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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Eighty-second Meeting
Montreal, 3-7 December 2018

COST-EFFECTIVE OPTIONS FOR CONTROLLING HFC-23 BY-PRODUCT EMISSIONS (DECISION 81/68(e))

Background

1. 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, should be funded by the Multilateral Fund to meet the obligations of Article 5 Parties. In addressing this decision, at its 77th meeting[1] the Executive Committee 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)), which was subsequently presented to the 78th meeting.[2] Since then, issues related to the HFC-23 by-product emissions have been considered at each meeting of the Executive Committee.[3]

Discussion at the 81st meeting

2. At its 81st meeting, the Executive Committee discussed the document on key aspects related to HFC-23 by-product control technologies (decisions 78/5(e), 79/47(e) and 80/77(b)), which contained a report produced by a consultant evaluating options for the destruction of HFC-23 from HCFC-22 facilities.

3. In the ensuing discussion, several members said that there was a need to better understand the costs and management of and conditions relating to HFC-23 emissions destruction and control in other countries, and not only in China where different conditions applied. Given that there were differences between the various countries producing HCFC-22 and generating HFC-23 as a by-product, there was a need to address the issue on a case-by-case basis in order to identify gaps in capacity to manage HFC-23 destruction.

[1] Montreal, Canada, 28 November – 2 December 2016.
[2] UNEP/OzL.Pro/ExCom/78/9 and Corr.1.
[3] UNEP/OzL.Pro/ExCom/79/48, Add.1 and Corrs. 1 and 2; UNEP/OzL.Pro/ExCom/80/56 and Add.1; UNEP/OzL.Pro/ExCom/81/54

4. In response to questions raised by members, the consultant said that no factory-by-factory analysis had been conducted, but data on the average production of all enterprises producing HCFC-22 and generating HFC-23 as a by-product in Argentina, China, India and Mexico had been examined. The report had found that, in HCFC-22 production lines with an on-site incineration facility, HFC-23 would be transferred through pipes, and any leaks would either not occur or could be fixed mechanically. For HCFC-22 plants that did not have the capacity to continuously destroy HFC-23, as long as such facilities had sufficient capacity to store compressed HFC-23, no HFC-23 would be emitted into the atmosphere. The most cost-efficient solution to extend the life of incinerators and reduce factory costs would be to have sufficient storage capacity and to run incinerators continuously at the level needed at each factory.

5. The Executive Committee established a contact group to further discuss the report. Subsequently, the Committee *inter alia* requested the Secretariat to prepare a document for the 82nd meeting, based on document UNEP/OzL.Pro/ExCom/79/48, on cost-effective options for controlling HFC-23 by product emissions, including information relevant to the cost of closure of HCFC-22 production swing plants, and options for monitoring, in light of the report by the consultant submitted to the 81st meeting and other relevant reports (decision 81/68(a) and (e)).

6. In response to decision 81/68(e), the Secretariat has submitted the present document to the 82nd meeting.

<u>Scope of the document</u>

7. The document has been prepared based on the documents on key aspects of HFC-23 by-product control technologies submitted to the 79th and 81st meetings; information included in verification reports; information gathered during a site visit to one swing plant in an Article-5 country; Article 7 data reporting; and publicly available information. The document contains information on the level of HCFC-22 production and HFC-23 by-product generation, cost-effective options for controlling HFC-23 by-product emissions, information relevant to the cost of closure of HCFC-22 production swing plants, options for monitoring, and concludes with the Secretariat's recommendation.

8. The document includes two annexes:

(a) Annex I: an extract from document UNEP/OzL.Pro/ExCom/81/54, which summarizes the report of the independent consultant evaluating options for the destruction of HFC-23 from HCFC-22 facilities; and

(b) Annex II: an extract from Chapter 7 of the Report of the TEAP, May 2017, Volume 4: Assessment of the funding requirement for the replenishment of the Multilateral Fund for the period 2018-2020 on the methodology for determining funding for HFC-23 mitigation as of 2020.[4]

HCFC-22 level of production and HFC-23 by-product generation

9. According to the data reported under Article 7 of the Protocol, 14 countries (seven Article 5 and seven non-Article 5 countries) produced HCFC-22 in 2017. The global HCFC-22 production in 2017 amounted to 895,459 metric tonnes (mt) as shown in Table 1.

[4] Report of the Technology and Economic Assessment Panel. May 2017. Volume 4: Assessment of the funding requirement for the replenishment of the Multilateral Fund for the period 2018-2020 (Chapter 7).

Table 1. Total* HCFC-22 production for the period of 2009 to 2017 (mt) (Article 7 data)

Country	2009	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	3,914	4,251	4,018	4,190	1,951	2,286	2,446	1,743	1,823
China	483,982	549,265	596,984	644,485	615,901	623,899	534,930	571,976	593,047 **
Democratic People's Republic of Korea (the)	504	498	480	521	579	526	498	451	451
India	47,657	47,613	48,477	48,178	40,651	54,938	53,314	56,959	64,509
Mexico	12,725	12,619	11,813	7,872	7,378	9,214	4,752	4,791	5,965
Venezuela (Bolivarian Republic of)	2,307	2,167	2,443	2,914	2,204	1,566	677	260	273
Republic of Korea	6,913	7,634	7,262	5,704	6,673	6,833	7,180	7,344	7,587
Sub-total for Article 5 countries	**558,002**	**624,047**	**671,475**	**713,864**	**675,336**	**699,262**	**603,796**	**643,523**	**673,656**
Non-article 5 countries	195,796	229,863	241,783	219,909	193,519	210,042	225,155	208,817	221,803
Total	753,798	853,910	913,258	933,773	868,856	909,304	828,952	852,340	895,459

*Total production includes all production for controlled and for feedstock uses, and does not subtract any HCFC-22 that may have been produced but subsequently destroyed.
** As reported in the 2017 verification report, which is different from the total production reported under Article 7.

10. Based on HCFC-22 production reported under Article 7, and information on the HFC-23 by-product generation rate (*w* rate[5]), 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	Lines	*w* (%)[a]	2013	2014	2015	2016	2017
Argentina	1	3.3	65[b]	76[b]	81[b]	58	61
China	32	2.44[c], 2.36[d]	17,129	17,351	13,604	13,949	13,966
Democratic People's Republic of Korea (the)	1	1.49	11	8	7	7	7
India	6	2.94	1,196	1,616	1,568	1,675	1,897
Mexico	2	2.20	176	203	101	105	131
Venezuela (Bolivarian Republic of)	1	3.00	66	47	20	8	8
Republic of Korea	1	3.00	200	205	204	220	228
Sub-total for Article 5 countries	43		18,842	19,506	15,585	16,022	16,298
Non-Article 5 countries		2.00	3,870	4,201	4,503	4,176	4,436
Total			22,713	23,707	20,089	20,199	20,734

[a] The HFC-23 by-product generation rate in 2016 and 2017.
[b] The HFC-23 by-product generation rate for 2013-2015 is 3.32 per cent based on the data provided in UNEP/OzL.Pro/ExCom/82/69.
[c] The HFC-23 by-product generation rate for 2016.
[d] The HFC-23 by-product generation rate for 2017.

11. The amounts of HFC-23 by-product generated for 2013-2015 are described in paragraph 12 of document UNEP/OzL.Pro/ExCom/79/48. The amounts for 2016 and 2017 are explained below:

(a) For Argentina, the *w* rate of 3.32 per cent was based on information provided by the HCFC-22 production facility in that country;[6]

(b) For China, the *w* rates reported in the verification reports submitted in line with the Agreement on the HCFC production phase-out management plan (HPPMP). The amounts of HFC-23 are measured in some plants through meters; where no meters are installed, the

[5] The generation rate *w* is the mass of HFC-23 generated per metric tonne of HCFC-22 produced, expressed as a percentage.
[6] UNEP/OzL.Pro/ExCom/82/69

amounts of HFC-23 are estimated using *w* rate of 3 per cent. The *w* rate has been decreasing in the last few years, with an average of 2.36 per cent in 2017;

(c) For the Democratic People's Republic of Korea, the *w* rate reported by the Government for 2015 was applied to 2016 and 2017;

(d) For India, the *w* rate was based on the average data from the CDM monitoring reports;

(e) For Mexico, the *w* rate reported by the Government for 2015 was applied to 2016 and 2017;

(f) For the Republic of Korea and for Venezuela (Bolivarian Republic of) the *w* rate of 3.00 per cent was used in the absence of data; and

(g) For all non-Article 5 countries, the *w* rate of 2.00 per cent was used in the absence of data.

Cost-effective options for controlling HFC-23 by-product emissions

12. Options for controlling emissions of HFC-23 by-product include on-site destruction, off-site destruction, conversion, and closure of the HCFC-22 production line.[7] The most cost-effective option for controlling HFC-23 by-product emissions will depend on site-specific factors. Closure of HCFC-22 swing plants would both permanently eliminate emissions of HFC-23 by-product and of HCFC-22, thereby providing both ozone and climate benefits.

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

13. Although a general cost model for production closure has not been developed, the CFC and HCFC production closure projects so far approved may provide a useful reference.

14. During CFC phase-out, the Executive Committee approved six multi-year agreement projects to phase out the production of Group I substances in six Article 5 countries. The total production phased out amounted to 82,626 mt. The overall cost-effectiveness (CE) of those closure projects, including the additional funding provided for the accelerated phase-out for some of the plans, ranges from US $2.88/kg to US $3.86/kg, with an average CE of US $3.45/kg as shown in Table 3.

Table 3. CE of CFC production phase-out projects

Country	Baseline (mt)	Funding (US $)	CE (US $/kg)	No of production lines	
				Swing	Non-swing
Argentina	2,745.30	10,600,000	3.86	1	0
China	47,003.90	160,000,000	3.40	0*	18
Democratic People's Republic of Korea (the)	414.99	1,421,400	3.43	0	1
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
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. It was identified that one CFC production line has been retrofitted to CFC/HCFC-22 swing line. Based on the Agreement for HCFC production phase-out management plan, this line will not be compensated under the HPPMP

[7] The Parties have not yet approved any destruction technologies for HFC-23. The Parties are considering information on destruction technologies for controlled substances at the Thirtieth Meeting of the Parties. The Secretariat is unaware of any current feedstock uses of HFC-23. Capture and use for controlled uses is expected to result in the eventual release of emissions of HFC-23, thus delaying rather than avoiding such emissions.

15. Based on the Agreements between the governments concerned and the Executive Committee, swing plants are not eligible under the HCFC production phase-out.

16. The total compensation for the HPPMP for China provided for funding of up to US $385 million, including all project costs, for the phase-out of 445,888 mt of HCFCs. The overall CE is calculated at US $0.86/kg.

17. The most cost-effective option for compensation for HCFC-22 swing plants to comply with the HFC-23 by-product control obligations of the Kigali Amendment will depend on a variety of factors, including whether the swing plant has an on-site destruction facility; the remaining lifetime of the swing plant and of the destruction facility, if one is present; the level of production of HCFC-22 in light of the Montreal Protocol phase-out schedule; the level of compensation provided for closure; the HFC-23 by-product generation rate; if there is an on-site destruction facility that is in dis-use, the incremental costs associated with re-starting that destruction facility; the level of IOCs for the continued operation of the destruction facility or of off-site destruction, and other factors.

18. The Executive Committee decided to consider possible cost-effective options for compensation for HCFC-22 swing plants to allow for compliance with the HFC-23 by-product control obligations of the Kigali Amendment (decision 79/47(c)). Accordingly, the Executive Committee could consider closure among the possible cost-effective options, and therefore, the CE from previous approved production phase-out projects could provide a reference for the level of compensation of HCFC-22 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.

19. The Secretariat compared the cost of HFC-23 by-product emission control through swing plant closure and on-site incineration, using the CE of the previously approved production phase-out projects and the range of IOCs estimated by the independent consultant for a 400 mt/yr and an 800 mt/yr destruction facility (i.e., between US $1.80/kg and US $4.37/kg) in document UNEP/OzL.Pro/ExCom/81/54. For reference, Table 4 provides the break-even point between closure and continued operation of the destruction facility at swing plants in India and Mexico based on:

(a) For India: the 2017 production of HCFC-22;[8] a by-product generation rate of 2.94 per cent; and assuming the same CE for closure as for the CFC production phase-out (i.e., US $3.76/kg), the break-even point ranges between 29 and 71 years. Using the CE of the China HCFC production phase-out of US $0.86/kg, the break-even point ranges between seven and 16 years; and

(b) For Mexico: the 2017 production of HCFC-22; a by-product generation rate of 2.20 per cent; and assuming the same CE for closure as for the CFC production phase-out (i.e., US $2.88/kg), the break-even point ranges between 30 and 73 years. Using the CE of the China HCFC production phase-out of US $0.86/kg, the break-even point ranges between nine and 22 years.

[8] The 2017 production includes HCFC-22 produced at a new, integrated production line used exclusively for feedstock. That production line is not a swing plant; however, the Secretariat is unable to exclude that production as only aggregated data is available.

Table 4. Break-even point between closure and continued operation of destruction facilities*

	CE of closure (US $/kg)	Break-even (years)	
		IOC (US $1.80/kg)	IOC (US $4.37/kg)
India	3.76	71	29
	0.86	16	7
Mexico	2.88	73	30
	0.86	22	9

* Assuming (constant) 2017 production.

20. The Secretariat did not assess break-even points for the facilities in the Democratic People's Republic of Korea and Venezuela (Bolivarian Republic of) as, to the best of the Secretariat's knowledge, those facilities do not have a destruction facility; moreover, the production line in the Democratic People's Republic of Korea is not a swing plant. Similarly, costs for facilities in China are not provided as those plants are not swing-plants and compensation for closure is already being addressed under the HPPMP. Document UNEP/OzL.Pro/ExCom/82/69 provides a detailed assessment of the costs of different HFC-23 by-product control options for the HCFC-22 swing plant in Argentina.

21. The break-even points provided in Table 4 are for reference only as they do not take into account national circumstances or circumstances that may be relevant to specific production facilities. For example, the break-even point is based on constant 2017 production. In both cases considered, the break-even point extends beyond the 2025 compliance obligation. As the 2017 production for both India and Mexico would be above the 2025 compliance obligation, production would either have to be reduced or the HCFC-22 used for feedstock. The Secretariat did not take into consideration the capacity of the destruction facility at each swing plant as that data was not available; however, the IOCs are expected to vary with capacity and extent of utilization of that capacity. Moreover, the Secretariat did not take into consideration the technology used by each destruction facility. For example, the destruction facility in Mexico uses plasma arc technology; IOCs for such technology are expected to be higher than for the fluor technology described in document UNEP/OzL.Pro/ExCom/81/54.

Options for monitoring

22. The guidelines for reporting emissions of greenhouse gases (GHGs) developed by the International Panel on Climate Change (IPCC) under the UNFCCC, and the methodology to monitor HFC-23 from the Clean Development Mechanism (CDM) have been described in document UNEP/OzL.Pro/ExCom/79/48. Therefore, this document will describe the current practices for monitoring HFC-23 emissions under the implementation of the HPPMP for China.

23. Under the Agreement with the Executive Committee for stage I of the HPPMP, the Government of China agreed to make best efforts to manage HCFC production and associated by-product production in HCFC plants in accordance with best practices. In order to monitor the impact of the implementation of the above activities, the Executive Committee requested that the World Bank's verification report should provide estimates of inadvertent emissions of HFC-23 and other by-products (decision 72/44(b)). The verifications conducted for 2013 through 2017 have included the relevant information on HFC-23 emission in the 16 HCFC-22 producers covered by the HPPMP. The three most recent verification report, for 2015, 2016 and 2017, document the progress made by the Government of China in reducing HFC-23 emissions, in line with regulations issued by the Government: the per cent HFC-23 by-product that was incinerated increased from 45 per cent in 2015, to 93 per cent in 2016, and to 98 per cent in 2017.

24. 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 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.

25. The Secretariat notes that all HCFC-22 production facilities seek to minimize fugitive emissions as such emissions would reduce the quantity of HCFC-22 they can sell, and would therefore represent a financial loss to the enterprise. Similarly, while processes used to separate HFC-23 from the HCFC-22 stream before destruction will not result in 100 per cent separation, production facilities will seek to maximize the separation efficiency to minimize losses of HCFC-22. Moreover, independent of technical feasibility, paragraph 6 of Article 2J of the Kigali Amendment specifies destruction of HFC-23 by-product "to the extent practicable," so it is not clear that perfect separation would be required under the Kigali Amendment. Other than atmospheric observations, the Secretariat is unaware of any analytic instrument that could be used to monitor fugitive emissions of HFC-23 from a distance.

26. A recent scientific publication[9] estimated HFC-23 emissions based on atmospheric observations. Emissions of HFC-23 were at a maximum in 2014 and then gradually decreased in 2016. The Secretariat notes that the gradual decrease is less than would be expected given the data in Table 2 of the present document and the reductions in emissions indicated in paragraph 23, though additional observations may clarify this issue as the scientific publication only included emission estimates through 2016.

Recommendation

27. The Executive Committee may wish to note the document on cost-effective options for controlling HFC-23 by-product emissions (decision 81/68(e)), contained in document UNEP/OzL.Pro/ExCom/82/68.

[9] Simmonds et al., "Recent increases in the atmospheric growth rate and emissions of HFC-23 (CHF_3) and the link to HCFC-22 ($CHClF_2$) production," Atmos. Chem. Phys., 18, 4153–4169, 2018. https://doi.org/10.5194/acp-18-4153-2018

Annex I

COST-EFFECTIVE OPTIONS FOR CONTROLLING HFC-23 BY-PRODUCT EMISSIONS

Extract from document UNEP/OzL.Pro/ExCom/81/54 (paras. 7-18)

Cost of incineration at an on-site destruction facility

7. The main conclusions of the consultant's evaluation are as follows:

(a) A conservative estimate of the total fixed capital costs of a new incinerator installed mid-2017 in Eastern Central China ranges between US $9 million for a 400 metric tonnes (mt)/yr incinerator to US $27.1 million for a 2,400 mt/yr incinerator. The lower-bound estimate for this same range is between US $6.3 million and US $18.5 million. Those costs are inclusive of all expected costs associated with the purchase and installation of a new incinerator, from permits, insurance and security, to procuring, shipping and installing the equipment, to all the costs associated with the start up and operation of the incinerator for at least 72 hours;

(b) Operating costs vary based on the capacity and extent of utilization of that capacity, varying between US $4.37/kg to US $1.45/kg as shown in Table 1.

Table 1: Upper- and lower-bound estimated operating costs as function of capacity and extent of utilization for on-site incinerators

	On-site incinerator capacity (mt/yr)							
	400		800		1,600		2,400	
Per cent utilization	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)
100	2.22	2.63	1.80	2.13	1.55	1.81	1.45	1.68
75	2.66	3.21	2.10	2.55	1.77	2.12	1.63	1.94
50	3.54	4.37	2.71	3.37	2.21	2.74	2.01	2.47

(c) Operating costs for existing incinerators are likely to be lower than those estimated for the case of a new incinerator. Such costs would likely be closer to the lower-bound estimates provided in the report, noting that specific costs can only be assessed based on site-specific characteristics; and

(d) The costs to start-up a facility that is currently in disuse are estimated to be US $575,000 and comprise new acid-resistant refractory, new equipment purchases and installation, new instrument probes, and an upgraded distributed control system. Those costs could vary based on the capacity of the incinerator and site-specific conditions.

Cost of incineration at an off-site destruction facility

8. The main conclusions of the consultant's evaluation are as follows:

(a) Costs to construct and operate a new, stand-alone incinerator are higher than for an on-site incinerator given the need for additional equipment (e.g., receiving facilities for HFC-23 to be destroyed) and the loss of synergy-related benefits, including those related to labor, supplies, overhead, and other costs;

(b) A conservative estimate of the total fixed capital costs of a new, stand-alone incinerator installed mid-2017 in Eastern Central China ranges between US $12.1 million for a 400 mt/yr incinerator to US $34.5 million for a 2,400 mt/yr incinerator. The lower-bound estimate for this same range is between US $8.8 million and US $24.5 million; and

(c) As in the case of an on-site destruction facility, operating costs vary based on the capacity and extent of utilization of that capacity, varying between US $5.59/kg to US $1.56/kg as shown in Table 2. Operating costs in Table 2 are inclusive of collection, transportation to the off-site facility, and incineration; i.e., those costs are the total costs to the HCFC-22 producer.

Table 2: Upper- and lower-bound estimated operating costs as function of capacity and extent of utilization for off-site incinerators

	Off-site incinerator capacity (mt/yr)							
	400		800		1,600		2,400	
Per cent utilization	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)	Lower-bound (US $/kg)	Upper-bound (US $/kg)
100	2.81	3.24	2.11	2.45	1.71	1.98	1.56	1.80
75	3.45	4.02	2.52	2.97	1.99	2.35	1.79	2.10
50	4.73	5.59	3.33	4.01	2.54	3.08	2.23	2.71

Cost of destroying HFC-23 by-product through irreversible transformation and other new technologies

9. Four technologies were assessed: pyrolysis of HFC-23 into carbonyl fluoride (COF_2); iodization of HFC-23 into trifluoroiodomethane (CF_3I);[1] conversion to HCFC-22, vinylidene difluoride (VDF), or TFE and hexafluoropropylene (HFP);[2] and chemical reaction with hydrogen and carbon dioxide.[3] Costs for the former three technologies could not be assessed as those technologies are still in the research stage. For the latter, the technology provider did not provide the needed information and limited information is publicly available to estimate costs. In particular, the consultant was not able to independently assess the operating costs suggested by the technology provider, nor was the consultant able to estimate the capital costs of the necessary equipment; both of those costs would determine the payback period of the technology relative to an incinerator. However, the consultant was able to assess the possible revenues from the technology based on publicly available information on the price of chemicals that would be produced through the conversion process. The consultant estimates that the potential annual revenue from the conversion of 900 mt of HFC-23 would be approximately US $565,000.

[1] http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/Effective%20Technologies%20for%20Conversion%20of%20HFC-23%20-%20Quan%20Hengdao.pdf

[2] http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/Treatment%20of%20HFC-23%20by%20conversion%20-%20Han%20Wenfeng.pdf

[3] http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/The%20Creation%20and%20Recovery%20of%20Valuable%20Organic%20Halides%20From%20the%20HFC-23%20-%20Lew%20Steinberg.pdf

Costs and measures to optimize the HCFC-22 production process to minimize the HFC-23 by-product and maximize the collection of HFC-23 by-product

10. While specific measures to minimize the generation of HFC-23 by-product and maximize its collection will depend on site-specific requirements, three process changes were identified that could be applicable to HCFC-22 production facilities:

(a) Improvements to the HCFC-22 product distillation column, including replacing the column tray internals with structured packing, operating the column at a lower pressure and condenser temperature, and increasing the reflux ratio, reducing the amount of HCFC-22 carry over in the HFC-23 stream from 8 per cent to 3 per cent;

(b) Convert the HCFC-22 reactor to plug flow to increase mixing of the hydrogen fluoride (HF) with chloroform, and thereby enhance selectivity, resulting in a reduced HFC-23 by-product generation rate of approximately 1.75 per cent; and

(c) Convert from a one-stage to a three-stage HCFC-22 reactor, resulting in a reduced HFC-23 by-product ratio of approximately 1.4 per cent. Reducing the HFC-23 by-product below 1.4 per cent would require research and development, particularly for new catalysts.

11. Costs of the above measures will vary based on the specific HCFC-22 production facility. As production facilities need to regularly replace equipment that reaches the end of its useful life, a facility would want to compare the additional costs of the measures with the benefits of their implementation when selecting the replacement equipment. Distillation columns are expected to be replaced approximately every ten years, and it is expected that columns with structured packing would be selected given the increased revenue from improved separation and the reduced maintenance costs. Reactor lifetimes range from 10 to 15 years. In selecting a new reactor, a production facility would compare the difference in cost between a three-stage and a one-stage reactor with the benefits associated with improved selectivity toward HCFC-22. For example, a 0.5 per cent increase in selectivity toward HCFC-22 at a facility producing 27,000 mt/yr of HCFC-22 can be expected to generate additional revenue of approximately US $300,000 per year when the price of HCFC-22 is US $2.20/kg.

12. The Secretariat was not able to undertake a detailed review of the summary of the investigation on reducing HFC-23 by-product ratio using best practices submitted by the World Bank on 10 March 2018 by the time of finalization of the present document. However, the following observations are relevant:

(a) The total capacity of China's 22 HFC-23 destruction facilities (comprising 16 incinerators, three plasma arc incinerators, and three superheated steam facilities) is 22,000 mt/yr. On average, the capacity of a destruction facility is 1,000 mt/yr. The Secretariat notes that some of the destruction facilities are on stand-by; of the 20,960 mt/yr capacity installed in 2016, 17,810 mt/y was in operation and 2,750 mt/yr was on stand-by. There is sufficient HFC-23 destruction capacity in China to destroy all HFC-23 by-product given HCFC-22 production levels and capacity in the country;

(b) The theoretical findings provided in the summary are consistent with those provided in the report of the consultant. In particular, key factors in determining the HFC-23 by-product generation rate include construction details of the reactor, the distillation column, the process conditions, and the mixing status in the reactor; lowering the liquid level in the reactor can substantially reduce the HFC-23 by-product generation rate without additional equipment investment and energy consumption. While those findings are consistent with those of the consultant, the consultant's proposal to convert to a three-stage reactor is likely to be a more effective means of achieving the same result as increasing the height to radius ratio of the reactor as proposed in the summary report by the World Bank. In particular, a three-stage reactor is expected to further decrease the liquid level in the reactor and further increase the degree of mixing and uniformity of HF in the reactor, thereby further reducing the HFC-23 by-product generation rate; and

(c) All the measures identified in the summary have a cost below US $1 million. For the facility noted above (i.e., facility producing 27,000 mt/yr of HCFC-22 with a 0.5 per cent increase in selectivity toward HCFC-22), this suggests a payback period of less than four years.

Costs of different monitoring and verification methods

13. The consultant recommended that the clean development mechanism (CDM) "Approved baseline and monitoring methodology AM0001/Version 06.0.0" be used to monitor the destruction of HFC-23 by-product. The costs of the monitoring have been included in the estimated costs noted above.

14. An independent verification should be performed by an independent third party with no conflicts of interest; the verifier would need access to plant operating data and financial books of HCFC-22/HFC-23 producers and destroyers. The cost of that verification would be additional to the estimated costs noted above.

Costs of different destruction technologies

15. The consultant assessed five destruction technologies: plasma radio frequency arc torch, fired-heater thermal oxidation furnaces, horizontal rotary-fired oxidation kiln, cement kiln oxidation, and high-temperature steam thermal decomposition:

(a) Plasma arc technology has excellent destruction efficiency but has the highest cost of the technologies assessed and would be best suited for small-scale destruction facilities. Operating costs are expected to be approximately US $3/kg. A facility that destroys approximately 100 mt/yr would be expected to need to invest approximately US $2.5 million in capital costs to enable the destruction of HFC-23;

(b) Fired-heater thermal oxidation furnace has excellent destruction efficiency and is expected to be the second highest cost technology, with operating costs of approximately US $2.40/kg. A facility that destroys approximately 100 mt/yr would be expected to need to invest approximately US $1.7 million in capital costs to enable the destruction of HFC-23;

(c) Horizontal rotary-fired oxidation kilns and cement kilns are well-commercialized and are expected to be among the most cost-effective destruction technologies; however, the destruction efficiency is expected be lower (approximately 99 per cent). Operating costs are expected to be approximately US $1/kg. A facility that destroys approximately 100 mt/yr would be expected to need to invest approximately US $0.5 million in capital costs to enable the destruction of HFC-23. Those costs would principally be associated with purchasing and installing the necessary equipment to receive containers with HFC-23 to be destroyed, transferring the HFC-23 to a storage tank, and feeding the HFC-23 into the kiln; and

(d) High-temperature steam thermal decomposition has excellent destruction efficiency. While there are three such facilities in operation in China, there is limited information on the costs, so those could not be assessed; however, it is expected that the costs could be lower than for a fired-heater thermal oxidation furnace.

16. HCFC-22 production facilities that have low levels of production, and therefore low quantities of HFC-23 by-product to be destroyed, that do not intend to continue production for feedstock uses, and that either do not have an on-site destruction facility or the facility is in disuse, could face substantially higher costs of HFC-23 destruction relative to production facilities with high volumes of HFC-23 by-product to be destroyed at an on-site facility.

17. The Secretariat notes that the Parties have not yet approved any technologies for destruction of HFC-23. If the Parties were to approve the use of destruction technologies with a destruction and removal efficiency below 99.99 per cent, (perhaps for a limited period of time), this could allow those facilities to use the more cost-effective destruction technologies identified, such as cement kiln oxidation and horizontal rotary-fired oxidation kiln, prior to phasing out their HCFC-22 production.

Comparison of costs with previous estimates

18. Based on the analysis of CDM data undertaken by the Secretariat at the 79th meeting,[4] the incremental cost of the reported consumables and waste of the destruction facility were always found to be below US $1/kg. However, that cost did not include maintenance, labour, costs associated with monitoring, or other expenses that may affect the IOC of destruction. Therefore, the Secretariat considered the incremental cost of the reported consumables and waste to represent a lower bound on the IOC. The costs estimated by the consultant, which are higher, are inclusive of all costs associated with the destruction of HFC-23, ranging from procuring and installing the equipment, to fees associated with construction, such as permits and insurance, to all operating costs, including consumables, wastewater treatment, monitoring, and process and cooling water. In line with Executive Committee practice and decisions, taxes and depreciation were excluded. The conservative estimate presented by the consultant includes 25 per cent in contingencies, and installation costs account for approximately 35 per cent of the fixed costs, including running the incinerator for at least 72 hours to demonstrate performance. Those costs are higher than typically found in projects submitted to the Multilateral Fund as they represent a conservative (upper-bound) estimate.

[4] UNEP/OzL.Pro/ExCom/79/48; 79/48/Add.1; 79/48/Corr.1; and 79/48/Corr.2.

7 Methodology for determining funding for HFC-23 mitigation as of 2020

7.1 Introduction

In the Kigali Amendment, HFC-23 has been added to the list of controlled (HFC) substances in Annex F, Group II. This Group II has been formed because HFC-23 is thought to fulfil a minor role in HFC consumption for emissive uses, however, it is largely produced in HCFC-22 production processes, where it is produced as a by-product that has often been vented to the atmosphere. It should not be misunderstood however that a certain small production of HFC-23 is used to form blends (such as R-508) which are used (and are essential because of no competitive or alternative refrigerants or blends) in very low temperature freezing equipment, furthermore, it is used in fire protection; both are emissive uses. There might also be some feedstock use for HFC-23.

The larger portion of the HFC-23 vented to the environment comes from the HCFC-22 production processes where HCFC-22 is produced for both emissive uses and for feedstock production. In non-Article 5 production processes the emission of HFC-23 is avoided via mitigation, i.e. the incineration of the by-product gas and the re-use or neutralization of the HF so obtained. The percentage of the HFC-23 formed in the total amount of gas produced (HCFC-022 and HFC-23) is maximum 4%, where this percentage can be reduced by optimising the process and by suitable use of regularly replaced catalysts; percentages in the order of 1.2-1.4% have been given in case of this optimization. Some of this optimisation has been applied in non-Article 5 HCFC-22 production plants, followed by collection and incineration of HFC-23.

Table 7-1 gives an overview of the Article 7 UNEP reported data related to HCFC-22 production during the period 2008-2015 for non-Article 5 and Article 5 feedstock and emissive uses.

HCFC-22 feedstock production in non-Article 5 parties did not decrease during 2008-2015, there has been an increasing trend in Article 5 parties (however, with one exception, which is for the year 2015). Production for emissive uses is decreasing since before the year 2008 in non-Article 5 parties and since the year 2012 in Article 5 parties (with a maximum of almost 412,000 tonnes in 2012).

Table 7-1 Production of HCFC-22 for feedstock and emissive uses in Non-Article 5 and Article 5 parties, period 2008-2015 (UNEP Article 7 reporting) (in this case all Article 5 parties are considered, including the Republic of Korea)

Production of HCFC-22 for feedstock and emissive uses 2008-2015 (metric tonnes)								
Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Non-Article 5 emissive	117621	74226	61372	47214	36609	28733	29700	19806
Article 5 emissive	330078	371418	379105	379925	411634	330071	341666	287774
Total emissive	447699	445644	440477	427139	448243	358804	371367	307580
Non-Article 5 feedstock	173957	120824	164588	186190	177301	159496	177178	199576
Article 5 feedstock	170916	173098	221761	263482	261815	323996	330910	293156
Total feedstock	344872	293923	386349	449671	459116	483491	508088	492733

As mentioned, HFC-23 is a by-product in all HCFC-22 production given in Table 7-1. Article 5 production for emissive and feedstock use was about 580 ktonnes in 2015.

Figure 7-1 and 7-2 show feedstock, emissive use and total HCFC-22 production for all parties as well as for Article 5 parties only.

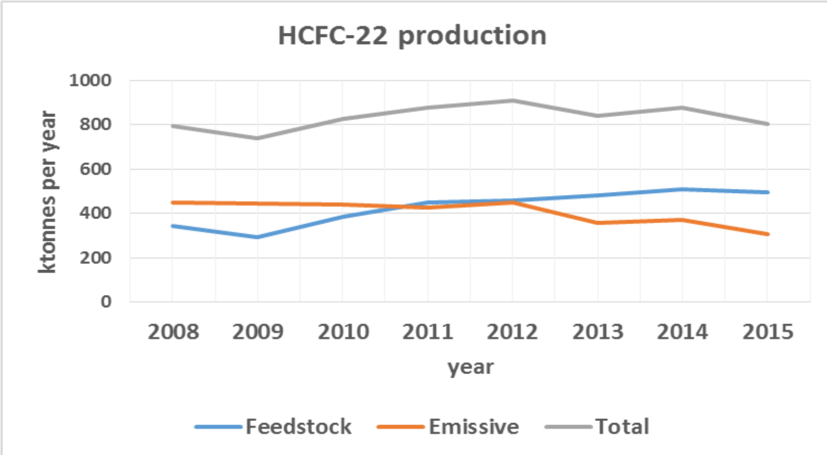

Fig. 7-1 HCFC-22 production for feedstock, emissive uses and total, for 2008-2015, as reported under Article 7 by all non-Article 5 and Article 5 parties

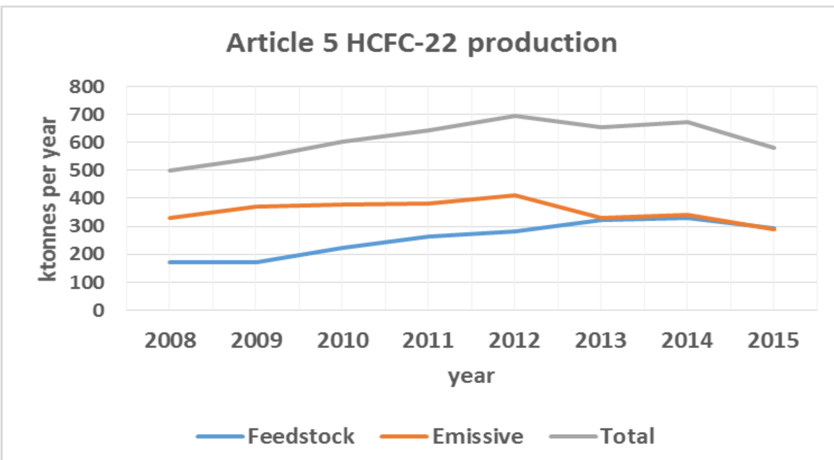

Fig. 7-2 HCFC-22 production for feedstock, emissive uses and total, for 2008-2015, as reported under Article 7 by all Article 5 parties

From Figures 7-1 and 7-2 it can be concluded that emissive use production is clearly decreasing, there is an upward trend for feedstock, however not that much during 2013-2015. The growth in feedstock production is difficult to forecast, it might be smaller than thought in the past, very much related to forecasts for PTFE use. For total HCFC-22 production in Article 5 parties, there may be a certain growth in feedstock production during the next 5 years, but the maximum of the year 2012 is not likely to be achieved. HCFC-22 is also used to make HFC-125 in e.g., China, although alternative production technologies may reduce its competitiveness.

With regard to the HFC-23 substance, the Kigali Amendment stipulates that:

- 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;

- 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;
- 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.

In decision XXVIII/2, parties request the Executive Committee to develop guidelines for financing the phase-down of HFC consumption and production. With regard to the production sector, the parties through decision XXVIII/2 requested the Executive Committee to make eligible 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. Such costs should be funded by the Multilateral Fund to meet the obligations of Article 5 parties. A further analysis of the expected mitigation and associated cost scenarios is given in sections 7.2 and 7.3.

The guidelines concerning the production of HFCs and all issues related to this production have first been discussed in April 2017 at ExCom-78. Final guidance where it concerns the funding of capital and operating costs for mitigation of HFC-23 is not yet clear, however, a range for the funding that would be required in the next triennium can be determined. In particular, it is noted that the control obligations related to HFC-23 are the earliest control obligations under the Kigali Amendment.

Paragraph 41 in ExCom document 77/70 for the ExCom-77 meeting in December 2016 mentions a number of issues related to HFC-23 mitigation. A document covering the key aspects related to HFC-23 was subsequently developed by the Secretariat and was published in March 2017 as UNEP/OzL.Pro/ExCom/78/9 (“Key aspects related to HFC-23 by-product control technologies”).

7.2 HFC-23 by-product production

A number of details on HFC-23 production and mitigation and how it has been dealt with in past years can be found in the Appendix to this chapter.

Table 7-2 Level of HFC-23 estimated in 2015 and destruction facilities in Article 5 countries (from ExCom 78/9)

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
DPR 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
BR Venezuela	**677**	20	3.00	1	0	0	0	1
Total	**596,591**	**15,499**		**42**	**21**	**16**	**1**	**4**

The ExCom 78/9 document gives HCFC-22 production data reported under Article 7 for 2015 for six Article 5 countries, namely Argentina, China, Democratic People's Republic of Korea, India, Mexico, and Bolivarian Republic of Venezuela, and concludes that they manufactured almost 600 ktonnes of HCFC-22 for controlled emissive and feedstock uses. That document estimates the total amount of HFC-23 generated at 15,499 tonnes (see table below, reproduced from the ExCom document).

Of the six Article 5 countries that reported HCFC-22 production under Article 7 (see above), only China has an approved HPPMP. The issue of the eligibility funding the closure of swing plants continues to be under discussion at ExCom level. Given the present guidelines (except for the DPR Korea), the Article 5 producing countries are not eligible to receive funding from the Multilateral Fund for closure of HCFC-22 (swing) plants. The following can be mentioned for the various countries:

7.2.1 Argentina

Data given mention that the HFC-23 generated in Argentina is about 3% of the HCFC-22 amount produced. It is being vented, where it was reported previously as vented under the CDM.

7.2.2 China

Table 7-3 Amounts of HCFC-22 produced in 2015 in various HCFC-22 production plants, as well as the HFC-23 amounts stored and/or incinerated in 2015. The information is available from the Chinese NRDC at NDRC at: http://qhs.ndrc.gov.cn/gzdt/201605/t20160527_805072.html

Producer	HCFC-22 prod. (ktonnes)	HFC-23 prod. (tonnes)	Incinerated HFC-23 (tonnes)	Comment
Shandong Dongyue Chemical Co	173.3	3614	1059	182 tonnes stored, two new incinerators completed late 2015
Zhengjiang Quhua Co	49.2	1441	1055	376 tonnes stored, new incinerator completed in December 2015
Jiangsu Meilan	63.9	1827	1418	
3F Changsu	40.9	1180	1180	
ZhongHao ChenGuang	17.2	474	466	
Linhai Limin Chemical (Zhejiang)	17.5	353	615	HFC-23 stored in the past included
Shandong ZhongFu	N/A	N/A	N/A	Data not available
Arkema Changshu (Jiangsu)	30.7	576	576	
Zhejiang Sanmei Chemical	14.4	368	0	350 tonnes sold, 18 tonnes stored, incinerator compl. April 2016
Jinhua Yonghe (Zhejiang)	12.0	240	0	165 tonnes sold, incinerator completed in March 2016
Zhejiang Lanxi Juhua	20.6	618	0	144 tonnes sold, 44 tonnes stored, incinerator compl. March 2016
Jiangxi YingGuang Chemical	0.0	0.0	0	Incinerator under construction
Jiangxi Sanmei Chemical	14.0	350	0	194 tonnes sold, 41 tonnes stored, without incinerator constr. plan
Sichuan Zigong Honghe Chemical	N/A	N/A	N/A	Data not available
Zhejiang Pengyou Chemical	10.0	270	0	Incinerator completed in April 2016
Totals	**463.7**	**11311**	**6369**	

China has a large number of HCFC-22 producing plants, of which a number of plants in operation for at least three years before 2004 were qualified for and equipped under the CDM with incineration units that incinerated part -- or the whole of the HFC-23 generated. In 2008, any new HCFC-22 lines built for use as a refrigerant were required by the Chinese government to have the capability to address HFC-23 and any new HCFC-22 production units for feedstock are required to destroy HFC-23 without subsidies related to capital investment or operating costs.

Table 7-3 gives 15 Chinese HCFC-22 production plants, of which 9 plants have an annual output between 0 and 40 ktonnes, 3 between 40 and 80 ktonnes; one has an annual output in the range of 150-200 ktonnes of HCFC-22. For two plants data are not available. Specific production data are given in the table, with a known total of 463.7 ktonnes. This is less than in the ExCom 78/9 table, because certain plant production lines are not reported (the amount in the ExCom 78/9 may also be overestimated; it may well be 22 ktonnes lower for 2015).

Article 7 reporting of HCFC-22 for emissive use and feedstock production by China amounts to about 514 ktonnes in 2015 (there is a difference of about 50 ktonnes with the amount mentioned in Table 7-2; 50 ktonnes may well have been produced in the two plants for which no data are available in Table 7-2). Based on the data in table 7-3, HFC-23 waste generation rates ranged from 2.9 to 1.9 per cent, with an average of 2.4 per cent; this is comparable to the data reported in ExCom 78/9, which indicated 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.

With the support of the Government, the construction of 13 HFC-23 destruction facilities at 15 HCFC-22 production lines not covered by the CDM was started in 2014. The Government also has committed to subsidise the operating costs during the period 2014-2019 to encourage the operation of destruction facilities. The CDM lines have been in operation since their start up. Once all new destruction facilities are completed, 30 out of 32 production lines will be equipped with a destruction (incineration) facility. It is estimated that 45 per cent of the HFC-23 generated was destroyed in 2015; 10 per cent was collected, sold or stored for use; and 45 per cent was emitted. For 2016, a percentage between 60 and 70 is estimated for destruction; the collection cannot be estimated.

7.2.3 Mexico

In Mexico, HFC-23 by-product from HCFC-22 production is partially emitted (and/or separated for a specific use), or destroyed. One destruction facility attached to one Quimibasicos plant (CDM project from 2006) was operated in 2015. The other plant (where it is not clear where it is located and whether the same destruction facility could be used for the HFC-23 amount generated here) is venting HFC-23 to the atmosphere. A HFC-23 waste generation of 2.44% has been reported.

7.2.4 India

In India, 5 HCFC-22 production facilities have implemented a CDM project, of which two are still in operation (until April 2017 and October 2018). Once the CDM projects will expire for the production facilities, a newly issued order by the Indian Government specifies that the destruction facilities continue to be operated. It is not clear whether that would mean that operating costs would be eligible under the Multilateral Fund. For the funding requirement calculated in this report it has been assumed that they would.

There may also be a sixth facility in India (not taken into consideration) producing HCFC-22 for feedstock.

7.2.5 Other Article 5 parties

The HCFC-22 production facilities in the DPR Korea and the Bolivarian Republic of Venezuela (one each) have never had a CDM project and did never build destruction facilities. It can therefore be assumed that HFC-23 is vented at those two facilities at a 3% level of the HCFC-22 production. There is also production in the Republic of Korea but this has not been further considered here.

7.3 HFC-23 by incineration; investment and operating costs

It will be difficult to give accurate numbers for future years, i.e., after the year 2020 (the first year in the Kigali Amendment), for capital and operating costs for HFC-23 mitigation.

This because:

- It is unclear what the HCFC-22 total production will be in the year 2020 and the years beyond, which very much depend on the increase (decrease) in production for feedstock, if any;
- It may be useful for certain existing plants to consider collection of HFC-23 rather than continuous destruction in an integrated system and transport to an incineration facility on- or off-site, however, costs for this operation are unknown as capital investment to improve the ability to collect HFC-23 may be needed to reduce emissions rates;
- It is unclear whether and when certain Article 5 production plants would consider closure, if they would become eligible for closure funds under the Protocol;
- Costs for investments for and operating costs of an incineration (thermal decomposition) plant vary widely;
- Neutralization and disposal costs or income generated by the acid waste stream will vary depending on local markets and the ultimate fate of the acid;
- Reduced HFC-23 generation through optimisation could further reduce operating costs for incineration and neutralisation.

An estimate of capital and operational costs is therefore given on the basis of the HFC destruction plants installed and the HFC-23 generated in 2015. This implies that it would concern 3 destruction facilities, and furthermore transport costs of HFC-23 to a destruction facility for two small production plants, as well as about 15.5 ktonnes HFC-23 generated per year (based on 575 ktonnes of HCFC-22).

Process optimisation is normally done to minimize the HFC-23 emissions; this is related to temperature, pressure, feed rates, catalyst concentration and catalyst renewal, where the latter is a very important factor in the production of HFC-23 as a percentage of HCFC-22. Non-Article 5 country producers are assumed to all have implemented either process optimization and/or thermal destruction to mitigate HFC-23 emissions. Process optimization will reduce generation rates to below 1.6 per cent of HCFC-22 production, but may require modifications to existing equipment and capital expenditure, as well as additional operating costs.

A report on an optimization project in China implemented under the stage I HPPMP is expected at the 79th Executive Committee meeting. Specifically, 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.

The USEPA (global mitigation report of 2013) estimated the costs for installing and operating a thermal oxidizer with a technical lifetime of 20 years: 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, operating and maintenance costs are approximately 2.0 to 3.0 per cent of total capital costs. Based on these assumptions, operating costs would be approximately US$ 0.22/kg (following ExCom document 78/9). Values in this range, even somewhat higher, have been mentioned in discussions with manufacturers in non-Article 5 parties. Higher estimates have been given by others sources consulted, varying between incremental capital costs of US$ 2-10 million for plants with a HCFC-22 production capacity of 10-50 ktonnes of HCFC-22 (China CDM report, IPCC-TEAP, 2005, manufacturers data) and as high as US$ 6/kg (see ExCom document 78/9).

Based on the ranges given, this study estimates the cost of a new incinerator for existing facilities at US$ 250,000-500,000 per year (based on a 20 years lifetime).

For the operating costs, a "best estimate" range of US$ 0.5-1.5 per kg has been derived[13]. In this amount the costs for possible optimization of the process before HFC-23 mitigation would be included.

The above would imply (see above) a funding of US$ 0.75-1.5 million for one year for three new facilities. For the operational costs (for 15.5 ktonnes of HFC-23 as mentioned in Table 8-2) a range of US$ 7.75-23.3 million would apply. This amount takes into account all operating costs for all Article 5 parties with HCFC-22 production, including those where subsidy programs are currently applied (PR China) or where an order (or regulation) to mitigate HFC-23 emission has entered into force (India).

To this amount the possible costs for the mitigation of 35 tonnes of HFC-23 from the facilities in DPR Korea and Venezuela would have to be added, but this is assumed to be small compared to the numbers mentioned for the range above. Costs for transport and incineration elsewhere could be assumed at US$ 2.5 per kg, which would bring the total to US$ 87,000 per year.

However, it may not be correct to consider the same HCFC-22 production amounts for emissive uses and for feedstock. One could assume that the emissive use production would decrease by 25% between 2015 and 2020 (the Montreal Protocol mandated reduction) and that feedstock production would increase by 10% based on the 2015 production. Since both amounts are comparable in the case of Article 5 countries it would mean that the operational costs would be lower in 2020, where the range of US$ 6.4-19.1 million can be determined (from the range of US$ 7.75-23.3 million above). Together with the annual investment costs as well as transport and incineration costs this would yield a total of US$ 7.2-20.7 million for HFC-23 mitigation.

In order to prepare for operation of a few facilities (not in operation) to incinerate HFC-23, enabling activities at a value of US$ 0.8 million are estimated.

Table 7-4 Funding for HFC-23 mitigation activities for the triennium 2018-2020 (US$ million)

HFC-23 mitigation	**2018-2020**
Enabling activities before 2020	0.8
Capital and operating costs (year 2020 only)	7.2-20.7
Total	**8.0-21.5**

13 Based upon estimates from various studies, data from the ExCom 78/9 document, and information on investments and operational costs from several HCFC-22 manufacturers

Appendix to Chapter 7

From the publication by Montzka (2010), one can take the following:

"HFC-23 (CHF_3) is a potent greenhouse gas with a global warming potential (GWP) of 14,800 for a 100-year time horizon, that is an unavoidable by-product of HCFC-22 ($CHClF_2$) production. HFC-23 is a relatively long-lived trace gas with a tropospheric lifetime of about 260–270 years…… The production of HCFC-22 for use as feedstock, however, is unrestricted. These two latter aspects of HCFC-22 production regulation have implications for the future production of the by-product HFC-23.

In contrast to the widespread industrial uses of HCFC-22, HFC-23 has limited industrial uses. These include use as feedstock in Halon-1301 ($CBrF_3$) production (nondispersive), in semiconductor fabrication (mostly non-dispersive), in very low temperature (VLT) refrigeration (dispersive) and in specialty fire suppressant systems (dispersive). Thus the bulk of the co-produced HFC-23 was historically considered a waste gas that has been and often continues to be vented to the atmosphere. Since the 1990s, some HCFC-22 producers in the developed countries have voluntarily reduced HFC-23 emissions by process optimization and/or incineration. Based on historical trends, McCulloch in 2004 concluded that "approximately half of the HFC-23 co-produced with HCFC-22 in the developed world is abated". Under the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC) 19 HCFC-22 production plants in five developing countries were approved for participation as CDM projects. These countries have reportedly incinerated the HFC-23 co-produced during 2007–2008 from 43-48% of the developing world's HCFC-22 production (Montzka, 2010). Typical HFC-23/HCFC-22 co-production ratios, often referred to as the waste gas generation ratio "w", range from 0.014 in optimized processes to upwards of about 0.04. This co-production relationship of HFC-23 and HCFC-22 provides a unique constraint in evaluating their emission and production trends as HFC-23 may act as a tracer of HCFC-22 production while the fate of HCFC-22 involves a more convoluted path of various end-uses and different release rates. To the extent that HCFC-22 production, waste gas generation ratio and HFC-23 incineration are known, a bottom-up emission history for HFC-23 can be derived. This is not subject of this section, however, has been important in deriving emissions from atmospheric abundance measurements.

To investigate the response of HFC-23 emissions to HCFC-22 production and recent HFC-23 emission abatement measures, a bottom-up HFC-23 emission history was constructed for comparison with our top-down HFC-23 emission history. The bottom-up history relies on HCFC-22 data provided by UNEP up to 2008, on HFC-23 data provided by UNFCCC for developed countries emissions to 2008, on CDM HFC-23 incineration monitoring reports for 2003-2009 and on annual HFC-23/HCFC-22 co-production ratios for developing countries deduced from these CDM reports. The top down versus bottom-up HFC-23 emission history comparison shows agreement within stated uncertainties for all years, with particularly close agreement during 1995-2005. The bottom-up history shows small, statistically insignificant departures to lower values in 2006 and 2008. Overall, this level of agreement supports a reasonable confidence in the HFC-23 emission data reported to the UNFCCC for developed countries and for HFC-23 incineration data reported by CDM projects, and for data reported to UNEP under Article 7 of the Montreal Protocol. In the 1990s, HFC-23 emissions from developed countries dominated all other factors controlling emissions, and thereafter they began to decline to an eventual six-year plateau. From the beginning of that plateau, the major factor controlling the annual dynamics of global HFC-23 emissions became the historical rise of HCFC-22 production for dispersive uses in developing countries to a peak in 2007. But incineration via CDM projects became a larger component during 2007-2009, reducing global HFC-23 emissions despite both a high HCFC-22 dispersive production and a rapidly rising feedstock production, both in the developing world. In the near future, the controlling factor determining whether there is resurgence or continued decline in HFC-23 emissions may be the extent to which incineration can keep pace to counteract potential growth in feedstock production."

This was the result of investigations reported up to 2010[14]. At that stage the future of any CDM project related to HFC-23 incineration was uncertain based upon the discussions that had started in 2006 within the UNFCCC framework. A further publication by Miller and Kuijpers (2011) investigated future global scenarios for HFC-23 abundances in the atmosphere, dependent on assumed CDM supported mitigation, feedstock production growth and emissive use production phase-down in Article 5 parties (Miller and Kuijpers, 2011). Fang (2014) published a study, which specifically develops HFC-23 emission scenarios through 2050 for China.

However, in the period 2010-2016 various developments have taken place where it concerns HFC-23 mitigation activities in various Article 5 parties. In the early versions of the approved baseline and monitoring methodology "Decomposition of fluoroform (HFC-23) waste streams" under the CDM, the waste generation rate was capped at 3.0 per cent. The most recent version of the methodology uses a waste generation rate of 1 per cent. Information provided in ExCom document 78/9 mentions that "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".

[14] In 2009 the MLF Secretariat had described the situation with regards to CERs, carbon credits via Certified Emission Reductions in UNEP/OzL.Pro/ExCom/57/62 (February 2009), Summary of Information publicly available on relevant elements of the operation of the Clean Development Mechanism and the amounts of HCFC-22 production available for credits