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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Eighty-first Meeting
Montreal, 18-22 June 2018

# KEY ASPECTS RELATED TO HFC-23 BY-PRODUCT CONTROL TECHNOLOGIES (DECISIONS 78/5(E), 79/17(B), 79/47(E) AND 80/77(B))

## Background

1. At the 79th meeting, the Executive Committee requested the Secretariat to contract an independent consultant to undertake an evaluation of cost-effective and environmentally sustainable options of HFC-23 destruction from HCFC-22 production facilities and submit this report to the 81st meeting.

2. The scope of the evaluation would include:

(a) An assessment of the costs of incineration at an on-site destruction facility, based on characteristics of the facility, including destruction capacity, quantity and frequency of HFC-23 to be destroyed, the expected remaining lifetime, location, and other relevant factors, including:

(i) Start-up costs for destruction facilities that might currently be in disuse;

(ii) Costs to install a new destruction facility if one was not currently installed;

(iii) Costs to operate a currently installed facility;

(b) An assessment of the costs of incineration at an off-site destruction facility, including collection, transportation and incineration, based on the quantity of HFC-23 to be destroyed, location, and other relevant factors;

(c) An assessment of the cost of destroying emissions of HFC-23 by-product through irreversible transformation and other new technologies, where information was available, based on the quantity of HFC-23 to be destroyed, location, and other relevant factors;

(d) An assessment of the costs and measures to optimize the HCFC-22 production process to minimize the HFC-23 by-product generation rate and maximize the collection of HFC-23 by-product for destruction based on characteristics of the facility, including capacity, quantity of HFC-23 by-product generated, the expected remaining lifetime, location, and other relevant factors;

(e) An assessment of the costs of different monitoring and verification methods; and

(f) An assessment of how the performance and costs of different destruction technology options would vary according to local conditions and the quantity of HFC-23 by-product to be destroyed.

Additional information related to HFC-23 requested by the Executive Committee

3. The Executive Committee requested the World Bank to submit the draft final report of the investigation on reducing HFC-23 by-product ratio using best practices to the 81st meeting (decision 79/17(b)). The summary of the report submitted by the World Bank is contained in Annex II of the present document.

4. The Executive Committee invited all relevant HCFC-22-producing Article 5 countries to provide to the Secretariat, on a voluntary basis, information relevant to the evaluation by 30 September 2017 (decision 79/47(f)), and subsequently extended to 1 December 2017 (decision 80/77(b)). At the time of finalization of the present document, no such information was submitted.

5. The Executive Committee requested the Secretariat to continue to explore whether there were HFC- or other HCFC-producing facilities in any party that generated HFC-23 emissions (decision 78/5(e)). The Secretariat undertook a review of the scientific literature, consulted with experts from the implementing agencies, and other organizations.[1] Based on that review, the Secretariat did not identify any production facilities other than those that produce HCFC-22 that generate HFC-23 by-product. The Secretariat notes that HCFC-22 is used as a feedstock in the production of other chemicals.[2] Integrated production facilities that generate HCFC-22 as an intermediate for the production of other chemicals would also generate HFC-23-by-product; however, that by-product is generated during the reaction to produce the HCFC-22 intermediate, rather than subsequent reactions between HCFC-22 and other chemicals to produce the desired product.

Secretariat's comments

6. In line with United Nations rules and regulations, a vacancy position for the consultancy was posted to Inspira and a link to the job posting and the terms of reference (TOR) for the position were advertised on the Secretariat's website. The consultant selected traveled to Montreal for in-depth discussions with the Secretariat on the methodology to respond to the TOR, and engaged in regular consultations with the Secretariat throughout the report-writing process. The Secretariat undertook an extensive review of the consultant's report, which is contained in Annex I to the present document. To facilitate the Executive Committee's review, the following section, which was reviewed by the consultant, summarizes the main conclusions of the report.

[1] Including Öko-Recherche, an independent environmental research institution and consultancy located in Germany.

[2] The largest use of HCFC-22 is as a feedstock in the production of tetrafluoroethylene (TFE); it can also be used as a feedstock in the production of HFC-4310mee, HFC-227ea, HFC-32, HFE-347pcf, HFE-7100, HCFE-235da2, HFE-236ea2, and possibly other chemicals. The Secretariat has no information on the prevalence of the use of HCFC-22 as a feedstock of those other chemicals.

*Cost of incineration at an on-site destruction facility*

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

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

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

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

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

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

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

*Cost of incineration at an off-site destruction facility*

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

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

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

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

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

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

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

9. Four technologies were assessed: pyrolysis of HFC-23 into carbonyl fluoride ($COF_2$); iodization of HFC-23 into trifluoroiodomethane ($CF_3I$);[3] conversion to HCFC-22, vinylidene difluoride (VDF), or TFE and hexafluoropropylene (HFP);[4] and chemical reaction with hydrogen and carbon dioxide.[5] 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*

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

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

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

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

[5]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

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

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

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

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

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

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

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

*Costs of different monitoring and verification methods*

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

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

*Costs of different destruction technologies*

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

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

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

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

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

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

17. The Secretariat notes that the Parties have not yet approved any technologies for destruction of HFC-23. If the Parties were to approve the use of destruction technologies with a destruction and removal efficiency below 99.99 per cent, (perhaps for a limited period of time), this could allow those facilities to

use the more cost-effective destruction technologies identified, such as cement kiln oxidation and horizontal rotary-fired oxidation kiln, prior to phasing out their HCFC-22 production.

*Comparison of costs with previous estimates*

18. Based on the analysis of CDM data undertaken by the Secretariat at the 79th meeting,[6] 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.

Secretariat's recommendation

19. The Executive Committee might wish to note the report on key aspects related to HFC-23 by-product control technologies (decisions 78/5(e), 79/17(b), 79/47(e) and 80/77(b)), contained in document UNEP/OzL.Pro/ExCom/81/54.

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

**Annex I**

**WAKIM CONSULTING**
***Petrochemicals, Energy & Mining***

Wakim Project 17100
28 May 2018

# HFC-23 DESTRUCTION FROM HCFC-22 FACILITIES EVALUATION OF COST - EFFECTIVE AND ENVIRONMENTALLY SUSTAINABLE OPTIONS

**Final Report**

Prepared for:

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# 1. EXECUTIVE SUMMARY

In response to the Terms of Reference, Wakim Consulting (Wakim) is pleased to present this Final Report to the Secretariat (Secretariat) of the Multilateral Fund for the Implementation of the Montreal Protocol; the report covers our evaluation of cost-effective and environmentally sustainable options for HFC-23 destruction from HCFC-22 producing facilities.

Given the specificity and specialty of the technical evaluation, the Secretariat requested Wakim to undertake the evaluation and prepare a report, in collaboration with its project review team. The findings will form the basis of the Secretariat document to be considered by the Executive Committee.

To perform the sought evaluation, Wakim, in collaboration with the Secretariat project review team, utilized the relevant background information available from previous Executive Committee decisions. Wakim also utilized information from its own extensive knowledge base of publicly available information. By so doing Wakim eliminated the need for travel to HFC-23 producing or destroying plants and reduced project costs.

Wakim's findings were presented to the Secretariat in five preliminary reports covering the five original tasks specified for this project. The preliminary reports are consolidated in this present Draft Final Report.

## FINDINGS

### Chemistry

Producers of HCFC-22 use chloroform ($CHCl_3$) and anhydrous hydrogen fluoride (HF); both products are traded internationally. Producers who own fluorspar ($CaF_2$), produce their own HF by reacting fluorspar with sulfuric acid ($H_2SO_4$).

The HF and $CHCl_3$ reaction produces predominantly HCFC-22 with small amounts of HFC-23, an undesirable by-product; producers try to minimize HFC-23 production; some HCFC-22 producers in Article 5 Parties reduced HFC-23 generation to 1.78% of HCFC-22 on a weight basis; others had ratios as high as 3.44% (Annex 21). Reductions in the by-product generation ratio below 1.78% are possible; however, HFC-23 by-product generation cannot be eliminated. A by-product generation ratio as low as 1.4% is possible given present know-how; additional research and development is needed for further advances.

### Cost estimation methodology

As costs of incineration vary by location, capacity and capacity utilization, and other factors, Wakim used a hypothetical incinerator design for its benchmark analysis. The chosen design is based on 5-year data averages obtained from CDM plants; the results are presented in Table 1.

Table 1: Incinerator Design Basis: Raw Material Consumption and By-Product Yields

| 5 Year Data | mt/mt HFC-23 |
|---|---:|
| HFC-23 destroyed | 1.000 |
| Natural Gas consumed | 0.144 |
| Electricity consumed, kwh | 1,785.6 |
| Steam consumed | 3.131 |
| Sodium hydroxide consumed | 0.150 |
| Ca(OH)2 consumed | 1.718 |
| 20% Dilute HF produced | 3.325 |

**Incinerator Capacity Selection**

HFC-23 by-product generation data was available to estimate average annual by-product generation for 17 producers: 10 in China, 5 in India, 1 in Mexico, and 1 in Argentina (Annex 21). Based on the available data, an incinerator capable of destroying 800 mt of HFC-23 was selected for the base case.

Several engineering companies such as Fluor Allied Companies (Annex 22), Nippon Steel (Annex 23), Vichem (Annex 24), Veolia Environmental (rotary kilns), Amec Foster Wheeler, John Zink Hamworthy NAO Inc. (thermal oxidizers), ATI Muller, and others have commercial incinerators for destruction of HFC-23.

Wakim Consulting chose the Fluor process for the hypothetical incineration plant for the following reasons:

- Similar plants are in operation in several countries
- It meets the specifications for HFC-23 destruction required in several countries
- It is easy to upscale or downscale incineration capacity
- Design information is available from several sources

**HFC-23 Incineration Costs at Hypothetical Onsite and Off-site HCFC-22 Plants'**

**Capital Costs**

To estimate capital costs of a new incinerator to be purchased in 2017, Wakim starts with information available from technology providers, equipment manufacturers, and other stakeholders; and applies the American Association of Cost Engineers (AACE) Model 3 to estimate capital cost for the project. The results from AACE model 3 represent a conservative capital cost estimate (high) and are usually adjusted to accommodate field conditions.

Because of the facts on the ground, the base case of 800 mt/y HFC-23 incineration capacity is flanked with 400 mt/y, 1,600 mt/y and 2,400 mt/y per year plants (Table 2). This capacity range encompasses about 95% or more of total installed HFC-23 destruction capacity in Article 5 parties.

The total fixed costs,[1] which comprise the inside and outside battery limits,[2] of a new, onsite 800 mt/y incinerator are about US$13.7 million; a 400 mt/y incinerator about US $9 million, while the 1,600 mt/y and 2,400 mt/y incinerators are estimated to cost US$21.1 million and US$27.1 million, respectively. Those estimated costs are inclusive of shipping, installation, commissioning, and all of the necessary ancillary equipment (Table 2).

Table 2: Capital Cost Estimates for Onsite HFC-23 Incinerators
(Mid-2017 Installed Basis, US$ Millions)

| Capacity (mt/y) | Inside battery limits | Outside battery limits | Total Fixed Capital Cost |
|---|---|---|---|
| 400 | 5.6 | 3.4 | 9 |
| 800 | 9 | 4.7 | 13.7 |
| 1,600 | 14.4 | 6.7 | 21.1 |
| 2,400 | 18.9 | 8.2 | 27.1 |

[1] The total fixed costs consist of site preparation, inside battery limits, off-sites, and contingency costs.

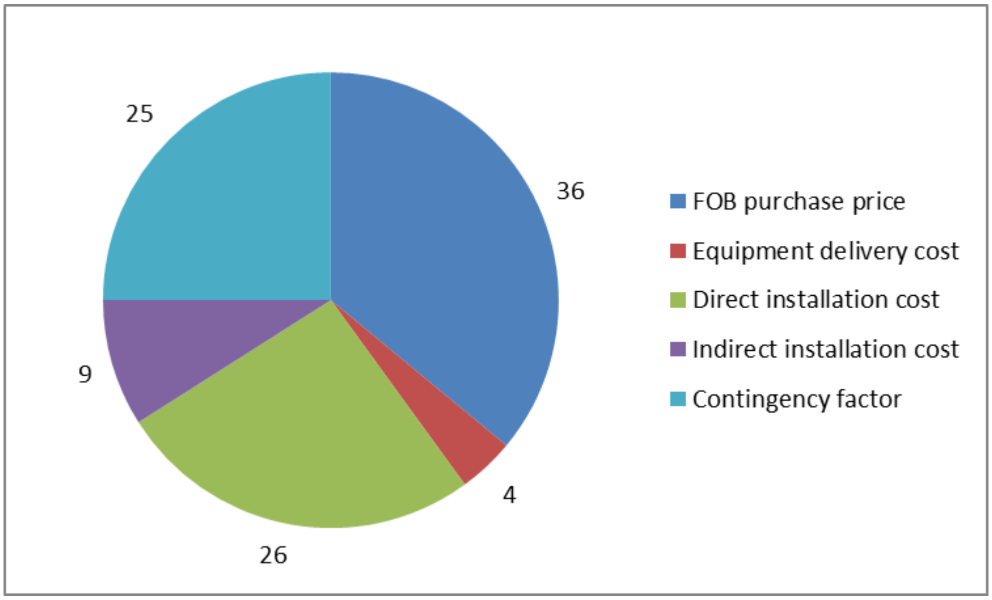
[2] Inside battery limits costs consist of procuring and installing process equipment, shipping, utilities, piping, catalysts, and other material needed for incinerator operation, and fees associated with construction, such as permits, insurance, and equipment rental. Outer battery limits (or off-site costs) are the costs associated with off-site developments such as fuel, electrical, water, inert gas and instrument air, tankage, general service facilities, security, water treatment, and emergency systems.

The segmentation of the base case total fixed cost (Chart A) indicates that the cost of equipment plus delivery is the largest cost element, accounting for 40% of total capital cost; followed by direct and indirect installation accounting for 26% and 9%, respectively. The contingency factor of 25% is usually adjusted according to conditions on the site; thus reducing total capital investment in some cases. In order to provide a lower-bound estimate of the total fixed costs, the following assumptions can be made: a 10% contingency rather than 25%, and using incinerators manufactured in China rather than imported incinerators. Those assumptions result in the following lower-bound estimates.

Table 3: Lower-bound Capital Cost Estimates for Onsite HFC-23 Incinerators
(Mid 2017 Installed Basis, US$ Millions)

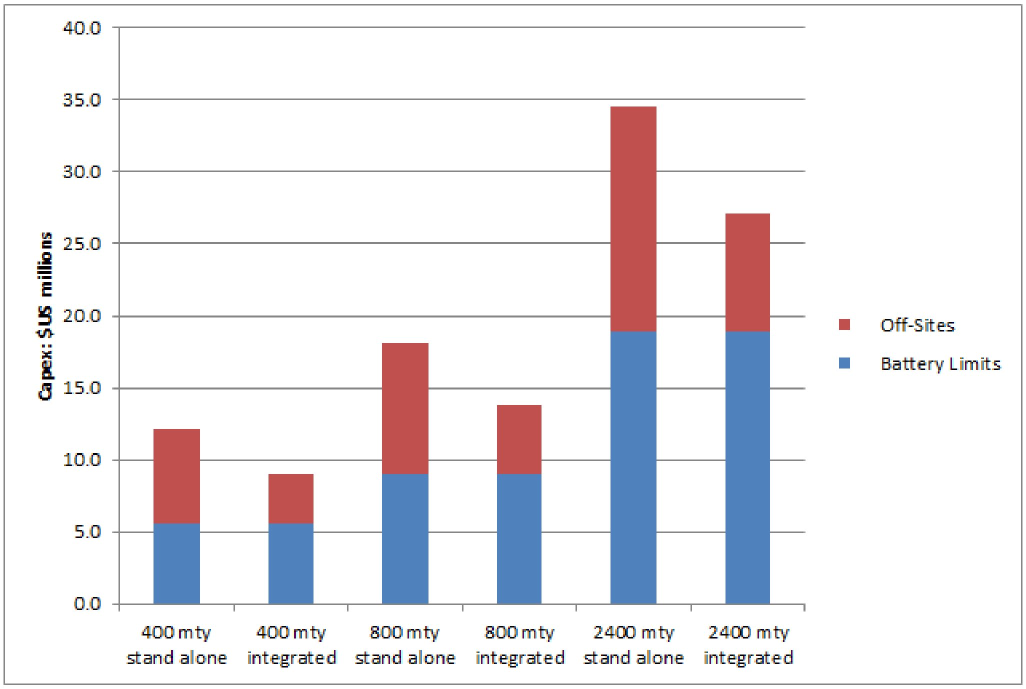
| **Capacity (mt/y)** | **Inside battery limits** | **Outside battery limits** | **Total Fixed Capital Cost** |
|---|---|---|---|
| 400 | 3.5 | 2.8 | 6.3 |
| 800 | 5.6 | 3.9 | 9.5 |
| 1,600 | 8.9 | 5.5 | 14.4 |
| 2,400 | 11.7 | 6.7 | 18.5 |

Chart A: Segmentation of Onsite Base Case Capital Cost %



A comparison of stand-alone and onsite HFC-23 plants' capital costs is presented in Chart B; and for stand-alone plants in Table 4.

Chart B




Decision 79/47(e)(ii) requested that the evaluation provide an assessment of the costs of incineration at an off-site destruction facility. The key difference between the total fixed costs of an onsite and off-site incinerator are the OSBLs; the ISBL for the two incinerators are the same. The total fixed costs of a new, off-site 800 mt/y incinerator are approximately US $18.1 million; a 400 mt/y incinerator is estimated to cost US $12.1 million, while the 1,600 mt/y and 2,400 mt/y incinerator are estimated to cost US $27.1 million and US $34.5 million, respectively (Table 4).

Table 4: Capital Cost Estimates for Stand Alone HFC-23 Incinerators
(Mid 2017 Installed Basis, $US Millions)

| Capacity (mt/y) | Inside battery limits | Outside battery limits | Total Fixed Capital Cost |
|---|---|---|---|
| 400 | 5.6 | 6.5 | 12.1 |
| 800 | 9.0 | 9.1 | 18.1 |
| 1,600 | 14.4 | 12.7 | 27.1 |
| 2,400 | 18.9 | 15.5 | 34.5 |

The differences between the costs of OSBL (off-sites) of a stand-alone and onsite base case incinerators are listed in Table 5.

Table 5

| | 800 mt/y ($US Million) | 800 mt/y ($US Million) |
|---|---|---|
| | Stand-Alone | Onsite |
| Battery Limits Investment | 8.97 | 8.97 |
| Off-Sites Installed Investment | | |
| Cooling Water | 1.10 | 0.53 |
| Process Water | 0.15 | 0.08 |
| Boiler Feed Water | 0.30 | 0.14 |
| Process Steam | 1.75 | 1.25 |
| Fuel Gas System | 0.05 | 0.03 |

| | 800 mt/y ($US Million) | 800 mt/y ($US Million) |
|---|---|---|
| | Stand-Alone | Onsite |
| Inert Gas and Instrument Air | 0.18 | 0.11 |
| Off-Sites Tankages | 0.55 | 0.18 |
| General Service Facilities | 1.05 | 0.54 |
| Waste Water Treatment | 1.25 | 0.72 |
| HFC-23 Receiving Facilities | 0.45 | 0.00 |
| Total Off-Sites | 6.83 | 3.58 |
| Off-Sites Contingency 25% | 2.28 | 1.20 |
| Total Off-Sites Capital Investment | 9.11 | 4.78 |
| Total Fixed Capital | 18.08 | 13.75 |

Segmentation of process equipment and off-sites' capital costs for the on-site plant base case in chart format are presented in Section 3; and for the stand-alone base case in Section 4 below.

**Operating Costs**

In estimating the operating costs, Wakim Consulting applied the methods it uses in process economic studies by evaluating:

- Representative production capacity
- Estimated capital cost
- Volume and unit cost of raw materials
- Energy and utility costs
- By-product credits
- Operating costs
- Maintenance costs
- Plant overhead costs
- Taxes and insurance costs
- Depreciation
- General and administrative costs

However, the focus of this evaluation is on destroying a product rather than producing it. Therefore, in this evaluation, we followed the same approach used in prior studies for the Secretariat; that is estimating only the eligible components of the operating costs. (Total operating costs excluding depreciation and taxes). The detailed results for the onsite plants are presented in Annex 31; and summarized in Table 6.

Table 6: Estimated operating costs for hypothetical onsite HFC-23 incinerators

| **Capacity, mt/y** | **400** | | **800** | | **1,600** | | **2,400** | |
|---|---|---|---|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **9.0** | | **13.7** | | **21.1** | | **27.1** | |
| **Operating Cost ($/mt of HFC-23)** | | **%** | | **%** | | **%** | | **%** |
| Variable Costs (Feedstocks + Utilities) | 890.8 | 33.9 | 890.8 | 41.8 | 890.8 | 49.1 | 890.8 | 53.0 |
| **Direct Operating Costs (Maintenance, labor, supplies)** | **1,041.6** | **39.6** | **731.6** | **34.3** | **534.6** | **29.5** | **451.5** | **26.9** |
| **Indirect Operating Costs (Overhead, insurance)** | **624.2** | **23.7** | **434.7** | **20.4** | **313.8** | **17.3** | **262.9** | **15.6** |
| G&A, R&D | 75.0 | 2.8 | 75.0 | 3.5 | 75.0 | 4.1 | 75.0 | 4.5 |
| **Total Operating Costs** | | | | | | | | |

| Capacity, mt/y | 400 | | 800 | | 1,600 | | 2,400 | |
|---|---|---|---|---|---|---|---|---|
| **At 100% Capacity** | **2,631.7** | **100** | **2,132.1** | **100** | **1,814.3** | **100** | **1,680.2** | **100** |
| At 75% Capacity | 3,212.0 | | 2,545.8 | | 2,122.1 | | 1,943.3 | |
| At 50% Capacity | 4,372.5 | | 3,373.3 | | 2,737.7 | | 2,469.6 | |

Therefore, at full capacity, operating costs range from US$1.68/kg of HFC-23 destroyed to US$2.63/kg of HFC-23 destroyed; at 75% capacity, they range from US$1.94/kg of HFC-23 destroyed to US$3.21/kg of HFC-23 destroyed; and at 50% capacity, they range from US$2.47/kg of HFC-23 destroyed to US$4.37/kg of HFC-23 destroyed. These costs represent a conservative estimate; using the assumptions identified earlier, results in the low-end estimates summarized in Table 7, i.e., operating costs ranging from US$1.45/kg of HFC-23 destroyed for a 2,400 mt/y incinerator operating at full capacity to US$3.54/kg of HFC-23 destroyed for a 400 mt/y incinerator operating at 50% capacity.

Table 7: Lower-bound estimated operating costs for a hypothetical on-site HFC-23 incinerator

| Capacity (mt) | 400 | 800 | 1,600 | 2,400 |
|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **6.3** | **9.5** | **14.4** | **18.5** |
| **Total Operating Costs** | | | | |
| **At 100% Capacity** | **2,216.5** | **1,801.0** | **1,550.0** | **1,448.6** |
| At 75% Capacity | 2,658.4 | 2,104.3 | 1,769.8 | 1,634.5 |
| At 50% Capacity | 3,542.2 | 2,711.1 | 2,209.3 | 2,006.4 |

Variable costs - raw materials (feedstocks) and utilities – typically account for the bulk of the costs of the finished product, which is used as a reference. However, in the present evaluation, HFC-23 is the main component and, along with all the other raw materials, are being destroyed to produce waste products. Therefore, we used HFC-23 as the reference product and related the metric tons of other consumables to a metric ton of HFC-23 destroyed; thus the variable costs are not affected by incinerator capacity.

Direct costs include costs incurred to cover maintenance materials, operating and maintenance labor, control laboratories and operating supplies. They are affected by economies of scale and, as the data in Table 6 indicates, they drop from 39.6% of total destruction costs for the 400 mt/y incinerator to 26.9% for the 2,400 mt/y incinerator.

Similarly, indirect costs benefit from economies of scale and drop from 23.7% of total destruction cost for the 400 mt/y incinerator to 15.6% for the 2,400 mt/y incinerator.

When all the cost elements are aggregated, total destruction costs per metric ton HFC-23 benefits from economies of scale drop from $2,632/mt of HFC-23 destroyed for the 400 mt/y incinerator to $1,680/mt of HFC-23 destroyed for the 2,400 mt/y plant.

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 this report, noting that specific costs can only be assessed based onsite-specific characteristics. In addition, while the estimates provided in this report include maintenance and other costs, they exclude depreciation and taxes.

### Operating Costs for Stand-Alone Plant

The operating costs for the stand alone incinerator in this section were estimated using the same methodology applied for the on-site incinerator. A summary of the findings is presented in Table 8 and a detailed version is presented in Annex 41.

Table 8: Incineration Cost Estimates for Hypothetical Stand-Alone HFC-23 Incinerator

| Capacity, mt | 400 | | 800 | | 16,00 | | 2,400 | |
|---|---|---|---|---|---|---|---|---|
| **Investment (US$ million)** | **12.1** | | **18.1** | | **27.1** | | **34.5** | |

| Destruction Cost ($/mt) | | % | | % | | % | | % |
|---|---|---|---|---|---|---|---|---|
| Variable Costs (Feedstocks + Utilities) | 890.8 | 27.5 | 890.8 | 36.3 | 890.8 | 44.9 | 890.8 | 49.5 |
| **Direct Operating Costs (Maintenance, labor, supplies)** | **1,383.3** | **42.7** | **902.4** | **36.8** | **620.0** | **31.2** | **508.4** | **28.3** |
| **Indirect Operating Costs (Overhead, insurance)** | **889.7** | **27.5** | **583.7** | **23.8** | **398.7** | **20.1** | **325.0** | **18.1** |
| G&A, Sales, R&D | 75.0 | 2.3 | 75.0 | 3.1 | 75.0 | 3.8 | 75.0 | 4.2 |
| **Total Destruction Costs** | | | | | | | | |
| **At 100% Capacity** | **3,238.8** | **100** | **2,451.9** | **100** | **1,984.6** | **100** | **1,799.3** | **100** |
| At 75% Capacity | 4,021.5 | | 2,972.3 | | 2,349.2 | | 2,102.1 | |
| At 50% Capacity | 5,586.8 | | 4,013.0 | | 3,078.3 | | 2,707.7 | |

Table 9: Lower-bound estimated operating costs for a hypothetical off-site HFC-23 incinerator

| Capacity (mt) | 400 | 800 | 1,600 | 2,400 |
|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **8.8** | **13.0** | **19.4** | **24.5** |
| **Total Operating Costs** | | | | |
| **At 100% Capacity** | **2,810.3** | **2,110.6** | **1,713.8** | **1,562.3** |
| At 75% Capacity | 3,450.1 | 2,517.1 | 1,988.1 | 1,786.1 |
| At 50% Capacity | 4,729.7 | 3,330.3 | 2,536.7 | 2,233.8 |

The data indicates that the trend lines are similar, but the values are different from onsite plants' results. The main reason for the differences arise from the fact that imbedded within the operating costs are cost elements that are fixed capital related; another is the loss of synergy-related benefits.

Also imbedded in the values listed in Tables 6 and 8 is the assumption that the HFC-23 is delivered FOB at the incineration plant; the HFC-23 producer is responsible for the delivery costs.

Overall HFC-23 destruction costs are US $3,239 per mt (US$3.24 per kg) for the 400 mt/y plant; US $2,452 per mt (US $2.45 per kg) for the 800 mt/y plant; US $1,985 per mt (US $1.98 per kg) for the 1,600 mt/y plant; and US $1,799 per mt (US $1.80 per kg) for 2,400 mt/y plant.

The values estimated for HFC-23 destruction in hypothetical onsite and stand-alone incinerators are based on the technology and location selected for this study; and destruction efficiency of 99.99% or higher.

A change of location or technology will affect the cost of destroying a mt of HFC-23.

## Converting HFC-23 to useful commercial products

### Midwest Research: Midwest Conversion Technology

Midwest Research (MWR) designed a 570 mt per year HFC-23 conversion plant. It is skid-mounted and ready for delivery in a 40-foot container. The plant is designed with the ability to receive isotanks and railcars; and store 450 mt of refrigerants.

MWR provided limited information on its technology. Wakim analyzed the available information in a presentation on the technology made at the 31st Open-Ended Working Group (OEWG).[3] In that presentation, MWR did not provide the capital costs or how the conversion cost of US$0.63 per kilogram

[3] Available at: 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

were estimated. In absence of this information, we only reviewed the chemical reactions involved in the process and revised the yields based on MWR's assumption that HFC-23 conversion and selectivity to useful products are 100% each. However, we used HF value as the average US HF import prices in 2017; and CO calorific value for recovered CO. The revised data is presented in Table 10.

Table 10: MWR Conversion Vs Oxidizer Costs Revised for yield and Product price

| | US $/Kg | KG | US $ Cost |
|---|---|---|---|
| MWR Conversion | 0.63 | 900,000 | 567,000 |
| Recovered HF | 1.436 | 741,429 | 1,064,692 |
| Recovered CO | 0.187 | 360,000 | 67,320 |
| Revenue -Conversion | | | 565,012 |

The above analysis suggests potential annual revenue from the conversion of 900 mt of HFC-23 of approximately US$565,000 rather than US $2.43 million. Wakim is not able to assess the operating costs of US$0.63/kg suggested by MWR, nor is Wakim 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.

Section 5 provides a summary of the document by "Effective Technologies for Conversion of HFC-23" and for that of "Treatment of HFC-23 by conversion to environmentally benign chemicals". It appears that both processes are still in the research stage.

**Assessment of HCFC-22 manufacturing process changes to minimize HFC-23 generation**

The following changes could minimize HFC-23 by-product generation:

- Process changes to reduce HFC-23 reduction
- Improvements to Distillation Section of the HCFC-22 Process Plant
- Improving HCFC-22 Product Distillation Column Performance
- Reaction Section of HCFC-22 Process Plant Improvement
- Converting Reactor Internals to enhance Plug Flow to reduce over-fluorination
- Convert Reactor Internals from 1 to 3-Stages to reduce over-fluorination

**Adopting recommended changes could reduce HFC-23 generation by:**

- Product distillation column changes can reduce HCFC-22 carry-over in HFC-23 from 8% to 3%
- Reactor changes can reduce HFC-23 byproduct production from 4% to about 2%
- Current state-of-the-art can reduce HFC-23 generation to about 1.75% based on HCFC-22 production. Use of a 3-stage reactor can be expected to achieve a HFC-23 by-product generation as low as 1.4%.

**Discussion of monitoring and verification methods' costs**

In consultation with the Secretariat Team, Wakim recommend the selection of the CDM's – Executive Board "Approved baseline and monitoring methodology AM0001/Version 06.0.0 (Annex 71 AM0001V6). This methodology is familiar to HCFC-22 producers participating in CDMs; it will be logical to extend its application to all HCFC-22 producers and stand-alone incineration plant operators.

**Comparison of HFC-23 destruction methods and relevance to quantities and local conditions.**

Wakim Consulting identified potential destruction options and discussed how their applications vary according to local conditions and volumes of HFCs. A summary of the conclusions and recommendations is presented in Annex 81 (Alternative Technologies).

In the absence of approved destruction efficiency standards, our intensive literature search identified a number of documents. Two prominent documents were issued by the "Office of Fluorocarbons Control Policy, Global Environment Bureau, Ministry of the Environment, Government of Japan" follow:

- Guidelines on the Destruction of CFCs in Japan, updated in March 1999
- Guidelines on the destruction of Halon in Japan, May 2006

Our research identified 5 potentially useful destruction technologies for HFC-23 and Wakim recommends their applications for:

1. Plasma radio frequency arc torch: Small-scale destruction plants
2. Fired heater thermal oxidation furnaces: Onsite and stand-alone destruction plants
3. Horizontal rotary fired oxidation kiln: Lowest cost solution where lime kilns exist
4. Cement kiln oxidation: Lowest cost solution where cement kilns exist
5. High temperature steam thermal decomposition: Limited data available on technology

Wakim estimated the costs of destroying HFC-23 using these technologies. Operating costs range from approximately US $1/kg of HFC-23 destroyed for the cement kiln and horizontal rotary fired oxidation kiln, to approximately US $3/kg of HFC-23 destroyed for the plasma arc technology. For each technology, some capital investments would be required; such investments are relatively limited (ranging from about US $1 to 5 million to destroy about 200 mt of HFC-23 per year).

## 2. HFC-23 PRODUCTION BACKGROUND

### Chemistry

The major raw materials for producing HCFC-22 are hydrogen fluoride (HF) and chloroform ($CHCl_3$); both are commercial products traded internationally. HF is produced by reacting fluorspar ($CaF_2$) with sulfuric acid ($H_2SO_4$); gypsum ($CaSO_4$) is a by-product.

The main chemical reactions for converting raw materials to HCFC-22 and HFC-23 follow.

$CaF_2 + H_2SO_4 \rightarrow CaSO_4 + 2HF$ Eq 2.1
$2HF + CHCl_3 \rightarrow CHClF_2$ (HCFC-22) + 2HCl Eq 2.2
$3HF + CHCl_3 \rightarrow CHF_3$ (HFC-23) + 3HCl Eq 2.3

The main chemical reactions for HFC-23 destruction follow.

$CHF_3 + H_2O + ½ O_2 \rightarrow CO_2 + 3HF$ Eq 2.4
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ Eq 2.5
$HF + NaOH \rightarrow NaF + H_2O$ Eq 2.6
$2HF + Ca(OH)_2 \rightarrow CaF_2 + 2H_2O$ Eq 2.7

Based on the above chemical reactions in the process, the design basis for the hypothetical incinerator is presented in Table 11.

Table 11: Incinerator Design Basis: Raw Material Consumption and By-Product Yields

| 5 Year Data | mt/Year | mt/mt HFC-23 |
|---|---|---|
| HFC-23 destroyed | 4243.118 | 1.000 |
| Natural Gas consumed | 6111.583 | 0.144 |
| Electricity consumed, kwh | 7,576,643 | 1,785.602 |
| Steam consumed | 13,286.896 | 3.131 |

| 5 Year Data | mt/Year | mt/mt HFC-23 |
|---|---|---|
| Sodium hydroxide consumed | 637 | 0.150 |
| Ca(OH)2 consumed | 0 | 1.718 |
| 20% Dilute HF produced | 14,109 | 3.325 |

The HF and $CHCl_3$ reaction produces predominantly HCFC-22; however it also produces HFC-23 as an undesirable by-product. HCFC-22 producers try to minimize HFC-23 production by controlling raw material ratios, reactor and distillation column design, and operating conditions. Data presented in Annex 21 indicates that some companies were able to reduce HFC-23 production to 1.78% of HCFC-22 on a weight basis; HFC-23 to HCFC-22 ratios were as high as 3.44% at some companies.

**Incinerator Capacity Selection**

A review of the available information indicated that sufficient data was available for 17 HCFC-22, and therefore HFC-23, producing companies of interest to the Secretariat: 10 in China, 5 in India, 1 in Mexico, and 1 in Argentina.

The data was available for at least 2 consecutive years from 2007 to 2012 for each of these companies. The names with average annual production of HCFC-22 and HFC-23 are listed in Annex 21.

The data in Annex 21 indicates that the Chinese companies had HFC-23 destruction capabilities ranging from 506 to 1,195 metric tons (mt) annually; (Data made available later in the study indicated additional 1,500 mt/y plants and two 1,200 mt/y lines sharing process units and operating as a single 2,400 mt/y plant were in operation.) Indian companies reported HFC-23 destruction ranging from 36 to 707 mt/y. Mexico had 1 company with an average annual destruction capability of 221 mt HFC-23; and Argentina had 1 company with an average annual destruction capability of 125 mt HFC-23. **Therefore, based on this data, we selected an incinerator capable of destroying 800 mt HFC-23 per year.**

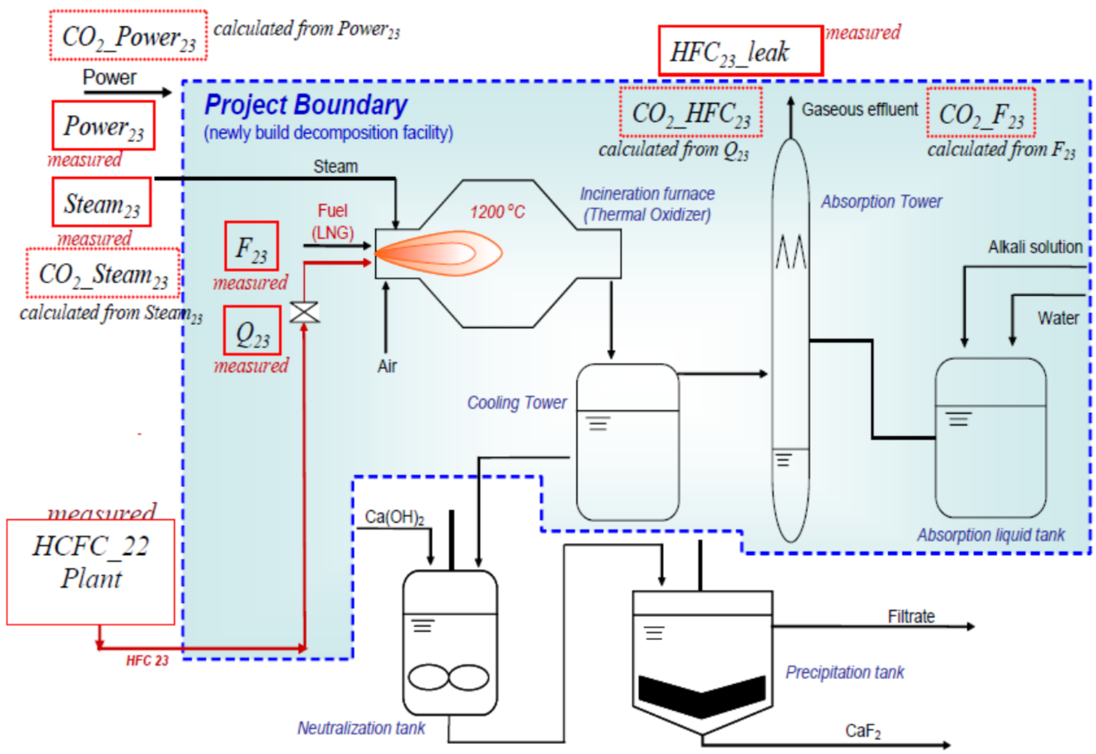
The data indicates that the average amount of HFC-23 produced by the Annex 21 companies varied from 1.78% to 3.44% of HCFC-22 production. **HFC-23 is a major global warming product with 1 mt equivalent to 14,800 mt of carbon dioxide ($CO_2$); and part of this HFC-23 production is still being emitted to the atmosphere in some Article 5 countries**.

There are commercial solutions to this problem. Some engineering companies, such as Fluor allied companies (Linde GmbH, Selas fired heaters), Vichem, Nippon Steel, Veolia Environmental (rotary kilns), Amec Foster Wheeler, John Zink Hamworthy NAO Inc. (thermal oxidizers), ATI Muller, and others have designed and commercialized incinerators that can destroy HFC-23.

Wakim Consulting chose the **Fluor process for the hypothetical incineration plant** for the following reasons:

- Similar plants are in operation in several countries
- It meets the specifications for HFC-23 destruction required in several countries
- It is easy to upscale or downscale incineration capacity
- Design information are available from several sources

A simplified process flow diagram for the incinerator follows.




**Incinerator Location Selection**

The data in Annex 21 indicates that those Chinese companies produced an average of 222,591 mt of HCFC-22 during the years for which data was available; and destroyed an average of 6,213 mt of HFC-23 annually.

A close look at the locations of the companies indicates that the majority of HFC-23 destroyed was by companies located on the Central East Coast region of China. **Therefore, the Central East Coast of China was selected as the location for the hypothetical HFC-23 incinerator**.

**Incinerator Startup and Shutdown Frequency Impact on Incinerator Life**

Incinerator life is determined mainly by number of cold starts; therefore to extend incinerator life, practice the following:

- Assure dry firebox conditions prior to startup
- Gradually increase firebox temperature so refractory can expand without cracking
- Shutdown incinerator by gradually reducing combustible feed
- Maintain firebox temperature while unloading incinerator
- Purge firebox with nitrogen gas after shutdown

**State-of-the-art Rules**

- Higher firebox temperatures reduce incinerator life
- Temperature stability increases incinerator life
- Replace refractory every 50,000 hours
- Overall rebuild incinerator every 100,000 hours

**Startup Procedure to Extend Incinerator Life**:

- Inspect firebox, fuel, air, and burner systems
- Check damper system movement
- Purge firebox with nitrogen
- Start forced draft or induced draft fan
- Light burners with fuel rather than HFC-23 and gradually bring firebox to design temperature
- Introduce HFC-23 feed only after firebox is at design temperature
- Check firing temperature and stack excess air content
- Increase feed rate to design conditions
- Continually monitor instrumentation

**Startup Costs for Idle Incinerator Typically Include:**

- Equipment upgrades
- Replacement of instrumentation as needed
- Recommissioning costs

**Estimated Recommissioning Costs for Hypothetical Plant (2017):**

| | |
|---|---|
| US$250,000 | new acid resistant refractory |
| US$100,000 | new equipment FOB purchases |
| US$50,000 | new equipment installation |
| US$25,000 | new instrument probes |
| US$150,000 | upgraded distributed control system |

## 3. ASSESSMENT OF HFC-23 INCINERATION CAPITAL AND OPERATING COSTS AT A HYPOTHETICAL ONSITE HCFC-22 FACILITY

**Capital Costs**

Based on the information developed in Section 2, the focus in Section 3 is to estimate the capital and operating costs for the hypothetical benchmark incinerator with predetermined chemistry, design basis, capacity, process technology, a process flow diagram, and location. Typically in such analyses, along with the base case, is included a smaller and a larger capacity plant. Because of the facts on the ground, the base case of 800 mt HFC-23 annual incineration capacity is flanked with 400 mt, 1,600 mt and 2,400 mt plants.

To do so, Wakim Consulting starts with information available from technology providers, equipment manufacturers, and other stake holders; and applies the American Association of Cost Engineers (AACE) Model 3 to estimate capital cost for the project. The results from AACE model 3 represent a conservative capital cost estimate (high). The results are usually adjusted to address specific field conditions.

After estimating the capital cost for the base case, we then use our proprietary algorithms to upscale and downscale the capital needed for the relevant incinerators.

The results are presented in Table 12 and Chart C.

Table: 12: Capital Cost Estimates for Integrated HFC-23 Incinerators
(Mid 2017 Installed Basis, $US Millions)

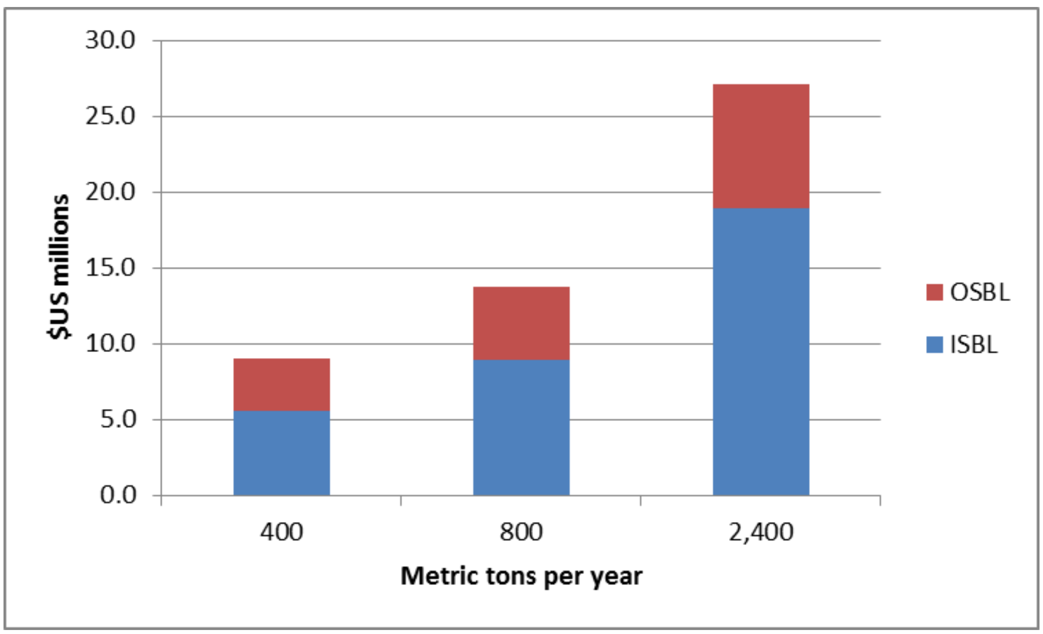
| Capacity | mty | ISBL | OSBL | TFC |
|---|---|---|---|---|
| ISBL: Inside battery limits | 400 | 5.6 | 3.4 | 9.0 |
| OSBL: Outside battery limits (off-sites) | 800 | 9.0 | 4.7 | 13.7 |
| TFC: Total Fixed Capital Cost | 1,600 | 14.4 | 6.7 | 21.1 |
| | 2,400 | 18.9 | 8.2 | 27.1 |

Chart C: Capital Cost Estimates for 400, 800 and 2,400 mty Integrated HFC-23 Incinerators
(Mid 2017 Installed Basis)

The estimates for capital investments incurred on inside battery limits (ISBL), outside battery limits (OSBL) and total fixed capital for the plants ranging from 400 mt to 2,400 mt per year in tabular form in Table 12 and in Bar Chart C.

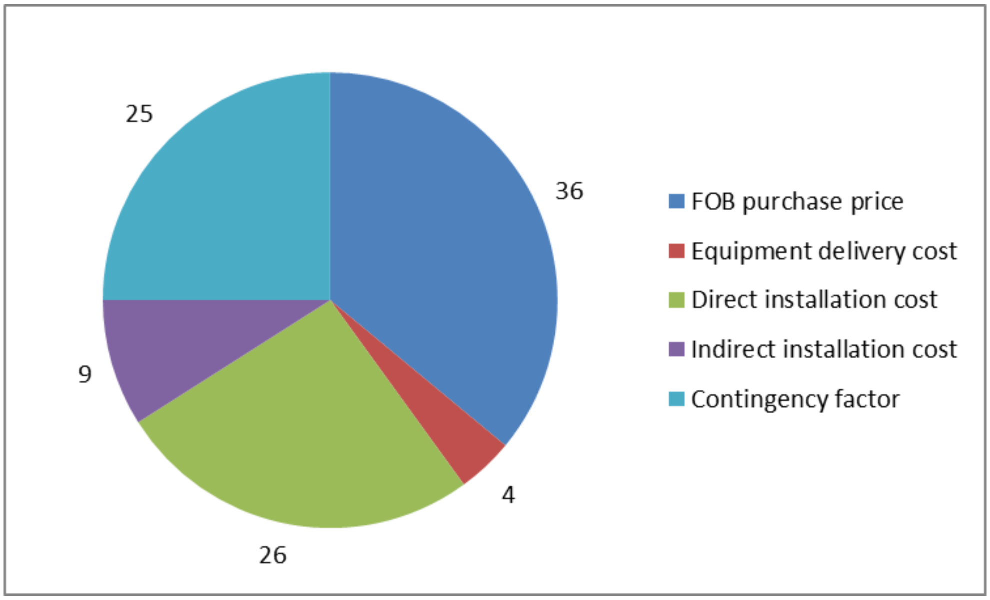
The outside battery limits cost compared to inside battery limits is lower than would be expected for all plants. The ratio of OSBL to ISBL for the 400, 800, 1,600 and 2,400 mt/y incinerators drops from 61% to 52% to 47% to 43% respectively. The reason is these plants are integrated with HCFC-22 manufacturing plants on the same site. Therefore, each of the incinerators will receive steam, electric power, and utilize infrastructures such as waste water treatment, environmental, health and safety services that are already available at the HCFC-22 plant.

Chart C



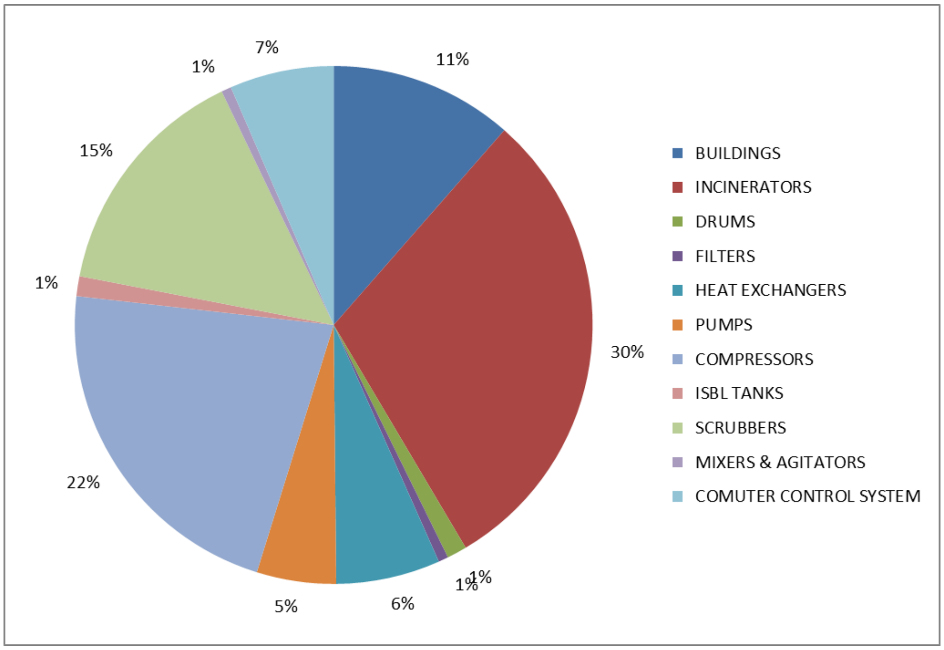

The segmentation of Base Case Capital Cost is presented in Chart D. Equipment plus delivery account for 40% of total cost; direct and indirect installation account for 26% and 9% respectively. Contingency factor is adjusted to reflect conditions on the site.

Chart D: Segmentation of Base Case Capital Cost %



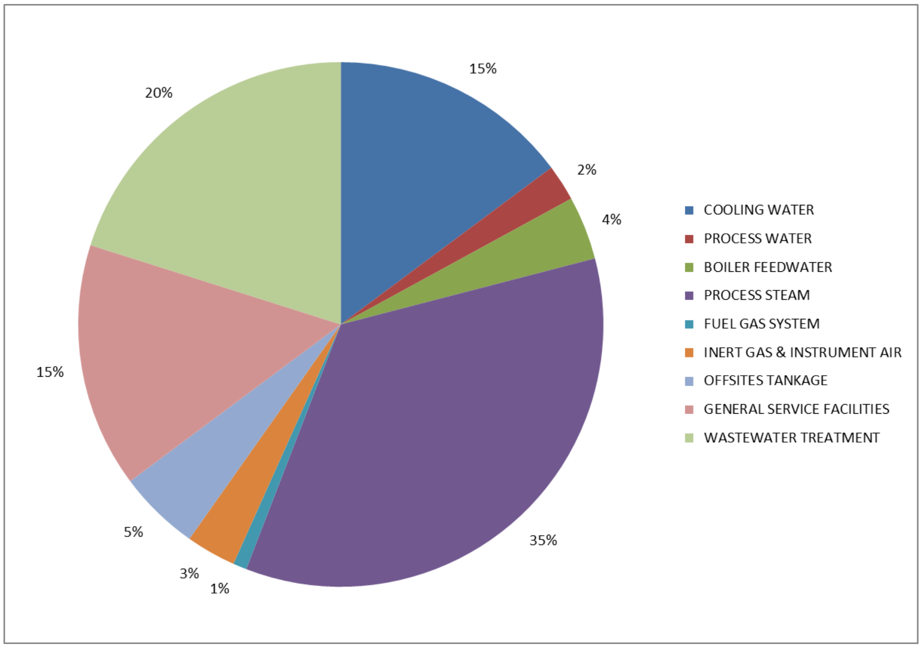

Process equipment (40% of capital) are also segmented. Incinerators account for 30%; heat exchangers account for 22%; scrubbers account for 15% of total capital. The complete segmentation of Process Equipment Costs is presented in Chart E.

Chart E: Segmentation of Base Case Process Equipment Cost %




Outside battery limits (OSBL or Off-sites), accounting for 52% of ISBL in base case, are segmented into cost elements in Chart F. Process steam equipment account for 35% of ISBL investment; waste water treatment equipment account for 20%; inert gas and instrument air, and cooling water equipment account for 15% each.

Chart F: Segmentation of On-site Base Case Offsite Component Cost %




**Operating Costs**

In estimating the operating costs, Wakim Consulting applied the methods it uses in process economic studies by evaluating:

- Representative production capacity
- Estimated capital cost
- Volume and unit cost of raw materials
- Energy and utility costs
- By-product credits
- Operating costs
- Maintenance costs
- Plant overhead costs
- Taxes and insurance costs
- Depreciation
- General and administrative costs

However, the focus of this evaluation is on destroying a product rather than producing it. In all other aspects, the evaluation follows the same approach we used in prior studies for the Secretariat; that is estimating only the eligible components of the operating costs. (Total operating costs excluding depreciation and taxes). The results are presented in Annex 31.

A summary of HFC-23 incineration cost estimates in a hypothetical benchmark facility integrated with HCFC-22 producing site is presented in Table 13.

Table 13: Incineration Cost Estimates for Hypothetical HFC-23 Plant Onsite an HCFC-22 Producing Site

| **Capacity, mt/y** | **400** | | **800** | | **1,600** | | **2,400** | |
|---|---|---|---|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **9.0** | | **13.7** | | **21.1** | | **27.1** | |

| Capacity, mt/y | 400 | | 800 | | 1,600 | | 2,400 | |
|---|---|---|---|---|---|---|---|---|
| **Operating Cost ($/mt of HFC-23)** | | **%** | | **%** | | **%** | | **%** |
| Variable Costs (Feedstocks + Utilities) | 890.8 | 33.9 | 890.8 | 41.8 | 890.8 | 49.1 | 890.8 | 53.0 |
| **Direct Operating Costs (Maintenance, labor, supplies)** | **1,041.6** | **39.6** | **731.6** | **34.3** | **534.6** | **29.5** | **451.5** | **26.9** |
| **Indirect Operating Costs (Overhead, insurance)** | **624.2** | **23.7** | **434.7** | **20.4** | **313.8** | **17.3** | **262.9** | **15.6** |
| G&A, R&D | 75.0 | 2.8 | 75.0 | 3.5 | 75.0 | 4.1 | 75.0 | 4.5 |
| **Total Operating Costs** | | | | | | | | |
| **At 100% Capacity** | **2,631.7** | **100** | **2,132.1** | **100** | **1,814.3** | **100** | **1,680.2** | **100** |
| At 75% Capacity | 3,212.0 | | 2,545.8 | | 2,122.1 | | 1,943.3 | |
| At 50% Capacity | 4,372.5 | | 3,373.3 | | 2,737.7 | | 2,469.6 | |

Variable costs typically include raw materials (feedstocks) and utilities that account for the bulk of the costs of the finished product which is used as a reference. However, in the present process, HFC-23 is the main component and, along with all the other raw materials, are being destroyed to produce waste products. Therefore, it is reasonable to use HFC-23 as the reference product and relate the metric tons of the other consumables to a metric ton of HFC-23 destroyed; by doing so, variable costs are not affected by incinerator capacity.

Direct costs include costs incurred to cover maintenance materials, operating and maintenance labor, control laboratories and operating supplies. They are affected by economies of scale and, as the data in Table 13 indicates, drop from 39.6% as percent of total destruction costs for the 400 mt/y plant to 26.9% for the 2,400 mt/y plant.

Similarly, indirect costs benefit from economies of scale and drop from 23.7% of total destruction cost for the 400 mt/y plant to 15.6% for the 2,400 mt/y plant.

When all the cost elements are aggregated, total destruction costs per metric ton HFC-23 benefits from economies of scale dropping from $2,632 per mt for a 400 mt/y plant to $1,680 for the 2,400 mt/y plant.

The above costs are a conservative (upper-bound) estimate of costs. In order to provide a lower-bound estimate of the total fixed costs, the following assumptions can be made: a 10% contingency rather than 25%, and using incinerators manufactured in China rather than imported incinerators. Those assumptions result in the lower-bound estimates shown in table 14. Based on those lower-bound capital costs, a lower-bound for the operating costs can be estimated at shown in table 15.

Table 14: Lower-bound Capital Cost Estimates for Onsite HFC-23 Incinerators
(Mid 2017 Installed Basis, US$ Millions)

| Capacity (mt/y) | Inside battery limits | Outside battery limits | Total Fixed Capital Cost |
|---|---|---|---|
| 400 | 3.5 | 2.8 | 6.3 |
| 800 | 5.6 | 3.9 | 9.5 |
| 1,600 | 8.9 | 5.5 | 14.4 |
| 2,400 | 11.7 | 6.7 | 18.5 |

Table 15: Lower-bound estimated operating costs for a hypothetical on-site HFC-23 incinerator

| Capacity (mt) | 400 | 800 | 1,600 | 2,400 |
|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **6.3** | **9.5** | **14.4** | **18.5** |
| **Total Operating Costs** | | | | |

| | | | | |
|---|---|---|---|---|
| **At 100% Capacity** | **2,216.5** | **1,801.0** | **1,550.0** | **1,448.6** |
| At 75% Capacity | 2,658.4 | 2,104.3 | 1,769.8 | 1,634.5 |
| At 50% Capacity | 3,542.2 | 2,711.1 | 2,209.3 | 2,006.4 |

## 4. ASSESSMENT OF HFC-23 INCINERATION COSTS AT A HYPOTHETICAL OFF-SITE LOCATION

In Section 4, for ease of comparison, Wakim Consulting used the same incinerator inside battery limits as used in Section 3 above. The incineration stand-alone facility is deprived of the synergy benefits enjoyed from being associated with an HCFC-22 plant on site.

Therefore the capital cost of the inside battery limits will remain the same. However, the capital costs for outside battery limits (off-site) will increase to include: power transformers, storage tanks, on-loading and off-loading ramps, raw material reception facilities, offices, control laboratories, and security systems, etc.

### Capital Costs

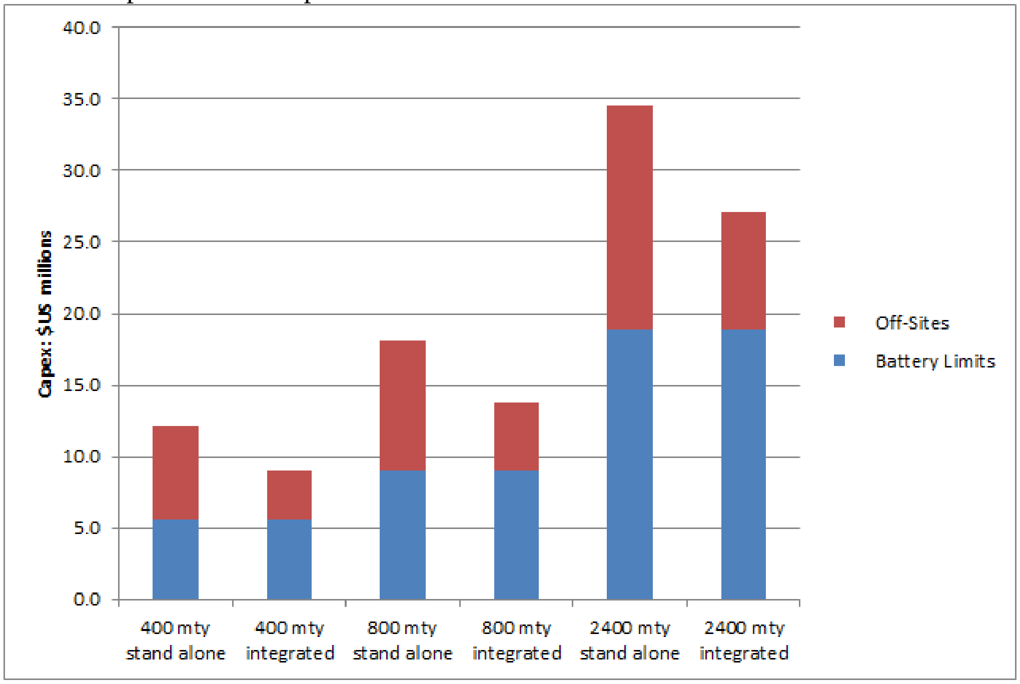
The capital cost estimate for stand-alone HFC-23 is presented in Table 16

Table 16: Capital Cost Estimates for Stand -Alone HFC-23 Incinerators
(Mid 2017 Installed Basis, US$ Millions)

| Capacity | Mt/y | ISBL | OSBL | TFC |
|---|---|---|---|---|
| ISBL: Inside battery limits | 400 | 5.6 | 6.5 | 12.1 |
| OSBL: Outside battery limits (off-sites) | 800 | 9.0 | 9.1 | 18.1 |
| TFC: Total Fixed Capital Cost | 1,600 | 14.4 | 12.7 | 27.1 |
| | 2,400 | 18.9 | 15.5 | 34.5 |

Chart G shows capital cost comparison for stand-alone and onsite incinerators.

Chart G: Capital Cost Comparison between Stand-Alone and Onsite HFC-23 Incinerators




The inside battery limits of the stand-alone plant are identical to those of the onsite plant. Therefore, the capital cost segmentation presented in Chart D and Chart E apply to both stand-alone and onsite plants.

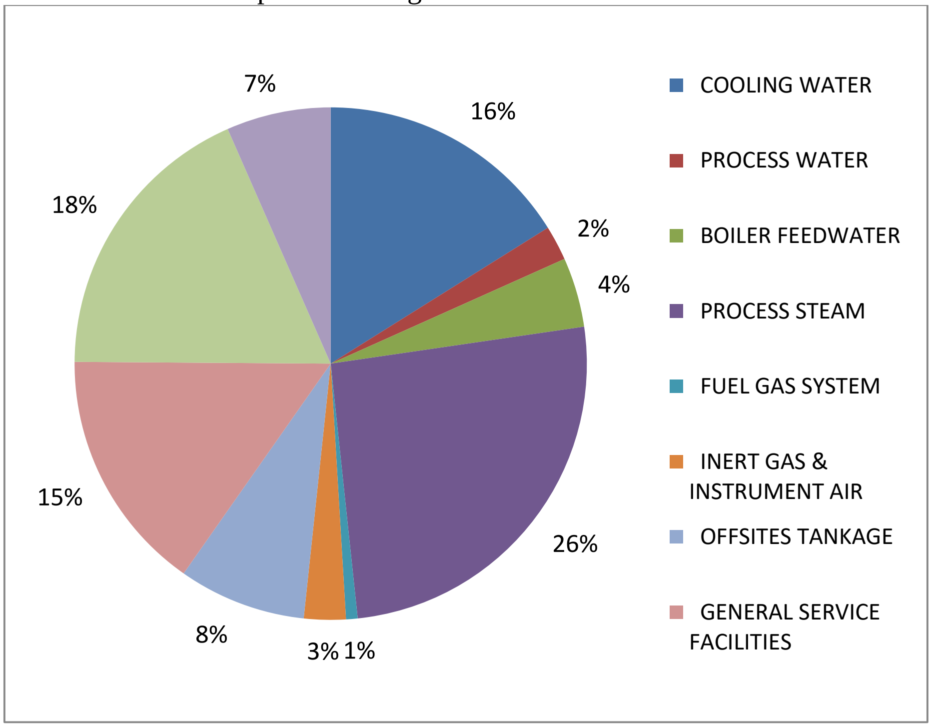
A detailed capital cost comparison of stand-alone and onsite base case incineration plants is presented in Table 17. The investment in Off-Sites increased from US$4.78 million for the onsite plant to US$9.11 million for the stand-alone plant. That increased the total capital investment from US$13.75 million for the onsite plant to US$18.08 million for the stand-alone plant.

Table 17: Comparative Capital Costs of Stand-Alone and Onsite 800 mty HFC-23 Incineration Plants

| | **800 mt/y ($US Million)** | **800 mt/y ($US Million)** |
|---|---|---|
| | **Stand-Alone** | **Onsite** |
| Battery Limits Investment | 8.97 | 8.97 |
| Off-Sites Installed Investment | | |
| Cooling Water | 1.10 | 0.53 |
| Process Water | 0.15 | 0.08 |
| Boiler Feed Water | 0.30 | 0.14 |
| Process Steam | 1.75 | 1.25 |
| Fuel Gas System | 0.05 | 0.03 |
| Inert Gas and Instrument Air | 0.18 | 0.11 |
| Off-Sites Tankages | 0.55 | 0.18 |
| General Service Facilities | 1.05 | 0.54 |
| Waste Water Treatment | **1.25** | **0.72** |
| HFC-23 Receiving Facilities | **0.45** | **0.00** |
| Total Off-Sites | **6.83** | **3.58** |
| Off-Sites Contingency 25% | **2.28** | **1.20** |
| Total Off-Sites Capital Investment | **9.11** | **4.78** |
| Total Fixed Capital | **18.08** | **13.75** |

The Off-Sites cost segmentation for the stand alone base case plant is presented in Chart H. The largest cost elements are: Process steam at 26%, Boiler feed water at 18%, cooling water at 16%, and inert gas and instrument air at 15%.

Chart H: Off-Sites Capital Cost Segmentation for Stand-Alone Base Case Plant




**Operating Costs**

The operating costs for the stand alone incinerator in this section were estimated using the same methodology applied in Section 3 above. A summary of the findings is presented in Table 18 and a detailed version is presented in Annex 41

Table18: Incineration Costs for Hypothetical Stand-Alone HFC-23 Incinerator

| **Capacity, mt** | **400** | | **800** | | **16,00** | | **2,400** | |
|---|---|---|---|---|---|---|---|---|
| **Investment (US$ million)** | **12.1** | | **18.1** | | **27.1** | | **34.5** | |
| **Destruction Cost ($/mt)** | | **%** | | **%** | | **%** | | **%** |
| Variable Costs (Feedstocks + Utilities) | 890.8 | 27.5 | 890.8 | 36.3 | 890.8 | 44.9 | 890.8 | 49.5 |
| **Direct Operating Costs (Maintenance, labor, supplies)** | **1,383.3** | **42.7** | **902.4** | **36.8** | **620.0** | **31.2** | **508.4** | **28.3** |
| **Indirect Operating Costs (Overhead, insurance)** | **889.7** | **27.5** | **583.7** | **23.8** | **398.7** | **20.1** | **325.0** | **18.1** |
| G&A, Sales, R&D | 75.0 | 2.3 | 75.0 | 3.1 | 75.0 | 3.8 | 75.0 | 4.2 |
| **Total Destruction Costs** | | | | | | | | |
| **At 100% Capacity** | **3,238.8** | **100** | **2,451.9** | **100** | **1,984.6** | **100** | **1,799.3** | **100** |
| At 75% Capacity | 4,021.5 | | 2,972.3 | | 2,349.2 | | 2,102.1 | |
| At 50% Capacity | 5,586.8 | | 4,013.0 | | 3,078.3 | | 2,707.7 | |

The data indicates that the trend lines are similar to those obtained for the onsite plant; however, the values are different. The main reasons for the differences arise from the fact that imbedded within the operating costs are cost elements that are capital related; another is the loss of synergy related benefits.

Also imbedded in the values listed in Table 18 is the assumption that the HF-23 is delivered FOB at the incineration plant receiving docks; in other words, the costs associated with delivery to the incinerator plant is allocated to the HFC-23 producer and is included in the costs above.

The individual differences are accumulated in the total HFC-23 destruction costs per mt. The total HFC-23 destruction costs are US $3,239 per mt (US $3.24 per kg) for the 400 mt/y plant; US $2,452 per mt (US $2.45 per kg) for the 800 mt/y plant; US $1,985 per mt (US $1.99 per kg) for the 1,600 mt/y plant; and US $1,799 per mt (US $1.80 per kg) for 2,400 mt/y plant.

The above costs are a conservative (upper-bound) estimate of costs. In order to provide a lower-bound estimate of the total fixed and operating costs, the same assumptions as made for the case of the on-site incinerator can be made: a 10% contingency rather than 25%, and using incinerators manufactured in China rather than imported incinerators. Those assumptions result in the lower-bound estimates shown in table 19.

Table 19: Lower-bound estimated operating costs for a hypothetical off-site HFC-23 incinerator

| **Capacity (mt)** | **400** | **800** | **1,600** | **2,400** |
|---|---|---|---|---|
| **Fixed capital cost (US$ million)** | **8.8** | **13.0** | **19.4** | **24.5** |
| **Total Operating Costs** | | | | |
| **At 100% Capacity** | **2,810.3** | **2,110.6** | **1,713.8** | **1,562.3** |
| At 75% Capacity | 3,450.1 | 2,517.1 | 1,988.1 | 1,786.1 |
| At 50% Capacity | 4,729.7 | 3,330.3 | 2,536.7 | 2,233.8 |

The data indicates that the trend lines are similar, but the values are different from onsite plants' results. The main

All the values estimated for the destruction of HFC-23 in hypothetical onsite and standalone incinerators are based on the technology and location specified earlier in this report; and the destruction efficiency is 99.99% or higher based on HFC-23 feed.

A change of location will affect the cost of destroying an mt of HFC-23; Wakim will gladly submit a separate proposal with scope of work and cost upon receipt of a request outlining the specific locations.

Similarly a change of technology will affect the destruction costs. We will be identifying and discussing qualitatively alternative destruction options, as specified in our mandate, in Section 8 below.

## 5. CONVERTING HFC-23 TO USEFUL COMMERCIAL PRODUCTS

At the request of the Secretariat, Wakim Consulting reviewed the following 3 documents and comments as follows:

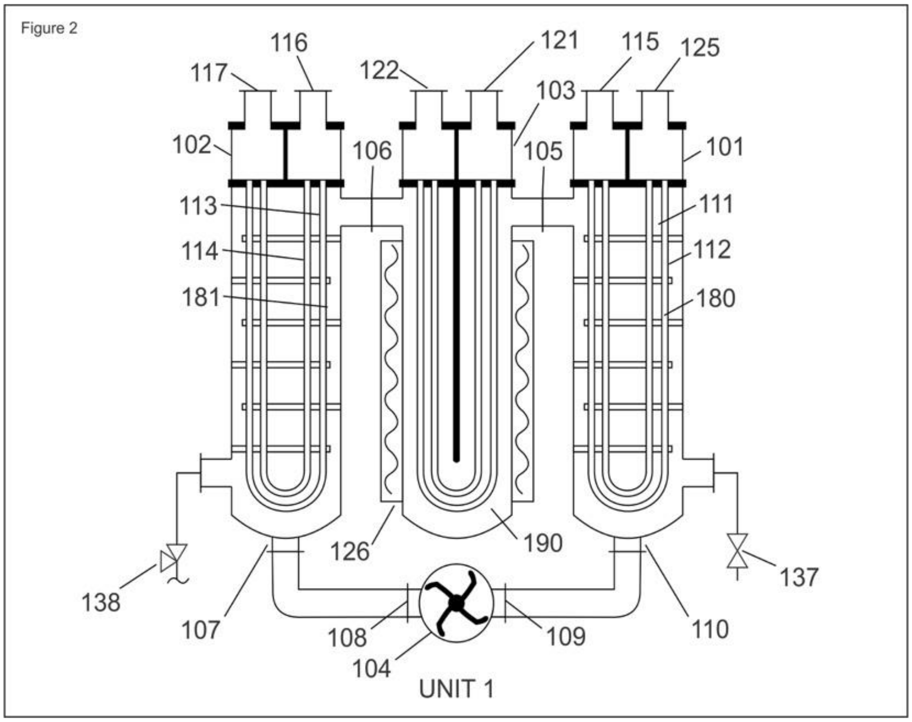
**1 Midwest Research**

Midwest Research is well advanced in its process development having designed a 570 mt/y HFC-23 conversion plant. It is skid mounted and ready for delivery in a 40 foot container. The plant is designed with the ability to receive isotanks and railcars; and can store 450 mt of refrigerants.

A second plant capable of converting 2,300 mt (5 million pounds) of HFC-23 per year is in the planning stage.

The schematics for the reactors used for conversion of HFC-23 to useful products is presented in Chart I and the claimed destruction costs in Table 20.

Chart I: MWR Reactors




**MWR Reactors** **Reactor 2** **Reactor 1**

Table 20: MWR Claimed Destruction Cost versus Conversion Cost

Reactor 1: $CO + H_2O \rightarrow CO_2 + H_2$ 300 – 900°C 1-30 atmosphere

Reactor 2: $CHF_3 + H_2 + CO_2 \rightarrow 3HF + 2CO$ 600 – 900°C 1-30 atmosphere

| | **$/kg** | **Kilograms** | **US$ Costs** |
|---|---|---|---|
| Destruction by Oxidizer | 1.17 | 900,000 | 1,053,000 |
| MWR Conversion Costs | 0.63 | 900,000 | 587,000 |
| Recovered AHF Value | 2.20 | 772,000 | 1,698,400 |
| Recovered CO value | 1.80 | 720,000 | 1,296,000 |
| Net Value | | | 2,427,400 |
| Conversion - Destruction | | | 3,480,400 |

MWR neither provided the capital costs for its skid mounted HFC-23 conversion plant nor how the conversion cost of US$0.63 per kilogram were estimated. In the absence of this information, we reviewed the chemical reactions involved in the process and revised the yields based on MWR's assumption that HFC-23 conversion and selectivity to useful products are 100%. However, we revised HF value to reflect HF U.S. average import prices in 2017; and recovered CO value to reflect its calorific fuel value. The revised data is presented in Table 21.

Table 21: MWR Conversion Vs Oxidizer Costs Revised for yield and Product price

| | US$/Kg | KG | US$ Cost |
|---|---|---|---|
| Oxidizer Cost | 1.17 | 900,000 | 1,053,000 |
| MWR Conversion | 0.63 | 900,000 | 567,000 |
| Recovered HF | 1.436 | 741,429 | 1,064,692 |

| | | US$/Kg | KG | US$ Cost |
|---|---|---|---|---|
| Recovered CO | | 0.187 | 360,000 | 67,320 |
| Revenue -Conversion | | | | 565,012 |
| Revenue -Oxidizer Cost | | | | -420,668 |

## 2. Effective Technologies for Conversion of HFC-23

By: Quan Hengdao
National Institute of Advanced Industrial Science and Technology (AISY), Japan
Beijing Institute of Technology, China

The researchers attempted to convert HFC-23 to intermediates or finished products by:

**Pyrolysis or Co-pyrolysis**

CHF3 → CF2=CF2 or CF3CF=CF2 Eq 5.2.1

**High temperature oxidation**

$2CHF_3 + O_2 \rightarrow 2COF_2 + 2HF$ Eq 5.2.2

Pilot plant for $COF_2$ production (100 mt/y)

**Chlorination with Chlorine and recycling unreacted HFC-23**

$CHF_3 + Cl_2 \rightarrow CHClF_2 + HCl$ Eq 5.2.3

**Iodization with iodine**

$3CHF_3 + 2I_2 + O_2 \quad 2CF_3I + 3HF + CO_2$ Eq 5.2.4

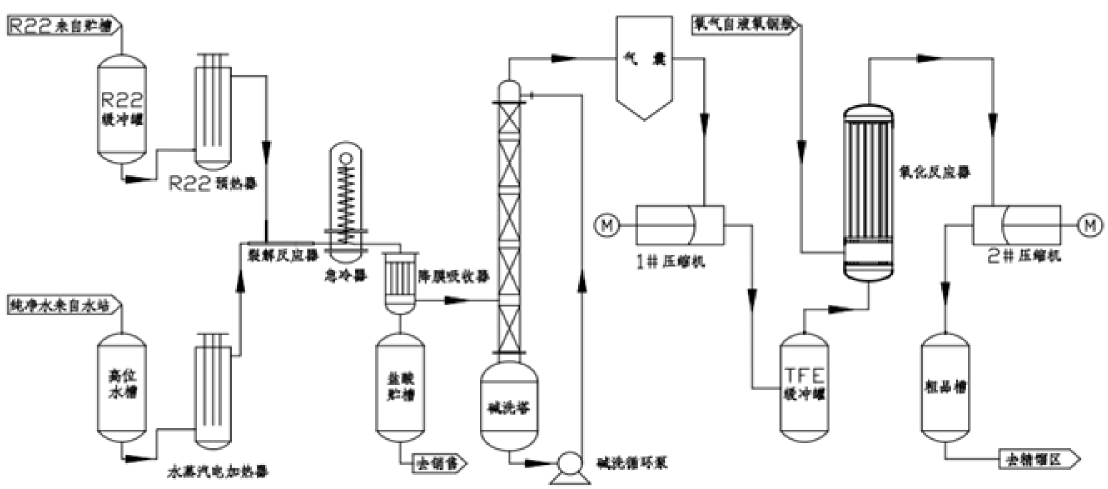
Pilot plant for preparing CF3I (50 mt/y)

**Bromination with bromine**

$CHF_3 + Br_2 \rightarrow CBrF_3 + HBr$ Eq 5.2.5

Our review indicated the conversion technology appears to be at the research and development level.

A Process Flow Diagram (PFD) and photo of 100 mty $COF_2$ production pilot plant follow.



**3 Treatment of HFC-23 by conversion to environmentally benign chemicals**

By: Han Wenfeng, Wang Shucheng, Liu Wucan and Zhang Jianjun
Zhejiang University of Technology
Zhejiang Research Institute of Chemical Industry
State Key Laboratory of Fluorinated Greenhouse Gases Replacement and Control Treatment

The researchers attempted to convert HFC-23 to alternative finished products; and reported the following information obtained from their research phase.

**Conversion to HCFC-22**

$CHCl_3 + CHF_3 \rightarrow CHClF_2 + CHCl_2F$ Eq 5.2.1

HFC-23 HCFC-22 HCFC-21

Atmospheric Pressure, <400°C

Selectivity to HCFC-21 and HCFC-22 > 95%

**Conversion to VDF**

$CH_4 + CHF_3 \rightarrow CH_2{=}CF_2 + C_2F_4$ Eq 5.2.2

HFC-23 VDF TFE

Atmospheric pressure, 700 to 900ºC

Conversion of HFC-23 >80%

Selectivity to VDF >83% 8 Additional byproducts reported

**$CBrF_3$ Catalyst**

Adding 0.07% $CBrF_3$ @ 850°C: Selectivity & yield of VDF increased to 55% and 16%

@900°C selectivity and yield increased to 77% and 26.6% respectively

Researchers also tried $CeO_2$ and LaOF as catalysts.

**Conversion to TFE and HFP**

$CHF_3 \rightarrow CF_2{=}CF_2 + CF_2{=}CFCF_3 + 5HF$ Eq 5.2.3

**TFE** **HFP**

Selectivity & yield were low with and without catalyst.

Conversion of HFC-23 60% @ 800 C

Selectivity to TFE >33%

Selectivity to HFP >23%

The conversion of HFC-23 and the selectivity and yield of the sought main products in Eq 5.2.1 to 5.2.3 varied significantly. Also, no additional data was provided for an attempt at estimating economics of production of the finished products.

## 6. ASSESSMENT OF HCFC-22 MANUFACTURING PROCESS CHANGES TO MINIMIZE HFC-23 PRODUCTION

The optimization of HCFC-22 manufacturing process to minimize HFC-23 production varies from plant to plant and depends on:

- Manufacturing process Technology
- Plant vintage
- Expected plant remaining lifetime
- Mechanical condition of process units
- Maintenance practices
- Computer process control systems
- Other factors

Therefore, plant optimization is site specific and requires technical audit of the manufacturing site.

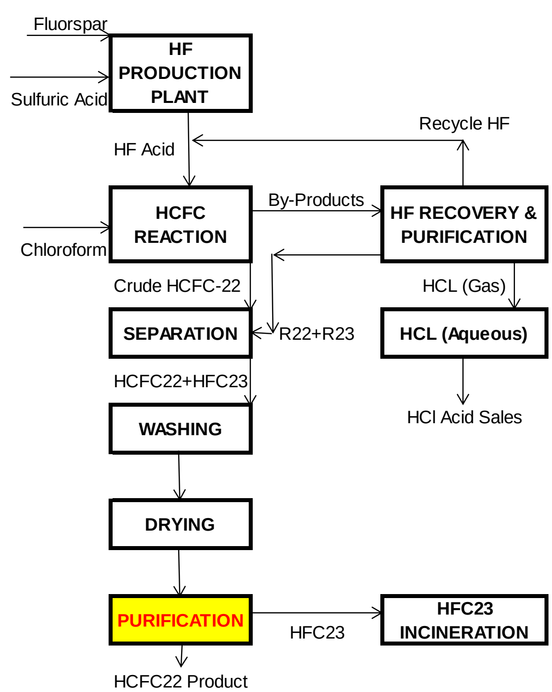
However, within the present project scope, we can discuss some changes that minimize HFC-23 generation without reducing HCFC-22 yields that follow.

### Process changes to reduce HFC-23 Production

- Improve HCFC-22 product distillation column to reduce HCFC-22 in HFC-23 product stream
- Convert HCFC-22 reactor internals to plug flow enhancing selectivity
- Convert HCFC-22 reactor to 3-stage rather than 1-stage process

### Distillation Section of HCFC-22 Process Plant Improvement

Make changes to the purification section high-lighted below and described in the following sections.

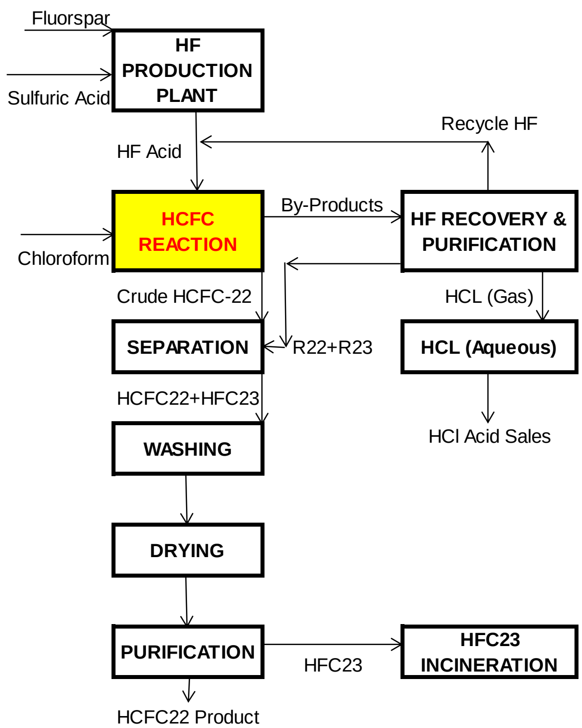


### Improving HCFC-22 Product Distillation Column Performance

- Typically HFC-23 overhead product stream contains 8% HCFC-22
- Replace column tray internals with structured packing
- Operate column at lower pressure
- Operate column at lower condenser temperature
- Increase reflux ratio

### Reaction Section of HCFC-22 Process Plant Improvement

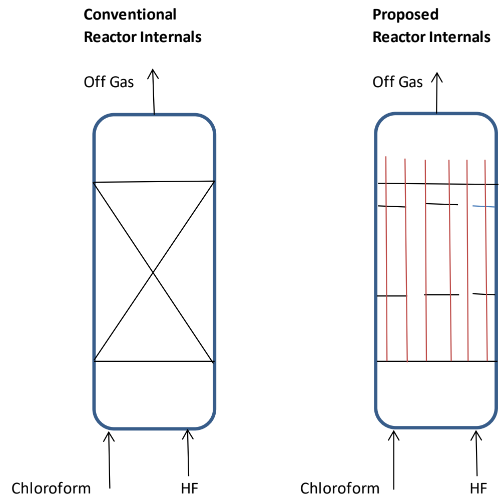
Make the recommended changes to the reaction section high-lighted below.




### Convert Reactor Internals to enhance Plug Flow (reduces over fluorination)

- Replace packed bed with vertical multichannel parallel tubes
- Insert 2 internal gas flow re-distribution trays within reactor

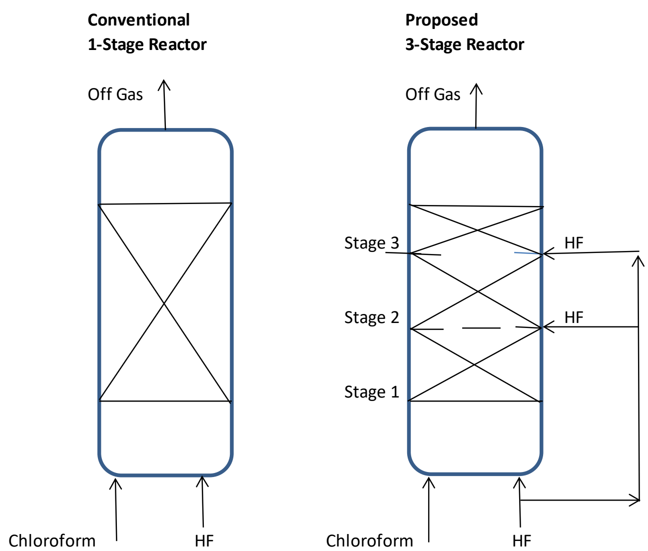
**Reactor Internals Configurations**




**Convert Reactor Internals from 1 to 3-Stages** (this change reduces over fluorination)

- Add less HF to 1st stage and additional HF to 2nd and 3rd stages
- Consider adding inter-stage coolers to simulate isothermal rather than adiabatic reaction
- Add flow re-distribution trays between stages

**Reconfiguration to 3-Stage Reactor**




**Adopting Recommended changes Could Reduce HFC-23 Production by:**

- Product distillation column changes can reduce HCFC-22 carry-over in HFC-23 from 8% to 3%
- Reactor changes can reduce HFC-23 byproduct production from 4% to about 2%
- Current state-of –the-art can reduce HFC-23 generation to about 1.75% based on HCFC-22 production. Use of a 3-stage reactor can be expected to bring the HFC-23 by-product generation rate down to about 1.4%.

The above recommended changes have already been made in Article 2 countries, and some Article 5 countries. The return on investment incurred for these changes is site specific and therefore beyond the scope of this project. However, the following general observations can be made:

- The typical lifetime of a distillation column used for this application is approximately ten years; therefore, production facilities are expected to regularly replace their distillation columns as a regular part of their operation. When they do so, it is expected that columns with structured packing rather than tray internals would be selected given the improved performance, including increased separation of HCFC-22, the product the enterprise is selling, and lower maintenance costs of such columns.
- HCFC-22 reactor lifetimes vary, but can be expected to range from 10 to 15 years. In selecting a new reactor, a production facility would wish to consider the cost of the design changes identified here with the benefits of increased selectivity of HCFC-22 in the HF + chloroform reaction.

Wakim Consulting will gladly submit a proposal for the change of scope and cost, once the sites of interest are identified.

## 7. DISCUSSION OF MONITORING AND VERIFICATION METHODS' COSTS

In Task 7, Wakim Consulting's mandate, in collaboration with the Secretariat Project Team, encompassed the discussion of different verification methods and selection of a representative candidate for recommendation to the Executive Committee. Our mandate also included explaining the responsibilities of HCFC-22 producers and those responsible for HFC-23 destruction; and recommendations for both parties to provide the Secretariat with the necessary information.

Our discussions lead to the selection of the CDM's –Executive Board "Approved baseline and monitoring methodology AM0001/Version 06.0.0 (Annex 71 AM0001V6); it is entitled "Decomposition of fluorocarbon (HFC-23) waste streams". This methodology is familiar to all HCFC-22 producers participating in CDMs; it will be logical to extend its application to all HCFC-22 producers and stand-alone incineration plant operators.

All HCFC-22/HFC-23 producers will be required to monitor their operations and record the data required presently of CDM participants. The operators of stand-alone incinerators will be required to monitor their operations and record similar data. This will ensure that all producers and handlers of HCFC-22 and HFC-23 monitor and record the production and destruction of both products. It will also instruct all participants to minimize HFC-23 production and emissions to the environment by following standards set by the Executive Committee.

The Annual Verification ensuring that all participants are complying with the directives issued by the Executive Committee should be performed by an Independent third Party who cannot derive financial benefits beyond its professional fees and out-of-pocket expenses. Such third party needs access to plant operating data and financial books of HCF-22/HFC-23 producers and destroyers.

## 8. COMPARISON OF HFC-23 DESTRUCTION METHODS AND RELEVANCE TO QUANTITIES AND LOCAL CONDITIONS.

In Section 8, Wakim Consulting's mandate consisted of identifying potential destruction options and discussing how their applications could vary according to local conditions and volumes of HFCs. A summary of the conclusions and recommendations is presented in Annex 81 (Alternative Technologies).

In the absence of approved destruction efficiency standards, our intensive literature search identified a number of documents. Two prominent documents were issued by the "Office of Fluorocarbons Control Policy, Global Environment Bureau, Ministry of the Environment, Government of Japan" follow:

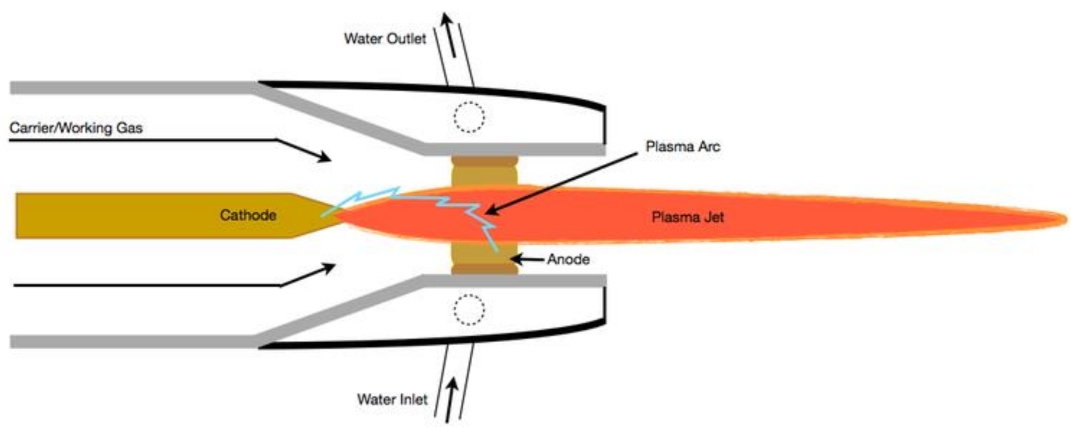
- Guidelines on the Destruction of CFCs in Japan, updated in March 1999
- Guidelines on the destruction of Halon in Japan, May 2006

Our research identified 5 potentially useful destruction technologies for HFC-23:

1. Plasma radio frequency arc torch
2. Fired heater thermal oxidation furnaces
3. Horizontal rotary fired oxidation kiln
4. Cement kiln oxidation
5. High temperature steam thermal decomposition

**1 Plasma Radio frequency arc torch**

- Requires exhaust gas treatment for acid removal
- HFC stream must be directed into arc plasma torch
- Exhaust gas must be cooled to less than 200°C
- Treatment must be provided for quench and scrubber purge
- The plasma arc's (represented below) operating principles follow:




- It is formed electrically between high voltage cathode and anode electrodes
- Plasma arc temperature exceeds 10,000°C
- HFC gas + water + air are injected at point of plasma arc
- Residence time in plasma arc is in milliseconds
- Steam is injected for waste gas hydrolysis
- Product vapor stream is quickly quenched in water
- Quench water is treated with lime, to neutralize acids, and dried to produce $CaF_2$ by-product
- Product vapor is scrubbed to remove residual acids
- HFC destruction efficiency exceeds 99.99%

**2 Fired heater thermal oxidation furnaces**

- Vaporized HFC enters bottom burners of fired furnace and flows upwards

- Fuel, air and steam are co-fired with HFC at greater than 1,200°C
- Additional fuel is added to second stage halfway up furnace
- Furnace vapors are quenched with water to cool and dissolve hydrogen fluoride and hydrogen chloride
- Water is then neutralized with lime forming $CaF_2$ precipitate
- Precipitate is filtered and dried
- Off-gas from quench tank is scrubbed using dilute sodium hydroxide to remove residual acids before releasing to the environment

**3 Horizontal rotary fired kiln method**

- Requires suspension preheater for HFCs
- HFCs are sprayed into kiln near feed burner
- HFC co-fired with lime feedstock at low concentration
- Requires oil filter to remove solids
- Requires continuous flow rate measurement
- Waste water treatment is needed to treat quench water and scrubber purge
- Slurry is dried to produce ash
- Kiln temperature ranges from 900 to 1,100°C or higher
- Gas residence time is 6-7 seconds in kiln
- Carbon monoxide (CO) exhaust is lower than 12%
- HFC concentration for co-combustion should be 2% or lower

**4 Cement Kiln oxidation method**

- Suspension pre-heater is requires
- Temperature approximately 1,450°C
- Exhaust gas treatment required to produce dry ash
- HFCs should be sprayed close to burner
- Liquid feed equipment should include oil filter, flow meter and flow rate controls
- Cement is alkaline and will react with acids producing clinker
- Acids content of clinker must be maintained below 10 ppm
- Electrostatic precipitator needed to remove exhaust dust

**5 High temperature thermal steam decomposition**

- HFCs decomposition occurs upon mixing with steam and burning LPG
- HFCs removal efficiency was tested at 99.999%
- Exhaust gas HFC concentration is greater than 4.4 ppb
- Reaction temperature is 1,200°C
- Reactor off-gas is quenched with water
- Water is neutralized with lime and slurry is filtered and dried
- Water tank off-gas is scrubbed with alkaline solution

## 9. COMPARATIVE ASSESSMENT OF DESTRUCTION TECHNOLOGY ALTERNATIVES

### (Annex 81)

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Commercial status | Pilot plants in HFC service | Well commercialized | Well commercialized in lime manufacturing | Well commercialized incement manufacturing | Pilot plants in HFC service |
| Firing temperature | > 10000 °C | > 1200 °C | 900 - 1100 °C | 1450 °C | 1200 °C |
| HFC Destruction | 99.99% | 99.99% | > 99% | > 99% | 99.999% |
| Residence time | 50 milliseconds | > 2 seconds | > 2 seconds, avg 6-7 | > 1 second | > 2 seconds |
| Perceived effectiveness | Very high | Very high | Adequate | Adequate | Potentially high |
| Applicability | High in HFC Service | High in HFC Service | Limited to lime manufacturing | Limited to cement manufacturing | High in HFC Service |
| Perceived economics | Very high cost | High cost | Low when comingled with lime manufacturing | Low when comingled withcement manufacturing | Potentially lower than thermal oxidation furnace |
| By-product disposition | Dry sludge | Dry sludge | Mixed in lime | Mixed in cement | Dry sludge |

### Economic Comparison of Technology Alternatives

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Capital cost ($/mty) | $US 25000 | $US 17000 | $US 5000 for acid scrubbing | $US 5000 for acid scrubbing | Not yet known |
| Operating cost ($/mt) | $US 3000 ex depreciation | $US 2400 ex depreciation | $US 1000 ex depreciation | $US 1000 ex depreciation | Not yet known |
| Fuel consumption | 2233 kwh/mt HFC | 0.144 mt $CH_4$/mt HFC | 0.05 mt $CH_4$/mt HFC | 0.05 mt $CH_4$/mt HFC | 0.1 mt $CH_4$/mt HFC |
| Relative ranking | Highest cost with good performance for small systems | High cost with best performance | Lowest cost with lowest destruction efficiency | Lowest cost with lowest destruction efficiency | Not yet known |

### Applicability of Technology Alternatives

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Recommendation | Not recommended for large scale HFC destruction plants | Recommended for integrated and isolated HFC destruction | Recommended for lowest cost solution where lime kilin exists | Recommended for lowest cost solution where cement kilin exists | Not recommended until commercially proven |

## 10. ANNEXES

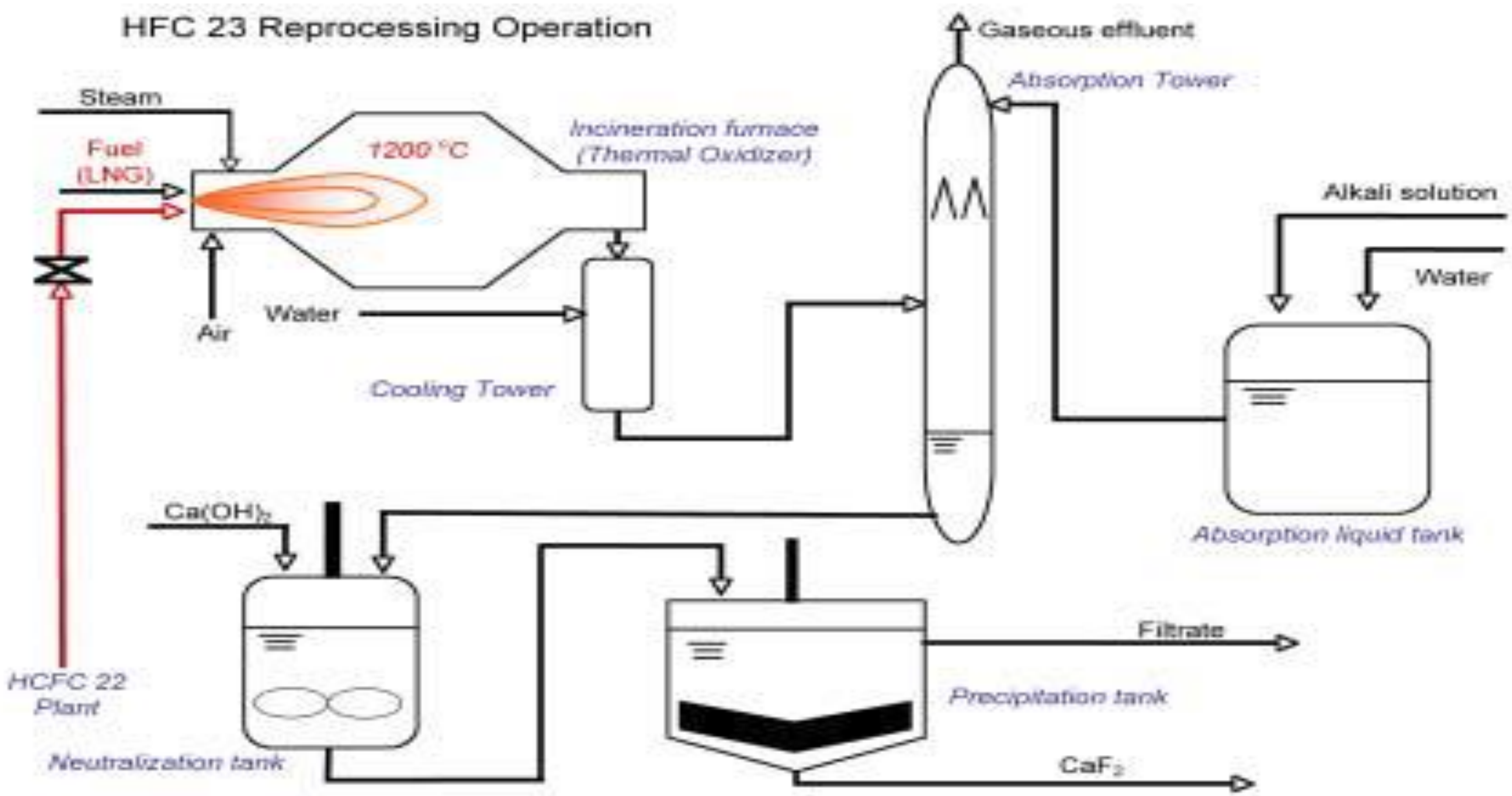
ANNEX 21 HCFC-22/HFC-23 PRODUCERS
ANNEX 22 FLUOR INCINERATOR
ANNEX 23 NIPPON STEEL INCINERATOR
ANNEX 24 VICHEM INCINERATOR
ANNEX 31 INTEGRATED HFC-23 COST ESTIMATES
ANNEX 41 STAND-ALONE HFC-23 COST ESTIMATES
ANNEX 71 AM001V6 MONITORING
ANNEX 81 ALTERNATIVE INCINERATION TECHNOLOGIES

Annex21

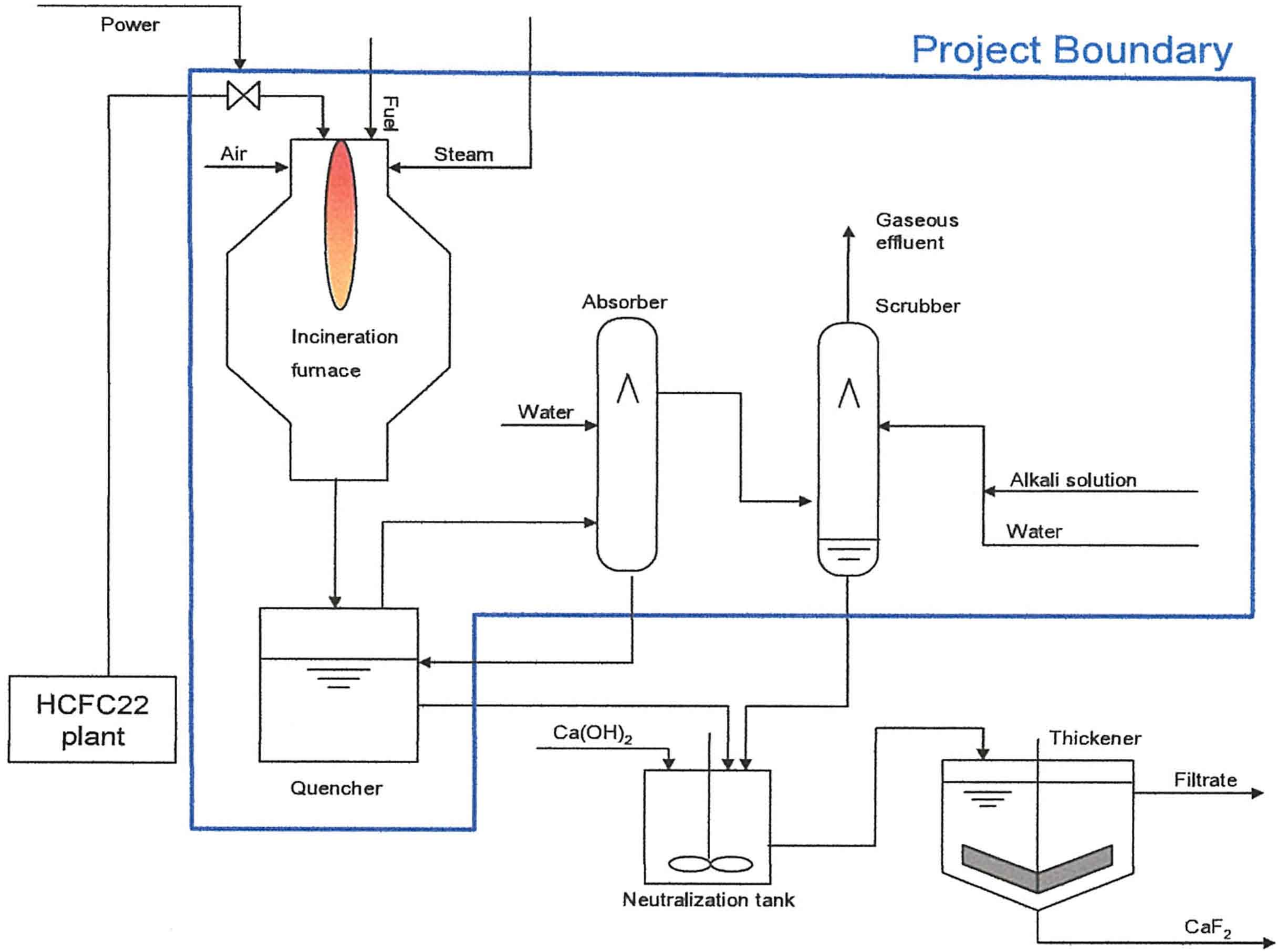
**HCFC-22/HFC-23 Producers Considered in Present Project**

| No. | HCFC-22/HFC-23 Producers | Lines | mt Av. Annual Production | | | |
|---|---|---|---|---|---|---|
| | **China** | | **HCFC-22** | **HFC-23** | **HFC-23/HCFC 22, %** | |
| 1 | Changshu 3F Zhonghao | | 41,308 | 1,195 | 2.89 | |
| 2 | Shandong Dongyue Chemical | | 35,998 | 864 | 2.40 | |
| 3 | Zhejiang Juhua Fluor-Chemistry | 703 & 4703 | 15,129 | 476 | 3.15 | |
| | Zhejiang Juhua Fluor-Chemistry | 2703 | 18,136 | 575 | 3.17 | 33,265 |
| 4 | Changshu Haike | | 28,409 | 506 | 1.78 | |
| 5 | Jiangsu Meilan Chemical | | 28,087 | 860 | 3.06 | |
| 6 | Yingpeng Chemical | | 23,399 | 713 | 3.05 | |
| 7 | Limin Chemical | | 16,502 | 517 | 3.13 | |
| 8 | Zhejiang Dongyang Chemical | | 15,623 | 507 | 3.25 | |
| 9 | China Fluoro Technology | | | | | |
| 10 | Zhonghao Chenguang Research Institute | 3 | | | | |
| | **Total China** | | **222,591** | **6,213** | | |
| | **India** | | | | | |
| 11 | Gujarat Fluorochemicals Limited | | 24,412 | 707 | 2.90 | |
| 12 | SRF | | 11,315 | 333 | 2.94 | |
| 13 | Navin Fluorine International | | 8,352 | 277 | 3.32 | |
| 14 | Chemplast Sanmar | | 1,957 | 59 | 3.01 | |
| 15 | Hindustan Fluorocarbons Limited | 4 | 1,148 | 36 | 3.14 | |
| | **Total India** | | 47,184 | 1,412 | | |
| | **Mexico** | | | | | |
| 16 | Quimobásicos | | **8,709** | **221** | 2.54 | |
| | **Argentina** | | | | | |
| 17 | Frio Industrias Argentinas | | 3,631 | 125 | 3.44 | |

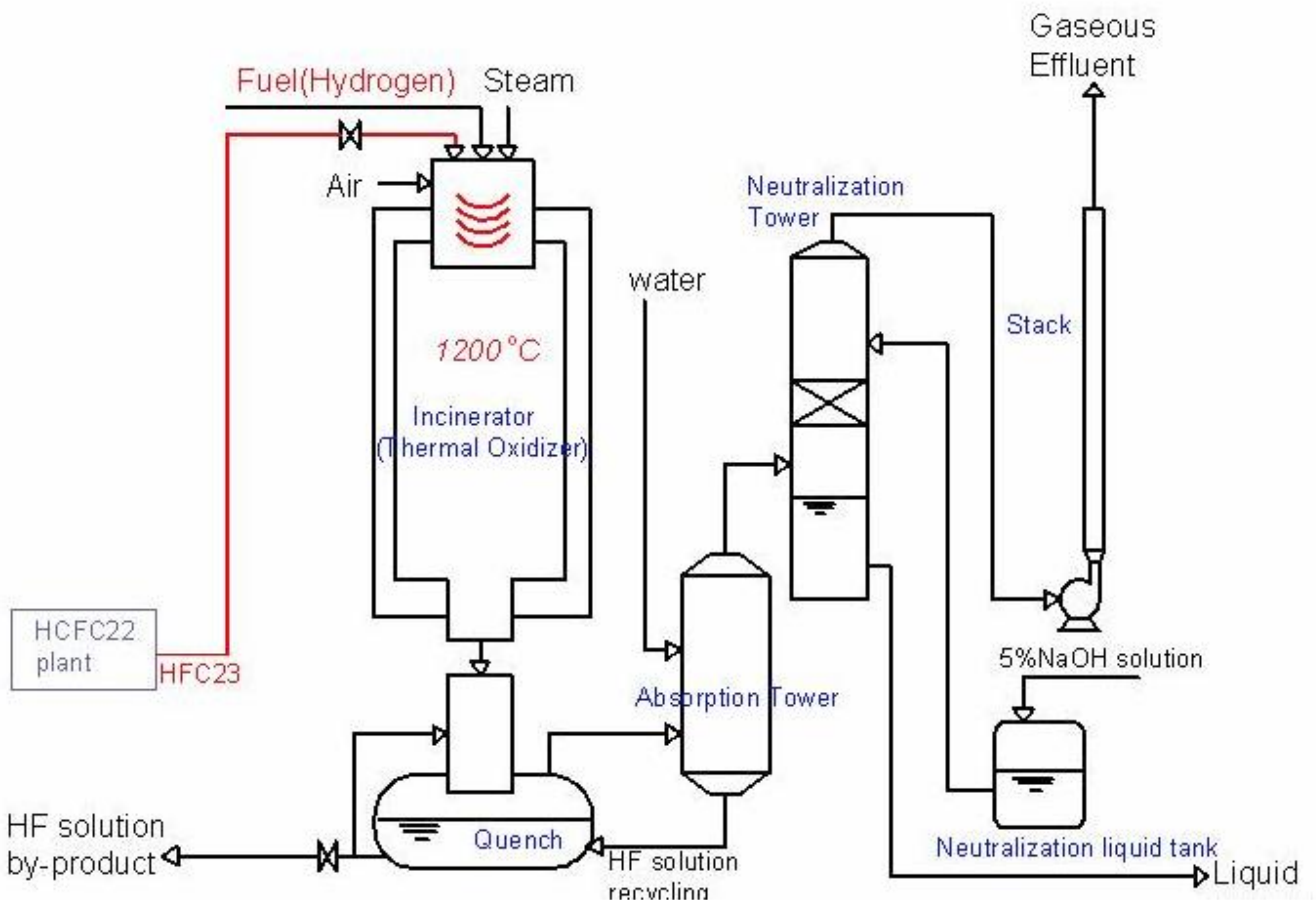
## Ineos Fluor Incineration System



# Nippon Steel Submerged Combustion Technology



## Vichem Incineration System




VichemA

# HFC-23 Onsite Incineration Cost Estimate in China Central East Coast

| | | | | | | |
|---|---|---|---|---|---|---|
| **HFC-23 Incineration Cost Estimate in China Central East Coast** | | | Annex312F2 | | | **$US/mt** |
| Integrated Incinerator | | | **Benchmark Destruction Cost** | | | 2500 |
| **Raw Material and Utility Costs** | | | | | | |
| | **Unit Cost** | | **Consumption** | | | |
| **Raw Materials** | | | | | | |
| Caustic Soda NaOH | 450 | $US/mt | 0.15 | mt/mt | | 67.5 |
| Lime consumption | 225 | $US/mt | 1.718 | mt/mt | | 386.55 |
| Minor Additives | 1500 | $US/mt | 0.005 | mt/mt | | 7.5 |
| Misc. chemicals | | | | | | 10 |
| By-Product Credits | | | | | | |
| Dilute HF (20%) | 50 | $US/mt | 0.01 | mt/mt | | 0.5 |
| **Net Raw Material Cost** | | | | | | 471.05 |
| **Utilities** | | | | | | |
| Scrubber process feed water | 0.22 | $US/mt | 0.505 | mt/mt | | 0.11 |
| Boiler Feed Water | 1.65 | ¢US/mt | 1.82 | mt/mt | | 3 |
| Cooling Water | 0.0365 | ¢US/mt | 2.05 | mt/mt | | 0.07 |
| Electricity | 0.14 | $US/kwh | 1786 | kwh/mt | | 250.04 |
| Process Steam Consumption | 33.88 | $US/mt | 3.131 | mt/mt | | 106.08 |
| Fuel Gas | 420 | $US/mt | 0.144 | mt/mt | | 60.48 |
| **Net Utility Cost** | | | | | | 419.79 |
| **Variable Costs** | | | | | | 890.84 |

## HFC-23 Onsite Incineration Cost Estimate in China Central East Coast

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity | MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| Destruction | MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| **Investment ($US millions)** | | | | | | | | | | | | | |
| Battery Limits | | 5.6 | | | 8.97 | | | 14.374 | | | 18.94 | | |
| Off-Sites | | 3.4 | | | 4.78 | | | 6.706 | | | 8.18 | | |
| Total Fixed Capital | | 9 | | | 13.7 | | | 21.081 | | | 27.1 | | |
| **DESTRUCTION COST ($/MT)** | | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** |
| Net Raw Materials | | 471.1 | | | 471.1 | | | 471.1 | | | 471.1 | | |
| Net Utilities | | 419.8 | | | 419.8 | | | 419.8 | | | 419.8 | | |
| | **Variable Costs** | 890.8 | 890.8 | 33.9 | 890.8 | 890.8 | 41.8 | 890.8 | 890.8 | 49.1 | 890.8 | 890.8 | 53.02 |
| **Direct Costs** | | | | | | | | | | | | | |
| Maintenance Materials | | 350 | | | 280.4 | | | 224.6 | | | 197.3 | | |
| Operating Supplies | | 26.3 | | | 13.1 | | | 6.6 | | | 4.4 | | |
| Operating Labor | | 262.8 | | | 131.4 | | | 65.7 | | | 43.8 | | |
| Maintenance Labor | | 350 | | | 280.4 | | | 224.6 | | | 197.3 | | |
| Control Laboratory | | 52.6 | 1042 | 39.6 | 26.3 | 731.6 | 34.3 | 13.1 | 534.6 | 29.5 | 8.8 | 451.5 | 26.87 |
| | **Total Direct Costs** | 1932.5 | | | 1622.4 | | | 1425.4 | | | 1342.3 | | |
| **Indirect Costs** | | | | | | | | | | | | | |
| Plant Overhead | | 399.2 | | | 262.8 | | | 182.1 | | | 149.9 | | |
| Insurance | | 225 | | | 171.8 | | | 131.8 | | | 113 | | |
| Depreciation | | 0 | 624.2 | 23.7 | 0 | 434.7 | 20.4 | 0 | 313.8 | 17.3 | 0 | 262.9 | 15.6 |
| | **Plant Gate Cost** | 2556.7 | | | 2057.1 | | | 1739.3 | | | 1605.2 | | |
| G&A, Sales, R&D | | 75 | 75 | 2.8 | 75 | 75 | 3.5 | 75 | 75 | 4.1 | 75 | 75 | 4.4637 |
| **TOTAL DESTRUCTION COST** | | | | | | | | | | | | | |
| **AT 100% CAPACITY** | | **2,631.7** | | **100** | **2,132.1** | | **100** | **1,814.3** | | **100** | **1,680.2** | | **100** |
| AT 75% CAPACITY | | 3,212.0 | | | 2,545.8 | | | 2,122.1 | | | 1,943.3 | | |
| AT 50% CAPACITY | | 4,372.5 | | | 3,373.3 | | | 2,737.7 | | | 2,469.6 | | |

## HFC-23 Onsite Incineration Cost Estimate in China Central East Coast

| | | | | | |
|---|---|---|---|---|---|
| **HFC-23 Incineration Cost Estimate in China Central East Coast** | | | Annex312F2A | | $US/mt |
| Integrated Incinerator | | | **Benchmark Destruction Cost** | | 2500 |
| **Raw Material and Utility Costs** | | | | | |
| | **Unit Cost** | | **Consumption** | | |
| **Raw Materials** | | | | | |
| Caustic Soda NaOH | 450 | $US/mt | 0.15 | mt/mt | 67.5 |
| Lime consumption | 225 | $US/mt | 1.718 | mt/mt | 386.55 |
| Minor Additives | 1500 | $US/mt | 0.005 | mt/mt | 7.5 |
| Misc. chemicals | | | | | 10 |
| By-Product Credits | | | | | |
| Dilute HF (20%) | 50 | $US/mt | 0.01 | mt/mt | 0.5 |
| **Net Raw Material Cost** | | | | | 471.05 |
| **Utilities** | | | | | |
| Scrubber process feed water | 0.22 | $US/mt | 0.505 | mt/mt | 0.11 |
| Boiler Feed Water | 1.65 | ¢US/mt | 1.82 | mt/mt | 3 |
| Cooling Water | 0.0365 | ¢US/mt | 2.05 | mt/mt | 0.07 |
| Electricity | 0.14 | $US/kwh | 1786 | kwh/mt | 250.04 |
| Process Steam Consumption | 33.88 | $US/mt | 3.131 | mt/mt | 106.08 |
| Fuel Gas | 420 | $US/mt | 0.144 | mt/mt | 60.48 |
| **Net Utility Costs** | | | | | 419.79 |
| **Variable Cost** | | | | | 890.84 |

## HFC-23 Onsite Incineration Cost Estimate in China Central East Coast

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| Destructio MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| | | | | | | | | | | | | |
| **Investment ($US millions)** | | | | | | | | | | | | |
| Battery Limits | 3.5 | | | 5.6 | | | 8.894 | | | 11.7 | | |
| Off-Sites | 2.8 | | | 3.9 | | | 5.533 | | | 6.7 | | |
| **Total Fixed Capital** | 6.3 | | | 9.5 | | | 14.427 | | | 18.5 | | |
| | | | | | | | | | | | | |
| **DESTRUCTION COST ($/MT)** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** |
| Net Raw Materials | 471.1 | | | 471.1 | | | 471.1 | | | 471.1 | | |
| Net Utilities | 419.8 | | | 419.8 | | | 419.8 | | | 419.8 | | |
| **Variable Costs** | 890.8 | 890.8 | 40.2 | 890.8 | 890.8 | 49.5 | 890.8 | 890.8 | 57.5 | 890.8 | 890.8 | 61.5 |
| | | | | | | | | | | | | |
| **Direct Costs** | | | | | | | | | | | | |
| Maintenance Materials | 216.6 | | | 173.5 | | | 139 | | | 122.1 | | |
| Operating Supplies | 26.3 | | | 13.1 | | | 6.6 | | | 4.4 | | |
| Operating Labor | 262.8 | | | 131.4 | | | 65.7 | | | 43.8 | | |
| Maintenance Labor | 216.6 | | | 173.5 | | | 139 | | | 122.1 | | |
| Control Laboratory | 52.6 | 774.8 | 35 | 26.3 | 517.8 | 28.8 | 13.1 | 363.4 | 23.4 | 8.8 | 301.1 | 20.8 |
| **Total Direct Costs** | 1665.6 | | | 1408.6 | | | 1254.2 | | | 1191.9 | | |
| Indirect Costs | | | | | | | | | | | | |
| Plant Overhead | 319.2 | | | 198.7 | | | 130.7 | | | 104.8 | | |
| Insurance | 156.8 | | | 118.6 | | | 90.2 | | | 76.9 | | |
| Depreciation | 0 | 475.9 | 21.5 | 0 | 317.3 | 17.6 | 0 | 220.9 | 14.2 | 0 | 181.7 | 12.5 |
| **Plant Gate Cost** | 2141.5 | | | 1726 | | | 1475 | | | 1373.6 | | |
| | | | | | | | | | | | | |
| G&A, Sales, R&D | 75 | 75 | 3.4 | 75 | 75 | 4.2 | 75 | 75 | 4.8 | 75 | 75 | 5.2 |
| | | | | | | | | | | | | |
| **TOTAL DESTRUCTION COST** | | | | | | | | | | | | |
| **AT 100% CAPACITY** | **2,216.5** | | **100** | **1,801.0** | | **100** | **1,550.0** | | **100** | **1,448.6** | | **100** |
| AT 75% CAPACITY | 2,658.4 | | | 2,104.3 | | | 1,769.8 | | | 1,634.5 | | |
| AT 50% CAPACITY | 3,542.2 | | | 2,711.1 | | | 2,209.3 | | | 2,006.4 | | |

# HFC-23 Stand-Alone Incineration Cost Esrimate in China Central East Coast

| | | | | | |
|---|---|---|---|---|---|
| **HFC-23 Incineration Cost Estimate in China Central East Coast** | | Annex412F2 | | | $US/mt |
| **Stand-Alone Incinerator** | | **Benchmark Destruction Cost** | | | 2,500 |
| Raw Material and Utility Costs | **Unit Cost** | | **Consumption** | | |
| Raw Materials | | | | | |
| Caustic Soda NaOH | 450 | $US/mt | 0.15 | mt/mt | 67.5 |
| Lime consumption | 225 | $US/mt | 1.718 | mt/mt | 386.55 |
| Minor Additives | 1500 | $US/mt | 0.005 | mt/mt | 7.5 |
| Misc. chemicals | | | | | 10 |
| | | | | | |
| By-Product Credits | | | | | |
| Dilute HF (20%) | 50 | $US/mt | 0.01 | mt/mt | 0.5 |
| **Net Raw Material Cost** | | | | | 471.05 |
| **Utilities** | | | | | |
| Scrubber process feed water | 0.22 | $US/mt | 0.505 | mt/mt | 0.11 |
| Boiler Feed Water | 1.65 | $US/mt | 1.82 | mt/mt | 3 |
| Cooling Water | 0.0365 | $US/mt | 2.05 | mt/mt | 0.07 |
| Electricity | 0.14 | $US/kwh | 1786 | kwh/mt | 250.04 |
| Process Steam Consumption | 33.88 | $US/mt | 3.131 | mt/mt | 106.08 |
| Fuel Gas | 420 | $US/mt | 0.144 | mt/mt | 60.48 |
| **Net Utility Cost** | | | | | 419.79 |
| **Variable Cost** | | | | | 890.84 |

# HFC-23 Stand-Alone Incineration Cost Esrimate in China Central East Coast

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| Destructior MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| **Investment ($US millions)** | | | | | | | | | | | | |
| Battery Limits | 5.6 | | | 8.97 | | | 14.4 | | | 18.9 | | |
| Off-Sites | 6.5 | | | 9.06 | | | 12.7 | | | 15.5 | | |
| Total Fixed Capital | 12.1 | | | 18.1 | | | 27.1 | | | 34.5 | | |
| **DESTRUCTION COST ($/MT)** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** |
| Net Raw Materials | 471.1 | | | 471.1 | | | 471.1 | | | 471.1 | | |
| Net Utilities | 419.8 | | | 419.8 | | | 419.8 | | | 419.8 | | |
| **Variable Costs** | 890.8 | 890.8 | 27.5 | 890.8 | 890.8 | 36.3 | 890.8 | 890.8 | 44.9 | 890.8 | 890.8 | 49.5 |
| **Direct Costs** | | | | | | | | | | | | |
| Maintenance Materials | 350 | | | 280.4 | | | 224.6 | | | 197.3 | | |
| Operating Supplies | 52.6 | | | 26.3 | | | 13.1 | | | 8.8 | | |
| Operating Labor | 525.6 | | | 262.8 | | | 131.4 | | | 87.6 | | |
| Maintenance Labor | 350 | | | 280.4 | | | 224.6 | | | 197.3 | | |
| Control Laboratory | 105.1 | | | 52.6 | | | 26.3 | | | 17.5 | | |
| **Total Direct Costs** | 2274.1 | 1383.3 | 42.7 | 1793.2 | 902.4 | 36.8 | 1510.9 | 620 | 31.2 | 1399.3 | 508.4 | 28.3 |
| Indirect Costs | | | | | | | | | | | | |
| Plant Overhead | 588.4 | | | 357.4 | | | 229.4 | | | 181.4 | | |
| Insurance | 301.3 | | | 226.3 | | | 169.4 | | | 143.6 | | |
| Depreciation | 0 | | | 0 | | | 0 | | | 0 | | |
| **Plant Gate Cost** | 3163.8 | 889.7 | 27.5 | 2376.9 | 583.7 | 23.8 | 1909.6 | 398.7 | 20.1 | 1724.3 | 325 | 18.1 |
| G&A, Sales, R&D | 75 | 75 | 2.3 | 75 | 75 | 3.1 | 75 | 75 | 3.8 | 75 | 75 | 4.2 |
| **TOTAL DESTRUCTION COST** | | | | | | | | | | | | |
| **AT 100% CAPACITY** | **3,238.8** | | **100** | **2,451.9** | | **100** | **1,984.6** | | | **1,799.3** | | **100** |
| AT 75% CAPACITY | 4,021.5 | | | 2,972.3 | | | 2,349.2 | | | 2,102.1 | | |
| AT 50% CAPACITY | 5,586.8 | | | 4,013.0 | | | 3,078.3 | | | 2,707.7 | | |

## HFC-23 Atand-Alone Incineration Cost Estimate in China Central East Coast

| | | | | | |
|---|---|---|---|---|---|
| **HFC-23 Incineration Cost Estimate in China Central East Coast** | | | Annex412F2A | | $US/mt |
| **Stand-Alone Incinerator** | | | **Benchmark Destruction Cost** | | 2500 |
| Raw Material and Utility Costs | **Unit Cost** | | **Consumption** | | |
| Raw Materials | | | | | |
| Caustic Soda NaOH | 450 | $US/mt | 0.15 | mt/mt | 67.5 |
| Lime consumption | 225 | $US/mt | 1.718 | mt/mt | 386.55 |
| Minor Additives | 1500 | $US/mt | 0.005 | mt/mt | 7.5 |
| Misc. chemicals | | | | | 10 |
| | | | | | |
| **By-Product Credits** | | | | | |
| Dilute HF (20%) | 50 | $US/mt | 0.01 | mt/mt | 0.5 |
| **Net Raw Material Cost** | | | | | 471.05 |
| **Utilities** | | | | | |
| Scrubber process feed water | 0.22 | $US/mt | 0.505 | mt/mt | 0.11 |
| Boiler Feed Water | 1.65 | $US/mt | 1.82 | mt/mt | 3 |
| Cooling Water | 0.0365 | $US/mt | 2.05 | mt/mt | 0.07 |
| Electricity | 0.14 | $US/kwh | 1786 | kwh/mt | 250.04 |
| Process Steam Consumption | 33.88 | $US/mt | 3.131 | mt/mt | 106.08 |
| Fuel Gas | 420 | $US/mt | 0.144 | mt/mt | 60.48 |
| **Net Utility Cost** | | | | | 419.79 |
| **Variable Cost** | | | | | 890.84 |

## HFC-23 Atand-Alone Incineration Cost Estimate in China Central East Coast

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| Destructior MT/Y | 400 | | | 800 | | | 1,600 | | | 2,400 | | |
| **Investment ($US millions)** | | | | | | | | | | | | |
| Battery Limits | 3.5 | | | 5.6 | | | 8.9 | | | 11.7 | | |
| Off-Sites | 5.3 | | | 7.5 | | | 10.5 | | | 12.8 | | |
| Total Fixed Capital | 8.8 | | | 13.0 | | | 19.4 | | | 24.5 | | |
| DESTRUCTION COST ($/MT) | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** | **$/mt** | **SubT** | **%** |
| Net Raw Materials | 471.1 | | | 471.1 | | | 471.1 | | | 471.1 | | |
| Net Utilities | 419.8 | | | 419.8 | | | 419.8 | | | 419.8 | | |
| **Variable Costs** | 890.8 | 890.8 | 31.7 | 890.8 | 890.8 | 42.2 | 890.8 | 890.8 | 52 | 890.8 | 890.8 | 57 |
| **Direct Costs** | | | | | | | | | | | | |
| Maintenance Materials | 216.6 | | | 173.5 | | | 139 | | | 122.1 | | |
| Operating Supplies | 52.6 | | | 26.3 | | | 13.1 | | | 8.8 | | |
| Operating Labor | 525.6 | | | 262.8 | | | 131.4 | | | 87.6 | | |
| Maintenance Labor | 216.6 | | | 173.5 | | | 139 | | | 122.1 | | |
| Control Laboratory | 105.1 | | | 52.6 | | | 26.3 | | | 17.5 | | |
| **Total Direct Costs** | 2007.2 | 1116.4 | 39.7 | 1579.4 | 688.6 | 32.6 | 1339.6 | 448.8 | 26.2 | 1248.8 | 358 | 22.9 |
| **Indirect Costs** | | | | | | | | | | | | |
| Plant Overhead | 508.4 | | | 293.3 | | | 178 | | | 136.3 | | |
| Insurance | 219.7 | | | 162.8 | | | 121.2 | | | 102.2 | | |
| Depreciation | 0 | | | 0 | | | 0 | | | 0 | | |
| Plant Gate Cost | 2735.3 | 728 | 25.9 | 2035.6 | 456.1 | 21.6 | 1638.8 | 299.2 | 17.5 | 1487.3 | 238.5 | 15.3 |
| G&A, Sales, R&D | 75 | 75 | 2.7 | 75 | 75 | 3.6 | 75 | 75 | 4.4 | 75 | 75 | 4.8 |
| **TOTAL DESTRUCTION COST** | | | | | | | | | | | | |
| AT 100% CAPACITY | **2,810.3** | | **100** | **2,110.6** | | **100** | **1,713.8** | | | **1,562.3** | | **100** |
| AT 75% CAPACITY | 3,450.1 | | | 2,517.1 | | | 1,988.1 | | | 1,786.1 | | |
| AT 50% CAPACITY | 4,729.7 | | | 3,330.3 | | | 2,536.7 | | | 2,233.8 | | |

**Approved baseline and monitoring methodology AM0001**

**“Decomposition of fluoroform (HFC-23) waste streams”**

## I. SOURCE AND APPLICABILITY

### Source

This methodology is based on a proposal from the HFC Decomposition Project in Ulsan, Republic of Korea whose Baseline study, Monitoring and Verification Plan and Project Design Document were prepared by INEOS Fluor Japan Limited (Japan), Foosung Tech Corporation Co., Ltd. (Korea) and UPC Corporation Ltd. (Korea) (version 2.4, July 8, 2003).

This methodology also refers to the latest approved versions of the following tools:

- “Tool to calculate project or leakage $CO_2$ emissions from fossil fuel combustion”;
- “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”;
- “Tool to assess the validity of the original/current baseline and to update the baseline at the renewal of a crediting period”.

For more information regarding the proposed new methodology and the tools as well as their consideration by the Executive Board please refer to <http://cdm.unfccc.int/goto/MPappmeth>.

The methodology also incorporates elements from the “Guidance on accounting eligible HFC-23”, contained in Annex 8 of the report of the thirty-ninth meeting of the CDM Executive Board. Therefore, this document is not applicable to this version of the methodology.

### Selected approach from paragraph 48 of the CDM modalities and procedures

“Existing actual or historical emissions, as applicable”.

### Definitions

The following definitions apply to this methodology:

**HCFC-22 production plant.** A chemical plant which produces chlorodifluoromethane (HCFC-22) either as an independent facility or as a part of an integrated complex. An HCFC-22 production plant may consist of one or several HCFC-22 production lines. The HCFC-22 production plant shall include all production lines located at the project activity site.

**HCFC-22 production line.** An HCFC-22 production line includes one or several HCFC-22 reaction units, the subsequent distillation process and storage tank. It is characterized by the feature that HCFC-22 produced in one production line can be identified from HCFC-22 produced in other production lines.

**HCFC-22 reaction unit.** The HCFC-22 reaction unit comprises the reactor, column and condenser where HCFC-22 is produced through chemical reaction and fluoroform (HFC-23) is formed through over-fluorination of HCFC-22.

**Swing plant.** A chemical plant which can produce either (a) HCFC-22 or (b) Chlorofluorocarbon-11 (CFC-11) and/or Chlorofluorocarbon-12 (CFC-12).

**HFC-23 decomposition facility.** A facility, such as an incinerator, which decomposes HFC-23 into $CO_2$, hydrogen fluoride (HF) and other gases that are neither greenhouse gases nor ozone depleting substances.

**Project activity site.** The project activity site includes the entire chemical complex where HCFC-22 is produced, including all production lines located at the complex.

**Waste generation rate *w*.** The ratio of mass of HFC-23 formed per unit mass of HCFC-22 produced in a HCFC-22 production line or plant.

**Emissive application.** The use of HCFC-22 for the purpose where HCFC-22 is not transformed in a chemical reaction into another compound. This includes, inter alia, the use of as refrigerant or foam blowing agent.

**Non-emissive application.** The use of HCFC-22 for purposes where HCFC-22 is transformed in a chemical reaction into another compound. This includes, inter alia, the production of polytetrafluoroethylene (PTFE).

**Monitoring period *m*.** The period for which a monitoring report is submitted, the verification is performed and for which issuance of CERs is requested by the Designated Operational Entity (DOE). A monitoring period can be of shorter duration than one year, but all the monitoring periods within a year *y* of the crediting period should add up to the duration of the year. For example, if a year includes four monitoring periods, the starting date of the first monitoring period should be the same as the starting date of the year *y* of the crediting period and the end date of the last monitoring period (fourth in this case) should be the end date of the year *y* of the crediting period. Under this methodology, emission reductions are calculated for each monitoring period *m*.

**Year *y* of the crediting period.** A year *y* of the crediting period is defined on the basis of the starting date of the crediting period of the project activity. For example, if the starting date of the crediting period is 15 June, then the year *y* of the crediting period for the project activity starts on 15 June and ends in the subsequent calendar year on 14 June.

## Applicability

This methodology is applicable to project activities which capture and decompose HFC-23 formed in the production of HCFC-22. The HFC-23 is decomposed in one or several HFC-23 decomposition facilities which are installed at the project activity site. A single HFC-23 decomposition facility may be used for decomposition of HFC-23 from one or several HCFC-22 reaction units. The HCFC-22 produced may be used for emissive and/or non-emissive applications. HFC-23 is formed as a by-product of the HCFC-22 production process, and is either released to atmosphere or (partially)

captured and sold to the market or decomposed in a HFC-23 decomposition facility. An example of a production process is illustrated in a figure in Annex 1 to this methodology.
This methodology is applicable under the following conditions:

- At least one HCFC-22 reaction unit at the project activity site has an operating history of at least three years between 1 January 2000 and 31 December 2004 and has been in operation from 2005 until the start of the project activity;
- The HFC-23 decomposition and, if applicable, any temporary storage of HFC-23, occurs only at the project activity site (i.e. no off-site transport occurs);
- No regulation requires the decomposition of the total amount of HFC-23 generated;
- Prior to the implementation of the project activity, no HFC-23 decomposition facility was installed at the project activity site and all HFC-23 generated at the project activity site was released to the atmosphere.
- Historical data on HCFC-22 production, HFC-23 formation and, in the case of swing plants, CFC production and the capacities of HCFC-22 and CFC production are available to project participants for each production line *k.*

In addition, the applicability conditions included in the tools referred to above apply.

## II. BASELINE METHODOLOGY

### Project boundary

All HCFC-22 production lines that are eligible for crediting as per the procedure in step 1 under "Baseline emissions" below shall be included in the project boundary. The emission sources included in, or excluded from the project boundary are shown in Table 1.

**Table 1: Emissions sources included in or excluded from the project boundary**

| | Source | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| Baseline Scenario | HFC-23 emissions from HCFC-22 production lines that are eligible for crediting | HFC-23 | Yes | Main emission source |
| Project Activity | Any remaining HFC-23 emissions from HCFC-22 production lines that are eligible for crediting | HFC-23 | Yes | May be an important emissions source |
| | Fossil fuel and electricity consumption for the operation of the HFC-23 decomposition | $CO_2$ | Yes | Small emission source but included as a conservative approach |
| | | $CH_4$ | No | Excluded for simplification. This emission source is assumed to be very small |

| | | | | |
|---|---|---|---|---|
| | facility(ies) | $N_2O$ | No | Excluded for simplification. This emission source is assumed to be very small |
| | Emissions from the decomposition of HFC-23 | $CO_2$ | Yes | Minor emission source but included as a conservative approach and as determination of this source does not require monitoring of additional parameters |

**Identification of the baseline scenario and demonstration of additionality**

In the absence of regulations requiring HFC-23 decomposition, HFC23 is typically released to the atmosphere because a HFC-23 decomposition facility entails capital and operating costs and the operator of the HCFC-22 production plant has no direct economic incentive to incur these costs. The baseline scenario is therefore the continuation of the current practice, i.e. the continued release of HFC-23 up to the amount that is allowed according to applicable regulations in the host country. If the quantity of HFC-23 emitted to the atmosphere under the project activity is lower than the baseline quantity, as calculated below, the project activity is deemed additional.

**Project emissions**

Under this methodology, project emissions are calculated for each monitoring period *m*. Project emissions include HFC-23 emissions, $CO_2$ emissions from fossil fuel consumption for the operation of the HFC-23 decomposition facility and $CO_2$ emissions from the decomposition of HFC-23 to $CO_2$. Project emissions in monitoring period *m* ($PE_m$) are calculated as follows:

$$PE_m = PE_{HFC23,m} + PE_{CO2,FF,m} + PE_{CO2,EL,m} + PE_{CO2/HFC23,m} \quad \textbf{(1)}$$

Where:

| | | |
|---|---|---|
| $PE_m$ | = | Project emissions in monitoring period *m* (t $CO_2$e) |
| $PE_{HFC23,m}$ | = | Project emissions of HFC-23 in monitoring period *m* (t $CO_2$e) |
| $PE_{CO2,FF,m}$ | = | Project emissions of $CO_2$ from fossil fuel consumption for the operation of the HFC-23 decomposition facility in monitoring period *m* (t $CO_2$) |
| $PE_{CO2,EL,m}$ | = | Project emissions of $CO_2$ from electricity consumption for the operation of the HFC-23 decomposition facility in monitoring period *m* (t $CO_2$) |
| $PE_{CO2/HFC23,m}$ | = | Project emissions of $CO_2$ from decomposition of HFC-23 in monitoring period *m* (t $CO_2$) |

The four emission sources are determined in the following three steps.

***Step 1: Determination of $PE_{HFC23,m}$***

Project emissions of HFC-23 in monitoring period *m* ($PE_{HFC23,m}$) include any HFC-23 emissions from all HCFC-22 production lines that are eligible for crediting as per the procedure in step 1 under “Baseline emissions” below. This includes emissions due to incomplete decomposition of HFC-23 in the HFC-23 decomposition facility, the direct venting of HFC-23 (e.g. through a by-pass to the HFC-23 decomposition facility) and fugitive emissions from storage and other devices connected to the HCFC-22 production lines that are eligible for crediting. Project emissions are not directly measured but are determined based on a HFC-23 mass balance, as the difference between the amount of HFC-23 generated in HCFC-22 production lines that are eligible for crediting ($\sum Q_{HFC23,gen,k,m}$) and the amount of HFC-23 generated as a by-product in these production lines and decomposed in the HFC-23 decomposition facility(ies) ($Q_{HFC23,dec,m}$), as follows:

$$PE_{HFC23,m} = \left( \sum_{k} Q_{HFC23,gen,k,m} - Q_{HFC23,dec,m} \right) \times GWP_{HFC23} \quad \textbf{(2)}$$

with

$$Q_{HFC23,dec,m} = \sum_{d} \left( Q_{HFC23,dec,d,inlet,m} - Q_{HFC23,dec,d,outlet,m} \right) \quad \textbf{(3)}$$

Where:

| | | |
|---|---|---|
| $PE_{HFC23,m}$ | = | Project emissions of HFC-23 in monitoring period *m* (t $CO_2e$) |
| $GWP_{HFC23}$ | = | Global Warming Potential of HFC-23 valid for the commitment period (t $CO_2e$ / t HFC-23) |
| $Q_{HFC23,gen,k,m}$ | = | Quantity of HFC-23 generated as a by-product in HCFC-22 production line *k* in monitoring period *m* (t HFC-23) |
| $Q_{HFC23,dec,m}$ | = | Quantity of HFC-23 that is generated as a by-product in HCFC-22 production lines that are eligible for crediting and that is decomposed in the HFC-23 decomposition facility(ies) in monitoring period *m* (t HFC-23) |
| $Q_{HFC23,dec,d,inlet,m}$ | = | Quantity of HFC-23 that is generated as a by-product in HCFC-22 production lines that are eligible for crediting and that is supplied to the inlet of the HFC-23 decomposition facility *d* in monitoring period *m* (t HFC-23) |
| $Q_{HFC23,dec,d,outlet,m}$ | = | Quantity of HFC-23 emitted at the outlet of the HFC-23 decomposition facility *d* due to incomplete decomposition of HFC-23 in monitoring period *m* (t HFC-23) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |
| d | = | HFC-23 decomposition facility(ies) operated under the project activity |

HFC-23 may be also temporarily stored, e.g. during maintenance of the HFC-23 decomposition facility. However, with the approach applied in equation (2) above, any HFC-23 added to the storage stock in monitoring period *m* is accounted as if it would be released to the atmosphere; when it is subsequently destroyed in monitoring period *m*+1 it is accounted as additional HFC-23 destruction and the project emissions are lowered by this amount. Over the two monitoring periods, the calculated project emissions correspond to the actual amount of HFC-23 released to the atmosphere. Note that this approach for accounting purposes may result in negative project emissions in some monitoring periods.

Project emissions are determined and accounted in this way for two reasons:

(1) The approach avoids that emission reductions could be claimed from long-term storage of HFC-23 and potential release of the stored HFC-23 after the end of the crediting period;

(2) The measurement of the quantity of HFC-23 generated and the quantity of HFC-23 decomposed is simpler and easier to verify than measuring all potential project emission sources which may include fugitive emission sources and different by-passes with varying volume flows and concentrations of HFC-23.

An example of the mass balance approach and the accounting of project emissions is provided in Table 2 below. In the example, 30 tons of HFC-23 are stored in the first monitoring period. In the second monitoring period, the stored amount is decomposed in the HFC-23 decomposition facility. For this reason, the amount of HFC-23 decomposed is larger than the amount of HFC-23 generated at the facility. In the first monitoring period, the amount of HFC-23 stored is accounted as project emission and therefore, the calculated project emissions (50 tons) are 30 tons larger than the actual amount released to the atmosphere. However, the second monitoring period accounts for the fact that the stored HFC-23 was decomposed. For this reason, the calculated project emissions are 30 tons less than the actual amount released to the atmosphere.

**Table 2: Example for a HFC-23 mass balance and accounting of HFC-23 project emissions (metric tons of HFC-23)**

| | A | B | C | D=A-B-C | E=A-B |
|---|---|---|---|---|---|
| **Monitoring report no** | **HFC-23 generated** | **HFC-23 decomposed** | **Addition to HFC-23 storage stock*** | **HFC-23 released to the atmosphere** | **Calculated project emissions** |
| 1 | 200 | 150 | 30 | 20 | 50 |
| 2 | 200 | 220 | -30 | 10 | -20 |
| **Total** | **400** | **370** | **0** | **30** | **30** |

*Positive values mean that the stock of stored HFC-23 was increased by this amount in monitoring period *m* and negative values mean that the stock of stored HFC-23 was reduced in monitoring period *m* and that the corresponding amount was either decomposed in the HFC-23 decomposition facility or released into the atmosphere.

***Step 2: Determination of $PE_{CO2,FF,m}$ and $PE_{CO2,EL,m}$***

Project emissions of $CO_2$ from fossil fuel and electricity consumption for the operation of the HFC-23 decomposition facility(ies) in monitoring period *m* ($PE_{CO2,FF,m}$ and $PE_{CO2,EL,m}$) shall be determined using the latest approved version of the “Tool to calculate project or leakage $CO_2$ emissions from fossil fuel combustion” and “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”. Project emissions from electricity consumption only have to be estimated if the HFC-23 is decomposed by a plasma technology.

The parameter $PE_{FC,j,y}$ used in the “Tool to calculate project or leakage $CO_2$ emissions from fossil fuel combustion” corresponds to the parameter $PE_{CO2,FF,m}$ in this methodology and the element process *j* in the tool corresponds to the consumption of fossil fuels for the operation of the HFC-23 decomposition facility(ies) in monitoring period *m*. The parameter $PE_{EC,y}$ used in the “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” corresponds to the parameter $PE_{CO2,EL,m}$ in this methodology and the project electricity consumption source *j* corresponds to the consumption of electricity for the operation of the HFC-23 decomposition facility(ies) using plasma technology in monitoring period *m*.

***Step 3: Determination of $PE_{CO2/HFC23,m}$***

Project emissions of $CO_2$ from decomposition of HFC-23 in monitoring period *m* ($PE_{CO2/HFC23,m}$) are determined based on the quantity of HFC-23 decomposed in monitoring period *m* ($Q_{HFC23,dec,m}$) and a conversion factor ($EF_{CO2/HFC23}$) expressing the amount of $CO_2$ generated per amount of HFC-23 decomposed, as follows:

$$PE_{CO2/HFC23} = Q_{HFC23,dec,m} \times EF_{CO2/HFC23} \quad \textbf{(4)}$$

Where:

| | | |
|---|---|---|
| $PE_{CO2/HFC23,m}$ | = | Project emissions of $CO_2$ from decomposition of HFC-23 in monitoring period *m* (t $CO_2$) |
| $Q_{HFC23,dec,m}$ | = | Quantity of HFC-23 decomposed in the HFC-23 decomposition facility(ies) in monitoring period *m* (t HFC-23) |
| $EF_{CO2/HFC23}$ | = | Conversion factor expressing the mass of $CO_2$ generated per unit mass of HFC-23 decomposed (t $CO_2$ / t HFC-23) |

**Baseline emissions**

Baseline emissions include only HFC-23 emissions. Baseline emissions are calculated separately for each HCFC-22 production line *k* which is eligible for crediting, as the minimum between:

(a) The quantity of HFC-23 that is formed in HCFC-22 production line *k* and can be emitted to the atmosphere in monitoring period *m* according to applicable regulations ($BE_{HFC23,REG,k,m}$); and

(b) The quantity of HCFC-22 production from production line *k* that is eligible for crediting in monitoring period *m* ($Q_{HCFC22,el,k,m}$), multiplied by the baseline waste generation rate for production line *k* in monitoring period *m* ($w_{BL,HFC23/HCFC22,k,m}$).

Accordingly, baseline emissions are calculated as follows:

$$BE_m = \sum_k GWP_{HFC23} \times MIN\left[BE_{HFC23,REG,k,m} ; Q_{HCFC22,el,k,m} \times w_{BL,HFC23/HCFC22,k,m}\right] \quad \textbf{(5)}$$

Where:

| | | |
|---|---|---|
| $BE_m$ | = | Baseline emissions in monitoring period *m* ($tCO_2e$) |
| $GWP_{HFC23}$ | = | Global Warming Potential of HFC-23 valid for the commitment period (t $CO_2e$ / tHFC-23) |
| $BE_{HFC23,REG,k,m}$ | = | Quantity of HFC-23 that is formed in HCFC-22 production line *k* and that can be emitted to the atmosphere in monitoring period *m* according to applicable regulations (t HFC-23) |
| $Q_{HCFC22,el,k,m}$ | = | Quantity of HCFC-22 that is produced in HCFC-22 production line *k* and that is eligible for crediting in monitoring period *m* (t HCFC-22) |
| $w_{BL,HFC23/HCFC22,k,m}$ | = | Baseline waste generation rate for HCFC-22 production line *k* in monitoring period *m* (t HFC-23 / t HCFC-22) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |

Both parameters, the quantity of HCFC-22 production that is eligible for crediting ($Q_{HCFC22,el,k,m}$) and the baseline waste generation rates ($w_{BL,HFC23/HCFC22,k,m}$), are determined in a conservative manner in order to avoid incentives that:

(a) More HCFC-22 is produced under the project activity than would be produced in the absence of the project activity; and/or

(b) The plant is operated under the project activity at a higher HFC-23/HCFC-22 ratio than in the absence of the project activity.

In the following steps, the required parameters are determined. Step 1 determines which HCFC-22 production lines *k* are eligible for crediting in monitoring period *m*. The quantity of HCFC-22 that is eligible in monitoring period *m* ($Q_{HCFC22,el,k,m}$) is calculated in step 2. Finally, Step 3 calculates the baseline waste generation rate ($w_{BL,HFC23/HCFC22,k,m}$).

***Step 1: Determination of HCFC-22 production lines k that are eligible for crediting in monitoring period m***

A HCFC-22 production line *k* is eligible for crediting in monitoring period *m* if all the following conditions are met:

- Commercial production of HCFC-22 and/or CFCs in the production line started before 1 January 2002 and has been recorded in each year until the start of the monitoring period *m*;
- The production line has produced HCFC-22 (and not only CFC-11 and/or CFC-12) in at least three calendar years in the period from 2000 to 2004;

All data supporting the determination which HCFC-22 production line *k* is eligible should be transparently documented in the CDM-PDD and in the monitoring reports. Project participants may quote data and documents submitted in previous monitoring reports instead of submitting them again.

***Step 2: Determination of $Q_{HCFC22,el,k,m}$***

The quantity of HCFC-22 production that is eligible for crediting in monitoring period *m* ($Q_{HCFC22,el,k,m}$) is determined separately for each HCFC-22 production line *k* which was identified to be eligible for crediting in monitoring period *m*.

In order to avoid incentives to produce more HCFC-22 than would be produced in the absence of the CDM, the amount of HCFC-22 eligible for crediting is capped on an annual basis to the average historical annual HCFC-22 equivalent production level in HCFC-22 production line *k* ($Q_{HCFC22e,k,hist}$).

The annual cap on historical production levels is applied to a monitoring period *m* on a pro-rata basis based on the duration of the monitoring period *m*.

Accordingly, $Q_{HCFC22,el,k,m}$ is determined as follows:

$$Q_{HCFC22,el,k,m} = MIN\begin{bmatrix} Q_{HCFC22,k,m} \\ Q_{HCFC22e,k,hist} \times \frac{d_m}{d_y} \end{bmatrix} \quad \textbf{(6)}$$

Where:

| | | |
|---|---|---|
| $Q_{HCFC22,el,k,m}$ | = | Quantity of HCFC-22 that is produced in HCFC-22 production line *k* and that is eligible for crediting in monitoring period *m* (t HCFC-22) |
| $Q_{HCFC22,k,m}$ | = | Amount of HCFC-22 produced in HCFC-22 production line *k* in monitoring period *m* (t HCFC-22) |

| | | |
|---|---|---|
| $Q_{HCFC22e,k,hist}$ | = | Average annual HCFC-22 equivalent production level in HCFC-22 production line *k* (t HCFC-22) |
| $d_m$ | = | Duration of the monitoring period *m* (days) |
| $d_y$ | = | Number of days in the year *y* of the crediting period (days) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |
| m | = | Monitoring period within year *y* of the crediting period for which issuance is requested |
| y | = | Year of the crediting period |

The historical HCFC-22 equivalent production level ($Q_{HCFC22e,k,hist}$) includes the actual HCFC-22 production, plus – in the case of swing plants – an HCFC-22 production equivalent of the CFC production, adjusted appropriately to account for the different production rates of HCFC22 and CFCs.

The historical production period shall include three calendar years *x* within the period from 2000 to 2004. The three last calendar years in which the plant produced HCFC-22 shall be used. If a swing plant produced only CFC-11 and/or CFC-12 in a particular year, this year shall not be included in the three calendar years. For example, if the plant produced HCFC-22 in all years from 2000 to 2004, the years 2002, 2003 and 2004 should be used. If the plant produced HCFC-22 in all years except for 2003, then the years 2001, 2002 and 2004 should be used.

The production of CFC-11 and CFC-12 is included as an equivalent HCFC-22 production only for those production lines *k* and only for those years *x* in which HCFC-22 was actually produced in the production line, i.e. the production of CFC-11 and CFC-12 should not be included for those years where no HCFC-22 production occurred in that production line. The CFC-11 and CFC-12 production is adjusted to an equivalent HCFC-22 production level based on the production capacities of the plant for HCFC-22 production and CFC-11 and CFC-12 production.

Accordingly, $Q_{HCFC22e,k,hist}$ is determined as follows:

$$Q_{HCFC22e,k,hist} = \frac{1}{3} \times \sum_{x} \left[ Q_{HCFC22,k,x} + Q_{CFC,k,x} \times \frac{C_{HCFC22,k}}{C_{CFC,k}} \right] \quad (7)$$

Where:

| | | |
|---|---|---|
| $Q_{HCFC22e,k,hist}$ | = | Average annual HCFC-22 equivalent production level in HCFC-22 production line *k* in the historical three year period from 2002 to 2004 (t HCFC-22 / yr) |
| $Q_{HCFC22,k,x}$ | = | Amount of HCFC-22 produced in HCFC-22 production line *k* in year *x* (t HCFC-22 / yr) |
| $Q_{CFC,k,x}$ | = | Amount of CFC-11 and CFC-12 produced in HCFC-22 production line *k* in year *x* (t CFC-11 and CFC-12 / yr) |
| $C_{HCFC22,k}$ | = | HCFC-22 production capacity of the production line *k* (t HCFC-22 / h) |
| $C_{CFC,k}$ | = | CFC production capacity of the production line *k* (t CFC-11 and CFC-12 / h) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |
| x | = | The three historical calendar years in the period from 2000 to 2004 identified as per the guidance above |

The HCFC-22 and CFC production capacities for each production line *k* ($C_{HCFC-22,k}$ and $C_{CFC,k}$) should be determined based on historical data from the period 2000 to 2004, by dividing the quantity of HCFC-22 or CFCs produced during a representative time period by that time period. The production capacities should be determined for all production lines separately. Furthermore, both production capacities (for HCFC-22 and the CFC production) should be determined for time periods where the production line was operating at the same load. Where such historical data is not available, project participants may undertake respective measurements of the HCFC-22 and CFC production capacity at the production line at full load operation. The ratio of $C_{HCFC-22,k}$ / $C_{CFC,k}$ should not exceed the ratio of the molecular weight of HCFC-22 (86.47) to the molecular weight of the mixture of CFC-11 (137.38) and CFC-12 (120.91) produced in the production line.

The historical production data of HCFC-22 and, in case of swing plants, of CFC-11 and CFC-12 in each production line *k* and the determination of the CFC and HCFC-22 production capacities ($C_{CFC,k}$ and $C_{HCFC-22,k}$) should be documented transparently in the CDM-PDD.

### *Step 3: Determination of $w_{BL,HFC23/HCFC22,k,y}$*

The baseline waste generation rate for HCFC-22 production line *k* in year *y* ($w_{BL,HFC23/HCFC22,k,y}$) is determined, as a conservative approach, as the minimum value between a conservative default value ($w_{default}$) and the lowest waste generation rate achieved in the production line in the past up to the monitoring period *m*.

Accordingly, $w_{BL,HFC23/HCFC22,k,y}$ is calculated as follows:

$$w_{BL,HFC23/HCFC22,k,y} = MIN\left[w_{default}; w_{MIN,k,m}\right] \quad (8)$$

Where:

| | | |
|---|---|---|
| $w_{BL,HFC23/HCFC22,k,m}$ | = | Baseline waste generation rate for HCFC-22 production line *k* in monitoring period *m* (t HFC-23 / t HCFC-22) |
| $w_{default}$ | = | Conservative default value for the baseline waste generation rate (t HFC-23 / t HCFC-22) |
| $w_{MIN,k,m}$ | = | Minimum waste generation rate achieved by HCFC-22 production line *k* up to monitoring period *m* (t HFC-23 / t HCFC-22) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |

The minimum waste generation rate achieved by HCFC-22 production line *k* up to monitoring period *m* ($w_{MIN,k,m}$) shall be selected from the period from the first year among the three historical years identified in Step 2 above up to the monitoring period *m*. For the time period before the start of the crediting period, the determination of $w_{MIN,k,m}$ shall be based on the average annual waste generation values. For these historical values, direct measurement of the HFC-23 release is to be used where the data is available, otherwise a mass balance based on the carbon efficiency and the flouring efficiency shall be used.
In applying this mass balance approach, it is assumed that 1% of the HCFC-22 is lost due to physical leakage based on a information by Midgley and Fischer (1993). As a conservative approach, the lower value between the carbon efficiency and the fluorine efficiency shall be used.

Accordingly, the historical waste generation rates are determined as follows if a mass balance approach is used:

$$w_{HFC23/HCFC22,k,x} = MIN\begin{bmatrix}(0.99 - FE_{k,x}) \times 0.540 \\ \\ (0.99 - CE_{k,x}) \times 0.809\end{bmatrix} \quad (9)$$

with

$$FE_{k,x} = \frac{M_{F,HCFC-22,k,x}}{M_{F,HF,k,x}} \quad (10)$$

and

$$CE_{k,x} = \frac{M_{C,HCFC-22,k,x}}{M_{C,CHCl3,k,x}} \quad (11)$$

Where:

| | | |
|---|---|---|
| $w_{HFC23/HCFC22,k,x}$ | = | Waste generation rate for HCFC-22 production line *k* in historical year *x* (t HFC-23 / t HCFC-22) |
| $FE_{k.x}$ | = | Flourine efficiency of HCFC-22 production line *k* in historical year *x* (dimensionless) |
| $CE_{k.x}$ | = | Carbon efficiency of HCFC-22 production line *k* in historical year *x* (dimensionless) |
| $M_{F,HCFC-22,k,x}$ | = | Mass of fluorine contained in the HCFC-22 produced in HCFC-22 production line *k* in historical year *x* (t F) |
| $M_{F,HF,k,x}$ | = | Mass of fluorine contained in the hydrogen fluoride fed into HCFC-22 reactor units of HCFC-22 production line *k* in historical year *x* (t F) |
| $M_{C,HCFC-22,k,x}$ | = | Mass of carbon contained in the HCFC-22 produced in HCFC-22 production line *k* in historical year *x* (t C) |
| $M_{C,HF,k,x}$ | = | Mass of carbon contained in the hydrogen fluoride fed into HCFC-22 reactor units of HCFC-22 production line *k* in historical year *x* (t C) |
| k | = | HCFC-22 production lines at the project activity site that are eligible for crediting in monitoring period *m* |
| x | = | The three historical calendar years in the period from 2000 to 2004 identified as per the guidance above |

From the time period after start of the crediting period, the determination of $w_{MIN,k,m}$ shall be based on the monthly average waste generation rates up to the start of the monitoring period *m*. The measurement procedures, calculations and assumptions used to determine *w* should be documented transparently in the CDM-PDD and in monitoring reports.

**Leakage**

Leakage emissions are deemed to be negligible and are accounted as zero.

**Emission reductions**

Emission reductions in monitoring period *m* ($ER_m$) are calculated as follows:

$$ER_m = BE_m - PE_m \quad \textbf{(12)}$$

Where:

| | | |
|---|---|---|
| $ER_m$ | = | Emission reductions in monitoring period *m* (t $CO_2$e) |
| $BE_m$ | = | Baseline emissions in monitoring period *m* (t $CO_2$e) |
| $PE_m$ | = | Project emissions in monitoring period *m* (t $CO_2$e) |

**Renewal of crediting period**

Project participants shall apply the "Tool to assess the validity of the original/current baseline and to update the baseline at the renewal of a crediting period".

In updating the parameter $w_{default}$ at the renewal of the crediting, the project participants shall evaluate the data from all registered HFC-23 CDM projects. The lowest average value achieved during a period of at least one month shall be used at the renewal of the crediting if this value is lower than the default value established in this methodology.

**Data and parameters not monitored**

| **Data / Parameter:** | $GWP_{HFC23}$ |
|---|---|
| Data unit: | t $CO_2$e / t HFC-23 |
| Description: | Global Warming Potential of HFC-23 valid for the commitment period |
| Source of data: | Decisions by COP/MOP |
| Value to be applied: | 11,700 for the first commitment period under the Kyoto Protocol |
| Any comment: | - |

| **Data / Parameter:** | $d_y$ |
|---|---|
| Data unit: | days |
| Description: | Number of days in the year *y* of the crediting period |
| Source of data: | - |
| Value to be applied: | 365 or 366 |
| Any comment: | - |

| **Data / Parameter:** | $Q_{HCFC22,k,x}$ |
|---|---|
| Data unit: | t HCFC-22 |
| Description: | Amount of HCFC-22 produced in HCFC-22 production line *k* in year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | If possible, cross-check production records with sales records as well as with information officially reported under the Montreal Protocol |
| Any comment: | - |

| **Data / Parameter:** | $Q_{CFC,k,x}$ |
|---|---|
| Data unit: | t CFC-11 and CFC-12 |
| Description: | Amount of CFC-11 and CFC-12 produced in HCFC-22 production line *k* in year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | If possible, cross-check production records with sales records as well as with information officially reported under the Montreal Protocol |
| Any comment: | Applicable in case of swing plants |

| **Data / Parameter:** | $C_{HCFC-22,k}$ |
|---|---|
| Data unit: | t HCFC-22 / h |
| Description: | HCFC-22 production capacity of production line *k* |
| Source of data: | This value is either based on historical records between 01 January 2000 and 31 December 2004 or measurements. Both should be at the same load levels as the corresponding data on the CFC production rate |
| Measurement procedures (if any): | If possible, cross-check production records with sales records as well as with information officially reported under the Montreal Protocol |
| Any comment: | Applicable in case of swing plants |

| **Data / Parameter:** | $C_{CFC,k}$ |
|---|---|
| Data unit: | t CFC-11 and CFC-12 / h |
| Description: | CFC production capacity of production line *k* |
| Source of data: | This value is either based on historical records between beginning of 2000 and end of 2004 or measurements. Both should be at the same load levels as the corresponding data on the HCFC-22 production rate |
| Measurement procedures (if any): | |
| Any comment: | Applicable in case of swing plants |

| **Data / Parameter:** | $M_{F,HCFC-22,k,x}$ |
|---|---|
| Data unit: | t F |
| Description: | Mass of fluorine contained in the HCFC-22 produced in HCFC-22 production line *k* in historical year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | |
| Any comment: | Applicable in the case a mass balance approach is used to determine the HFC-23 waste generation rate for years prior to the implementation of the project activity |

| **Data / Parameter:** | $M_{F,HF,k,x}$ |
|---|---|
| Data unit: | t F |
| Description: | Mass of fluorine contained in the hydrogen fluoride fed into HCFC-22 reactor units of HCFC-22 production line *k* in historical year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | |
| Any comment: | Applicable in the case a mass balance approach is used to determine the HFC-23 waste generation rate for years prior to the implementation of the project activity |

| **Data / Parameter:** | $M_{C,HCFC-22,k,x}$ |
|---|---|
| Data unit: | t C |
| Description: | Mass of carbon contained in the HCFC-22 produced in HCFC-22 production line *k* in historical year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | |
| Any comment: | Applicable in the case a mass balance approach is used to determine the HFC-23 waste generation rate for years prior to the implementation of the project activity |

| **Data / Parameter:** | $M_{C,HF,k,x}$ |
|---|---|
| Data unit: | t C |
| Description: | Mass of carbon contained in the hydrogen fluoride fed into HCFC-22 reactor units of HCFC-22 production line *k* in historical year *x* |
| Source of data: | Records by project participants |
| Measurement procedures (if any): | |
| Any comment: | Applicable in the case a mass balance approach is used to determine the HFC-23 waste generation rate for years prior to the implementation of the project activity |

| **Data / Parameter:** | $EF_{CO2/HFC23}$ |
|---|---|
| Data unit: | t $CO_2$ / t HFC-23 |
| Description: | Conversion factor expressing the amount of $CO_2$ generated per amount of HFC-23 decomposed |
| Source of data: | Molecular weight balance of the chemical process of conversion of HFC-23 into $CO_2$. |
| Value to be applied: | 0.62857 |
| Any comment: | - |

| **Data / parameter:** | $w_{default}$ |
|---|---|
| Data unit: | t HFC-23 / t HCFC-22 |
| Description: | Conservative default value for the baseline waste generation rate |
| Source of data: | As a conservative approach, a value of 0.01is used. The IPCC and TEAP reported that thermal oxidation would be required to reduce HFC-23 formation below a 1% level (IPCC/TEAP 2007, page 410). This value also corresponds approximately to the lowest reported and verified waste generation rates achieved by plants in developing countries. |
| Value to be applied: | 0.01 |
| Any comment: | - |

## III. MONITORING METHODOLOGY

### General monitoring provisions

Describe and specify in the CDM-PDD all monitoring procedures, including the type of measurement instrumentation used, the responsibilities for monitoring and QA/QC procedures that will be applied. Where the methodology provides different options (e.g. use of default values or on-site measurements), specify which option will be used. Meters should be installed, maintained and calibrated according to equipment manufacturer instructions and be in line with national standards or, if these are not available, international standards (e.g. IEC, ISO).

In the case of measurements of the flow of streams containing HFC-23, the flow meters shall be calibrated every six months by an officially accredited entity. The zero check on the flow meters shall be conducted every week. If the zero check indicates that the flow meter is not stable, an immediate calibration of the flow meter shall be undertaken.

The quantities of gaseous effluents (CO, HCl, HF, Cl2, dioxin and $NO_X$) and liquid effluents (PH, COD, BOD, n-H (normal hexane extracts), SS (suspended solid), phenol, and metals (Cu, Zn, Mn and Cr) are measured every six months to ensure compliance with environmental regulations.
All data collected as part of the monitoring should be archived electronically and be kept at least for two years after the end of the last crediting period. 100% of the data should be monitored if not indicated differently in the comments in the tables below.

### Establishment of a HFC-23 balance

For each monitoring period *m*, a HFC-23 mass balance shall be established. The mass balance should include all HCFC-22 production lines that are eligible for crediting. The HFC-23 mass balance shall include the following information:

- The stock of HFC-23 stored at the beginning of the monitoring period (measured);
- HFC-23 generated in each production line *k* in the monitoring period (measured);
- HFC-23 sold to third parties in the monitoring period (measured/recorded);
- HFC-23 added to or taken from the stock of HFC-23 stored in the monitoring period (measured);

- HFC-23 sent to the inlet of each HFC-23 decomposition facility in the monitoring period (measured);
- HFC-23 released to the atmosphere through incomplete decomposition of HFC-23 in each HFC-23 decomposition facility in the monitoring period (measured);
- HFC-23 released to the atmosphere through venting or other sources (calculated based on the remainder of the mass balance);
- The stock of HFC-23 stored at the end of the monitoring period (calculated based on the stock of HFC-23 stored at the beginning of the monitoring period and any additions/subtractions to the stock of HFC-23 stored).

The mass balance shall be conducted for each calendar month as well as for the duration of the monitoring period *m* and shall be documented transparently in a table in the monitoring report.

**Data and parameters monitored**

| **Data / Parameter:** | $Q_{HFC23,gen,k,m}$ |
|---|---|
| Data unit: | t HFC-23 |
| Description: | Quantity of HFC-23 generated as a by-product in HCFC-22 production line *k* in monitoring period *m* |
| Source of data: | Measurements by project participants |
| Measurement procedures (if any): | The quantity of HFC-23 generated is a key parameter for the calculation of overall emission reductions. The quantity shall be measured separately for each HCFC-22 production line *k* that is eligible for crediting as per the procedure in step 1 under "Baseline emissions". To measure this quantity accurately, two flow meters shall be used for each production line. The flow meters shall be installed in a manner which ensure that no HFC-23 from the production process can by-pass the flow meters.<br>Where the flow meter readings differ by greater than twice their claimed accuracy (for example 10% if the accuracy is claimed to be ±5%) then the reason for the discrepancy shall be investigated and the fault remedied.<br>For the sake of conservativeness, for each meter reading *t*, the higher value of the two readings shall be used to estimate $Q_{HFC23,gen,k,m}$:<br>$$Q_{HFC23,gen,k,m} = \sum_{t} MAX\left(Q_{HFC23,gen,k,meter\ 1,t};Q_{HFC23,gen,k,meter\ 2,t}\right)$$<br>The concentration of HFC-23 in the stream shall be measured by sampling using gas chromatography. The average flow rate should be multiplied with the average HFC-23 concentration in the stream to derive the amount of HFC-23 generated |

| | |
|---|---|
| Monitoring frequency: | Flow measurements: continuously, meter integrated for at least every hour<br>Concentration measurements: at least weekly in constant measurement intervals |
| QA/QC procedures: | A quality team should be formed to audit these procedure according to relevant national or international standards |
| Any comment: | The amount of HFC-23 generated shall be reported in monitoring reports for each production line separately and for each calendar month as well as for the entire monitoring period *m* |

| **Data / Parameter:** | $Q_{HFC23,dec,d,inlet,m}$ |
|---|---|
| Data unit: | t HFC-23 |
| Description: | Quantity of HFC-23 that is generated as a by-product in HCFC-22 production lines that are eligible for crediting and that is supplied to the inlet of the HFC-23 decomposition facility(ies) *d* in monitoring period *m* |
| Source of data: | Measurements by project participants |
| Measurement procedures (if any): | The quantity shall be measured separately for each HFC-23 decomposition facility *d* at the project activity site. To measure this quantity accurately, two flow meters shall be installed at the inlet of each HFC-23 decomposition facility. The flow meters shall be installed in a manner that they only measure the quantity of HFC-23 that is generated as a by-product in HCFC-22 production lines that are eligible for crediting.<br><br>Where the flow meter readings differ by greater than twice their claimed accuracy (for example 10% if the accuracy is claimed to be ±5%) then the reason for the discrepancy shall be investigated and the fault remedied.<br><br>For the sake of conservativeness, for each meter reading *t*, the lower value of the two readings shall be used to estimate $Q_{HFC23,dec,d,inlet,m}$:<br><br>$Q_{HFC23,dec,d,inlet,m} = \sum_{t} MIN\left(Q_{HFC23,dec,d,inlet,meter\,1,t}; Q_{HFC23,dec,d,inlet,meter\,2,t}\right)$<br><br>The concentration of HFC-23 in the stream shall be measured by sampling using gas chromatography. The average flow rate should be multiplied with the average HFC-23 concentration in the stream to derive the amount of HFC-23 supplied to the inlet of the HFC-23 decomposition facility |
| Monitoring frequency: | Flow measurements: continuously, meter integrated for at least every hour<br>Concentration measurements: at least weekly in constant measurement intervals |
| QA/QC procedures: | A quality team should be formed to audit these procedure according to relevant national or international standards |
| Any comment: | The amount of HFC-23 supplied to the inlet of the HFC-23 decomposition facility shall be reported in monitoring reports for each HFC-23 decomposition facility separately and for each calendar month as well as for the entire monitoring period *m* |

| **Data / Parameter:** | $Q_{HFC23,dec,d,outlet,m}$ |
|---|---|
| Data unit: | t HFC-23 |
| Description: | Quantity of HFC-23 emitted at the outlet of the HFC-23 decomposition facility(ies) *d* due to incomplete decomposition of HFC-23 in monitoring period *m* |
| Source of data: | Measurements by project participants |
| Measurement procedures (if any): | The quantity shall be measured separately for each HFC-23 decomposition facility *d* at the project activity site<br>The concentration of HFC-23 in the stream shall be measured by sampling using gas chromatography. The average flow rate should be multiplied with the average HFC-23 concentration in the stream to derive the amount of HFC-23 emitted at the outlet of the HFC-23 decomposition facility |
| Monitoring frequency: | Flow measurements: continuously, meter integrated for at least every hour<br>Concentration measurements: at least weekly in constant measurement intervals |
| QA/QC procedures: | A quality team should be formed to audit these procedure according to relevant national or international standards |
| Any comment: | The amount of HFC-23 emitted at the outlet of the HFC-23 decomposition facility shall be reported in monitoring reports for each HFC-23 decomposition facility separately and for each calendar month as well as for the entire monitoring period *m* |

| **Data / Parameter:** | $Q_{HCFC22,k,m}$ |
|---|---|
| Data unit: | t HCFC-22 |
| Description: | Amount of HCFC-22 produced in HCFC-22 production line *k* in monitoring period *m* |
| Source of data: | Measurements by project participants |
| Measurement procedures (if any): | - |
| Monitoring frequency: | Continuously, aggregated monthly and for the duration of the monitoring period *m* |
| QA/QC procedures: | Cross-check measured data with sales data |
| Any comment: | If more than one HCFC-22 production line exists at the project activity site, the production in each production line shall be separately measured and reported |

| **Data / Parameter:** | $BE_{HFC23,REG,k,m}$ |
|---|---|
| Data unit: | t HFC-23 |
| Description: | Quantity of HFC-23 that is formed in HCFC-22 production line *k* and that can be emitted to the atmosphere in monitoring period *m* according to applicable regulations |
| Source of data: | Relevant regulations |
| Measurement procedures (if any): | - |
| Monitoring frequency: | For each monitoring report |
| QA/QC procedures: | - |
| Any comment: | - |

| **Data / Parameter:** | $w_{MIN,k,m}$ |
|---|---|
| Data unit: | t HFC-23 / t HCFC-22 |
| Description: | Minimum waste generation rate achieved by HCFC-22 production line *k* up to monitoring period *m* |
| Source of data: | Plant records |
| Measurement procedures (if any): | Follow the guidelines in baseline emissions section |
| Monitoring frequency: | For the period before the crediting period starts: Average annual values shall be determined.<br>During crediting period: Monthly values shall be determined |
| QA/QC procedures: | - |
| Any comment: | - |

## IV. REFERENCES

Midgley P.M. and D.A. Fisher, 1993: The Production and release to the atmosphere of chlorodifluoromethane (HCFC-22), *Atmos. Environ., 27A*, **14**, 2215-2223.

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## Annex 1

**Example of HCFC-22 production process**

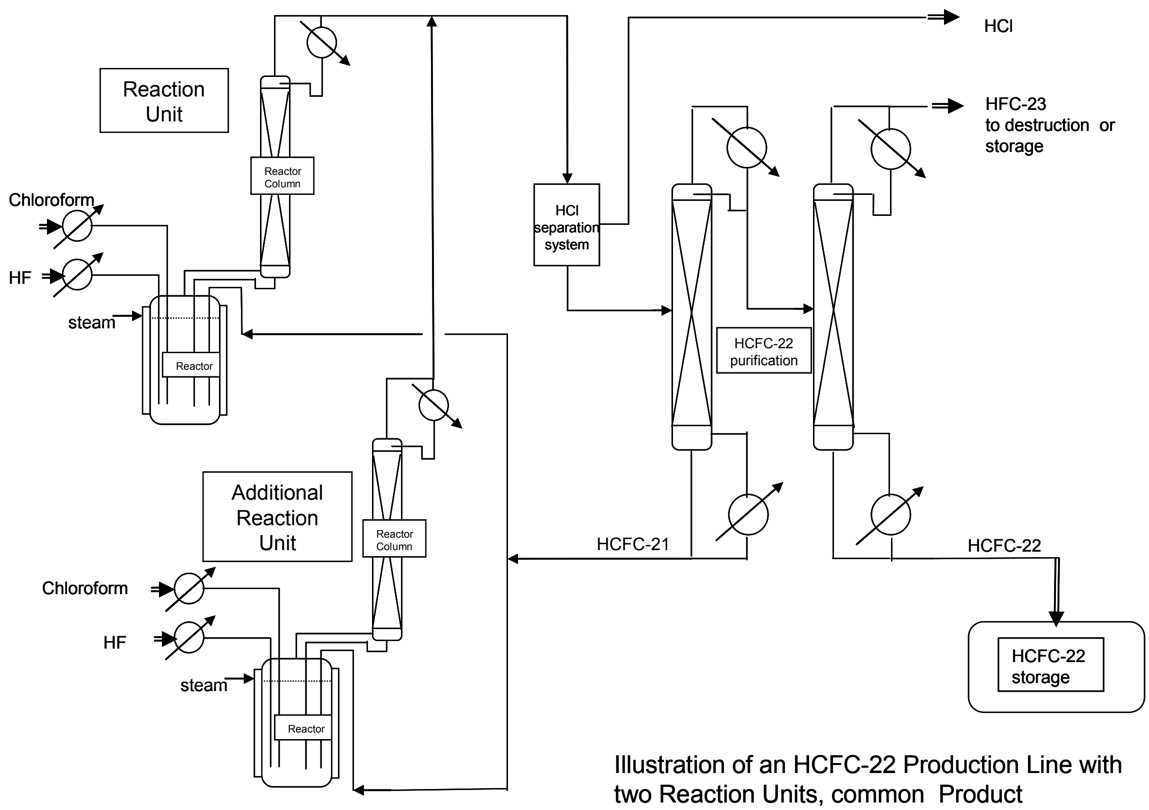


Illustration of an HCFC-22 Production Line with two Reaction Units, common Product Purification and Single Storage Facility

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**History of the document**

| Version | Date | Nature of revision(s) |
|---|---|---|
| 06.0.0 | EB 65, Annex 10<br>25 November 2011 | Revision of the methodology to address issues identified by the methodologies panel in a report to the CDM Executive Board at its 46th meeting. The changes include, inter alia:<br>• Change of the title from “Incineration of fluoroform (HFC-23) waste streams” to “Decomposition of fluoroform (HFC-23) waste streams”;<br>• The introduction of a lower cap on the HFC-23 generation rate, i.e. the amount of HFC-23 formed per amount of HCFC-22 produced; and<br>• The use of the average (and not maximum) historical HCFC-22 production to determine the amount of HCFC-22 that is eligible for crediting<br>• Other changes, including a separation of project and baseline emissions, the provision of definitions for key terms, the determination of emissions for monitoring periods instead of years, a separate determination of baseline emissions for each production |

| | | |
|---|---|---|
| | | line, modified provisions to account for the temporary storage of HFC-23, use of applicable tools to determine project emissions, additional guidance on an HFC-23 mass balance, provisions for the renewal of the crediting period, revised monitoring requirements and additional guidance to determine the historical waste generation rate.<br>Due to the overall modification of this document, no highlights of the changes are provided. |
| 05.2 | 3 December 2007 | In equation (5), the variable HFC23(max,y) was replaced with HCFC(max,y) on the right hand side of the equation. |
| 05.1 | 27 July 2007 | Editorial revision to:<br>• Amend the first row of the data monitoring table, to reflect the calibration requirements for the flow meters measuring the quantity of HFC-23 supplied to the destruction process (q_HFC23y) as stipulated in Section III of the baseline and monitoring methodology;<br>• Amend the footnote to table D.6, to reflect the correct frequency of calibration of the flow meters measuring the quantity of HFC-23 supplied to the destruction process. |
| 04 | EB 24, Annex 3<br>12 May 2006 | Revision to reflect an interpretation of "lower of the two readings" in the methodology in accordance with the Board's guidance provided at its twenty-third meeting. With this revision the methodology clearly states that monthly recording of HFC23 flow is the sum of the lower of the two periodic readings taken by the two flow meters. |
| 03 | EB 19, Annex 4<br>13 May 2005 | • The applicability conditions were modified to limit the methodology to existing HCFC22 production facilities which have at least three (3) years of operating history between beginning of the year 2000 and the end of the year 2004;<br>• The eligible production of HCFC-22 at the HCFC-22 production facility is capped to the maximum historical annual production level during any of the last three (3) years between beginning of the year 2000 and the end of the year 2004, including CFC production at swing plants adjusted appropriately to account for the different production rates of HCFC22 and CFCs;<br>• Clarification is made that the waste generation rate w should be estimated based on the three (3) most recent years of operation up to 2004. The requirements for measurement of this parameter are further clarified, including with regard to the use of a fluorine balance;<br>• The cap on the waste generation rate w is lowered from 4% to 3% (0.03 tonnes of HFC 23 produced per tonne of HCFC 22 produced).<br>• The requirement is specified that in case insufficient data is available for the calculation of HFC23 release for all three (3) most recent years of operation up to 2004, then the default value for w to be used is 1.5%;<br>• New requirements on HFC23 measurement during the crediting period are added in monitoring methodology. |
| 02 | EB 15, para. 12<br>7 April 2004 | • Clarification is provided on how the quantity of waste HFC23 destroyed is calculated;<br>• A footnote was added to clarify that the quantity of HFC23 used to calculate the waste generation rate w is the sum of HFC 23 recovered for sale plus the waste HFC 23;<br>• Several changes were made in the monitoring tables;<br>• Editorial revisions such as different nomenclature for some of the variables were made. |
| 01 | 26 September 2003 | Initial adoption. |

**Decision Class**: Regulatory
**Document Type**: Standard
**Business Function**: Methodology

# PRO/CON QUALITATIVE ASSESSMENT OF TECHNOLOGY ALTERNATIVES

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Commercial status | Pilot plants in HFC service | Well commercialized | Well commercialized in lime manufacturing | Well commercialized incement manufacturing | Pilot plants in HFC service |
| Firing temperature | > 10000 °C | > 1200 °C | 900 - 1100 °C | 1450 °C | 1200 °C |
| HFC Destruction | 99.99% | 99.99% | > 99% | > 99% | 99.999% |
| Residence time | 50 milliseconds | > 2 seconds | > 2 seconds, avg 6-7 | > 1 second | > 2 seconds |
| Perceived effectiveness | Very high | Very high | Adequate | Adequate | Potentially high |
| Applicability | High in HFC Service | High in HFC Service | Limited to lime manufacturing | Limited to cement manufacturing | High in HFC Service |
| Perceived economics | Very high cost | High cost | Low when comingled with lime manufacturing | Low when comingled withcement manufacturing | Potentially lower than thermal oxidation furnace |
| By-product disposition | Dry sludge | Dry sludge | Mixed in lime | Mixed in cement | Dry sludge |

# ECONOMIC COMPARISON OF TECHNOLOGY ALTERNATIVES

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Capital cost ($/mty) | $US 25000 | $US 17000 | $US 5000 for acid scrubbing | $US 5000 for acid scrubbing | Not yet known |
| Operating cost ($/mt) | $US 3000 ex depreciation | $US 2400 ex depreciation | $US 1000 ex depreciation | $US 1000 ex depreciation | Not yet known |
| Fuel consumption | 2233 kwh/mt HFC | 0.144 mt $CH_4$/mt HFC | 0.05 mt $CH_4$/mt HFC | 0.05 mt $CH_4$/mt HFC | 0.1 mt $CH_4$/mt HFC |
| Relative ranking | Highest cost with good performance for small systems | High cost with best performance | Lowest cost with lowest destruction efficiency | Lowest cost with lowest destruction efficiency | Not yet known |

# APPLICABILITY OF TECHNOLOGY ALTERNATIVES

| Metric | 1 Plasma radio frequency arc torch | 2 Fired heater thermal oxidation furnace | 3 Horizontal rotary fired oxidation kiln | 4 Cement kiln oxidation | 5 High temperature steam thermal decomposition |
|---|---|---|---|---|---|
| Recommendation | Not recommended for large scale HFC destruction plants | Recommended for integrated and isolated HFC destruction | Recommended for lowest cost solution where lime kilin exists | Recommended for lowest cost solution where cement kilin exists | Not recommended until commercially proven |

# Annex II

## Study on Viable Technology Approaches for Reducing HFC-23 Byproduct in the Production Process of HCFC-22

Beijing University of Chemical Technology

## Summary

The study made a thorough survey of all existing producers of HCFC-22 in China as of 2017, 16 in total, via questionnaire and site visit. On this basis, findings on the production status of HCFC-22 and the byproduct ratio of HFC-23, the process technology and the operational conditions used, and the disposal treatment of HFC-23 were obtained. The controlling factors for reducing the HFC-23 ratio were analyzed. The technical approaches for reducing the byproduct ratio of HFC-23 were proposed through thorough discussion with various experts from enterprises, industrial research institutes and the fluorochemical sector. The main results and conclusions are as follow:

1) Liquid fluorination technology is adopted for all domestic producers of HCFC-22 with production capacity of reactor unit varying from 3,000 to 30,000 t/a. There are 30 sets of production lines with total production capacity of HCFC-22 of 720 kt/a and actual output of 589 kt/a in 2016. Nearly 33.04% of the production capacity is from Dongyue Chem., and 28.53% from Jiangsu Meilan Chem. and Juhua Fluorochem. Ind.

2) From 2014 to 2016, the total production of HCFC-22 for the enterprises surveyed was 1,724 kt with 44.67 kt of HFC-23 byproduct. The byproduct ratio of HFC-23 varied from 1.9% to 3.0% with an average value of 2.59% for the whole sector.

3) For disposal of HFC-23, three technologies are used in China, i.e. fuel incineration, decomposition with superheated steam, and plasma incineration. There are a total of 22 sets of incineration units with treatment capacity of HFC-23 of 22,007 t/a. Among them, 16 are fuel incinerators, 3 are plasma incinerators, and 3 are decomposition with superheated steam.

4) HFC-23 is an inevitable byproduct of HCFC-22, its best controlled ratio is about 1.4% in the world, while the average ratio of HFC-23 is 2.59% in China. To destroy the by-produced HFC-23 thoroughly, an incineration unit is indispensable. At present, almost all the HCFC-22 producers in China have built incineration facilities to dispose their own HFC-23 by-product.

5) Further reduction of HFC-23 ratio can be achieved via (1) equipment modification or (2) process optimization. In theory, approach (2) is recognized to be more

advantageous when considering the various restrictions of approach (1), e.g. site limitation, variation of utility, size of capital investment, etc.

6) The construction details of the reactor including refluxing tower, the process conditions, and the mixing status in the reactor are key controlling factors for the byproduct ratio of HFC-23. Commercial software simulation indicates that (1) reaction temperature and pressure have little influence on the byproduct ratio of HFC-23; (2) HFC-23 increases with the increasing feeding rate of HF; (3) lowering the liquid level can greatly reduce the amount of HFC-23 (up to 50%) without additional equipment investment and energy consumption.

7) Experiences from experts and HCFC-22 producers were collected, and the relevance analysis was made between process conditions and HFC-23 ratio. On this basis, along with theoretical analysis and the available process simulation results, the following factors are pointed out to be crucial for the reduction of HFC-23 ratio: (1) lowering the liquid level in reactor and shortening the residence time of reactants therein; (2) increasing the vaporization amount and the turbulent degree in the reactor to reduce the over-fluorination of catalyst and HCFC-22 by local excessive HF; (3) reducing the reflux amount of HCFC-22 back to the reactor; (4) using mixture feeding of HF and chloroform to improve the uniformity of HF in the reactor; (5) enlarging the ratio of height to radii to 6-8; and, (6) pretreating the feedstocks by deep dehydration to keep a better and longer catalytic activity of the catalyst.

8) Nine technological measures are proposed based on our best understanding on all factors influencing the by-product ratio of HFC-23. These measures are primarily achieved by the addition of new equipment and the modification for the relevant facilities in use. The enterprise can select the measures according to their specific conditions, i.e. the byproduct ratio of HFC-23, the process parameters used, running status of the equipment and facilities, and, allowable conditions for technical renovation. (a) For the enterprises with lower HFC-23 byproduct ratio of about 2%, small renovation to the reactor may be applicable, for example, by using mixture feeding of reactants, multi-flow feeding into the reactor, liquid distributor inside the reactor, or casing mixer in the reactor. (b) For the enterprises with higher HFC-23 byproduct ratio of about 3% with older and smaller reactors, a new reactor with a larger ratio of height to radii is suggested along with other appropriate measures.

9) Five technological renovation approaches derived from an appropriate combination of the above technological measures are recommended (see the following table), which adopt the experiences of various experts from fluorochemical sector, HCFC-22 production enterprises, and the state of the art advancement in the literature. These approaches provide a guide or reference for the relevant HCFC-22 production enterprises to further reduce their byproduct ratio

of HFC-23. The renovation investment was estimated to vary from 0.8 to 6 million RMB. However, the viability of the recommended technological renovation approaches has yet to be verified in practice, and thus there exist some technical risks or uncertainty. To reduce the implementation risk and push forward smooth technical renovation, we propose to demonstrate these measures on a 25 kt/a HCFC-22 production line, and then to safely apply to other enterprises upon success.

| Recommended renovation approaches | Capital cost RMB | Total cost of renovation (incl. capital cost) RMB | Note |
|---|---|---|---|
| 1 | 400 | 615 | Use new reactor with appropriate design; dilute HF feeding by the liquid stream from reflux tower. |
| 2 | 150 | 231 | Dilute the reactants greatly, and use draft tube to increase the turbulence inside reactor |
| 3 | 150 | 231 | Premix the feeding reactants, and dilute the feeding reactants further by reflux liquid, use liquid distributor inside reactor |
| 4 | 70 | 108 | Minor modification for enterprises with about 2% of HFC-23, which includes (1) premixing the feeding reactants, and (2) further diluting the feeding reactants by the liquid stream from reflux tower. |
| 5 | 50 | 77 | Minor modification for enterprises with about 2% of HFC-23 through diluting the feeding reactants by the liquid stream from reflux tower. |