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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

KEY ASPECTS RELATED TO HFC-23 BY-PRODUCT CONTROL TECHNOLOGIES: OPTIONS RELATED TO THE CONTROL OF HFC-23 BY-PRODUCT EMISSIONS IN ARGENTINA (DECISION 81/68)

Background

1. At its 81st meeting, the Executive Committee requested the Secretariat to contract an independent consultant to prepare a report for the 82nd meeting, providing information:

(a) On options and all costs and savings related to the control of HFC-23 by-product emissions in Argentina, based on the quantities of HCFC-22 and HFC-23 produced at the plant and information included in relevant past reports to the Executive Committee, including the option of shipping HFC-23 for off-site destruction;

(b) On estimates of fugitive emissions and options for monitoring, leak detection and control of HFC-23 by-product at the plant; and

(c) On the costs, technical feasibility, and logistical, legal and transaction issues associated with shipping HFC-23 for off-site destruction by means of a technology such as the fluor process described in document UNEP/OzL.Pro/ExCom/81/54.

2. The Executive Committee also requested the Government of Argentina to provide, on a voluntary basis, relevant information for the report, and allocated, from existing Secretariat resources, up to US $25,000 for the contract of the independent consultant (decision 81/68(b), (c) and (d)).

Scope of the document

3. In line with decision 81/68(b), the Secretariat contracted an independent consultant to undertake the study. The consultant, together with two staff members from the Secretariat, visited the HCFC-22 production facility Frio Industrias Argentinas (FIASA) located in San Luis, Argentina on 28 to 30 August 2018. The team also met with the representatives of the Government of Argentina and discussed the options for HFC-23 by-product control, including requirements for off-site destruction of HFC-23 by-product.

4. Based on the data collected from the mission to Argentina and relevant documents that were previously considered, the consultant submitted a report detailing options for HFC-23 by-product control and their costs for the consideration of the Executive Committee. The Secretariat undertook an extensive review of the consultant's report, which is contained in Annex I to the present document. The report consists of an executive summary (including findings); it describes the HCFC-22 production and generation of HFC-23 at FIASA; it describes the physical and mechanical conditions of the incinerator available at the production facility, and the estimated costs for restoring it; the potential for fugitive emissions of HFC-23; it presents a cost analysis of onsite destruction of HFC-23 and transporting HFC-23 for off-site incineration. The report also includes five annexes, including an analysis of the estimated capital cost to restore the incinerator (Annex II); estimated cost for incinerating HFC-23 at FIASA (Annex III); and the amounts of HCFC-22 production and the estimated HFC-23 by-product generated from 2019 to 2029 (based on three different generations rates), and the costs of destruction at three facilities (in-situ, in a cement kiln in the vicinity of FIASA, and in a plasma arc incinerator in Monterrey, Mexico).

5. To facilitate the Executive Committee's review of the consultant's report, the present document consists of the following sections:

- Regulatory framework for the transport and/or export of HFC-23
- Technologies approved for destruction of HFC-23
- Summary of the conclusions of the consultant's report
- Additional information for consideration by the Executive Committee on: rotary kilns, monitoring, closure, and the time of project initiation
- Summary
- Recommendation

Regulatory framework for transport and/or export of HFC-23

6. Regulations related to the transport and/or export of HFC-23 depend on whether it is intended for controlled uses, in which case it is treated as a product, or for destruction, in which case it is treated as a hazardous waste. In particular, HFC-23 by-product for destruction is considered a hazardous waste under Argentinian law. The transport of such waste within Argentina would require strict adherence to a number of conditions, including: permits would have to be obtained from each province through which the waste is transported, and the waste could only be transported on federal (and not provincial) roads by an entity that was registered to transport hazardous waste.

7. Similarly, the regulations related to the export of HFC-23 by-product for destruction in Argentina are different from the regulations related to the export for the controlled use of HFC-23 (e.g., fire protection applications or low-temperature refrigeration). For the latter, HFC-23 is treated as a product and its export would therefore not fall within the meaning of the Basel Convention or other regulations related to the export of waste. The same export requirements would apply for HFC-23 that is used as a refrigerant as would apply to other HFC refrigerants, noting that the use of a substance as a refrigerant may need to be demonstrated if there is no apparent market.

8. Under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (the Basel Convention),[1] a waste is considered a hazardous waste if it falls within one of the categories of Annex I ("y categories") unless they do not possess any of the characteristics specified in Annex III ("h characteristics") of the Convention; or if it considered or defined as a

[1] The Basel Convention is an international treaty to reduce the movements of hazardous waste between nations, to prevent transfer of hazardous waste from developed to less developed countries (LDCs), and to minimize the amount and toxicity of wastes generated, to ensure their environmentally sound management as closely as possible to the source of generation. As of October 2018, 186 states and the European Union are parties to the Convention.

hazardous waste under the domestic legislation of the importing, exporting or transiting Party. The Government of Argentina considers that HFC-23 by-product for destruction would fall within category y45 of Annex I of the Basel Convention and, therefore, a hazardous waste.[2]

9. In line with obligations under the Convention, the Government therefore considers that permission would have to be received from both the country to which the waste was being exported to, and any transit countries through which the waste is shipped (i.e., the countries of intermediate ports, if any, before the waste was delivered to the final country where the destruction would take place). While the process of obtaining the necessary permits is onerous, that is the process that has been used for all other shipments of hazardous waste that fall under the Basel Convention from Argentina, and the Government would follow a similar process for the case of export of HFC-23 by-product for destruction.

Technologies approved for destruction of HFC-23

10. Subsequent to the 81st meeting, the consultant starting working in line of the requirements of decision 81/68, and in consultation with the Secretariat, considered relevant to evaluate three options for the control of HFC-23 by-product in Argentina, including incineration at a cement kiln located 160 km from FIASA.

11. Subsequent to the finalization of the consultant's report, the Thirtieth Meeting of the Parties[3] adopted a decision,[4] wherein the Parties approved technologies for the destruction of HFC-23. The incinerator currently at FIASA and the plasma arc incinerator in Mexico are both among the technologies approved by the Parties for destruction of HFC-23. While the Parties approved cement kilns for the destruction of Annex F group I substances, they did not approve cement kilns for the destruction of HFC-23 as information on the destruction and removal efficiency (DRE) for HFC-23 was lacking. Until the Parties decide to approve cement kilns for the destruction of HFC-23, the Government of Argentina could not use that technology to comply with the HFC-23 by-product control obligations under the Kigali Amendment.

12. As the consultant's report had assessed the cost for destruction of HFC-23 at a cement kiln prior to the Thirtieth Meeting of the Parties, the Executive Committee may wish to consider this analysis only as a reference.

Summary of the conclusions of the consultant's report

13. The consultant's report addressed all the requirements of decision 81/68, and evaluates three options for the control of HFC-23 by-product in Argentina based on quantities of HFC-23 by-product generated:

(a) Restarting FIASA's incinerator and destruction of HFC-23 by-product on-site;

(b) Transporting the HFC-23 by-product to a cement kiln in San Luis province for incineration; and

(c) Exporting HFC-23 by-product for incineration to an off-site destruction facility.

[2] The law on hazardous waste in Argentina differs from the Basel Convention in that if a waste either falls within one of the categories of Annex I ("y categories") or has one or more of the characteristics specified in Annex III ("h characteristics") of the Convention, then it is considered a hazardous waste and the Government would consider that the Basel Convention obligations would apply.

[3] Quito, Ecuador 5-9 November 2018.

[4] The report of the meeting showing decisions numbers, has not been issued at the time of finalizing the present document.

HFC-23 by-product generation rate

14. Absent additional data, the consultant assumed that the production of HCFC-22 would be maintained at the level of production in 2017 of 1,823 mt (the last year for which data was available) until 2024, at which time production would decrease to 1,531 mt from 2025 to 2029, in accordance with the Montreal Protocol control schedule. The quantity of HFC-23 to be destroyed is based on FIASA's historic by-product generation rate of 3.32 per cent i.e., the average rate when FIASA was generating credits under the Clean Development Mechanism (CDM). Accordingly, about 61 mt of HFC-23 by-product would be generated annually between 2019 and 2024, and 50 mt annually between 2025 and 2029, and cease from 2030 onward.

15. Process improvements, which would involve additional capital investments, can reduce the by-product generation rate to as low as 1.4 per cent.[5] The consultant also estimated the quantity of HFC-23 to be destroyed using a by-product generation rate of 2.0 per cent and 1.45 per cent.

Restarting FIASA's incinerator

16. FIASA has an on-site thermal oxidation incineration system purchased from SGL Carbon Group of Meitingen, Germany that was shut down in October 2013 and has been idle since. The capacity of the on-site incinerator is 613 metric tonnes (mt)/yr.

17. The on-site incinerator at FIASA, at 100 per cent of design capacity, can destroy 613 mt of HFC-23 in 365 days. FIASA's highest HFC-23 by-product generation was 134 mt in a year. During the period in which FIASA was destroying HFC-23 for credits under the Clean Development Mechanism (CDM), FIASA installed a 40 mt cryogenic storage tank to improve the control of HFC-23 feed to the incinerator. The cryogenic tank is a key part of the incineration system. It allows for storage of HFC-23 generated in 109 days at the record production of 134 mt per year; and 243 days at HFC-23 generation of 60 mt per year, given current HCFC-22 and HFC-23 production and generation levels. Therefore, the incinerator can be operated at 50 per cent of design capacity in campaigns that destroy the cumulative content of the cryogenic tank and minimize the shutdowns and start-ups of the incinerator, thus extending its life.

18. The estimated costs required to refurbish the incinerator are US $897,840[6] (as described in Annex II of the consultant's report). Incremental operating costs (IOCs) will be a function of the extent of utilization of the incinerator capacity.[7] The consultant estimated IOCs between US $1.10/kg (100 per cent capacity) and US $2.22/kg (50 per cent capacity) (Table 4 of the consultant's report). Annual operating costs for incineration will also depend on the HFC-23 by-product generation ratio (Annex 5 of the consultant's report).

Transporting the HFC-23 to a cement kiln in San Luis province for incineration

19. In order to minimize the legal and logistical issues required for off-site destruction, a cement kiln within San Luis province where FIASA is located was considered as a possible destruction facility. The cement kiln is not registered to destroy hazardous waste and in order to obtain the necessary permits, it is likely that the Government of Argentina and the province of San Luis would require the kiln to perform a test burn to demonstrate that 99.99 per cent of HFC-23 is destroyed.

[5] As indicated in document UNEP/OzL.Pro/ExCom/81/54.

[6] Under normal conditions, the consultant would rely on estimates from three independent contractors for the capital investment needed to restore FIASA's incineration system. However, in the absence of independent contractors' estimates, the consultant relied on FIASA's estimated cost for the restoration of the incinerator.

[7] As reported in document UNEP/OzL.Pro/ExCom/81/54.

20. FIASA would need to purchase two 8.6 mt-capacity isotanks to transport the HFC-23 from FIASA to the cement kiln at a cost of US $460,000. The safe transport of HFC-23 requires the use of an isotank with thick, steel walls given the high vapor pressure of HFC-23.[8] The isotanks when filled have a gross weight of approximately 14.36 mt, i.e., the weight of the tank itself is almost as much as the HFC-23 contained therein.

21. The consultant estimated the costs of destruction at the cement kiln of approximately US $1.05/kg, including the cost of transportation, and excluding the capital costs of the two isotanks (Table 5 of the consultant's report).

Exporting the HFC-23 to Mexico for destruction at a plasma arc incinerator

22. The consultant assessed the option of exporting HFC-23 for destruction at the plasma arc incinerator in Monterrey, Mexico.[9] That facility has demonstrated the destruction of HFC-23 with a DRE of at least 99.99 per cent under the CDM. The HFC-23 would be transported by truck from FIASA to the port in Buenos Aires, by ship to the port in Tampico, Mexico, and then by truck to the plasma arc incinerator in Monterrey. Permits would need to be obtained for each leg of the journey, as well as for each province between San Luis and Buenos Aires, Argentina. In addition, FIASA would need to obtain prior informed consent from the Government of Mexico.

23. The consultant estimated the transportation costs to be US $1.09/kg, and assumed incineration costs of US $7.40/kg,[10] resulting in a cost of US $8.49/kg (Table 6 of the consultant's report). In addition, FIASA would need to purchase two isotanks suitable for the transport of HFC-23 at US $460,000.

Fugitive emissions

24. All HFC-23 by-product currently generated at FIASA is vented to the atmosphere, and not monitored. Emissions of HFC-23 from the vent stack of the incinerator, when it was in operation, were below the 1.14 parts per million (ppm) detection limit of the gas chromatograph used to monitor the stack emissions.[11]

25. FIASA seeks to minimize fugitive emissions from its HCFC-22 production in order to maximize its collection of HCFC-22, the product it sells. To do so, among the measures, the enterprise checks every flange joint and other connections using a soap solution every couple of weeks. In addition, the enterprise closely monitors the HCFC-22 production process variables. The packaging area has a leak detection system but sniffers or other detection instruments are not used by the enterprise, with the exception of the incinerator (when it is in operation) which includes monitoring of the exhaust gases (including of HFC-23).

[8] The vapour pressure of HFC-23 is 681 pounds per square inch (PSI) at 25 °C, which is five times higher than that of HCFC-22. For added safety, the isotanks have a pressure rating of 2,400 PSI.

[9] Argentina, as a party to the Basel Convention, would likely be precluded from shipping HFC-23 for destruction to the United States of America, unless the Governments were to enter into a bilateral agreement related to the treatment of hazardous waste. The consultant therefore did not estimate the costs of shipping the HFC-23 by-product for destruction via the United States of America. The difference between shipping HFC-23 to Tampico, or to Brownsville, Texas are likely to be negligible. In contrast, the costs of shipping the HFC-23 by rail from Brownsville to Monterrey are likely to be lower than the costs of transporting the HFC-23 by truck from Tampico to Monterrey.

[10] Cost as reported by UNIDO in UNEP/OzL.Pro/ExCom/80/12.

[11] Two methods are used to measure the stack gases, USEPA 040 for sampling and method ME-48 for chromatographic analysis. The gas chromatograph is an Agilent Technologies Model 6890.

26. All the process units in the HCFC-22 production line and incineration system operate as a closed system with no chance for fugitive emissions in between. Should an unexpected leak occur it will be of such magnitude that it cannot be missed and will be fixed immediately for safety considerations.

Additional information for consideration by the Executive Committee

Incineration at rotary kilns

27. Among the technologies approved by the Thirtieth Meeting of the Parties for the destruction of HFC-23, is rotary kilns. While the consultant did not assess the estimated costs of incineration using rotary kilns, the Executive Committee will considered at its 82nd meeting the synthesis report on the pilot ODS disposal projects.[12] This document indicates that destruction costs at rotary kilns in Germany and Poland range between US $1.87/kg and US $2.45/kg, based on bids received from these facilities that are registered for ODS destruction in the European Union. The Secretariat also notes that costs to transport HFC-23 from FIASA to a rotary kiln in either Germany or Poland can be expected to be up to twice the cost of transportation to the plasma arc incinerator in Mexico (i.e., up to US $2.17/kg). Based on this data, the total cost of destruction would range between US $4.04/kg and US $4.62/kg; and an additional, capital cost of US $460,000 for two isotanks.

Costs related to the monitoring of destruction of HFC-23

28. The IOCs estimated by the consultant included costs related to the monitoring of HFC-23 emissions from the incinerator stack, including the costs to operate the sampling and monitoring equipment, including for its calibration. However, the consultant did not include costs related to provincial or federal government monitoring, or costs related to an independent audit or verification. As reference, stage II of the HCFC phase-out management plan (HPMP) for Argentina, includes US $8,333 per year for annual monitoring of HCFC-22 production and stockpiles, and in situ verification by experts (for a total of US $50,000). Monitoring and verification of HFC-23 by-product emissions would be an additional task. An additional 50 per cent of the annual cost to monitor HCFC-22 production and stockpiles, and verification, could be considered to also monitor and verify HFC-23 emissions, bringing the total annual monitoring and verification costs to US $12,500 for both HCFC-22 production and HFC-23 emissions.

Preliminary estimated cost of closure of HCFC-22 production

29. The Executive Committee decided to consider possible cost-effective options for compliance with the HFC-23 by-product control obligations under the Kigali Amendment, including closure of HCFC-22 swing plants (decision 79/47(c)). Within the budget available, the consultant was unable to undertake a techno-economic analysis to assess the lost profits that would be associated closure of FIASA.

30. In order to provide a comparison between alternative approaches for management of HFC-23 by-product emissions in line with the Kigali Amendment and the closure of the HCFC-22 swing plant, the Secretariat broadly assessed the lost profits for FIASA that would be associated with early closure. Such a determination is complicated by the following factors:

(a) An enterprise's profits are determined in part by the difference between the revenue generated from the sales of the product and the costs to produce and sell that product. The major costs to produce HFCF-22 include the costs for the raw materials (anhydrous hydrogen fluoride and chloroform), labour costs and, to a lesser degree, maintenance costs. While the HCFC-22 is sold locally, raw materials are imported, and therefore profits at the enterprise will depend on the exchange rate of the local currency (i.e.,

[12] As indicated in document UNEP/OzL.Pro/ExCom/82/21.

Argentina Peso).[13] Maintenance costs may vary as the equipment in the production line (except of a distillation column that was replaced in 2006) is the original equipment used to manufacture CFCs (i.e., 31 years old);

(b) On any given year, the level of production of HCFC-22 has been lower than the production capacity of the enterprise (i.e., 7,792 mt/yr as reported by the Government of Argentina or 5,000 mt/year based on the consultant's estimation), and every year HCFC-22 is imported into the country (Table 1 of the consultant's report), suggesting that FIASA may be able to command a higher price than for imported HCFC-22, increasing its profitability by an unknown amount. In contrast, decreasing utilization of production capacity is expected to result in increasingly variable profitability. Table 1 below shows the extent of utilization of quotas and capacity at FIASA.

Table 1: Utilization (per cent) of quotas and production capacity in Argentina

Utilization (per cent)	2013	2014	2015	2016	2017
Import quota	89	91	95	92	100
Production quota	48	56	67	47	50
Capacity (7,792 mt/yr)	25	29	31	22	23
Capacity (5,000 mt/yr)	39	46	49	35	36

31. In accordance with Argentina's laws and regulations, workers who are laid off are provided compensation according to the number of years the employee has worked for the enterprise. Based on the years of service of the employees at FIASA and their salaries, and assuming the HCFC-22 production line were to close on 1 January 2020, the compensation to workers would be approximately US $1,775,000.

32. In the absence of data, a profit margin of approximately 5 per cent of the sales revenue for commodity chemicals can be assumed. On that basis, and assuming: the 2017 production levels (1,823 mt) are maintained until the 1 January 2025 control target, at which point production would be reduced to the Montreal Protocol control target (1,531 mt/yr) until 1 January 2030, when production would cease; the price of HCFC-22 reported by FIASA for 2017; and a 5 per cent inflation rate, results in a net present value of lost profit for the period of 2020-2030 of approximately US $4,500,000. Varying the profit margin by ±2 per cent results in a range of the net present value of lost profit of approximately US $2,700,000 to US $6,300,000.

33. Following CFC agreements, the CFC/HCFC reactors and distillation column would need to be destroyed, dismantled or rendered unusable; in contrast, the incinerator and the scaffolding holding the reactors, for example, could be used for another purpose or sold. In addition, the site would not need to be de-contaminated to comply with environmental regulations if the site were to continue to be used as a chemical plant.

34. Closure of FIASA would provide both ozone and climate benefits, as neither HCFC-22, an ODS, nor HFC-23 by-product, a potent greenhouse gas, would be produced or generated by the facility. Moreover, the monitoring of closure would be substantially easier than if the facility were to continue to operate and destroy HFC-23 either on- or off-site.

Time of project initiation

35. FIASA currently is venting all the HFC-23 by-product generated during the production of HCFC-22. The HFC-23 emission control obligation under the Kigali Amendment commence on 1 January 2020. However, there are no technical impediments that would preclude destruction to commence before then. Reconnecting the pipes to the cryogenic tank to allow the HFC-23 to be stored for

[13] During the last six months, the value of the Argentina Peso relative to the US dollar, the Euro, and the Renminbi has decreased by approximately 50 per cent.

subsequent destruction could be accomplished within days or at most several weeks. At current production levels, FIASA would then have at least six months to complete all the work needed to restart the incinerator or finalize all the necessary arrangements required for off-site destruction. In order to maximize the climate benefits of HFC-23 by-product control, the Executive Committee could consider, on an exceptional basis, to provide additional funding for the control of HFC-23 starting on 1 January 2019. This would provide an additional 890,368 mt-CO_2eq of climate benefits.

Summary

36. FIASA could be the first HCFC-22 swing plant for which compensation is provided to control HFC-23 by-product emissions in line with decision 79/47(c).

37. At the 79th meeting, the Committee recognized that a number of challenges were faced when considering of HFC-23 by-product control technologies including, *inter alia*, the wide range of incremental operating costs reported, the burden on production companies and the need for funding to assist with disposal and destruction activities, that the destruction of HFC-23 could be considered to be part of the regular cost of doing business, that it was necessary to ensure that the application of particular funding modalities did not create perverse incentives that encouraged an increase in by-product output, and the need for a flexible approach, among other challenges.[14]

38. Accordingly, the Executive Committee faces a number of policy decisions (e.g., the number of years for which IOCs are provided, the by-product generation rate used to determine IOCs, the benefits of closure versus continued production of HCFC-22 and destruction of the HFC-23 by-product, and possible additional compensation to maximize the climate benefits of HFC-23 control, amongst others). Without prejudice to those decisions, Table 2 summarizes the costs of different HFC-23 by-product control options in Argentina.

Table 2. Costs of HFC-23 by-product control options in Argentina

Option	Minimum	Maximum	Average	Years	Total
On-site incinerator					
Refurbish incinerator					897,840
Incineration 2019-2024	29,131	133,379	81,255	6	487,530
Incineration 2025-2030	24,464	112,011	68,238	6	409,425
Total on-site incinerator					1,794,795
Plasma arc, Mexico					
Isotanks (2)					460,000
Incineration 2019-2024	224,326	510,535	367,431	6	2,204,583
Incineration 2025-2030	188,385	428,738	308,562	6	1,851,369
Total plasma arc					4,515,952
Cement kiln,* San Luis					
Isotanks (2)					460,000
Incineration 2019-2024	27,677	62,990	45,334	6	272,001
Incineration 2025-2030	23,243	52,898	38,071	6	228,423
Total cement kiln					960,424
Rotary kiln, European Union					
Isotanks (2)					460,000
Incineration 2019-2024	106,797	277,948	192,373	6	1,154,235
Incineration 2025-2030	89,687	233,420	161,554	6	969,322
Total rotary kiln					2,583,557
Production closure					
Worker compensation					1,775,000
Lost profits	2,701,871	6,304,366	4,503,119	n/a	4,503,119

* Not a technology approved by the Parties for the destruction of HFC-23.

[14] See paragraph 154 of UNEP/OzL.Pro/ExCom/79/51.

39. The Government of Argentina indicated that it would wish to select UNIDO as the implementing agency for an HFC-23 by-product control project that could be approved under the Multilateral Fund.[15] To facilitate discussion during the meeting, the Executive Committee may wish to consider the text below as the basis for a recommendation if funding for control of HFC-23 by-product were to be approved at the present meeting:

(a) Approving US $[…], plus agency support costs of US $[…] for UNIDO, to enable the Government of Argentina to comply with the HFC-23 by-product control obligations under the Kigali Amendment on the understanding that:

(i) The Government of Argentina would ensure that, starting 1 January [2019][2020], emissions of HFC-23 by-product were destroyed to the extent practicable;

(ii) The Government of Argentina would have flexibility to use the funding approved by the Executive Committee for any of the options for the destruction of HFC-23 by-product identified in document UNEP/OzL.Pro/ExCom/82/69;

(iii) That UNIDO would submit independent verification reports documenting the Government of Argentina's compliance with sub-paragraph (a)(i) of the present decision;

(iv) That a penalty of US $[…]/kg of HFC-23 would be applied to emissions of HFC-23 by-product that were determined not to have been destroyed to the extent practicable;

(v) The Government of Argentina, through UNIDO, would provide annual reports on the status of the project, including the level of disbursement, the quantity of HFC-23 by-product generated, destroyed and emitted, at the last meeting of the year until the completion of the project;

(vi) That the project would be completed by 1 January 2030 or upon closure of FIASA, whichever comes first;

(vii) That UNIDO would submit the project completion report six months after project completion, and that any remaining balances after the completion of the project would be returned the Multilateral Fund;

(viii) That any penalty applied in line with sub-paragraph (a)(iv) of the present decision would be returned to the Multilateral Fund by the Government of Argentina, through UNIDO, to the meeting following the determination that HFC-23 by-product that was generated was not destroyed to the extent practicable; and

(b) Requesting the Treasurer to transfer US $[…], plus agency supports costs of US $[…] for UNIDO once the Government of Argentina had submitted its instrument of ratification, acceptance or accession of the Kigali Amendment to the Headquarters of the United Nations in New York.

[15] As per the letter of 14 November 2018 from the Ministry of Foreign Affairs and Worship of Argentina to the Secretariat.

Recommendation

40. The Executive Committee may wish to consider:

(a) Noting the report on key aspects related to HFC-23 by-product control technologies: options related to the control of HFC-23 by-product emissions in Argentina (decision 81/68) contained in document UNEP/OzL.Pro/ExCom/82/69;

(b) Noting with appreciation the relevant information provided by the Government of Argentina, on a voluntary basis, that allowed the preparation of document UNEP/OzL.Pro/ExCom/82/69; and

(c) Considering any technical and financial assistance it wishes to provide to the Government of Argentina to allow for compliance with the HFC-23 by-product control obligations of the Kigali Amendment of the Montreal Protocol, and in light of the information contained in document UNEP/OzL.Pro/ExCom/82/69.

WAKIM CONSULTING
Petrochemicals, Energy & Mining

Wakim Project 18100
12 November 2018

Control of HFC-23 Emissions in Argentina, Based on Quantities Produced

Final Report

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EXECUTIVE SUMMARY

In Compliance with the Executive Committee decision 81/68(b)(i), (ii), and (iii), Wakim Consulting (Wakim) is pleased to present this Draft Final Report to the Secretariat (Secretariat) of the Multilateral Fund for the Implementation of the Montreal Protocol (MLF). The report covers our evaluation of control of HFC-23 emissions in Argentina based on quantities produced and options of:

- Restarting FIASA's incinerator and destruction of HFC-23 onsite
- Transporting HFC-23 to an off-site facility in San Luis Province for incineration
- Exporting HFC-23 for incineration at an off-site facility overseas

Given that this is a site specific technical evaluation, the Secretariat requested Wakim to undertake the evaluation and prepare a report, in collaboration with its project review team.

To perform the sought evaluation, Wakim and Secretariat representatives visited the FIASA plant and collected available data with the kind cooperation of FIASA's management and staff.

FINDINGS

HCFC-22 and HFC23 Quantities Produced

Wakim updated the production data from the HCFC-22 plant startup in 2007 to July 2018. Wakim also, with the help of the government of Argentina representatives, collected the HCFC-22 trade statistics. The results are presented in Table 1. Quantities of HFC-23 by-product generated were provided by FIASA based on fiscal years of October 15, 2007 to October 14, 2008; and continuing for following years until October 14, 2013. For all other years, HFC-23 generation data is based on HCFC-22 production data provided by FIASA and an average of by-product generation rate of 3.32%.

Table 1. Argentina HCFC-22 Supply and Demand and HFC-23 By-product Generation

	HCFC-22 Annual Data (mt)				HFC-23 By-product (mt)
Year	Production	Imports	Exports	Apparent Consumption	Generation
2018*	681*	N/A	N/A	N/A	23
2017	1823	641	0	2464	61
2016	1742	582	0	2324	58
2015	2446	601	4	3043	81
2014	2286	636	17	2904	76
2013	1951	624	1	2574	86
2012	4190	4539	2201	6529	134
2011	4018	4221	1669	6570	134
2010	4251	4283	2669	5866	132
2009	3914	3266	3326	3854	121
2008	2857	2359	396	4821	93
2007	818	3852	507	4163	N/A

* 2018 data is for January to July (only)

Market forces and the desire of the Government of Argentina to minimize the emission of HFC-23 to the atmosphere shaped the market for HCFC-22 and consequently the generation of HFC-23.

Background

Restoring the FIASA incinerator and destruction of HFC-23 onsite

Wakim and Secretariat representatives visited the plant in Villa Mercedes, San Luis Province, Argentina from August 27 to September 1, 2018. The management and staff courteously gave us ample time to inspect all the process units in the incineration system.

Overall, the process units seemed to be in good physical condition; with an update or replacement needed in very few units. We could not assess the mechanical condition of the process units because the plant was shut down due to an electric power outage of the main grid in the area.

Fugitive emissions

All the process units in the incineration system operate as a closed system with no chance for fugitive emissions in between. Should an unexpected leak occur it will be of such a magnitude that it cannot be missed and will be fixed immediately for safety consideration.

FIASA did measure HFC-23 stack emissions (fugitive emission monitoring required under the CDM methodology) for the period it received credits under the CDM. For example, from 1/1/2013 to 10/14/2013 (287 days) HFC-23 stack emissions were less than 1.14 ppm of stack gases (which is the lowest

detection limit of the measuring device); the 1.14 ppm is equivalent to 2.8 kg HFC-23 emitted in the 287 days. During the same period, FIASA generated 30,974 kg (31 metric tons – mt) of HFC-23.

The last CDM crediting period for FIASA ended on October 14, 2013. Since that time, FIASA ceased measuring the stack emissions and, without any law in Argentina prohibiting the practice, started venting all the HFC-23 by-product to the atmosphere.

Without an operating incinerator, FIASA would have emitted 30,974 kg instead of 2.8 kg of HFC-23 to the atmosphere.

Restoring the Incinerator and Destroying HFC-23 Onsite

Under normal conditions, Wakim would rely on estimates from 3 independent contractors for the capital investment needed to restore FIASA's incineration system. However, for this study and in the absence of independent contractors' estimates, we relied on FIASA's estimate of US$ 897,840 needed for the restoration of the incineration system.

HFC-23 Destruction Costs Onsite FIASA's Restored Incineration Facility

Starting with the premise that the capital investment needed to restore FIASA's incineration system is US$ 897,840 Wakim's HFC-23 incineration cost estimates are presented in Annex 3 and summarized in Table 4 below (page 10).

Based on our recommended blocked out operation of the incinerator, described **below**, allows FIASA to perform any needed planned maintenance work on the incinerator and HCFC-22 plants without interference with the operation of either of the two plants. It will minimize incinerator start-up and shut downs and minimize the cost of destroying HFC-23 to about US$ 1.10 per kilogram.

HFC-23 Destruction Cost Off-site In Argentina

Wakim previously reported to the Executive Committee Alternative incineration technologies for destroying HFC-23, including rotary cement kilns. Subsequently, the Secretariat identified a number of ODS destruction projects funded by the MLF, including a demonstration of a regional strategy for ODS waste management and disposal in the Europe and Central Asia region.[1] The projects included incineration of HFCs, including some HFC-23, in rotary kilns in Poland and Germany. Also, successful ODS destruction pilot tests were performed at the cement kiln of Holcim Mexico Tocoman Plant on behalf of UNIDO. These projects indicate that there is no technical reason a well-run cement kiln could not reach destruction efficiencies comparable to other thermal oxidation technologies. This is consistent with the results of the ODS destruction projects, and the report of the TEAP Task Force on destruction technologies.[2]

The Government of Argentina and FIASA informed us that "Cementos Avellaneda" owns a cement kiln located 163 kilometers from FIASA in San Luis Province.

Using the available information, we estimated the cost of incinerating HFC-23 in similar cement kilns. The findings are presented in Table 5.

[1] Document UNEP/OzLPro/ExCom/80/12 available at http://multilateralfund.org/80/Document%20Library1/1/8012.pdf

[2] http://conf.montreal-protocol.org/meeting/mop/mop30/presession/Background-Documents/TEAP-DecXXIX4-TF-Supplemental-Report-May2018.pdf

Table 5. Estimate of HFC-23 Destruction Cost in Cementos Avellaneda Cement Kiln

HFC-23 Destruction Cost Estimate Off-site in Argentina			
Cementos Avellaneda Cement Kiln, San Luis Province: Distance from FIASA is 163 Km			
Gross Wt Kg	**Net Wt Kg**	**Freight US $**	**US $/mt HFC-23**
14,360	8,620	405	47
Incineration Cost			1,000
Total Destruction Cost Estimate			**1,047**

The results indicate that HFC-23 incineration cost in such kilns is expected to be around US $1.05 per kilogram.

Exporting HFC-23 for incineration at an off-site facility overseas

HFC-23 destined for export for destruction is considered a hazardous waste under rules and regulations of Argentina, and would trigger obligations under the Basel Convention. In such cases, prior consent is needed from both the destination country and any transit countries through which the waste is shipped.

A short and most likely economical route to ship FIASA's HFC-23 from Buenos Aires to Monterrey is via the Port of Brownsville, Texas; continuing by a short train leg to Monterrey. However, the United States is not a signatory of the Basel Convention; therefore, following this route would require significant international negotiations for the hazardous waste to go through.

Consequently, Wakim selected Mexico, a Basel Convention signatory, as the overseas destination. FIASA's HFC-23 can be transported from Villa Mercedes to Buenos Aires Port and loaded on ships travelling directly to Tampico Port, Mexico; then transported overland to Monterrey, a distance of about 454 kilometers. With a Plasma Arc Incinerator owners' concurrence, HFC-23 can be incinerated and the empty isotanks returned to FIASA for follow-up use.

Assuming that the appropriate formalities are agreed to by all stake holders, Wakim's estimates of HFC-23 destruction costs are presented in Table 6.

Table 6. HFC-23 Destruction Cost Estimates at Plasma Arc Incinerator in Monterrey Mexico

HFC-23 Destruction Cost Estimate Off-site in Mexico Plasma Arc Incinerator: Monterrey, Mexico			
Gross Wt Kg	Net Wt Kg	Freight US$	US$/mt HFC-23
16,200	9,000		
FIASA to Buenos Aires		1,865	207
Buenos Aires to Tampico Port		1,160	129
Tampico Port to Monterrey		1,865	207
Subtotal Freight		**4,890**	**543**
Isotank return to FIASA		**4,890**	**543**
Total Freight			**1,086**
Plasma Arc Incineration Cost			**7,400**
Total Destruction Cost Estimate			**8,486**

The results indicate that the freight cost alone (about US$ 1.09 per kg of HFC-23) is of the same order of magnitude as the total destruction cost at FIASA's restored incinerator or the San Luis cement kiln.

A similar argument can be made for attempting to incinerate HCFC-23 from Argentina in China, India or Europe.

Conclusions

Wakim Consulting concludes:

1. The semi-finalists in the competition for lowest cost HFC-23 destruction options are: FIASA's restored incineration system, and the Cement Kiln in San Luis.
2. The final winner will emerge from the negotiations between FIASA and the cement kiln owners on incineration costs.
3. With a restored incineration system and MLF support, FIASA can be as successful as numerous HCFC-22 producers elsewhere without CDM support.

BACKGROUND

Wakim Consulting mandate consists of assessing options and all costs and savings related to the control of HFC-23 by-product emissions in Argentina, based on the quantities of HCFC-22 and HFC-23 produced at the plant.

The study is site specific to FIASA's HCFC-22 and HFC-23 plant in Villa Mercedes, San Luis Province, Argentina; it is also specific to comparison of:

- Restoring the incinerator and destruction of HFC-23 onsite
- Transporting HFC-23 for incineration at an off-site facility in San Luis Province, Argentina.
- Exporting HFC-23 for incineration at an off-site facility overseas.

The FIASA plant produced CFC-11 and CFC-12 until 2007 when it was converted to a swing plant producing HCFC-22; and inevitably produced HFC-23 as a by-product. Aside from replacing the distillation tower, the conversion process left all other infrastructure and major capital equipment intact; the reactors are still in use to this day.

In 2008, FIASA produced 2,857 metric tons (mt) of HCFC-22; increasing production to a high of 4,251 mt in 2010; which remained the record high to our visit on August 27, 2018.

On October 15, 2007 FIASA commissioned a new thermal oxidation incineration system purchased from SGL Carbon Group of Meitingen, Germany. FIASA entered into a Clean Development Mechanism Contract (CDM) which was in effect from October 15, 2007 to October 14, 2013. During this period, FIASA added a 40 mt cryogenic tank to the incineration system to store the HFC-23 stream and improve the control of HFC-23 feed to the incinerator.

After that time, the incinerator was shut-down according to the manufacturer's instructions and idled; the pipe delivering the stream (consisting of about 93% HFC-23 and the balance mainly HCFC-22) was severed; and the stream was vented to the atmosphere.

HCFC-22 and HFC-23 Production

The HCFC-22 annual production, imports, exports and apparent consumption are presented in Table 1. The 2018 HCFC-22 production value represents production for January to July.

The waste ratios (HFC-23/HCFC-22%) were obtained from plant records provided by FIASA as part of its reporting to the CDM for the period 2008 to 2013; the average ratio of 3.32% was used to estimate HFC-23 generation in the remaining years. The presence of the cryogenic plant onsite made it possible that some HFC-23 generated in a previous period could be destroyed in a later reporting period.

HCFC-22 production was below 1,800 mt in 2016 and reached 1,823 mt in 2017. The level of production is not expected to be surpassed from 2019 to 2024, resulting in an estimated equivalent to

60.2 mt per year of HFC-23, and 1,531 mt (equivalent to 50.5 mt per year of HFC-23) from 2025 to 2029; then production will cease from 2030 onward, in line with the Montreal Protocol control schedule.

Based on these assumptions, HFC-23 generation from 2015 through 2017 (the last 3 years of incinerator operation) ranged from 61 to 81 mt per year; and is expected to remain at about 61 mt/y through 2024. From 2025 through 2029, HFC-23 generation is expected to drop to about 50 mt per year; and cease from 2030 onward.

Table 1. Argentina HCFC-22 Supply and Demand and HFC-23 Generation

	HCFC-22 Annual Data mt				HFC-23 mt
Year	Production	Imports	Exports	Apparent Consumption	Generation
2018*	681	N/A	N/A	N/A	23
2017	1823	641	0	2464	61
2016	1742	582	0	2324	58
2015	2446	601	4	3043	81
2014	2286	636	17	2904	76
2013	1951	624	1	2574	86
2012	4190	4539	2201	6529	134
2011	4018	4221	1669	6570	134
2010	4251	4283	2669	5866	132
2009	3914	3266	3326	3854	121
2008	2857	2359	396	4821	93
2007	818	3852	507	4163	N/A

* 2018 data is for January to July

Whereas FIASA's ratio of HFC-23 generation as a percent of HCFC-22 production is expected to remain unchanged without modifications to the process units, newer plants are expected to have lower ratios. Therefore lower ratios of 2.0% and 1.45% resulting in decreased annual and cumulative production are presented in Table 2.

Table 2. HFC-23 Produced Based on HCFC-22 Production and HFC-23 Generation Rate

	HFC-22 Production 2019-2024 1,823 mt/y				HFC-22 Production 2025-2029 1,531 mt/y		
HFC-23 Gen Rate %	3.3	2.0	1.45		3.3	2.0	1.45
HFC-23 Production mt/y	60.16	36.46	26.43		50.52	30.62	22.20
Cumulative HFC-23 Production mt	360.95	218.76	158.60		252.62	153.10	111.00

Matching Incinerator Operating Data with HFC-23 Generation

The SGL operating manual for the incinerator (Annex 1) indicates that it was designed for destruction of significantly larger amounts of HFC-23 than those typically produced by FIASA's HCFC-22 plant. A summary of the data is presented in Table 3. It indicates that running at 100 percent of design capacity, the incinerator destroys 613 mt of HFC-23.

Under typical operating conditions, the HCFC-22 plant would need to produce 18,464 mt of HCFC-22 to cogenerate 613 mt of HFC-23; as compared to 4,251 mt HCFC-22, the record volume produced by FIASA.

For the incinerator to operate at 36 percent of design capacity, the HCFC-22 plant would need to generate 221 mt HFC-23 per year. 36 percent of design capacity is the lowest operating rate at which the incinerator can operate in automatic mode. Therefore, the optimum range for operating the incinerator is

from 36 percent of design capacity (at which it can be operated in automatic mode) and 100 percent (above which the manufacturer's warranty becomes void).

Based on the above findings, and taking into consideration the expected declining generation of HFC-23, **Wakim Consulting recommends that the HCFC-22 plant be run until the cryogenic tank is about full of the HFC-23 stream; initially, a period of about 6 months. Then the incinerator can be started and run at about 50 percent of design capacity until the stored HFC-23 is destroyed. At that point, the incinerator can be shut down in an orderly manner as recommended by the manufacturer. This cycle can be repeated as needed.**

A summary of incinerator operating data is presented in Table 3.

Table 3. SGL Carbon Group Incinerator Data

				mt/y	**mt/d**		SGLOpDataF
HCFC-22 Annual production, mt				2,500	6.849		
HCFC-22 production, mt					1,061	1,667	2,273
Days to produce HCFC-22 in row 3					**155**	**243**	**332**
HFC-23 generation, mt					**35**	**55**	**75**
Waste: (HFC-23/HCFC-22*100)							3.3
% of Design	HFC-23 Stream Destroyed				Operating Days to Destroy mt HFC-23		
	Kg/H	mt/D	mt/y		**35**	**55**	**75**
36	25.2	0.605	221		57.9	90.9	124.0
40	28.0	0.672	245		52.1	81.8	111.6
50	**35.0**	**0.840**	307		**41.7**	**65.5**	**89.3**
60	42.0	1.008	368		34.7	54.6	74.4
70	49.0	1.176	429		29.8	46.8	63.8
80	56.0	1.344	491		26.0	40.9	55.8
90	63.0	1.512	552		23.1	36.4	49.6
100	70.0	1.680	613		20.8	32.7	44.6
			HCFC-22 mt		**HFC-23 mt**		
Production in , days		365	2,500		82.5		
		292	**2,000**		**66.0**		
MLF Assumed Production mt/y			1,823		60.2		

Restoring Incinerator and HFC-23 Destruction onsite

Wakim Consulting representatives accompanied by two Secretariat representatives visited FIASA's plant in Villa Mercedes, San Luis Province, Argentina from August 27 to September 1, 2018. The purpose of the visit was to discuss options for controlling HFC-23 emissions and observing firsthand the physical and mechanical condition of the incineration system in the plant. The management and staff were very courteous and gave us ample time to inspect all the components from the valve at which the HFC-23 stream left the HCFC-22 plant to the stacks for the exhaust of the incinerator and every process unit in between. It is a closed system with no chance for fugitive emissions in between.

Fugitive Emissions

Wakim Consulting reported during the 80th meeting of the Executive Committee that FIASA's HFC-23 stack emissions (fugitive emissions required under the CDM agreement) were measured regularly and were lower than 1.14 ppm (which is the lowest detection limit by the measuring device); estimated as 2.8 kg from 1/1/2013 to 10/14/2013. (287 days)

At the expiration of the CDM agreement, FIASA ceased measuring the stack emissions and, without any law in Argentina prohibiting the practice, started venting all the HFC-23 (30,974 kg in 287 days) cogenerated with the HCFC-22 to the atmosphere.

Physical and Mechanical Condition of Incineration System

Our understanding is that FIASA shut down the incineration system in an orderly and planned manner following the instructions of the incinerator manufacturer; and the system has been idle since October 2013. Shortly after, the pipe delivering the HFC-23 stream away from the HCFC-22 plant was cut and the valve was sealed.

We followed the pipeline and observed its physical condition all the way through the internal battery limits of the incineration system until it entered the incinerator. It seemed to be in good physical condition. Similarly, the HF absorption tower and scrubber seemed to be in good condition with some parts needing updating or replacement.

At the conclusion of our discussions, FIASA agreed to provide the Secretariat with following documents:

- A listing of the equipment and estimate of capital investment needed to restore the incinerator to working condition
- A bid from SGL Carbon Group to restore the incineration system
- Bids from 2 local engineering firms to restore the incineration system.

FIASA has kindly provided its listing of equipment and estimate of capital investment needed for the restoration; attached as Annex 2. However, to date the other bids have not been received.
In the absence of the other independent bids, and to keep the project on schedule, Wakim Consulting reviewed FIASA's list. It is comprehensive and helpful. A summary of the major improvements to the incineration system follows.

- Replacement of storage tanks and pumps
- Replacement of secondary scrubber
- Updating the Pressure Swing Oxygen Adsorption system (PSA)
- Updating the nitrogen stream from the PSA unit to replace purchased nitrogen used as inert gas
- Updating incineration system software and DCS
- Updating the reverse osmosis system
- Updating system for monitoring combustion gases
- Inclusion of contingency in estimating total investment needed to restore the incineration system

FIASA's estimate of total investment needed for the restoration is US$ 897,840.

Under normal conditions, for an investment of this magnitude, 3 independent bids would be required.

Wakim Consulting suggests that FIASA's requested upgrades will improve the efficiency of the incineration system and reduce the cost incurred per metric ton of HFC-23 destroyed. Therefore, in the absence of independent bids for the capital investment, we used FIASA's capital investment estimate to determine HFC-23 destruction costs at FIASA's incineration facility.

HFC-23 DESTRUCTION COSTS ONSITE FIASA'S RESTORED INCINERATION FACILITY

To estimate the cost of incinerating HFC-23 at the FIASA plant, Wakim Consulting applied the same methodology used over the last 20 years for the Secretariat; including the most recent project presented to the Executive Committee in its 80th meeting in Montreal earlier this year.

The present study is a site specific study based on cost element data kindly provided by FIASA. As is often the case in such studies, any additional values needed were acquired from our extensive knowledge base.

The incinerator was not in operation in 2017; however, if it was, the cost elements provided by FIASA such as cost of: Consumables, utilities, labor, plant overhead, etc. would have applied to the incinerator. Then it is reasonable to apply the capital investment estimated by FIASA for a restored incinerator to create a hypothetical incinerator and assume it was in operation in 2017. Under this scenario, the HFC-23 incineration cost estimates for the hypothetical plant are presented in Annex 3 and summarized in Table 4.

Table 4. HFC-23 Incineration Cost Estimates in 2017

FIASA HFC-23 Incineration Cost Estimate		**Benchmark Destruction Cost**			
2017 Average		**Restored Incineration System**			
Raw Material and Utility Costs	**Unit Cost**		**Consumption**		**US$/mt**
Raw Materials					
Additives: Reverse Osmosis	9160.00	US$/mt	0.000298	mt/mt	2.73
Cooling water dispersant	3890.00	US$/mt	0.003810	mt/mt	14.82
Cooling water biocide	2,510.00	US$/mt	0.000631	mt/mt	1.58
Zeolite for PSA O2 Plant					3.50
By-Product Revenue					
Dilute By-Product HF (50%)	177.20	US$/mt	1.75	mt/mt	310.10
Net Raw Material Cost					**-287.47**
Utilities					
Scrubber demineralized water	3.5	US$/mt	0.75	mt/mt	2.63
Purchased municipal water	0.75	US$/mt	36	mt/mt	27.00
Cooling Water	0.125	US$/mt	120	mt/mt	15.00
Electricity	0.1006	US$/kwh	462.5	kwh/mt	46.53
Process Steam Consumption	0	US$/mt	0	mt/mt	0.00
Natural Gas	0.1949	US$/$Nm^3$	511.37	Nm^3/mt	99.67
O2 97% from PSA Plant					0
N2 Inert blanket gas from PSA Plant					0
Net Utility Cost					**190.82**
Variable Cost					**-96.65**

Table 4 (Continued). HFC-23 Incineration Cost Estimates in 2017

Capacity mt/y	600
mt/y Destroyed	35
Investment	
US$ millions	
Battery Limits	0.8978
Off-Sites	0
Total Fixed Capital	0.90
Destruction Cost	**US$/mt**
Net Raw Materials	-287.5
Net Utilities	190.8
Variable Costs	**-96.7**
Operating Days	41.7
Maintenance Materials	48.6
Operating Supplies	52.7
Operating Labor	526.9
Maintenance Labor	48.6
Control Laboratory	26.3
Total Variable + Direct Costs	689.3
Indirect Costs	
Plant Overhead	361.1
Insurance	19.4
Plant Gate Cost	1,069.8
G&A, Sales, R&D	32.1
Eligible Destruction Cost	**1,101.9**
Total Destruction Cost	
At 100% Capacity	**1,101.9**
At 75% Capacity	1,473.9
At 50% Capacity	2,217.7

The incineration cost estimates presented in Table 4 are based on our recommendations mentioned above (page 9). **Incinerator starts operating at 50 percent of design capacity with a cryogenic tank full of HFC-23 in a blocked out mode until the HFC-23 is destroyed; typically about 41.7 days and shut down in an orderly manner as recommended by the manufacturer.** Then the cycle is restarted when the cryogenic tank is full in about 6 months**.**

Our recommended blocked out operation of the incinerator allows FIASA to perform any needed planned maintenance work on the incinerator and HCFC-22 plants without interference with the operation of both plants; thus minimizing incinerator start-up and shut downs and minimizing the cost of destroying HFC-23 to about US$ 1.10 per kilogram.

HFC-23 DESTRUCTION COST OFF-SITE IN ARGENTINA

Wakim Consulting presented to the Executive Committee in its 80th Meeting in Montreal alternative incineration technologies for destroying HFC-23 including rotary cement kilns. Subsequently, the Secretariat identified ECA region approved projects that incinerated HFC's including HFC-23 in rotary kilns. Specifically, HFCs, including HFC-23, from the region have been incinerated in rotary kilns in Poland and Germany. Also, successful ODS destruction pilot tests were performed at the cement kiln of Holcim Mexico Tocoman Plant on behalf of UNIDO. The cement kiln undertook a test burn that demonstrated that 99.99 per cent DRE of the waste including HFC-134a.

The cost of incinerating HFCs in the Polish and German kilns ranged from 1.9 to 2.5 US$ per Kilogram of HFC-23.

With the assistance of representatives of the Government of Argentina and FIASA, we found that "Cementos Avellaneda" owns a cement kiln located 163 kilometers from FIASA in San Luis Province. An aerial photo of the plant is presented in Annex 4.

The Government of Argentina classifies HFC-23 destined for destruction as a hazardous waste. Consequently, it must be transported on federal (and not provincial) roads by an entity registered to transport hazardous waste.

To incinerate HFC-23 in Cementos Avellaneda cement kiln, the following issues need to be addressed:

- **Technical feasibility**: Similar cement kilns have incinerated HFCs, including HFC-23, in Poland and Germany in ODS destruction projects funded by the MLF; and Holcim Mexico cement kiln also incinerated HFCs. Therefore, it is technically feasible to use Cementos Avellaneda's cement kiln for the same application. However, it is likely that the government of Argentina and the Province of San Luis may require Cementos Avellaneda to perform a test burn to demonstrate that 99.99 percent destruction of HFC-23 is possible in its cement kiln.

- **Logistical issues**: Cementos Avellaneda Cement Kiln is only 163 kilometers from FIASA's plant; the distances HFCs in Europe and Mexico were shipped to the incineration sites were significantly larger. Therefore, logistically it is feasible to transport HFC-23 from FIASA's plant to the incineration site. However, a permit to transport HFC-23 cylinders over the highways may be required by the governments of Argentina and San Luis Province. A note for the record, similar sized cylinders containing anhydrous hydrogen fluoride are presently transported on highways in San Luis and other provinces all the way to Buenos Aires.

- **Cost Issues:** FIASA is presently transporting cylinders of HCFC-22 overland and kindly provided us with the freight rates and distances. Using this data, we calculated the average freight rate per ton-kilometer; and used this value to estimate the freight costs for transporting HFC-23 163 kilometers from FIASA's plant to Cementos Avellaneda Cement Kiln.

We then estimated the cost of incinerating HFC-23 in similar cement kilns. The findings are presented in Table 5.

Table 5. Estimate of HFC-23 Destruction in Cementos Avellaneda Cement Kiln

HFC-23 Destruction Cost Estimate Off-site in Argentina Cementos Avellaneda Cement Kiln, San Luis Province: Distance from FIASA is 163 Km			
Gross Wt Kg	**Net Wt Kg**	**Freight US$**	**US$/mt HFC-23**
14,360	8,620	405	47
Incineration Cost			1,000
Total Destruction Cost Estimate			**1,047**

The results indicate that HFC-23 incineration cost at Cementos Avellaneda kiln is expected to be around US $1.05. This is lower than incineration costs at the kilns in Poland and Germany for the following reasons:

- Proximity of the Kiln to FIASA's HCFC-22 Plant (163 Km)
- Transportation efficiency; from second trip onwards, truck carries full HC-23 container on outbound leg from FIASA and returns with empty container
- The HFC-23 stream consists of about 93% HFC-23 and balance is mostly HCFC-22.
- No crossing of international or provincial boundaries

In addition to the costs above, FIASA would have to purchase two isotanks to transport the HFC-23 from its facility to the cement kiln. HFC-23 is a high pressure gas, with a vapor pressure of about 681 PSI at 25 C. Therefore, for safety considerations, typical pressure rating of isotanks used for shipping HFC-23 is around 2,400 PSI. To withhold the high pressure the tare weight of the isotank can be 1 to 1.5 times the weight of the HFC-23 it contains; and the cost of each isotank is about US$ 230,000.

EXPORTING HFC-23 FOR INCINERATION AT AN OFF-SITE FACILITY OVERSEAS

HFC-23 destined for export for destruction is considered a hazardous waste under rules and regulations of Argentina, and would therefore trigger restrictions and obligations under the Basel Convention. In such a case, the Government of Argentina considers that prior informed consent would be needed from both the country to which the waste was being exported to, and any transit countries through which the waste is shipped.

The process of obtaining the necessary permits is onerous; however, it has been used for all other shipments of hazardous waste from Argentina that fall under the Basel Convention. The MLF has some experience in exporting waste for destruction in accordance with the Basel Convention; for example, the MLF funded ODS destruction projects in Ghana, the ECA region, and Turkey that included transportation of ODS waste.

FIASA's HFC-23 is expected to be transported from Villa Mercedes to Buenos Aires Port (after obtaining the appropriate permits). After obtaining prior informed consent from Mexico; it is then loaded on ships travelling directly to Tampico port in Mexico. It will then be transported from Tampico to Monterrey, a distance of about 454 kilometers by land (after obtaining the appropriate permits).
With the Plasma Arc Incinerator owner's concurrence, the HFC-23 can be incinerated and the empty isotanks returned to FIASA for follow-up use.

Assuming that the appropriate formalities are agree to by all stakeholders, Wakim Consulting estimated the HFC-23 destruction costs at a plasma arc incinerator in Monterrey Mexico. Wakim used the costs of incineration at the Monterrey facility as reported in document UNEP/OzL.Pro/ExCom/80/12. In addition to the costs below, capital costs of US$ 460,000 would be required to purchase two isotanks to transport the HFC-23 to and from the incinerator. The results are presented in Table 6.

Table 6. HFC-23 Destruction Cost Estimates at Plasma Arc Incinerator in Monterrey Mexico

HFC-23 Destruction Cost Estimate Off-site in Mexico Plasma Arc Incinerator: Monterrey, Mexico			
Gross Wt Kg	Net Wt Kg	Freight US$	US$/mt HFC-23
16,200	9,000		
FIASA to Buenos Aires		1,865	207
Buenos Aires to Tampico Port		1,160	129
Tampico Port to Monterrey		1,865	207
Subtotal Freight		**4,890**	**543**
Isotank return to FIASA		**4,890**	**543**
Total Freight			**1,086**
Plasma Arc Incineration Cost			**7,400**
Total Destruction Cost Estimate			**8,486**

The results indicate that the transportation cost alone (about US$ 1.09 per kg of HFC-23) is of the same order of magnitude as the total destruction cost at FIASA's hypothetical restored incinerator or the San Luis cement kiln.

Our research indicates that the operating cost for plasma arc incineration is significantly higher than that of the restored FIASA incinerator. Obviously, the final actual costs will be those negotiated between FIASA and the HFC-23 incinerating company. With that said, we believe that the total incineration cost for HFC-23 from Argentina using a plasma arc incinerator in Mexico will be significantly higher than at FIASA; or at a cement kiln in San Luis, Argentina.

A similar argument can be made for attempting to incinerate HFC-23 from Argentina at incineration facilities in China, India or Europe.

CONCLUSIONS

The cost to refurbish the onsite incinerator, as provided in FIASA's estimate, is US$ 897,840. Annual operating costs for the on-site incinerator vary between US$ 133,379 and US$ 29,131, depending on HFC-23 generation ratio and incineration cost per kilogram of HFC-23, between 2019 and 2024; and between US $112,011 and US$ 24,464 between 2025 and 2029 (see Annex 5). The cost of two high-pressure isotanks, which would be needed for either of the off-site destruction options, is US$ 460,000. Similarly, annual destruction costs at the San Luis cement kiln, including transportation, vary between US$ 62,990 and US$ 27,677 between 2019 and 2024, and between US$ 52,898 and US$ 23,243 between 2025 and 2029. Annual destruction costs at the plasma arc incinerator in Mexico, including transportation, vary between US$ 510,535 and US$ 224,326 between 2019 and 2024, and between US$ 428,738 and US$ 188,385 between 2025 and 2029.

Therefore, Wakim Consulting concludes that the remaining semi-finalists in this competition are FIASA's restored incineration system and the cement kiln in San Luis. The final winner will be determined as a result of the negotiations between FIASA and the cement kiln owners. With a restored incineration system, FIASA can be as successful as numerous HCFC-22 producers elsewhere without CDM support.

ANNEXES

ANNEX 1 SGL CARBON GROUP OPERATING MANUAL
ANNEX 2 FIASA'S ESTIMATE OF CAPITAL INVESTMENT
ANNEX 3 HFC-23 INCINERATION COST ESTMATE
ANNEX 4 SAN LUIS CEMENT KILN
ANNEX 5 ARGENTINA ASSUMED HCFC-22 PRODUCTION AND ESTIMATED HFC-23 DESTRUCTION COSTS

12 Normal Operating Data

Warranty capacity 70 kg/h HFC 23 / 22
Equipment design capacity 77 kg/h HFC 23 / 22
Instruments design capacity 77 kg/h HFC 23 / 22

Exceeding capacity 77kg/h releases SGL Carbon from all warranty obligations.

In case of any queries concerning warranty/damages of the reaction unit we recommend to record the main process data electronically. Only this can be accepted to prove correct operation by SGL CARBON (Data logger, DCS...).

Methane (97,0% dry); Oxygen (99,7% dry); HFC 23 / 22 (92% / 3% dry)

Controller Mode	Design Capacity	Capacity HF100%	HFC23 FIC802	HFC23 FIC802	CH4 FI804b	Oxygen FI801	Abs. Water FI805	Product Acid 50 wt%	Product Acid 50 wt%	Oxygen Excess
	%	kg/h	kg/h	Nm3/h	Nm3/h	Nm3/h	kg/hr	m3/h	kg/h	Vol. %
	Start	0,0	0,0	0,0	10,0	30,0	12,0	----	----	100
manual	15%	8,4	10,5	3,4	10,0	30,0	12,0			
manual	36%	20,2	25,2	8,1	10,0	30,0	12,1	0,0	40,3	
automatic	**36%**	**20,2**	**25,2**	**8,1**	**9,5**	**25,2**	**12,1**	**0,027**	**40,3**	**14**
automatic	40%	22,4	28,0	9,0	10,6	28,0	13,4	0,030	44,8	14
automatic	50%	28,0	35,0	11,2	13,2	35,0	16,8	0,038	56,0	14
automatic	60%	33,6	42,0	13,4	15,8	42,0	20,2	0,045	67,2	14
automatic	70%	39,2	49,0	15,7	18,5	49,0	23,5	0,053	78,4	14
automatic	80%	44,8	56,0	17,9	21,1	56,0	26,9	0,060	89,6	14
automatic	90%	50,4	63,0	20,2	23,8	63,0	30,2	0,068	100,8	14
automatic	**100%**	**56,0**	**70,0**	**22,4**	**26,4**	**70,0**	**33,6**	**0,075**	**112,0**	**14**
automatic	110%	61,6	77,0	24,6	29,0	77,0	37,0	0,083	123,2	14

Annex 2 - FIASA Estimate of Capital Investment Needed to Restore the Incinerator

Item	Descripción		U$S	Description File: Capital-Inv
Valvulas agujas de 1/2	Son unas 12		8,000	**Needle valves, there are 12**
Mirilla incinerador cuarzo revestido	Son dos		1,000	There are 2
Vidrio de fluoruro de calcio proteccion detector de llama	Son dos		2,500	**Flame detectors, there are 2**
Agua de enfriamiento	Manometro entrada	PG804	500	Input manometer
	Medidor de caudal switch	FIS812	2,000	Flow meter switch
	Temperatura entrada	TI800	500	Entry temperature
	Temperatura salida	TI805	500	Output temperature
Solución HF diluido (50%) y HCl	Temperatura solucion HF recirculada	TI803		Recycled HF solution temperature
	Rotametro teflonado con salida 4-20mA y switch de caudal teflonado	FISAL8012	5,000	Teflon rotameter with 4-20mA output and teflon flow switch
	Bomba acido acople magnetico teflonada	P800A y P800B	9,000	Teflon-shaped magnetic coupling acid pump
	Manometro sello HF y HCl	PG805 y PG806	3,000	Manometer seal HF and HCl
	Válvula salida de solución HF de la planta	LV800	7,500	HF solution outlet valve for the plant
	Medidor de densidad comuesto por tres elementos	AT800 T802 AIC800	12,500	Density meter composed of three elements
	Valvula ingreso agua osmosis scrubber primario	FV805	7,500	Valve entry water osmosis scrubber primary
	Medidor cauda ingreso agua a scrubber primario	FT805	4,000	Primary scrubber acid temperature output 4-20mA
	Temperatura acido scrubber primario salida 4-20mA	TT804	1,500	Primary scrubber acid temperature output 4-20mA
	Bomba acido acople magnetico teflonada	P800A y P800B	18,000	Teflon-shaped magnetic coupling acid pump
	Filtro Y acero revestido teflon y filtro teflonado para bombas P800		4,000	Filter and steel coated with teflon and teflon filter for P800 pumps

Annex 2 - FIASA Estimate of Capital Investment Needed to Restore the Incinerator

Item	Descripción		U$S	Description
	Reemplazo tk 800 revestido en hard rubber	TK800	35,000	Replacement tk 800 coated with hard rubber
	Reemplazo tk stock de HF 50%. Tk PRFV revestido en PVDF		40,000	Stock replacement of HF 50%. Tk PRFV coated in PVDF
	Bomba neumatica para HF salida tanque stock		10,000	Pneumatic pump for HF output tank stock
	Radar nivel TK800	LT800	3,900	Radar level TK800
	Radar tanque stock		3,900	Radar tank stock
	Medidor switch para alto nivel TK800 (tipo orquilla vibrante)	LSAH801	3,250	TK800 high level switch meter (vibrating shoe type)
	Medidor switch para alto nivel TK800 (tipo orquilla vibrante)	LSAL801	3,250	TK800 high level switch meter (vibrating shoe type)
Scrubber de seguridad	Scrubber secundario la torre propiamente dicha	T801	90,000	Secondary scrubber the tower itself
	Rotametro teflonado con salida 4-20mA y switch para agua osmosis	FIAL801	3,500	Teflon rotameter with 4-20mA output and osmosis water switch
	Nivel switch bajo nivel (tipo orquilla vibrante) para acido	LSAL802	3,250	Low level switch level (vibrating fork type) for acid
	Bomba acido acople magnetico teflonada	P801A y P801B	28,000	Teflon-shaped magnetic coupling acid pump
	Filtro Y acero revestido teflon y filtro teflonado para bombas P801		4,700	Filter and steel coated teflon and teflon filter for pumps P80
	Manometro con sello para acido entrada recirculacion a T801	PG809	1,500	Manometer with seal for acid recirculation to T801
	Manometro sello HF y HCl salida bombas P801	PG807 y PG808	3,000	Manometer with seal HF and HCl for output pumps P801
Metano	Transmisor de caudal	FT804b	4,000	Flow transmitter
	Valvula de control de metano	FV804b	5,000	Methane control valve
	Valvula bloqueo metano	XV805b	2,500	Methane block valve
	Válvula de venteo	XV809b	1,200	Venting valve
	Presostato alta presión metano	PS802b	500	High pressure methane pressure switch
	Presostato baja presion metano	PS805b	500	Pressure switch low methane pressure

Annex 2 - FIASA Estimate of Capital Investment Needed to Restore the Incinerator

Item	Descripción		U$S	Description
	Presostato prueba fuga	PS809b	500	Pressure test switch
Alimentación R23	Caudal R23	FT802	9,000	Flow rate R23
	Valvula caudal R23	FV802	3,500	Flow valve R23
	Valvula bloqueo	XV802	1,500	Lock valve
	Manometro con switch presión de entrada	PIS801	1,000	Pressure gauge with input pressure switch
Oxigeno	Zeolita PSA		8,000	Zeolite PSA
	Válvulas del PSA (8 de ellas)		12,000	PSA valves (8 of them)
	Reacondicionamiento compresor y secador PSA		5,000	Reconditioning compressor and dryer PSA
	Medidor de concentracion		2,000	Concentration meter
	Medidor caudal Oxigeno	FT801	4,000	Oxygen flow meter
	Manometro con switch	PIS801	1,000	Manometer with switch
	Válvula ingreso oxigeno	FV801	4,000	Oxygen inlet valve
	Válvula bloqueo	XV801	1,500	Lock valve
Sistema ignición y control de llama	Detector de llama D-LE 603	XSA800	4,500	Flame detector D-LE 603
	Monitor de llama D-UG 660		6,000	Flame monitor D-UG 660
	Unidad neumatica D-VE 500		4,500	Pneumatic unit D-VE 500
	Quemador de repuesto		12,000	Spare burner
	Chispero	BX800	5,000	Spark igninter, lighter
	Sensor chispero posicion base	GOS800	400	Base position spark sensor
	Sensor chipero posicion chispa	GOS801	400	Spark sensor position spark
	Válvula ingreso chispero	XV808	8,000	Spark entry valve
	Sensor final de carrera válvula ingreso chispero	GOS808	800	Final limit switch valve igniter
Nitrogeno	Válvula purga línea metano	XV804	2,500	Methane line purge valve
	Válvula purga línea oxigeno	XV800	2,500	Oxygen line purge valve
	Válvula purga línea quemador	XV807	2,500	Purge line burner line
	Rotametro con switch medicion caudal purga nitrogeno línea metano	FIS803	3,000	Rotameter with metering switch flow rate nitrogen purge methane line
	Rotametro con switch medicion caudal purga nitrogeno línea oxigeno	FIS800	3,000	Rotameter with switch flow measurement nitrogen purge oxygen line

Annex 2 - FIASA Estimate of Capital Investment Needed to Restore the Incinerator

Item	Descripción		U$S	Description
	Conectores para llevar nitrogeno (20)		2,500	**Connectors for carrying nitrogen (20)**
	Rotametros medicion caudal permanente de nitrogeno (6) F1806, F1807, F1808, F1809, F1810	FI813	6,000	**Rotameters measurement of permanent flow of nitrogen (6)**
Sistema disco ruptura	Detector rotura disco	PSE800	1,000	Disc break detector
	Soporte disco de ruptura con entrada para N2 y el sensor		2,500	Support rupture disk with input for N2 and sensor
	Disco de ruptura		650	Break disk
Sistema de control	Posibilidad de que tenga que venir gente de SGL a cargar nuevamente el software	Control system	40,000	**Possibility that SGL people have to come to load the software again**
			9,500	
Contenedores para a despacho del acido	Se necesitan contenedores para acido producido. Es necesario cambiar el Stock completo de los mismos		15,000	Need of containers for the acid produced. It is necessary to change the whole stock.
Iluminación en toda la planta	Es necesario un sistema de iluminación nuevo		5,000	It is necessary to get a new lighting system
Medidor gases de la combustion			55,000	**Guages to monitor combustion gases**
Osmosis			50,000	**Reverse osmosis system**
			10,000	
Sistema DCS para mejorar la interfase con el Operador			35,000	DCS System
Trabajo sobre la estructura	Arreglos y pintura general de estructura de la planta		10,000	General arrangements and painting of the structure of the plant
PC operadores de planta			500	
Generador Nitrogeno	**Opcional a utilizar nitrogeno liquido a granel. Compresor, secador equipo mebrana o PSA**		40,000	**Optional to use liquid nitrogen in bulk. Compressor, dryer mebrana or PSA**
Safe Rings	Para proteger de perdidas en las uniones bridadas		6,000	To protect from losses in flanged joints
Equipos de respiracion autonomo			2,500	
Traje clase A			5,000	
Varios			10,000	
		Total US$	748,200	**Total Investment**
		20% Contingency	149,640	**897,840**

Annex 3 - FIASA HFC-23 Incineration Cost Estimate for Restored System

FIASA HFC-23 Incineration Cost Estimate			**Benchmark Destruction Cost**		**$US/mt**	**Capacity mt/y**	600
2017 Average			**Restored Incineration System**		1,500	**mt/y Destroyed**	35
Raw Material and Utility Costs	**Unit Cost**		**Consumption**		**$US/mt**	**Investment**	
Raw Materials						**US$ millions**	
Caustic Soda NaOH	$US/ mt	$US/mt	0.0000	mt/ mt	0.00	**Battery Limits**	0.8978
Additives: Reverse Osmosis	9160.00	$US/mt	0.000298	mt/ mt	2.73	**Off-Sites**	0
Cooling water dispersant	3890.00	$US/mt	0.003810	mt/ mt	14.82	**Total Fixed Capital**	0.90
Cooling water biocide	2,510.00	$US/mt	0.000631	mt/ mt	1.58		
Zeolite for PSA O2 Plant					3.50	**Destruction Cost**	**$US/mt**
By-Product Credits						**Net Raw Materials**	-287.5
Dilute By-Product HF (50%)	177.20	$US/mt	1.75	mt/ mt	310.10	**Net Utilities**	190.8
Net Raw Material Cost					**-287.47**	**Variable Costs**	**-96.7**
Utilities							
Scrubber demineralized water	3.5	$US/ mt	0.75	mt/ mt	2.63	**Operating Days**	41.7
Purchased municipal water	0.75	$US/ mt	36	mt/ mt	27.00	Maintenance Materials	48.6
Cooling Water	0.125	$US/ mt	120	mt/ mt	15.00	Operating Supplies	52.7
Electricity	0.1006	$US/ kwh	462.5	kwh/ mt	46.53	Operating Labor	526.9
Process Steam Consumption	0	$US/ mt	0	mt/ mt	0.00	Maintenance Labor	48.6
Natural Gas	0.1949	$US/ Nm^3	511.37	Nm^3/ mt	99.67	Control Laboratory	26.3
O2 97% from PSA Plant					0		
N2 Inert blanket gas from PSA Plant					0	**Total Variable+Direct Costs**	689.3
Net Utility Cost					**190.82**	**Indirect Costs**	
Variable Cost					**-96.65**	Plant Overhead	361.1
						Insurance	19.4
						Plant Gate Cost	1,069.8
						G&A, Sales, R&D	32.1
						Eligible Destruction Cost	**1,101.9**
						Total Destruction Cost	
						At 100% Capacity	**1,101.9**
						At 75% Capacity	1,473.9
						At 50% Capacity	2,217.7

Annex 4

Cementos Avellaneda Cement Plant San Luis Province Argentina
Ruta 35 Km 13, D5719XBX La Calera

Annex 5 - Argentina Assumed HCFC-22 Production and Estimated HFC-23 Destruction Costs

Assumed Annual HCFC-22 Produced and Cost of Destroying HFC-23 Generated

Based on US$/kg HFC-23 destruction targets, HFC-23 Generation Rates, and IOC US$/kg

Location: FIASA		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
IOC (US$/kg HFC-23 Destroyed)	Assumed HCFC-22 production (mt)	1,823	1,823	1,823	1,823	1,823	1,823	1,531	1,531	1,531	1,531	1,531
		US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt	US$/mt
2.217	3.3% HFC-23	133,379	133,379	133,379	133,379	133,379	133,379	112,011	112,011	112,011	112,011	112,011
1.102	generation rate	66,299	66,299	66,299	66,299	66,299	66,299	55,677	55,677	55,677	55,677	55,677
2.217	2.0% HFC-23	80,836	80,836	80,836	80,836	80,836	80,836	67,885	67,885	67,885	67,885	67,885
1.102	generation rate	40,181	40,181	40,181	40,181	40,181	40,181	33,744	33,744	33,744	33,744	33,744
2.217	1.45% HFC-23	58,606	58,606	58,606	58,606	58,606	58,606	49,217	49,217	49,217	49,217	49,217
1.102	generation rate	29,131	29,131	29,131	29,131	29,131	29,131	24,464	24,464	24,464	24,464	24,464

HCFC-22 Production in 2030 = 0 HCFC-22 Base line <2025 = mt 4,082.73 HCFC-22 Base line >2025 = mt 1,531.02

w% H 3.3 3.3 w% M = 2.0 w% L = 1.45

Location: San Luis Cement Kiln

HFC-23 Produced Based on HCFC-22 Production - HFC-23 Generation Rates - and Incineration Cost at IOC of $/kg HFC-23 = 1.047

HFC-23 Gen Rate%	**Assumed HCFC-22 Production, mt**	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
		1,823	1,823	1,823	1,823	1,823	1,823	1,531	1,531	1,531	1,531	1,531
3.30	HFC-23 Gen mt	60.16	60.16	60.16	60.16	60.16	60.16	50.52	50.52	50.52	50.52	50.52
	US$/mt	62,990	62,990	62,990	62,990	62,990	62,990	52,898	52,898	52,898	52,898	52,898
2.00	HFC-23 Gen mt	36.46	36.46	36.46	36.46	36.46	36.46	30.62	30.62	30.62	30.62	30.62
	US$/mt	38,176	38,176	38,176	38,176	38,176	38,176	32,059	32,059	32,059	32,059	32,059
1.45	HFC-23 Gen mt	26.43	26.43	26.43	26.43	26.43	26.43	22.20	22.20	22.20	22.20	22.20
	US$/mt	27,677	27,677	27,677	27,677	27,677	27,677	23,243	23,243	23,243	23,243	23,243

Location: Monterrey Mexico Plasma Arc

HFC-23 Produced Based on HCFC-22 Production - HFC-23 Generation Rates - and Incineration Cost at IOC of $/kg HFC-23 = 8.486

HFC-23 Generation	**Assumed HCFC-22 Production, mt**	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
		1,823	1,823	1,823	1,823	1,823	1,823	1,531	1,531	1,531	1,531	1,531
3.30	HFC-23 Gen mt	60.16	60.16	60.16	60.16	60.16	60.16	50.52	50.52	50.52	50.52	50.52
	US$/mt	510,535	510,535	510,535	510,535	510,535	510,535	428,738	428,738	428,738	428,738	428,738
2.00	HFC-23 Gen mt	36.46	36.46	36.46	36.46	36.46	36.46	30.62	30.62	30.62	30.62	30.62
	US$/mt	309,415	309,415	309,415	309,415	309,415	309,415	259,841	259,841	259,841	259,841	259,841
1.45	HFC-23 Gen mt	26.43	26.43	26.43	26.43	26.43	26.43	22.20	22.20	22.20	22.20	22.20
	US$/mt	224,326	224,326	224,326	224,326	224,326	224,326	188,385	188,385	188,385	188,385	188,385