costs were estimated at £1/kg of HFC-23 destroyed (US \$1.53/kg, using a 2015 conversion rate of approximately US \$1.53), of which 20-30 per cent was allocated to maintenance and under five per cent to testing and monitoring; noting that HF was not recovered. With regards to the lifespan of the equipment, the design life of 15 years is expected with possible extension to 20-25 years with good maintenance, consistent operation and reliable services.
5. One producer provided information at three fluorochemical production facilities. One facility, based in Europe, uses an on-site destruction device to destroy HFC-23 by-product. The estimated incremental operating costs of that destruction is approximately 0.25 €/kg of HFC-23 (US \$0.28/kg of HFC-23). This cost does not include the cost of neutralization, which varies as the facility recovers HF and sells a portion of that recovered HF to a commodity manufacturer. Any HF that it is not able to sell, the facility neutralizes at an off-site facility at a cost of approximately 340 €/mt of waste (approximately US \$0.33/kg of HFC-23, taking into account that each molecule of HFC-23 generates three molecules of HF). Another facility, based in the United States of America, collects the HFC-23 by-product and destroys it an off-site facility incurring only transportation costs (approximately US \$0.25/kg) as the producer has facilities with excess incineration capacity.
6. The third site, also located in the United States of America, destroys other non-HFC-23 by-products on site using a natural gas-fuelled incinerator. Should the incinerator need to be shut down for maintenance, plant operations are halted so that the by-products are not emitted or vented. The producer estimated total maintenance costs of the incinerator to be approximately 1-2 per cent of the capital costs. The facility recovers and neutralizes HF generated from the destruction; the cost of the

chemicals needed to neutralize the HF is estimated to account for approximately half of the operating costs.

7. The producer also indicated that with proper maintenance, including re-bricking approximately every six years, an incinerator can last 20 years. In addition, replacing the catalyst is a key determinant of yield. In general, the timely replacement of the catalyst can keep the generation rate w at an optimal level.

8. The Government of Argentina provided information in response to decision 77/59(c) indicating that the enterprise in the country has a destruction facility, which is currently not being used. The enterprise believes that to start up the HFC-23 destruction plant again, investments should be made to replace the damaged absorption tower, repair valves, and buy zeolite for the oxygen generator, among other issues. The enterprise estimated operating cost for the destruction of HFC-23 at 90 Argentinian pesos per kg of HFC-23 (US \$5.68/kg of HFC-23) for a monthly production of 200 mt of HCFC-22 and a corresponding generation of approximately 6 mt of HFC-23.

Annex IV

Monitoring methodologies for HFC-23 by-product

Methods to estimate HFC-23 emissions following IPCC Guidelines for National Greenhouse Gas Inventories

1. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides three approaches to estimate HFC-23 emissions from plants producing HCFC-22: Tier 1, Tier 2 and Tier 3. Tier 3 is considered the most accurate; Tier 1 is the least accurate and could be used where limited or no plant-level measurements for HFC-23 are available. Tier 2 and Tier 3 methodologies can only be used when monitoring data are available from HCFC-22 producing plants.
2. Tier 3 consists of three methods, depending on the data available at the plants, and aims at estimating the composition and flow-rate of gas streams vented to the atmosphere:
 - (a) Tier 3a is based on frequent or continuous measurement of the concentration and flow-rate from the vent at the plant. Periods when the vent stream is processed in an HFC-23 destruction facility would be discounted from the calculated emissions;
 - (b) Tier 3b can be used where continuous measurements of HFC-23 emissions are not available, but measurements were taken during an intensive process survey or plant trial through which a relationship between the emission and a process parameter (e.g., operating rate) is established, and the resulted relationship from the trial may be used to provide a proxy for calculating emissions during normal plant operation. In such case, emissions can be estimated based on continuous monitoring of a process parameter related to the emission when continuous or frequent monitoring of the waste stream is not available. The process operating rate (e.g., feed rate of raw materials into the HCFC-22 reactor) is considered a suitable parameter for most cases to use as a proxy. This method requires that no major changes in process design, construction or operating parameters take place between when the proxy was established and the reporting period. For situations where a simple function relating the emissions to the operating rate cannot be determined from testing, the proxy method is not considered appropriate and continuous measurement is desirable; and
 - (c) Tier 3c is based on monitoring the HFC-23 concentration in the reactor outlet and the production of HCFC-22. This provides a basis for estimating the quantity of HFC-23 released based on the monitored concentration of HFC-23 and the mass flow of HCFC-22 produced, assuming that there is no destruction of HFC-23.
3. Emissions of HFC-23 under Tier 2 are estimated based on plant efficiencies. This method uses the difference between the expected and the actual production of HCFC-22 due to loss of raw materials, HCFC-22 and conversion to by-products, including HFC-23. While the efficiency loss due to generation of HFC-23 is specific to each plant, it is commonly the most significant efficiency loss. To calculate the HFC-23 emission factor, the carbon and the fluorine efficiency are used. Annual average carbon and fluorine balance efficiencies should be available at the HCFC-22 plants. The calculated emission factor is then applied to the quantity of HCFC-22 produced during which time the HFC-23 stream was released to the atmosphere untreated.

4. Tier 1 method applies a default emission factor to the quantity of HCFC-22 produced and assumes that there is no destruction of HFC-23. If plant level production for HCFC-22 is available, the emission factor can be applied to this data; otherwise, national HCFC-22 production can be used. The guidelines indicate a default emission factor of modern plants at 3 per cent.

5. Tier 3 methods are significantly more accurate than Tier 2 and Tier 1. Regular sampling of the vent stream, as in Tier 3a, can achieve an accuracy of one to two per cent at a 95 per cent confidence level in HFC-23 emissions; the same may be valid for using proxy, as in Tier 3b, method. For Tier 2, if carbon and fluorine efficiencies can be measured to within 1 per cent (which will require rigorous accounting of all raw materials and products for sale), then the error using this method is estimated at less than 20 per cent. The guidelines suggest an error of approximately 50 per cent to be considered for Tier 1.

Method to monitor HFC-23 emissions from the Clean Development Mechanism (CDM)

6. The CDM first developed a facility-level methodology for monitoring HFC-23, termed AM0001, in 2003. The methodology was developed based on the proposal from the HFC-23 decomposition project in Ulsan, Republic of Korea and is applicable to CDM projects that capture and decompose HFC-23 formed in the production of HCFC-22. That AM0001 methodology was revised several times, with the latest (sixth) version prepared in 2011.¹ While AM0001 may have developed a useful method to allow HFC-23 emissions to be monitored, it was not developed for that purpose. Rather, AM0001 was developed to allow for the accurate and transparent accounting of the carbon credits generated from HFC-23 destruction in the relevant reporting period.

7. Under AM0001, a single HFC-23 decomposition facility may be used for decomposition of HFC-23 from one or several HCFC-22 reaction units.² The HCFC-22 produced may be used for emissive and/or non-emissive applications. Emissions of HFC-23 include any HFC-23 emissions from all HCFC-22 production lines that are eligible for crediting, including emissions due to incomplete decomposition of HFC-23 in the HFC-23 decomposition facility, the direct venting of HFC-23 (e.g. through a by-pass to the HFC-23 decomposition facility) and fugitive emissions from storage and other devices connected to the HCFC-22 production lines that are eligible for crediting. Emissions are not directly measured but are determined based on a HFC-23 mass balance, as the difference between the amount of HFC-23 generated in HCFC-22 production lines that are eligible for crediting and the amount of HFC-23 decomposed in the HFC-23 decomposition facility. HFC-23 may be also temporarily stored, e.g., during maintenance of the HFC-23 decomposition facility. However, any HFC-23 added to the storage stock in a monitoring period is accounted as if it would be released to the atmosphere; when it is destroyed in a subsequent monitoring period it is accounted as additional HFC-23 destruction in that monitoring period and the project emissions are lowered by this amount. Leakage emissions are deemed to be negligible and are accounted as zero.

8. AM0001 requires measurements of the following parameters: quantity of HFC-23 generated; quantity of HFC-23 sent to the inlet of HFC-23 decomposition facility; quantity of HFC-23 emitted due to incomplete decomposition; the stock of HFC-23 stored at the beginning of the monitoring period; HFC-23 added to or taken from the stock; and HFC-23 sold. All monitoring procedures must be described and specified, including the type of measurement instrumentation used, and the responsibilities for monitoring and quality assurance/quality control procedures that will be applied. Meters should be installed, maintained and calibrated according to equipment manufacturer instructions and be in line with national standards or, if these are not available, international standards (e.g. IEC, ISO).

¹ AM0001/Version 06.0.0 is available at https://cdm.unfccc.int/filestorage/5/0/K/50KH2J9V6011QNBSPALXYU GRCZFED7.1/EB65_repan10_AM0001_ver06.0.0_v02.pdf?t=Vkn8b3B0Mjk3fDDPcXbfFKfk6t0T8nlLBbGP

² The HCFC-22 reaction unit comprises the reactor, column and condenser where HCFC-22 is produced through chemical reaction.

9. To measure the quantity of HFC-23 generated, the methodology requires that two flow meters be used for each production line (measurements are continuous, meters integrated at least every hour). Where the flow meter readings differ by greater than twice their claimed accuracy, the reason for the discrepancy shall be investigated and the fault remedied. For each meter reading, the higher value of the two shall be used. The concentration of HFC-23 in the stream shall be measured by sampling with the gas chromatography at least weekly in constant measurement intervals. The same requirements are applied to the measurement of the quantity of HFC-23 sent to the inlet of HFC-23 decomposition facility, except that for each meter reading, the lower value of the two readings shall be used. To measure the quantity of HFC-23 emitted at the outlet of the destruction facility due to incomplete decomposition gas chromatography will be used

10. For all the three measurements above, audit of the procedure should be performed according to the relevant national or international standards. The meters shall be calibrated every six months by an officially accredited entity. The zero check on the meters shall be conducted every week and if it indicates that the flow meter is not stable, an immediate calibration of the flow meter shall be undertaken. The quantities of gaseous and liquid effluents are to be measured every six months to ensure compliance with environmental regulations.
