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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**

# 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]](#footnote-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]](#footnote-2) Since then, issues related to the HFC-23 by-product emissions have been considered at each meeting of the Executive Committee.[[3]](#footnote-3)

Discussion at the 81st meeting

# 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.

# 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.

# 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.

# 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)).

# In response to decision 81/68(e), the Secretariat has submitted the present document to the 82ndmeeting.

Scope of the document

# 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.

# The document includes two annexes:

## 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

## 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]](#footnote-4)**

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

# 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.

**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.

# Based on HCFC-22 production reported under Article 7, and information on the HFC-23 by‑product generation rate (*w* rate[[5]](#footnote-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 |  65b  |  76b  |  81b  |  58  |  61  |
| China | 32 | 2.44c, 2.36d |  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.

# 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:

## 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]](#footnote-6)

## 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 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;

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

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

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

## 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

## 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**

# 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]](#footnote-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**

# 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.

# 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

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

# 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.

# 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.

# 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.

# 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:

## For India: the 2017 production of HCFC-22;[[8]](#footnote-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

## 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.

**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.

# 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.

# 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**

# 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.

# 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.

# 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.

# 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.

# A recent scientific publication[[9]](#footnote-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**

# 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.

**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*

# The main conclusions of the consultant’s evaluation are as follows:

## 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;

## 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 |

## 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

## 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*

# The main conclusions of the consultant’s evaluation are as follows:

## 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;

## 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

## 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*

# Four technologies were assessed: pyrolysis of HFC-23 into carbonyl fluoride (COF2); iodization of HFC-23 into trifluoroiodomethane (CF3I);[[10]](#footnote-10) conversion to HCFC-22, vinylidene difluoride (VDF), or TFE and hexafluoropropylene (HFP);[[11]](#footnote-11) and chemical reaction with hydrogen and carbon dioxide.[[12]](#footnote-12) 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.

## *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*

# 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:

## 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;

## 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

## 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.

# 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.

# 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:

## 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;

## 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

## 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*

# 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.

# 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*

# 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:

## 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;

## 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;

## 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

## 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.

# 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.

# 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*

# Based on the analysis of CDM data undertaken by the Secretariat at the 79th meeting,[[13]](#footnote-13) 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.

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1. Montreal, Canada, 28 November – 2 December 2016. [↑](#footnote-ref-1)
2. UNEP/OzL.Pro/ExCom/78/9 and Corr.1. [↑](#footnote-ref-2)
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 [↑](#footnote-ref-3)
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). [↑](#footnote-ref-4)
5. The generation rate *w* is the mass of HFC-23 generated per metric tonne of HCFC-22 produced, expressed as a percentage. [↑](#footnote-ref-5)
6. UNEP/OzL.Pro/ExCom/82/69 [↑](#footnote-ref-6)
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. [↑](#footnote-ref-7)
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. [↑](#footnote-ref-8)
9. Simmonds et al., “Recent increases in the atmospheric growth rate and emissions of HFC-23 (CHF3) and the link to HCFC-22 (CHClF2) production,” Atmos. Chem. Phys., 18, 4153–4169, 2018. <https://doi.org/10.5194/acp-18-4153-2018> [↑](#footnote-ref-9)
10. http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/Effective%20Technologies%20for%20Conversion%20of%20HFC-23%20-%20Quan%20Hengdao.pdf [↑](#footnote-ref-10)
11. http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/Treatment%20of%20HFC-23%20by%20conversion%20-%20Han%20Wenfeng.pdf [↑](#footnote-ref-11)
12. 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 [↑](#footnote-ref-12)
13. UNEP/OzL.Pro/ExCom/79/48; 79/48/Add.1; 79/48/Corr.1; and 79/48/Corr.2. [↑](#footnote-ref-13)