United Nations Industrial Development Organization

Demonstration Project for Disposal of Unwanted ODS in Mexico

2017

United Nations Industrial Development Organization

And the Government of France

Demonstration Project for Disposal of Unwanted ODS in Mexico

Project Manager:

Riccardo Savigliano

Prepared by:

Alan Bastida &
Conrado Martínez

September 2017

Contents

Acronyms

CAA	Clean Air Act
CEMS	Continuous Emissions Monitoring System
CFC	Chlorofluorocarbon
CRT	Climate Reserve Ton
DRE	Destruction and Removal Efficiency
EPA	Environmental Protection Agency of the United States
FIDE	Trust Fund for Electricity Savings (as per its acronym in Spanish)
GoM	Government of Mexico
GWP	Global Warming Potential
HARP	Home Appliances Replacement Program
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPMP	HCFC Phase-Out Management Plan
LGPGIR	General Law for Prevention and Integral Management of Residues (as per its acronym in Spanish)
MLF	Multilateral Fund for the Implementation of Montreal Protocol
MP	Montreal Protocol on Substances that deplete the Ozone Layer
MRV	Monitoring Reporting and Verification
NOM	Mexican Official Standard (as per its acronym in Spanish)
NPP	National CFC Phase-Out Plan
ODS	Ozone Depleting Substances
PLASCON	Argon Plasma Arc
R&R Center	Recovery and Recycling Centers
RAC	Refrigeration and Air Conditioning
RCRA	Resource Conservation and Recovery Act
SEMARNAT	Ministry of Environment and Natural Resources (as per its acronym in Spanish)
SISSAO	ODS Information and Tracking System (as per its acronym in Spanish)
TEAP	Technology and Economic Assessment Panel
THC	Total hydrocarbons
TPS	Total Suspended Particles
UNEP	United Nations Environmental Programme
UNIDO	United Nations Industrial Development Organization

Executive Summary

Mexico´s Demonstration Project for unwanted ODS disposal has been one of the first project supported by the Multilateral Fund for high volume consumption Article 5 countries to be successfully realized. Its implementation led to the environmentally-sound destruction of 113 tonnes of unwanted ODS banks, which implied the mitigation of over 504 thousand tCO_2e. In other words, this mitigation is equivalent to the emissions that would have been produced by 140 thousand vehicles in circulation during one year.

Beyond ozone and climate benefits, the Demonstration Project encouraged the first Mexican facilities to obtain license authorizations to incinerate and co-process unwanted ODS, while proving the feasibility of ODS destruction using two different technologies: Argon plasma arc and Cement kiln.

The Demonstration Project outcomes will contribute to develop cost-effective financing schemes that enable the destruction of additional amounts of ODS, while the lessons accumulated during its implementation will help relieve associated barriers to implement future unwanted ODS disposal projects.

Project justification

The Montreal Protocol on Substances that deplete the Ozone Layer has successfully controlled the production and consumption of Ozone Depleting Substances (ODS) across the world. However, this has led, in certain cases, to the accumulation of unwanted ODS banks from refrigeration, air conditioning, aerosols and foams, among other sectors.

Following previous decisions in order to address ODS banks disposal, the Executive Committee of the Multilateral Fund approved in 2011 the funding of a Demonstration Project for disposal of unwanted ODS in Mexico, to be implemented by UNIDO and the Government of France.

In the last years, Mexico has been phasing out ODS through different programs, including the NPP and HPMP, as well as energy efficiency initiatives. As a result this projects, an increasing amount of waste ODS stockpiles has emerged.

Sources of ODS banks in Mexico

Banks of unwanted ODS were collected principally from stockpiles out of specification materials, end-of-life appliances recovery programs and confiscation of illegal trading. One of the most relevant banks resulted from the virgin CFCs accumulated in the pharmaceutical industry followed by the unwanted ODS generated as a result of FIDE´s Home Appliances Replacement Program (HARP), a financing scheme to replace old and inefficient refrigerators and air conditioners. Likewise, important quantities of HCFC-22 were seized by customs officers in Mexico.

Unwanted ODS from different sources were handled by Recovery and Recycling Centers, which are certified entities enabled to manage hazardous waste ODS, as per Mexican regulations.

Mexico's Demonstration Project destroyed 113 tonnes of unwanted ODS banks, as summarized in Table 1.

Table 1 ODS banks destroyed in Mexico´s Demonstration Project

ODS banks source	Amount (tonnes)
Pharmaceutical industry	36
HARP program	35
Illegal trading prevention	27
R&R Centers	15
Total	**113**

Source: UNIDO and SEMARNAT.

Legislation and regulations

Destruction of unwanted ODS is regulated by Technology and Economic Assessment Panel, an advisory body to the Montreal Protocol Parties, that established the list of ODS destruction technologies which comply performance and environmental criteria set by the Parties of the Montreal Protocol. Thirteen technologies were identified, including Argon plasma arc and cement kiln, among other.

Furthermore, as unwanted ODS banks are classified as hazardous waste by Mexican regulations, several procedures have to be followed by generators, importers, exporters and handling, transportation and disposal service providers. Transboundary movements of hazardous waste also follow international policies, including Basel Convention requirements.

Before 2011 no facilities within Mexico were licensed to destroy unwanted ODS. As a result of the implementation of the Demonstration Project, two companies were granted such authorizations by Mexican authorities, after attesting no safety or environmental concerns were risen due to ODS destruction at their facilities.

Demonstration Project implementation and outcomes

Mexico´s Demonstration Project implementation was performed in phases, according to the progressive consolidation of ODS banks and the alleviation of other barriers which arose during the project lifetime. Though the project was approved in 2011, certain preliminary activities were performed between 2011 and 2013. A relevant aspect which delayed the project implementation was the difficulty to consolidate ODS banks, as HARP centers were not recovering predicted amounts of waste refrigerant. Preliminary activities consisted of training and recovery equipment endowment to HARP centers, design of MRV system, organization of awareness workshop and, most noticeably, execution of ODS destruction pilot tests and licensing approval for Mexican companies.

<u>Stage 1A</u>

Actual implementation of the Demonstration Project began in 2014 (Stage 1A), in which ODS banks were intended to be exported to the USA for disposal, as no authorized facilities were

available within Mexico by that time. This stage was not implemented up to the point of the destruction phase, since handling and exportation costs were higher than expected. Nonetheless, aggregation and consolidation of ODS banks was achieved during Stage 1A (Table 2).

Stage 1B

Following the attempt to export ODS banks, by March 2014, the first Mexican facility got the approval to destroy ODS. This facility was a state of the art Argon plasma arc, operated by Quimobásicos in the city of Monterrey, located in the northwest of Mexico. Stage 1B was implemented in the fall of 2015 and ended at the beginning of 2016. During this stage about 74 tonnes of unwanted ODS banks were destroyed in the Argon plasma arc, involving a reduction equivalent to 351 thousand tCO_2e. Overall implementation costs (including handling, transportation, destruction and MRV) were in average 9.2 USD per kg of ODS destroyed (Table 2).

Stage 2

The second stage of the Demonstration Project was executed after Holcim Mexico acquired a license to co-process unwanted ODS at their cement kiln situated in the southeast of Mexico in the municipality of Tecomán. Moreover, a second batch of ODS banks had been collected and stored. Between 2016 and 2017 Holcim Mexico destroyed about 39 tonnes of unwanted ODS, which are equivalent to the reduction of 153 thousand tCO_2e. Overall implementation costs (including co-financing of ODS transportation by generators and destruction and MRV by destruction facility) were in average 8.0 USD per kg of ODS destroyed (Table 2).

Table 2 Summary of Demonstration Project stages and outcomes

Project phases	Technology and destruction Facility	Status	Unwanted ODS destroyed (tonnes)	GHG emission reductions (thousand tCO_2e)	Implementation costs (USD/kg ODS)	Cost-effectiveness (USD/tCO_2e)
Stage 1A	Export to USA	Not executed	0	0	11.0[a]	NA
Stage 1B	Quimobásicos Argon plasma arc	Completed	74	351	9.2	1.9
Stage 2	Holcim Mexico cement kiln	Completed	39	153	8.0	2.0
Total			**113**	**504**	**9.4**[b]	**2.0**

[a] Intended but not implemented costs
[b] Average cost

1 Background

The Government of Mexico (GoM) has been very active in implementing the NPP and HPMP[1] during the last years, phasing-out Chlorofluorocarbons (CFCs) and advancing on the phase-down of Hydrochlorofluorocarbons (HCFCs). One of the effects of these activities has been the accumulation of ODS banks along the country, which are not readily managed and treated due to several technical and economic barriers.

Most of these residual banks contain CFCs and HCFCs, chemicals that feature both ozone depleting effects and high global warming potential. Due to these overlapping impacts, proper handling and destruction of unwanted ODS could provide co-benefits allowing the accelerated recovery of the ozone layer and mitigation of the climate change.

Due to its leadership within the region, in 2011 Mexico was appointed by the Multilateral Fund to implement one of the first pilot ODS disposal projects, henceforth **Demonstration Project**. This project would allow to test feasibility of ODS destruction technologies and generate know-how to prove cost-efficiency of such projects among Article 5 countries.

1.1 Approval of Mexico's Demonstration Project

The Montreal Protocol on Substances that Deplete the Ozone Layer (MP), the protocol to the Vienna Convention on the Protection of the Ozone Layer, has been successful at reducing global production and consumption of Ozone Depleting Substances (ODS). Following decision XX/7[2] in 2008, the Parties requested the Executive Committee of the Multilateral Fund (MLF) to consider pilot projects covering transportation, storage and destruction of ODS, with a focus on assembled stocks with high net global warming potential (GWP), and in regionally diverse Article 5 countries.

During the 57th and 58th meetings of the Executive Committee in 2009, the MLF provided grants through UNIDO and the World Bank, respectively to develop a pilot ODS disposal demonstration project for Mexico, based on the fact that it showed feasibility and included methods of leveraging co-funding.

Finally, on the 63rd Meeting in 2011 the Executive Committee decided to approve funding for a demonstration project on ODS waste management and disposal in Mexico amounting to US $1,427,915 to be implemented by the Government of France and UNIDO.

Unlike the original project proposal, which included a financial leverage through sales of carbon credits in the voluntary carbon market, the actual project was approved in line with Decision 63/28 of the Executive Committee as state below:

a) To note with appreciation the submission by the Government of Mexico of a demonstration project for ODS destruction to destroy a total of 166.7 metric tonnes of ODS waste;

[1] NPP: National CFC Phase-Out Plan; HPMP: HCFC Phase-Out Management Plan.

[2] Twentieth Meeting of the Parties (Doha, 16-20 November 2008). Decision XX/7: Environmentally sound management of banks of ozone depleting substances. Paragraph 2.

b) To approve the implementation of a demonstration project for ODS destruction in Mexico, in line with decision 58/19, at the amount of US $1,427,915, comprising US $927,915, plus agency support costs of US $69,594 for UNIDO, and US $500 ,000, plus support costs of US $65,000 for the Government of France, noting that approval was on the understanding that:

   i. No further funds would be available for Mexico for any ODS disposal projects in the future;
   ii. Any marketing of greenhouse gas (GHG) emission reductions generated by or associated with the project would be subject to a decision by the Executive Committee; and

c) To establish a monitoring system for the operation and the activities associated with the ODS disposal demonstration project and to report thereon to the Executive Committee at the completion of the project in 2014, ensuring that no marketing of GHG emission reductions had taken place.

Therefore, the restriction to produce carbon credits radically modified the original project scope and objectives which included, among others, the creation of producer responsibility legislation and a new facility for de-manufacturing end-of-life refrigerators and recovering of ODS including foams blowing agents.

Following project approval under aforementioned provisions, activities were rearranged as indicated below:

- Original ODS destruction target is maintained at 166.6 tonnes of ODS waste.
- Scope of substances are widened from CFC-12 only (due to Voluntary Carbon Market provisions) to other ODSs as no limitations prevailed any more.
- Destruction activities in the US were still considered as a viable alternative due to non-existence of available facilities in Mexico at the time of the project approval.
- A dedicated monitoring system would be established for the operation and activities associated with the ODS disposal demonstration project.
- Contrary to preliminary estimations, ODS recovery rates at HARP centers were lower than expected, therefore leading to the need of further developing capacities and identification of additional consolidated ODS banks.

1.2 Unwanted ODS in Mexico

Mexico´s Demonstration Project was sourced from various ODS stockpiles found along the country, which were originated from ODS phase-out projects and energy efficiency activities.

One of the main sources of ODS banks in Mexico came from the implementation of the Home Appliances Replacement Program (HARP) by the Trust Fund for Electricity Savings (FIDE), a national energy efficiency program which provided support for replacement and safe disposal of about 1.9 million units of old and inefficient refrigeration and air conditioning (RAC) equipment between 2009 and 2012 (The World Bank, 2016).

Other sources of ODS banks included the national network of Recovery and Recycling Centers established since 2007 with support of SEMARNAT and UNIDO. Additionally, ODS confiscated from illicit traffic at customs and certain stocks of propellants within the pharmaceutical sector after CFCs phase-out activities also increased existing banks which needed an environmentally-sound management and destruction.

1.3 Former ODS destruction activities in Mexico

Prior to the ODS disposal project approved by MLF in 2011, Mexico had performed an ODS destruction test at one of the state-of-the-art cement kilns facilities within Mexico. This test was funded and executed in 2008 by Holcim Mexico with the support and coordination of SEMARNAT and UNIDO. In this destruction test, 794 kg of a CFC-12 and HCFC-22 blend were fed into the main burner of the cement kiln, while performance and environmental criteria were monitored according to national standards and TEAP recommendations[3]. Though only a small destruction test, these results showed that infrastructure capacity, and technical and environmental conditions were satisfactory for the future implementation of a full-scale project in Mexico.

Other relevant studies had been performed before the implementation of the ODS destruction project. As part of the HARP activities, UNIDO and the World Bank provided a grant to Mexico to carry out a study that identified sources of unwanted ODS in Mexico, and for their transportation, packaging, storage and final disposal. This study[4], particularly, assessed ODS disposal methodologies and criteria addressed to CFCs collected in the HARP project, which was financed by the International Bank for Reconstruction and Development in the World Bank Group. One of the main objectives was to analyze the funding mechanism of ODS disposal projects through voluntary carbon markets (Pandey, 2012). It is worth mentioning that later in 2011, it was established that any marketing of GHG emission reductions generated by MLF-supported ODS disposal projects would be subject to a decision by the Executive Committee (decision 58/19).

1.4 ODS destruction projects via Voluntary Carbon Markets

The Climate Action Reserve (CAR) is a carbon offset program in the USA. This program was initially launched in California and later reached across the USA and abroad. The CAR encourages GHG emission reductions projects while ensuring environmental benefits, integrity and transparency. It is the largest accredited registry for the California compliance market and has a key role for the cap-and-trade program. In the voluntary market, CAR has established high quality standards for the carbon offset projects, oversees independent third-party verification bodies and issues and tracks the transaction of carbon credits (Climate Reserve Tonnes or CRTs) (Climate Action Reserve, 2015). Issuance of CRTs from some project types are also eligible in Mexico.

The CAR currently has 5 project protocols which are available for projects located within Mexico[5]. In particular, the Mexico Ozone Depleting Substances Project Protocol is applicable to ODS

[3] See chapter on International standards for ODS disposal for further detail.

[4] Study on Disposal of ODS Collected from Refrigerator and Air Conditioners under the Mexican Efficient Lighting and Appliances Program. March 2012.

[5] Boiler efficiency, Forest, Landfill, Livestock and ODS. For more information see: www.climateactionreserve.org/how/protocols/

sourced from Mexico and destroyed at facilities in Mexico. Before this protocol was launched in 2015, the United States Ozone Depleting Substances Project Protocol and the Article 5 Ozone Depleting Substances Project Protocol provided guidance for projects that destroy ODS sourced from the US or Article 5 countries, respectively. These protocols were first adopted in February 2010.

Between 2010 and 2012 two projects registered using the Article 5 ODS project protocol, which ODS were sourced from Mexico. Project details are summarized in Table 3.

Table 3 Article 5 ODS projects registered in CAR sourcing ODS from Mexico

Project Developer	Destruction facility in the US	ODS destroyed	ODS source in Mexico	ODS destroyed (tonnes)
Remtec	Remtec Clean Harbors El Dorado, Arkansas	Virgin ODS (CFC-12) stockpiles	Quimobásicos facilities in Monterrey, Mexico	285
OEKO Service Luxembourg (OSL)	Remtec Clean Harbors El Dorado, Arkansas	Unwanted ODS (CFC-12) from end-of-life appliances	Ecofrigo R&R Center in Celaya. Mexico	13

Source: Own elaboration based on Climate Action Reserve (2017).

2 ODS Banks

ODS banks for the implementation of the Demonstration Project were sourced from mainly four different activities and programs:

1) Mixed ODS from Recovery and Recycling Centers.
2) Mixed ODS from Home Appliances Replacement Program.
3) Virgin CFC-11, CFC-12 and CFC-114 stockpiles from pharmaceutical industry phase-out projects.
4) Out-of-specification ODS from Illegal trading prevention activities at customs.

It is relevant to highlight that regardless of the original point sources of the ODS waste, all of the stockpiles had to be consolidated by the Recovery and Recycling Centers (R&R Centers), as they are the only service providers authorized to handle hazardous waste, including discarded and unwanted CFCs, HCFCs and Hydrofluorocarbons (HFCs).

As further explained below, the Demonstration Project destroyed a total of 113 tonnes of unwanted ODS banks, as summarized in Table 4.

Table 4 ODS banks disposed in Mexico´s Demonstration Project

ODS banks source	Amount (tonnes)
Pharmaceutical industry	36
HARP program	35
Illegal trading prevention	27
R&R Centers	15
Total	**113**

Source: UNIDO and SEMARNAT.

2.1 Role of Recovery and Recycling Centers

It is important to mention that since CFCs and HCFCs wastes are classified in Mexico as a hazardous residues according to the current national regulations, every ODS bank has to be consolidated, transported and handles by a fully certified company with all the required permits. In the case of ODS, these companies are represented by the R&R Centers disseminated all around the country.

R&R Centers constitute the main places for ODS stockpiled in Mexico. These centers were created in 2007 as part of the NPP, when SEMARNAT and UNIDO implemented a program for the installation of 14 recycling centers through Mexico in order to provide recovery, recycling and storage services to refrigeration technicians, FIDE´s HARP centers, RAC service and maintenance companies, customs offices, the pharmaceutical sector, among other stakeholders.

Figure 1 Recovery and Recycling (R&R) Center facilities in Celaya, Mexico

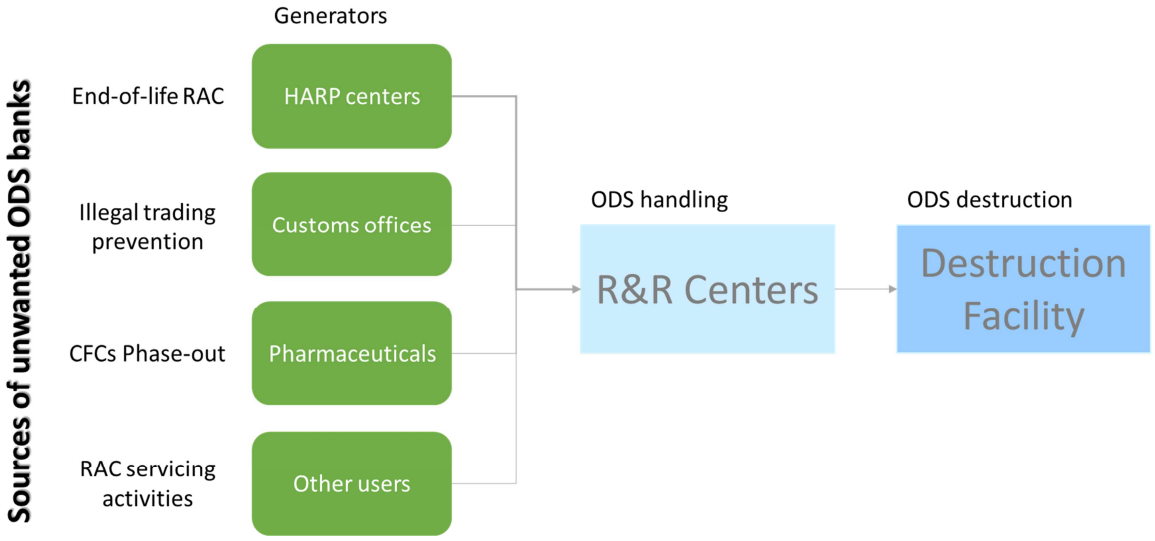
Source: SEMARNAT.

2.2 Sources of unwanted ODS in Mexico

ODS banks that need to be discarded because they are no longer useful, pose relevant concerns to the global climate because they threaten to leak into the atmosphere if they are not correctly handled, stored and destroyed.

Several activities ranging from appliances energy efficiency programs, confiscation of illicit ODS at customs, implementation of ODS phase-out projects (through NPP and HPMP) and national actives in order to support proper management and disposal of ODS have resulted in large amounts of ODS banks in Mexico that need to be handled in an environmentally-sound manner. As depicted in Figure 2, ODS banks were collected and handled by R&R Centers. Each source of unwanted ODS is briefly described below.

Figure 2 Unwanted ODS aggregation and handling by R&R Centers



Source: Own elaboration.

2.2.1 Home Appliances Replacement Program in Mexico (HARP)

One of the main sources of ODS banks for Mexico´s Demonstration Project came from the implementation of the HARP. Since 2005 the GoM through the FIDE, implemented this national energy efficiency program which provided support for replacement and safe disposal of old domestic refrigerators and air conditioning units. This project, implemented in two phases, 2005-2008 and 2009-2012, replaced over 1.7 million refrigerators and 200 thousand air conditioners contributing to energy savings of 9,242 gigawatt hours. (The World Bank, 2016). Old RAC units were collected from customers and substituted for new energy efficient units while the old ones were sent to scrapping centers established by FIDE for dismantling and recovery of materials, including refrigerants, resulting in large quantities of ODS stockpiles.

FIDE established 110 scrapping centers for receiving all the old equipment. In the NPP framework, 98 HARP centers were equipped as well as the FIDE's current infrastructure was enhanced using national recovery and recycling network. For this purpose, 14 training centers covering the country and managing the program using a regional approach were selected.

These facilities recover ODS from domestic refrigerators and air conditioners using a two-step approach:

1. In Step I, the refrigerant (mainly CFC-12, HCFC-22 and HFC-134a) and the oil are removed from the refrigeration cycle; refrigerant is recovered; while the oil is removed directly to the compressor.
2. In Step II, the appliances without refrigerant and oil are dismantled, materials such as copper and polyurethane foam insulation panels are sorted in order to dispose properly.

While this program was a big success in terms of energy efficiency, recovery rates of ODS were low during the first phase.

Through the dismantling and recovery activities, about 35 tonnes of refrigerant waste were collected by the end of the program which were dispersedly stored throughout Mexico.

Figure 3 End-of-life RAC appliances from HARP program

Source: SEMARNAT.

2.2.2 Prevention of ODS illegal trade

When consumption of substances is controlled or restricted, this usually creates a potential black market and ODS are no exception to this rule. That is the reason why the MP has required all parties to implement an import/export licensing system to track commerce and facilitate data collection.

Training has also been a key to curtailing illegal trade. As part of the NPP and HPMP, the GoM and UNIDO have conducted workshops to train customs and other officials on ODS illegal trade. The importance of these programs is becoming increasingly apparent, not just for the Montreal Protocol, but for other environmental agreements.

According to the Mexican Customs Law, all the materials confiscated from illegal trade must to be sent directly to destruction with no possibility to obtain incomes for its sales or other sources such as carbon credits.

ODS confiscated from illicit trade at customs are an extraordinary achievement, nevertheless they suppose a continuous increment of refrigerants waste to be managed. Also, illegal refrigerants storage represents a high cost for customs offices, so it is necessary to send the confiscated banks to an appropriate R&R Center which can consolidate the ODS in a proper DOT cylinders, and after the correct handling, confiscated ODS must to be shipped to the destruction facilities.

One of the most notable efforts to stop illegal trade in Mexico has been performed at the Manzanillo Customs Office located in the southeast of Mexico, where trained customs officers have detected and confiscated important amounts of illegal ODS. Thanks to these actions, 27 tonnes of confiscated ODS were handled and destroyed as part of this project.

Figure 4 Terminal Container at Mexican customs

Source: SEMARNAT.

2.2.3 Pharmaceutical Industry

Since the phase-out of CFCs was first agreed, the pharmaceutical industries have to research into alternative substances to use as propellants in the aerosol manufacturing, particularly MDIs. The result is that technically and economically feasible alternatives to CFCs now exist and are available almost everywhere. The increased availability of clinically effective, technically and economically feasible alternatives meant that CFCs no longer could be authorized for the manufacture of MDIs.

Due to the NPP implementation in Mexico, two pharmaceutical industries based in the country, SALUS Labs and Boehringer Ingelheim, had to change the substances they used as propellants, mainly CFCs. NPP activities included funding for new aerosol filling machines, propellant pumps, ventilation and extraction systems, as well as other safety equipment and technical assistance. This change in the manufacturing scheme generated important CFC banks of which 36 tonnes were destroyed in the Demonstration Project.

Figure 5 Unwanted ODS stockpiles from pharmaceutical industries generated after phase-out of CFC blends used as propellants in meter-dosed inhalers

Source: SEMARNAT.

2.2.4 ODS banks collected by R&R Centers from other users

As mentioned before, R&R Centers began to operate in 2007, and they were responsible for recovering refrigerants contained in appliances and systems. They offered these services to refrigeration technicians and other users interested in the correct disposal of refrigerant gases such as hotels, restaurant and supermarkets. Originally, R&R were thought to recover or recycle refrigerant available for reuse, which would reduce the need for virgin refrigerants and allow existing equipment to operate until the end of its economic life.

R&R Centers played a key role for the HARP as they worked coordinately with the FIDE centers mainly for refrigerant recovery activities, nevertheless they continued to execute their regular services and accumulated additional unwanted ODS banks that needed to be destroyed. 15 tonnes that were stored in the R&R centers were disposed as part of the Demonstration Project.

Figure 6 ODS recovery by Mexican servicing technicians

Source: SEMARNAT.

3 Legislation and regulations

While there are several technologies that have been recommended and approved by the Parties to the MP, there are other relevant international and local regulations that must be taken in to account for the handling and disposal of unwanted ODS, as in some countries like Mexico, they are considered hazardous waste.

3.1 International standards for ODS disposal

In 1990 the Technology and Economic Assessment Panel (TEAP) was established as the technology and economics advisory body to the Montreal Protocol Parties. TEAP provides, at the request of Parties, technical information related to the alternative technologies that have been investigated and employed to make possible the elimination of ODS (such as CFCs and Halons), that harm the ozone layer.

The TEAP released a report in 2002 on recommendations of ODS destruction technologies. The report assessed 45 technologies out of which sixteen met screening criteria, while twelve met recommended criteria specific to ODS destruction performance[6] of technologies for destruction of concentrated and diluted (foams) sources (UNEP/TEAP, 2002).

Technical performance criteria that represent the minimum destruction and removal efficiencies and maximum emissions of pollutants to the atmosphere in order to get approval by the Parties of the MP as ODS destruction technologies are summarized in Table 5.

Table 5 Summary of technical performance criteria for destruction of ODS stocks

Performance qualification	Units	Diluted sources	Concentrated sources
DRE	%	95	99.99
PCDDs/PCDFs[a]	ng-ITEQ/Nm^3	0.5	0.2
HCl/Cl_2	mg/Nm^3	100	100
HF	mg/Nm^3	5	5
HBr/Br_2	mg/Nm^3	5	5
Particulates (TSP)	mg/Nm^3	50	50
CO	mg/Nm^3	100	100

[a] PCCDs: Polychlorinated dibenzo-paradioxins; PCFDs: Polychlorinated dibenzofurans.

Source: UNEP/TEAP (2002).

Moreover, three of the technologies were in commercial use by the time of the report publication[7]. The TEAP identified the following technologies for destruction of concentrated and diluted ODS, that complied with the technical performance criteria and the technical capability specification, which included demonstration of destruction of CFCs, HCFCs, or halons at least on

[6] Screening criteria developed by UNEP TFDT for technologies to be used by signatories of the MP to dispose of surplus inventories of ODS are 1) Destruction and Removal Efficiency (DRE), 2) Emissions of dioxins/furans, 3) Emissions of other pollutants (acid gases, particulate matter, CO), 4) Technical capability.

[7] These were Argon plasma arc, Reactor cracking, and High temperature incineration technologies, eg MSW incinerators, rotary kiln incinerators.

pilot or demonstration scale, and a capacity of not less than 1.0 kg/h, in the case of concentrated CFCs and HCFCs:

Concentrated sources:	**Diluted sources (foams):**
• Cement kilns • Liquid injection incineration • Gaseous/Fume Oxidation • Reactor cracking • Rotary kiln incineration • Argon plasma arc • Inductive-Coupled Radio-Frequency Plasma • Nitrogen Plasma Arc • Microwave Plasma • Gas phase catalytic dehalogenation • Super-heated steam reactor	• Municipal solid waste incinerators • Rotary kiln incinerators

Source: UNEP/TEAP (2002).

3.2 National regulations on ODS handling and disposal

Unwanted ODS are categorized as a "hazardous waste" under the Mexican regulation. Therefore, several restrictions and indications must be followed in order to handle, transport and dispose such substances, as further described below.

The LGPGIR is a general law that regulates management of solid residues, including hazardous waste. Other Mexican Official Standards relevant for ODS handling are NOM-052-SEMARNAT-2005, which identifies waste classified as hazardous. NOM-002-SCT-2001 and NOM-003-SCT-2008 establish transportation and labelling specifications for hazardous waste. Furthermore, NOM-098-SEMARNAT-2002 determines performance and environmental criteria which waste incineration facilities must comply. On the other hand, NOM-161-SEMARNAT-2011 stipulates the special handling wastes which are subject to a Waste Management Plan, and includes end-of-life RAC equipment produced by so-called large generators. Finally, NOM-040-SEMARNAT-2002 regulates emissions and performance of cement facilities. These regulations are further described in Table 6.

Table 6 Applicable regulations to unwanted ODS in Mexico

Regulation of unwanted ODS	Applicable legislation	Description
Waste management	LGPGIR	General law that regulates solid waste management activities, including that of hazardous waste (generation, handling, transportation and disposal).
	NOM-052-SEMARNAT-2005	Classification and identification of hazardous waste (standard). It classifies unwanted ODS as hazardous waste.
	NOM-002-SCT-2011	Transportation of hazardous materials and waste.
	NOM-003-SCT-2008	Packaging and labeling of hazardous materials and

Regulation of unwanted ODS	Applicable legislation	Description
		waste.
	NOM-161-SEMARNAT-2011	Classification of special management waste and waste management plans. It includes refrigerators and air conditioners discarded by large generators.
Disposal / Destruction	NOM-098-SEMARNAT-2002	Environmental criteria for waste incineration facilities.
	NOM-040-SEMARNAT-2002	Environmental criteria for cement manufacturing facilities, including co-processing.
Import and export	Basel Convention	Trans-boundary movements of hazardous waste (International treaty).
	LGPGIR and its rules of procedure (*reglamento*).	It specifies obligations and procedures for hazardous waste import and export into and from Mexico.

3.2.1 Handling of unwanted ODS hazardous waste

The **General Law for Prevention and Integral Management of Residues** (LGPGIR) [8] issued in 2003, determines that the federal government, through SEMARNAT, is responsible for regulating hazardous waste (Art. 7-II) and authorizing provision of handling services (Ar. 7-IX).

The Title Fifth of the law establishes all the provisions and considerations applicable to the handling and management of hazardous waste. It determines there are three categories of generators of hazardous waste: large (>10 tonnes per annum), small (equal or more than 400 kg and less than 10 tonnes per annum) and micro generators (<400 kg per annum) (Art. 44). Large generators must be registered after SEMARNAT, they should present a Management Plan and report their generation (Art. 46). Micro-generators are regulated and controlled by either state or municipal governments, according to the local legislation (Art. 49). The following activities, among others, are subject to an authorization from SEMARNAT: waste management service provision, utilization of hazardous waste in production processes, collection and storage, incineration, transport, confinement, thermal treatment, import and export (Art. 50).

All types of generators are obliged to identify, classify and handle the hazardous waste they produce (Art. 45). They must hire handling services of authorized companies. The handling and disposition liability falls on the hazardous waste generator and on the service providers when waste are transferred to these (Art. 42).

In regards hazardous waste generated at households, housing units, offices, institutions, dependencies and entities in quantities equal or less than micro generators shall follow municipal authorities' requirements on solid waste management (Art. 23).

[8] Ley General para la Prevención y Gestión Integral de los Residuos (last version published in DOF, 22-05-2015).

Currently waste legislation does not include any provisions on extended producer responsibility, though this has been analyzed as a relevant gap on the waste management regulation in Mexico[9]. Nevertheless, LGPGIR update discussions, including extender producer responsibility, have been halted during this administration. **LGPGIR rules of procedure** (*reglamento*)[10] establish a series of proceedings and specifications that must be fulfilled on topics such as the preparation of waste management plans, authorizations of hazardous waste handling, imports and exports of hazardous waste, remediation of polluted sites, as well as means of control, inspection and enforcement available to the authorities.

The regulation specifies the following means to identify a hazardous waste (Art. 35): those considered in LGPGIR, those included and listed in Mexican Official Standards (NOM), mixture of hazardous waste with other type of waste, as well as those identified by the generator based on experience (Art. 37).

Chapter III of the Forth Title describes the requirements and procedures to authorize handling activities of hazardous waste. The Chapter IV of the Title IV (bis) establishes several operation criteria on hazardous waste handling activities for generators and service providers, including storage, collection and transport, reuse, recycling and co-processing, treatment and disposal (Art. 82 to 106).

In regards to transport of hazardous waste from generation sources, according to Art. 86, generators must deliver a manifest, which states the volume and handling activities, to the authorized service provider (Art. 86).

The **NOM-052-SEMARNAT-2005**[11] establishes the procedures to identify a hazardous waste, including a list of such and their hazard characteristics. The standard includes five lists of hazardous waste, according to 1) specific source, 2) non-specific source, 3) out-of-specification or out-of-date chemical products (acute toxics), 4) idem (chronic toxics), and 5) waste subject to particular handling conditions.

This standard explicitly mentions two ODS substances as hazardous waste: CFC-12 and CFC-11 in the list number four regarding out-of-specification or out-of-date chemical products that pose environment toxicity.

In the case of other ODS waste, including CFCs and HCFCs, not explicitly listed, NOM-052 also determines that if certain kind of waste are not included in the lists, these might be identified as hazardous based on scientific knowledge or empiric evidence of their hazard characteristics[12]. This

[9] See, for example, the discussion by Dra. Cristina Cortinas on extended producer responsibility in the Mexican regulation on hazardous waste: http://www.ceja.org.mx/articulo.php?id_rubrique=193&id_article=2111.

[10] Reglamento de la Ley General para la Prevención y Gestión Integral de los Residuos (last version published on DOF, 31-10-2014).

[11] NORMA Oficial Mexicana NOM-052-SEMARNAT-2005, Que establece las características, el procedimiento de identificación, clasificación y los listados de los residuos peligrosos (published in DOF, 23-06-2006).

[12] Explosive, Biological and Infectious, Corrosive, Reactive, Flammable, Environmental Toxic.

would be the case of other ODS waste, which are normally mixed with used lubricant oils. These are classified as hazardous waste subject to management plan in LGPGIR Article 31-I. According to these criteria, all of the discarded ODS from servicing and scrapping should be considered hazardous waste, subject to applicable regulations.

NOM-002-SCT-2011[13] identifies and classifies the most usually transported hazardous substances and materials, and it is based on the Model Regulation for Transportation of Hazardous Goods of the United Nations, which is used by the North America Free Trade Agreement signatory parties. The standard is mandatory to all dispatchers, carriers and recipients of dangerous substances and materials, transported through terrestrial, maritime and aerial general communication pathways.

The list of substances of this standard includes several common refrigerants, such as CFC-12, HCFC-22, HFC-134a, R-404A, HFC-143a, among others. It also includes provisions for generic refrigerants, which are Not Specified Somewhere Else (NEP, as per its acronym in Spanish), only applicable to non-flammable and non-toxic gases.

NOM-003-SCT-2008[14] establishes the characteristics, dimensions, symbols and colors of labels that packaging and wrapping must carry, in order to identify the risk class that hazardous substances, materials and waste pose during their transportation. This standard is based on the Model Regulation for Transportation of Hazardous Goods of the United Nations, which is used by the North America Free Trade Agreement signatory parties.

NOM-161-SEMARNAT-2011[15] establishes the criteria to determine which special handling wastes are subject to a Waste Management Plan, in terms of LGPGIR and its regulation, as well as a list of those wastes.

Among the special handling waste classified in this standard and subject to a waste management plan are included a list of products discarded at end of its lifetime, and includes a category of products which are generated by a large generator (as defined by LGPGIR). In this list the refrigerators and air condoning units are found.

[13] NORMA Oficial Mexicana NOM-002-SCT-2011, Listado de las substancias y materiales peligrosos más usualmente transportados (published in DOF, 27-01-2012).

[14] NORMA Oficial Mexicana NOM-003-SCT-2008, Características de las etiquetas de envases y embalajes, destinadas al transporte de substancias, materiales y residuos peligrosos (published in DOF, 15-08-2008).

[15] NORMA Oficial Mexicana NOM-161-SEMARNAT-2011, Que establece los criterios para clasificar a los Residuos de Manejo Especial y determinar cuáles están sujetos a Plan de Manejo; el listado de los mismos, el procedimiento para la inclusión o exclusión a dicho listado; así como los elementos y procedimientos para la formulación de planes de manejo (Which establishes the criteria to classify the Waste of Special Management and determine which are subject to Management Plan; the list of these, the procedure for their inclusion or exclusion to that listing; as well as the elements and procedures for the formulation of the management plans) (published in DOF, 01-02-2013).

Figure 7 Unwanted ODS are classified as hazardous waste in Mexico

Source: SEMARNAT.

3.2.2 Import and export of unwanted ODS hazardous waste

In terms of import and export of hazardous waste, **LGPGIR** stipulates that the federal government is empowered to approve the importation, exportation or transit of hazardous waste across the national territory (Art. 7-XIII).

Moreover, LGPGIR specifies that hazardous waste imports are only allowed into the country if they are to be reused or recycled (Art. 85). The import of persistent organic compounds is utterly forbidden under any circumstances (Art. 86). In order to authorize export of hazardous waste, this will be issued only when those requesting it have the prior consent of the importing country and, where applicable, the government of the countries through which the waste travel (Art. 87), as per Basel Convention requirements. Moreover, when requesting an import or export authorization, it is necessary to present insurance or guarantee policy for any contingencies and payment of damages that could arise during movement of the hazardous waste (Art. 89).

The Fifth Title of **LGPGIR rules of procedures** describes the requirements and proceedings that must be followed in order to import and export hazardous waste, as well as their return, following LGPGIR considerations.

3.2.3 Unwanted ODS destruction

In Mexico there is no specific regulation on disposal of ODS. However, as these are considered as hazardous waste, the same criteria and provisions are applicable to these. Regarding disposal of unwanted ODS, i.e. their destruction, **LGPGIR** Articles 61, 62 and 63, establish the conditions that must be followed for incineration, thermal treatment and co-processing of solid residues[16], including compliance with national standards and international treaties, and monitoring specifications. SEMARNAT should specify if certain types of waste are not susceptible for incineration or co-processing as alternative fuels, due to environmental concerns.

According to the **LGPGIR rules of procedure**, Chapter III of the Forth Title describes the requirements and procedures to authorize handling activities of hazardous waste. In order to authorize recycling and co-processing of hazardous waste, the requester must describe in regards the facility, procedures and methods, waste load capacity, emissions and control parameters, energy balance and waste´s calorific value, among others (Art. 49-III). Furthermore, a facility willing to provide incineration services must indicate the type of process applied, capacity, process temperature, efficiency, gas residence time, feeding system characteristics, fuels utilized, monitoring and control of emissions provisions (Art. 48.-VI), as well as a test protocol proposal (Art. 51-I). These requirements are applicable to pyrolysis, plasma and gasification technologies as well.

NOM-098-SEMARNAT-2002[17] sets the operation specifications, as well as the atmospheric emission limits applicable to waste incineration facilities. This standard is not applicable to

[16] Environmentally-sound integration of any type of waste that is generated by an industry or a known source, and used a feedstock in other productive process (Art. 5-IV).

[17] NORMA Oficial Mexicana NOM-098-SEMARNAT-2002, Protección ambiental – Incineración de residuos, especificaciones de operación y límites de emisión de contaminantes (published in DOF, 01-10-2014).

crematory and industrial furnaces or boilers which use residues as fuel.

As per this standard, incineration includes any kind of thermal oxidation processes, under controlled conditions, that complies with efficiency, efficacy and environmental criteria established in the NOM-098. This definition, according to the standard, includes pyrolysis, gasification and plasma technologies, whenever the fuel byproducts generated in those processes are brought under oxygen-rich combustion.

The standard forbids the incineration of bio-accumulative and persistent organic compounds, organochlorine-based pesticides and waste batteries that contain toxic metals, as long as there is a more suitable treatment technology, as established in LGPGIR.

Among the performance criteria for incineration facilities, the standard foresees that the facility design, installation and operation must warrant a minimum temperature of the incineration gases of 850 °C, for at least two seconds, in the case of non-hazardous waste. For hazardous waste these conditions should be of at least 1,100 °C during at least two seconds.

Table 7 Emissions limits for waste incineration facilities

Pollutant	Emission limit	Units	Measurement frequency
CO	63	mg/m^3	Continuous
HCl	15	mg/m^3	Quarterly
NO_x	300	mg/m^3	Biannual
SO_2	80	mg/m^3	Biannual
Arsenic, Selenium, Cobalt, Nickel, Manganese, Tin	0.7	mg/m^3	Biannual
Cadmium	0.07	mg/m^3	Biannual
Lead, Total Chromium, Copper, Zinc.	0.7	mg/m^3	Biannual
Mercury	0.07	mg/m^3	Biannual
Dioxins and Furans TEQ (New facilities)	0.2	ng ITEQ/m^3	Annual
Dioxins and Furans TEQ (Existing facilities)	0.5	ng ITEQ/m^3	Annual

Source: Own elaboration based on NOM-098-SEMARNAT-2002.

NOM-040-SEMARNAT-2002[18] establishes atmospheric emission limits for facilities that manufacture cement.

This standard defines three types of fuels which combustion is allowed, following certain requirements: 1) conventional fuels or fossil fuels, such as natural gas and petroleum coke; 2) formulated fuels are those controlled mixtures of liquid or solid residues, including hazardous waste, with sizable calorific value, and produced in a dedicated and authorized plant; 3) recovery

[18] NORMA Oficial Mexicana NOM-040-SEMARNAT-2002, Protección ambiental – Fabricación de cemento hidráulico – Niveles Máximos Permisibles de emisión a la atmósfera (published in DOF, 18-12-2002)

fuels are those waste or materials, with calorific value is higher than 15 MJ/kg, and with no need to be formulated previously. Among recovery fuels include used oils and lubricants, textiles impregnated with the former, tires, as well as non-hazardous waste. The standard excludes in the composition of formulated fuels the following: pesticides, polychlorinated dioxins, polychlorinated dibenzofurans, radioactive waste, compressed gases, biological and infectious waste, cyanides and organochlorine compounds.

The standard NOM-040 sets emission limits of atmospheric pollutants for different production processes, cement types (gran and white) and geographical locations within the country (Table 8). Furthermore, it determines the fraction of conventional fuels that are allowed to be substituted by formulated or recovery fuels, and the corresponding emissions control and monitoring provisions that must be fulfilled accordingly.

It is further clarified that whenever a cement facility uses recovery or formulated fuels that contain hazardous waste (including ODS), it should therefore request an authorization from SEMARNAT, in terms of the applicable regulations.

Table 8 Key emission parameters for cement manufacturing facilities

Parameter	Units	Emissions limits [a]
CO	mg/m^3	3,000 – 4,000
HCl	mg/m^3	70
NO	mg/m^3	800 - 1,200
SO_2	mg/m^3	400 – 1,200
Total Hydrocarbons (HC)	mg/m^3	70
Dioxins and furans	ng ITEQ/m^3	0.2

[a] Emission limits for gray cement production. Range applicable to different geographical locations.

Source: Own elaboration based on NOM-040-SEMARNAT-2002.

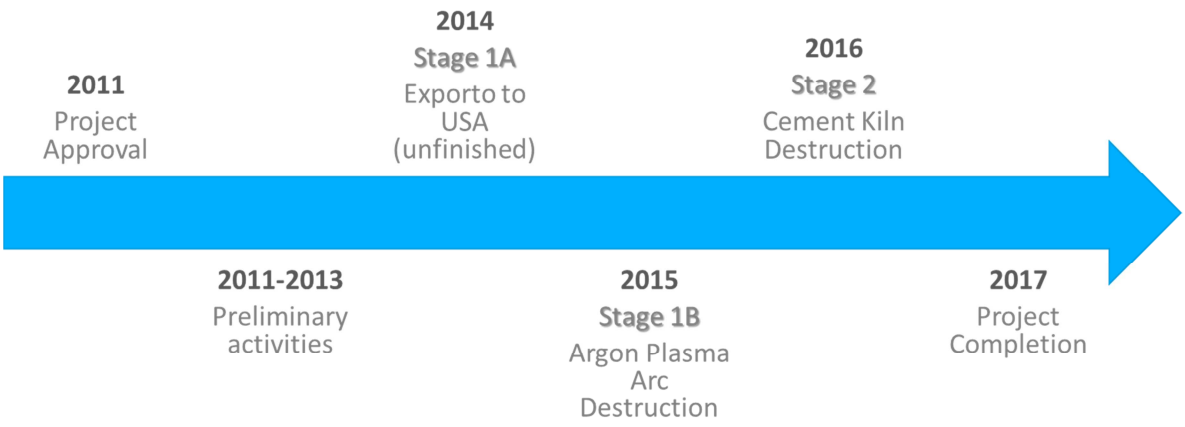
4 ODS destruction project implementation

Mexico´s Demonstration Project was implemented in phases, according to the progressive consolidation of ODS banks and the alleviation of other barriers which arose during the project lifetime. Several preliminary activities were performed between 2011 and 2013, including training to HARP centers, equipment of the training centers, upgrading of the recycling centers, design of Monitoring, Report and Verification (MRV) system, organization of awareness workshop and execution of ODS destruction pilot tests and licensing approval for Mexican companies.

Actual implementation of the Demonstration Project began in 2014 (Stage 1A), in which ODS banks were intended to be exported to the USA for disposal, as no authorized facilities were available within Mexico by that time. This stage was not implemented up to the point of the destruction phase, since handling and exportation costs were higher than expected.

In 2014 and 2015, two Mexican companies were granted license authorizations to destroy ODS using two different technologies, respectively. Stage 1B implemented by Quimobásicos in 2015 led to destroy about 74 tonnes of ODS using Argon plasma arc. Accordingly, Stage 2 implemented by Holcim Mexico in 2016 destroyed 39 tonnes of ODS at one of their cement kilns. The 113 tonnes of unwanted ODS disposed resulted in the mitigation of 504 thousand tCO_2e, as further explained in the following sections.

Figure 8 Project implementation timeline



4.1 Preliminary activities

As the Demonstration Project was a first-of-its-kind in Article 5 countries, there were a number of tasks which needed to be carried out for a smooth implementation. In first place, disposal facilities within Mexico had to be authorized to destroy unwanted ODS, as they are classified like hazardous waste. On the other hand, though Mexico´s program to replace old household (HARP) had been very successful, optimum disposal of ODS refrigerant gases was still an issue, especially among small scrapping centers which lacked advanced expertise. Furthermore, the GoM deemed appropriate to perform an awareness workshop among local stakeholders, considering that a level of concern had arisen among local NGOs as this was the first time such a project was implemented

in the country. Finally, the design and implementation of a MRV system was required as per the Executive Committee decision.

4.1.1 Pilot tests and license to destroy ODS waste in Mexico (Stage 1B and 2)

As further described, the Demonstration Project was finally implemented in two stages involving two different facilities in Mexico and two technologies, i.e. Argon plasma arc and Cement kiln. Since unwanted ODS banks are classified as hazardous wastes in Mexico their destruction via incineration, recycling or co-processing, must comply with stringent regulations. In particular they had to be issued with a destruction license, which involves the realization of destruction pilot tests that warrant compliance of environmental and performance criteria, in addition to further legal, technical and environmental requirements.

For instance, in the case of hazardous waste incineration processes, which include destruction in argon plasma arc, NOM-098-SEMARNAT-2002 requires to facility owners to perform a test protocol, in which the system destruction efficiency, emissions control and monitoring and other environmental specifications are tested and verified by SEMARNAT[19]. Similarly, NOM-040-SEMARNAT-2002 includes similar provisions for co-processing hazardous waste, including the test protocol.

As part of the Demonstration Project two test protocols were performed, one connected to Phase 1B for Argon plasma arc destruction, and one more for Phase 2 for cement kiln destruction. Phase 1A does not apply to this requisite as destruction was intended at the US. In this case only exportation licensing applies, as it would be mentioned in section 4.2.

In 2013, Quimobásicos performed an incineration test protocol of ODS hazardous waste at its Plasma II facility located in northern Mexico, and utilizes state-of-the-art Argon plasma arc (PLASCON) technology. The test protocol was executed in four cycles, consisting of the following compositions. First and second cycles with 120 kg 100% HFC-134a each, and third and fourth cycles with 120 kg of 85%/15% HFC-134a/HCFC-22 each. Quimobásicos staff and representatives of SEMARNAT, PROFEPA, the local environmental agency, and other industrial stakeholders, were present during the different destruction tests.

In each one of the four destruction tests a validation of the ODS purity was analyzed by an authorized lab. Later on, the ODS were fed into the plasma arc, and outflow emissions were sampled for their analysis. It is worth mentioning that the ODS samples were analyzed in the USA, since there a no certified labs in Mexico. The average destruction and removal efficiency of the test was 99.9994%[20].

Following the verification of the protocol test results and compliance of other relevant requirements, SEMARNAT issued in 2014 the first license to incinerate ODS hazardous waste in Mexico to Quimobásicos. This license allowed the company provide services to destroy ODS waste

[19] Facility owners shall follow the procedure specified in “Trámite SEMARNAT-07-012” (Authorization of hazardous waste handling for reuse, recycling, treatment or incineration) (DOF, 29-05-2003). The protocol test is supervised and verified by the General Direction of Hazardous Materials and Activities (DGGIMAR)

[20] See Annex III. ODS destruction pilot test results in Argon plasma arc, for further details.

up to 525.6 tonnes per year, including collection and storage, pretreatment (cleaning and filtering), destruction using Argon plasma arc technology, and their effluents control and treatment. This authorization was valid for two years and established monitoring and reporting provisions. The overall license issuance process took two years, and about eight months from the pilot test completion. Annex III. ODS destruction pilot test results in Argon plasma arc, describes further details of the pilot test results.

Stage 2 Cement kiln pilot test and license

In May 2015 Holcim Mexico and sister company Geocycle (formerly Ecoltec) performed a destruction pilot test at one of their most advanced cement kiln facilities located in Tecomán in the Southwest state of Colima. Prior to the Demonstration Project this plant already was authorized for co-processing of alternative fuels, including hazardous materials and waste.

In the pilot test about two tonnes[21] of a mixture of unwanted refrigerant wastes from ODS banks were destroyed. The ODS wastes were fed together with conventional and alternative fuels into the kiln #1 of Tecomán plant. Geocycle oversees the formulation and supply of fuels into the cement kiln operated by Holcim Mexico. Moreover, Geocycle performed sampling and analysis of fuels and waste fed into the cement kiln.

The feeding of ODS was performed through a dedicated installation built for this purpose. The ODS were fed into the kiln´s main burner, while the fuels were fed in parallel by existing supplying systems. Pilot test average feed rate were 43 and 153 kg/h, in each of the test dates.

Outflow emissions were measured in Continuous Emission Monitoring Systems according to NOM-040-SEMARNAT-2002 provisions for NO_x, SO_2, HCl, CO, particles and hydrocarbons. Moreover, punctual measurements were performed to analyze Dioxins and Furans, heavy metals and ODS.

Destruction efficiency of ODS was calculated at 99.99865%, while emissions remained below the NOM-040-SEMARANT-2002 and Montreal Protocol criteria. It was moreover proven that the clinker quality was not altered due to the destruction of ODS. A reduction of NO_x concentrations was also identified during the pilot test as a co-benefit. In summary, it was validated that ODS destruction in the cement kiln facilities is compatible with the clinker manufacturing process, while compliance of efficiency and emission parameters is achieved.

Following the verification of the protocol test results and compliance of other relevant requirements, SEMARNAT issued in 2015 the first license to recycle and co-process (and the second one to destroy) ODS hazardous waste in Mexico to Holcim plant in Tecomán. The license was issued for 3.5 years and established handling, monitoring and reporting provisions, while allowing them to co-process CFCs, HCFCs, HFCs and their blends. The process to issue this license took about 18 months from the moment the company start activities with respect to the modification to its previous license, which did not include ODS co-processing.

[21] As this gas was sourced from the collected banks, it is further quantified in the total amount of unwanted ODS destroyed.

4.1.2 Training scheme for HARP centers

By the time of the Demonstration Project implementation, over a hundred of HARP scrapping centers were in operation, while their unwanted ODS were sent to one of the 14 R&R centers along the country. Though HARP centers had been provided with ODS recovery and collection equipment within previous projects, it was recognized through SEMARNAT´s monitoring that technicians at these centers needed further training on safe and environmental handle of unwanted ODS in order to increase their recovery rates.

In order to overcome this barrier, under the HPMP framework, UNIDO with support of SEMARNAT, organized a training scheme in which 14 technical schools were supplied with equipment, while two certified instructors were appointed to provide the courses, which involved theoretical and practical training on issues such as analysis and detection of ODS, recovery methods and good handling practices, and ODS environmental impact.

Between October and November 2011, 14 courses were given in which 360 staff members were trained, including technicians from HARP centers, R&R centers, schools, as well as FIDE officers involved in the HARP program. The activities of this training scheme under the R&R training programme gave rise to in an increase in more than 100% of the ODS recovery rates per appliance, leading to the collection of additional 35 tonnes of refrigerant waste to be handled and disposed the Demonstration Project.

Figure 9 Unwanted CFC-12 recovered

Source: SEMARNAT.

4.1.3 MRV system design and implementation

After the Executive Committee decision on the 63rd Meeting to approve the implementation of Mexico´s Demonstration Project, it was required to establish a monitoring system for the operation and activities associated to the project.

An MRV system was built on the ODS Information and Tracking System (SISSAO), which is managed by SEMARNAT through the National Ozone Unit, and has enabled the implementation of NPP and HPMP plans. SISSAO has five modules, three of them which are directly related to the ODS disposal project.

Table 9 SISSAO Modules

1)	Monitoring of ODS Imports, Exports and Production
2)	Monitoring of R&R Centers
3)	Registry of gases, foams and lubricant oil recovered at FIDE´s HARP Centers
4)	Monitoring of ODS destruction facilities
5)	Implementation of Methyl bromide projects

Source: (SEMARNAT, 2005).

Modules 2 tracks down the information related to the activities of the R&R Centers, including the amounts of substances they recover, recycle and dispose. Module 3 was designed to serve specifically the HARP Centers, and included a registry system where the amounts of appliances, foams, refrigerants and lubricant oil. It also allowed the users to specify the R&R Centers to which unwanted ODS were sent. Module 4 is a dedicated interface that allows the monitoring of ODS disposal from the destruction facilities side.

Module 4, as the core of the Demonstration Project MRV, is integrated by three subsystems, one of each serve, respectively, the ODS generators, the destruction facilities and the authority (SEMARNAT) which is also the system manager.

Each of the three subsystems allow the users to report and validate the information regarding the quantities and specifications of unwanted ODS to be destroyed, the information of transport service providers from the generation point source to the R&R Centers and from these ones to the destruction facilities. It also allows destruction facilities to report the details of the destruction events, including the amount, destruction period, destruction rate, efficiency of destruction and removal, dioxins and furans, HCl and HF emissions. Moreover, the authority is enabled to check and validate the information on recovery of unwanted ODS banks for destruction, as well as to approve the Destruction Certificate. This certificate is the final verification evidence of the unwanted ODS disposal, and it is required to be submitted by the destruction facility in order to apply for the ODS destruction payment issuance.

Figure 10 Subsystems within the MRV ODS destruction module

ODS generator	Report of unwanted ODS for destruction, including hired transport and destruction service providers. ODS release for destruction (release and delivery of unwanted ODS).
Destruction Facility	Consultation and validation of ODS sent for destruction. Report of information and proves of destroyed ODS. Destruction Certificate. Return of empty containers to the ODS generators.
Authority (Administrator)	Consultation of ODS recovery from authorized R&R Centers. Validation of destroyed ODS amounts and issuance of the Destruction Certificate.

Source: SEMARNAT.

Figure 11 ODS destruction monitoring at Holcim Mexico

Source: SEMARNAT.

4.1.4 Awareness workshop

Being a first-of-its-kind project in Mexico, the Demonstration Project initially arose concerns among certain stakeholders. These concerns indicated that there was a degree of misperception of such type of projects, in terms of the climate and ozone layer benefits and the local safety and environmental assurance of the destruction technologies to be used.

In 2012, after the Demonstration Project was approved, the GoM and UNIDO organized an awareness workshop, which purpose was to communicate to the society the benefits of the ODS Demonstration Project. This workshop accounted with the participation of local parties, including NGOs, academia and other stakeholders. The organization of this workshop was very relevant and it allowed for a smooth implementation of the project. In particular, it clarified the global and local benefits that the project would bring about.

4.2 Stage 1A. Handling and Destruction of unwanted ODS in the United States of America

The Stage 1 of the Demonstration Project was the first destruction trial performed in which ODS banks were to be exported to a ODS destruction facility in the USA. The activities initiated in 2013 involving the bidding process, the aggregation of ODS banks in one centralized facility as well as the procedure to issue export and import permits. The so-called Stage 1A was not culminated due unexpectedly high costs involved in the handling, transport and disposal of the ODS in authorized destruction facilities in the USA.

4.2.1 Bidding Process

In 2013 UNIDO launched an international bidding process in order to undertake the transport and destruction of 74.1 tonnes of ODS waste banks collected in Mexico. There were no restrictions or prerequisites to perform this locally or at a foreign facility. However, at the time Stage 1A bidding was unveiled no companies in Mexico were authorized to destroy ODS even if TEAP-recommended technologies were available in the country (i.e. Argon plasma arc and Cement kilns).

After evaluation of all received offers, a contract was awarded to a consortium consisting of companies RemTec (United States) and PGES (Saudi Arabia). After signature of the contract, the selected consortium initiated implementation works with the centralization of all the ODS, aggregated ODS would be transported by land from centralized facilities in Mexico to RemTec and Veolia's facilities located in Ohio and Texas, respectively, and they would be transported in special tanks and ISO containers.

59 tonnes of CFCs, HCFCs and HFCs blends were to be destroyed at RemTec's Plasma Arc, while 16 tonnes of virgin CFC-11 would be destroyed at Veolia´s high-temperature incineration facilities. These two facilities complied with TEAP emission and performance standards, while these companies have extensive experience in the field.

4.2.2 ODS regulations in the USA

ODS waste import into the USA must comply with several environmental requirements. Federal regulations include, mainly, the Stratospheric Ozone Protection Regulations under the Clean Air Act (CAA), and the Resource Conservation and Recovery Act (RCRA).

As part of the CAA and its phase-out plan, ODS are regulated as Class I or Class II controlled substances[22]. Among Class I, CFCs, have been completely phased out, while new production and import of Class II, HCFCs, will be phased out by 2020. Importing of virgin and used Class I or Class II ODS must comply with particular requirements, including recordkeeping and reporting (40 CFR 82.13). For example, virgin Class I ODS imports are forbidden unless it they fall under certain exemptions, including their transformation or destruction (EPA, 2017a).

On the other hand, RCRA regulates ODS classified as hazardous waste, which is relevant both for import authorization and destruction facilities regulation and compliance. Whether an ODS is considered a hazardous waste or not depends on the RCRA provisions, as specified in 40 CFR Part 61, Subpart D. ODS or ODS-containing waste may fall in one of the following categories: wastes from non-specific sources (Code F), commercial chemical products (Code U), characteristic wastes (Code D), or wastes from specific sources (Code K). In general, Code F applies to CFCs, HCFCs, among other, which have been used as solvents prior to disposal. Meanwhile, Code U applies to ODS which are discarded in pure form, as it was the case for CFC-11 waste from pharmaceutical industry in the Demonstration Project. Code D includes ODS that may exhibit ignitability, corrosively, reactivity or toxicity characteristics, being the last one the most likely as in the case of carbon tetrachloride wastes. Code K applies to ODS produced in specific sources, such as carbon tetrachloride production wastes. (ICF International, 2009)

According to CAA, surplus ODS must be stored, reused (after recycling or reclamation), or destroyed. Currently, the following facilities are commercially available to destroy ODS in the USA. It must be noted that not all the facilities necessarily are allowed to manage hazardous waste ODS.

Table 10 ODS Destruction Facilities in the USA

Company name	Facility Location
Chill-Tek, Inc.	Las Vegas, Nevada
Clean Harbors Environmental Services, Inc.	Aragonite, Utah (Aragonite)
	El Dorado, Arkansas (El Dorado)
	La Porte, Texas (Deer Park)
A-Gas Americas (Rem Tec)	Bowling Green, Ohio
Veolia ES Technical Solutions, L.L.C.	Sauget, Illinois
	Port Arthur, Texas

Source: EPA (2017b).

[22] Class I substances have an ozone depletion potential of 0.2 or higher, and include halons, CFCs, methyl chloroform, carbon tetrachloride, and methyl bromide. Class II have an ozone depletion potential less than 0.2, and are all HCFCs

It is relevant to point out that in the Stage 1A of the Demonstration Project, one of the destruction facilities that had been selected was authorized to destroy pure CFC-11 (Code U) hazardous waste ODS (i.e. Port Arthur´s incinerator), while the other (i.e. Rem Tec´s argon plasma arc) was able to destroy only non-hazardous waste ODS, as per RCRA considerations, which included the rest of unwanted CFCs, HCFCs and HFCs[23].

4.2.3 Export and import of hazardous waste from Mexico to the USA

Transboundary movement of hazardous waste is subject to international treaties, such as the Basel Convention and OCDE decisions, as well as national regulations, in which exporting, importing and transit countries rulings are relevant. In the Demonstration Project Stage 1A, the approval process involved the issuance of a hazardous waste export authorization from the Mexican government through SEMARNAT and an import approval from the U.S. EPA. This process took about one year to be completed.

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal[24] was adopted in 1989 and entered into force in 1992, currently having 186 ratified Parties[25]. It states the obligations on transboundary movements of wastes between Parties. Most remarkably, the Convention requires that exporting States must notify in writing to any States concerned of any proposed transboundary movement of hazardous wastes. Importing States, as well as transit States, shall consent, deny or request further information on the movement, and notify the final response to the concerned States which are Parties. No transboundary movements shall commence before this procedure takes place.

In addition, the Basel Convention Ban Amendment[26] forbids the export of hazardous waste from OCDE countries to non-OCDE Countries, which are intended for final disposal or which are included in Annex I of the Convention and are destined for reuse, recycling or recovery. Due to this decision Mexico may only allow export of hazardous wastes to OCDE countries, the European Union and Liechtenstein.

It is worth mentioning that the USA is signatory of the Basel Convention but it has not ratified it as a Party. However, Mexico and the USA have signed a cooperation agreement on environmental protection of their common border, known as “La Paz Agreement” or “Acuerdo de la Paz”[27]. Annex III, signed in 1986, which deals with transboundary movements of hazardous wastes and materials, fits the Basel Convention Article 11 on multilateral agreements, and establishes very similar procedures for transboundary movements of hazardous waste, including the requirement for prior notification between concerned countries.

[23] For a full list of RCRA-permitted hazardous waste facilities see: https://www3.epa.gov/enviro/facts/rcrainfo/search.html.
[24] Full text available at: http://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx.
[25] http://www.basel.int/Countries/StatusofRatifications/PartiesSignatories/tabid/4499/Default.aspx
[26] See: http://www.basel.int/Implementation/LegalMatters/BanAmendment/Overview/tabid/1484/Default.aspx.
[27] See full text in: https://www.epa.gov/sites/production/files/2015-09/documents/lapazagreement.pdf.

Article XI within the Annex III of the Agreement establishes that any hazardous waste generated in manufacturing or economic processes, from which raw materials have been used and temporarily admitted, shall be continued to be readmitted by the country of origin of the raw materials.

Hazardous waste transboundary procedures must be followed by interested parties whenever wastes to be moved or traded fall into a relevant category, which in the case of Mexico includes the following lists of wastes (SEMARNAT, n.d.):

1. Basel Convention Annexes I, II, VII and IX, as well as those defined as hazardous wastes under the legislation of any of the exporting, importing or transiting Parties.
2. OCDE decision C (2002)107, Appendixes 1 and 4.
3. La Paz Convention Annex III.
4. LGPGIR Article 31.
5. NOM-052-SEMARNAT-2005 lists and identification criteria.
6. Customs Article 6 for goods regulated by SEMARNAT (DOF, 30-junio-2007).

According to Mexican LGPGIR and its regulation, exporters of hazardous waste must fulfill the following requirements in order to get an authorization:

- Export manifest.
- Proof of address of the exporter.
- Description of the measures to control environmental contingencies.
- Export notification according to Basel Convention or applicable treaties, and OCDE´s movement form.
- Acceptance letter of the importing company.
- Insurance policy of the exporting company.
- Payment.

4.2.4 Handling and storage of ODS banks

As previously described, ODS banks were spread along the country among HARP centers, customs warehouses, pharmaceutical industry facilities and R&R Centers. Provided that unwanted ODS feature hazardous properties it is required to comply with regulations and provisions related to handling, transport and disposal of such materials, particularly if they are via exported to the USA for their destruction.

In order to comply with the relevant regulations and to ease the logistics and monitoring of the unwanted ODS destruction, the identified banks needed to be further consolidated in large containers and in key locations, preferably handled by a single authorized service provider[28].

The company designated by the aforementioned awarded consortium to perform this task was Ecofrigo S.A. de C.V., an R&R Center located on the center of Mexico. Ecofrigo is a leading provider of handling services for old refrigeration and air conditioning equipment and unwanted ODS.

[28] This was particularly relevant in the case the ODS banks were to be exported for disposal, as it was originally planned in the initial phase of the project, as the import-export permit process is complex and lengthy. Therefore it is recommended that a single entity request such permit.

As previously mentioned, under the R&R training programme Ecofrigo was one of the 14 companies supported by UNIDO and SEMARNAT to purchase new equipment and tools to enable recovering and recycling activities as well as allow proper storage of unwanted ODS banks generated and identified along the country.

Figure 12 Aggregation containers for ODS consolidation, storage and handling

Source: SEMARNAT.

4.2.5 Costs

At the time o project preparation, project implementation costs were estimated at about 780 thousand USD or 10.5 USD per kilogram of ODS destroyed. ODS destruction accounted for about half of the project costs, while local and international transportation represented 13% of the cost structure. These costs are applicable to the destruction of about 74 tonnes of ODS waste that were meant to be destroyed in two different destruction facilities in the USA during 2015. During the implementation, it was identified that project costs were heavily underestimated by the designated company, since consolidation and internal transportation costs were not thoroughly taken into account in the economic offer. Furthermore, the fees related to cover the environmental insurance policy, and requirements related to transboundary movements of hazardous waste (i.e. Basel Convention and other bilateral treaties) had not been considered in the project structure. Due to this situation, Stage 1A could not be fully executed, while only transportation of ODS banks from generation sources to the R&R Center Ecofrigo for consolidation was performed. These costs related to these activities are summarized below.

Table 11 Stage 1A Project costs for internal transportation and consolidation of unwanted ODS banks

Project concepts	Total Cost (USD)	Unit Price (USD/kg)
Transportation within Mexico	42,000	0.6
Consolidation & Centralization	58,000	0.8
Total	**100,000**	**1.4**

Source: UNIDO.

4.3 Stage 1B. Handling and Destruction of unwanted ODS in Argon plasma arc in Mexico

Following a first attempt to perform the destruction activities of the Demonstration Project in the USA, UNIDO acknowledged the advancement that had been took along during Stage 1A and decided to launch a second international bidding process, which resulted fruitful as already one facility in Mexico had been issued an ODS waste incineration permit. After a comprehensive technical evaluation by UNIDO, the Mexican company Quimobásicos was chosen to perform the first stage of the Demonstration Project, which involved 74.1 tonnes of unwanted ODS destroyed in a state-of-the-art Argon plasma arc, one of the ODS destruction technologies recommended by the TEAP. The destruction was performed between October 2015 and January 2016, complying with local and Montreal Protocol´s environmental and performance criteria, and rendering the first demonstration of an MLF-supported ODS destruction project.

4.3.1 Bidding Process

After a second bidding process initiated by UNIDO in 2015, the Mexican company Quimobásicos was designated to implement the first stage of the Demonstration Project, which involved final transportation of ODS from the storage location and their destruction via argon plasma arc. Unlike the first bidding process, this one did not involve the consolidation of the ODS banks, as this had been already performed during Stage 1A.

It should be emphasized that this second bidding process was successful due to the fact Quimobásicos had recently acquired the first incineration license to destroy hazardous waste ODS in Mexico[29] .This was one of the main requisites bidders must prove. By that time, Quimobásicos was the only company allowed to provide such services.

4.3.2 Quimobásicos Argon plasma arc facility

PLASCON technology is an *in-flight* plasma process in which waste stream is mixed directly with the inert argon plasma jet. In this process, wastes are rapidly heated to about 2,500 °C, where pyrolysis takes place. As steam is injected with the waste, oxygen ensures any carbon is converted to CO_2. Hydrogen moreover prevents formation of CF_4. The pyrolysis phase is followed by rapid alkaline quenching from about 1,200°C to less than 100°C, which prevents formation of dioxins and furans. Quenched gas is scrubbed with alkaline liquor to neutralize HCl and other gases. The off-gas consists mainly of CO_2 and Ar. This technology is recommended by TEAP, which reports DRE values that exceed 99.9998%, while its technical and commercial capability to destroy ODS

[29] See section on Pilot tests and license to destroy ODS waste in Mexico.

have been proven. (UNEP/TEAP, 2002)

Quimobásicos PLASCON unit has a capacity to destroy between 40 to 60 kilograms per hour of ODS. The facility consists of an ODS feeding tank, a main torch device, a cooling chamber, an alkaline tank and a gas absorption column. The unit is fully automated, controlled and monitored via PLC. A prior preparation phase in which oil is removed from the ODS stream is performed in a two-stage separation process. Liquid effluents are neutralized and transferred to a water treatment plant.

The PLASCON unit typically has more than 99.999% of destruction efficiency, and emissions to the atmosphere are substantially lower than recommended standards (typical results 0.000802 ng/m^3). Dioxins and furans emissions are null because the temperature is ultrahigh (up to 12,500 °C) and residence time is very short (23 milliseconds).

Figure 13 Argon plasma arc at Quimobásicos facilities in Monterrey, Mexico

Source: SEMARNAT.

4.3.3 Project MRV

The project MRV involves a series of activities to verify the amount of unwanted ODS destroyed, as well as that safety and environmental provisions are fulfilled. In every destruction cycle, batches of unwanted ODS are received at Quimobásicos facilities, while containers are inspected for leakages, weighed, registered and identified. Received ODS are transferred to storage tanks, which later are fed into the PLASCON unit for destruction.

Unwanted ODS collected in the storage tank are sampled and analyzed prior to their destruction. The identification and quantification of ODS is made by gas chromatography at the certified lab

present in the facility. These results are reported and registered and then destruction can take place. While destruction takes place, PLASCON operational conditions, oil content, emissions, %ODS destroyed and effluent pH are registered via PLC and a logbook. Destruction results are finally reported in the SISSAO system to SEMARNAT, which upon verification issues the related destruction certificate.

Weight and composition of destroyed ODS batches is compared to the originally reported figures in order to guarantee that the required amount of unwanted ODS is destroyed. Relevant procedures are taken in order to empty, refurbish and load cylinders into the truck to send them back to generators.

In the Stage 1B of the Demonstration Project 74.1 tonnes of unwanted ODS were destroyed by Quimobásicos in four destruction cycles from August to December, 2015. Every destruction cycle lasted about a month in average.

4.3.4 Costs

Destruction costs at Argon plasma arc by Quimobásicos in Mexico were $9.2 USD per kg of ODS in 2015. This include transportation of ODS batches from storage facility in Celaya, Mexico to Quimobásicos in Monterrey, Mexico, ODS handling and destruction in the PLASCON unit and MRV. These unitary prices are representative to the destruction of more than 15 tonnes of ODS.

Table 12 Stage 1B Project costs for unwanted ODS destruction using Argon plasma arc in Mexico

Project concepts	Unit Price (USD/kg)
Transportation from storage facility to Quimobásicos	0.5
ODS handling and destruction in PLASCON unit	7.4
MRV	0.1
VAT	1.3
Total	**9.2**

Source: Quimobásicos and UNIDO.

4.4 Stage 2. Handling and Destruction of ODS in a cement kiln in Mexico

In 2015 the cement manufacturing company Holcim Mexico was authorized by SEMARNAT to co-process unwanted ODS at one of its facilities located in Tecomán, Colima. By this time, a second batch of unwanted ODS had been collected at different R&R Centers throughout the country. Moreover, a surplus amount of resources from the Demonstration Project were left after Phase 1B was completed. These circumstances gave rise to the launch of a second bidding process by UNIDO, in which Holcim Mexico was appointed to execute Phase 2 of the project that destroyed 39 tonnes of unwanted ODS. Overall the implementation was very successful, as this was the second destruction technology tested during the Demonstration Project, while a cost reduction was achieved in comparison to the first stage.

4.4.1 Bidding Process

After completing the destruction of a first batch of unwanted ODS amounting to 74.1 metric tons, a new international bidding process was open by UNIDO in 2015 with the aim of undertaking the

destruction of 60.9 additional metric tons of ODS from different sources. Upon the evaluation of all received offers, and in line with the agreement between SEMARNAT and UNIDO by which all contract-related activities have to be undertaken in Mexico, a contract was awarded to Holcim Mexico. After signature of the contract, the selected company will initiate implementation activities in the second half of 2016.

In the bidding process, all offers were reviewed and evaluated in accordance with UNIDO's rules and regulations by which the most cost-effective and technically acceptable offer was awarded the contract. However, the proposed total price was in all cases above the available budget and, consequently, the contractor was approached with a request to reduce the unit price per kilogram to be destroyed. Unfortunately, the company was unable to provide any discount and, therefore, it was agreed to reduce the scope of supply from 60.9 tons to 37.2 tons in order to be able to match the funds available. This company had been recently authorized to co-process ODS hazardous waste at one cement kiln facility located in its Tecomán plant in Mexico[30].

Taking into consideration the remaining funds, in Stage 2 of the Demonstration Project, ODS banks were not aggregated nor stored in a single storage facility, as it was performed in Stage 1 (A and B). In the second stage, the transportation of ODS banks from the source point (i.e. customs office, R&R centers, pharmaceuticals) to Holcim Mexico facilities were covered by the generators themselves. This co-financing strategy was achieved thanks to the collaboration among Mexican authorities, the generators and service providers, and allowed the destruction of a larger batch, as transportation costs account for about 10% of the overall unitary destruction costs. ODS bank generators were required a competent handling service provider authorized to transport hazardous waste. On the other hand, Holcim Mexico was committed to receive, handle and destroy the unwanted ODS via co-processing at the cement kiln facilities.

For the amounts not covered by the project (a total of 23,7 tons), Holcim Mexico has committed to provide the same price (US$ 6 per kg plus VAT) to those companies who decide to destroy this remaining quantities at its facilities.

4.4.2 Cement kiln destruction at Holcim

Cement kilns are one of the technologies recommended by the TEAP to destroy unwanted ODS. Cement kilns are tilted, rotating brick-lined cylinders. Raw materials are fed into the rotating in the top (cold) side of the rotating cylinder and they are slowly transformed in to clinker which is received at the lower side of the kiln. As temperatures in the kiln´s burning zone are over 1,500°C and residence times are up to 10 seconds, these facilities are adequate to destroy ODS, and other hazardous substances. Acid gases produced by ODS thermal destruction are neutralized by the alkaline clinker that is being produced. It is relevant to optimize and control the feeding rate of ODS in order to guarantee fluorine and chlorine feed contents are below the required operating conditions. While no additional emissions are expected due to destruction of ODS, cement kiln facilities require modification of the feeding systems as well as a stringent monitoring of hazardous emissions (UNEP/TEAP, 2002).

[30] See section on Pilot tests and license to destroy ODS waste in Mexico.

Tecomán's cement kiln is 55 m in length and 4.4 m in diameter. The hot end of the kiln is maintained between 1,500-2,000°C. The production capacity of the kiln is 5,000 tonnes of clinker per day, while the ODS can be fed at 35 kg/h as minimum. Gas effluent from the cement kiln are controlled with in a bag house, where dust and particles are collected, while other emissions comply with NOM-040-SEMARNAT-2002 limits and ODS DRE has been certified above the Montreal Protocol requirements. No liquid wastes are generated in the process.

Figure 14 Cement kiln at Holcim Mexico facilities in Colima, Mexico

Source: SEMARNAT.

4.4.3 Project MRV

The project MRV involves a series of activities to verify the amount of unwanted ODS destroyed, as well as that safety and environmental provisions are fulfilled. In every destruction cycle, batches of unwanted ODS are received at Holcim Mexico facilities. Geocycle tracks down the shipment of ODS banks with each of the generators and programs its arrival to cement kiln facilities. The loaded transport is weighed in a certified scale and registered in an electronic log along with the identification data of the transport, including its manifest for hazardous waste handling. Geocycle must verify that the transport service provider

Upon arrival of the ODS batches, there are inspected and registered in the system. Unloaded transport is weighed and registered in the electronic log, while a printed copy is given to the driver. ODS containers are stored in the warehouse until destruction takes place.

The destruction process begins with the cylinders transported to the ODS feeding area and weighed in an electronic scale. The cylinder is connected to the main burned feeding system and to an air purge. Once the cylinder is empty of contents it is weighed in order to determine the

amount of gas that has been destroyed. Empty tanks are replaced for new ones until the whole shipment has been destroyed. A destruction certificate is generated for each of the shipments.

Each one of the ODS containers received is analyzed to verify its composition. For this purpose, a non-dispersive infrared refrigerant analyzer is utilized. In the registration system tank and gas weighs are reported, as well as the ODS composition of each tank. Moreover, the following information of destruction is registered:

1. Initial and final date of destruction
2. ODS feed rate
3. DRE
4. Emission concentration of HCl
5. Emission concentration of HF
6. Emission concentration of Dioxins and Furans
7. Batch identification number

In the Stage 2 of the Demonstration Project a total of 39.1 tonnes of unwanted ODS were destroyed by Holcim Mexico from October 2016 to February 2017, as previously mentioned, 1.9 metric tonnes were destroyed in the pilot test, while 37.2 metric tons were co-process in project implementation.

Destruction results are finally reported in the SISSAO system to SEMARNAT, which upon verification issues the related destruction certificate.

4.4.4 Costs

Overall costs of Stage 2 were $8.0 USD per kg of ODS in 2015. The main components corresponds to the ODS destruction in the cement kiln at 6.0 USD/kg. Handling and transportation paid by the ODS generators, via the co-financing scheme, accounted in average for about 1.0USD/kg (Table 13).

Table 13 Stage 2 Project costs for unwanted ODS destruction at cement kiln

Project concepts	Unit Price (USD/kg)
Handling and transportation within Mexico (co-financed by the generator)	1.0
ODS destruction at cement kiln and MRV	6.0
VAT	1.0
Total	**8.0**

Source: Holcim Mexico and UNIDO.

4.5 Comparison of destruction scenarios

In summary, Stage 1A destruction phase was not implemented due to underestimation of the intended costs. Stage 1B and Stage 2 were successfully implemented in Mexico at Argon plasma arc and cement kiln facilities, respectively. The Demonstration Project determined that these two facilities acquired the first permits to destroy unwanted ODS in Mexico, therefore paving the way

for other organizations.

Before starting the procedures for the final disposal of the received unwanted chemicals, the two destruction facilities performed a detailed laboratory analysis (HPLC technology and infrared analysis) of the composition of the received chemicals to be destroyed in order to properly define and optimize the set-up of their respective destruction modalities. According to their assessments, the exact composition of the 113 tonnes of unwanted blends being destroyed are summarized in Table 14.

Table 14 Summary of unwanted ODS destroyed with Mexico's Demonstration Project

Unwanted ODS destroyed (tonnes)			
ODS	**Stage 1B** Argon plasma arc	**Stage 2** Cement kiln	**Overall project**
CFC-11	21.6	3.2	24.7
CFC-12	3.2	8.0	25.3
CFC-114	0.1	0.4	0.5
HCFC-22	22.5	17.6	40.1
HCFC-141b	0	0.2	0.2
HFC-134a	12.6	8.8	21.5
R-407	0	0.9	0.9
Total	**74.1**	**39.1**	**113.2**

Source: SEMARNAT.

More details are available in Annex III and Annex IV of the same report.

This destruction represents the mitigation of about 504 thousand tCO_2e, in both project stages[31]. In turn, this figure is equivalent to the GHG emissions that would have been produced by about 200 thousand vehicles in circulation during one year[32].

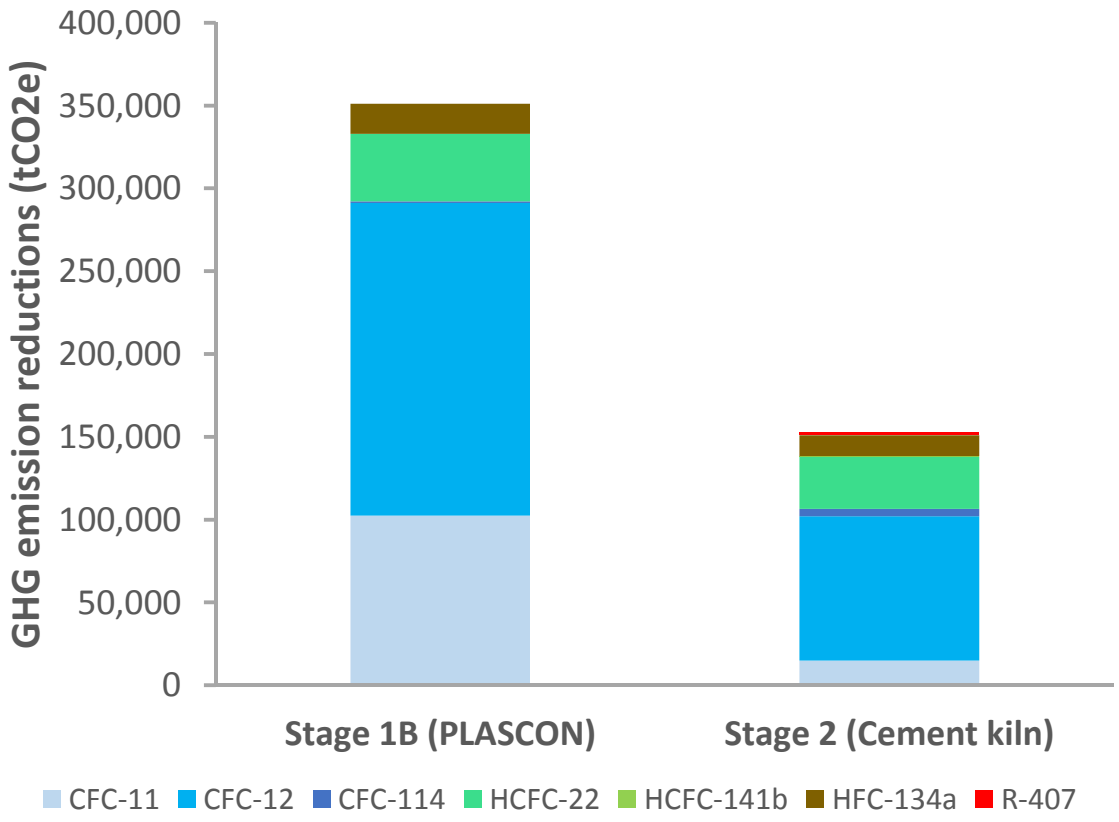
Though HCFC-22 share is the largest in tonnes of substance, its GWP is about 50% of CFC-12, the ODS with the highest value. Therefore, the largest contribution of CO_2 reductions corresponds to CFC-12 destruction (38%), which came from HARP, R&R centers and pharmaceuticals. Climate mitigation is followed by the contribution of HCFC-22 (28%), sourced mainly from customs confiscations and end-of-life appliances. CFC-11 from pharmaceuticals contributed with 22% of GHG reductions, while HFC-134a accounts for 11% (Figure 15) sourced from the blend of refrigerant recovered in domestic refrigerators.

It has to be emphasize two important issues: first one is that all HFC destroyed under this project was contained within an unwanted blend of CFC-12 and HFC-134a recovered from the fridges which could not be recycled or separated before destruction, and the second issue, HCFC-22 destroyed under the project was connected directly from confiscation of illegal trading, so at the time of the consolidation, the exact composition of the ODS was not known due to several

[31] GHG emission reductions estimated with GWP 100-years, from IPCC Fourth Assessment Report: Climate Change 2007. Working Group I: The Physical Science Basis. 2.10.2 Direct Global Warming Potentials, Table 2.14.
[32] Considering an average CO2 emission factor of 3.6 tCO2/vehicle/year in Mexico City.

customs rules which prohibit the analysis of this kind of materials before to abandon the customs facilities. The seized refrigerant cylinders were generally labeled as "*Illegal Freon*", leading to the confusion on their exact composition. Furthermore, the exact composition of those cylinders was found to be mixtures of different refrigerant, including CFC-12, other ODSs and various HFCs.

Figure 15 GHG emission reductions achieved with ODS destruction in Mexico´s Demonstration Project



Note: GHG emission reductions estimated with GWP 100-years, from IPCC Fourth Assessment Report: Climate Change 2007, 2.10.2 Direct Global Warming Potentials, Table 2.14.

Source: SEMARNAT.

A comparison of technical, environmental, economic and legal aspects for each implementation stage is summarized in Table 15. In brief, exportation to the USA (Stage 1A) turned out unfeasible due to increased export costs while regulatory requisites are stringent. Stage 1B and 2 were both successful. Argon plasma arc destruction (Stage 1B) advantages are high destruction efficiency and low emissions and byproducts, however current market is reduced, destruction costs are high and is not compatible with ODS imports due to regulatory restrictions. On the other hand, cement kiln (Stage 2) features lower implementation costs and the possibility to co-process ODS waste as part of a valuable product (cement). Moreover, cement co-processing could be suitable for unwanted

ODS importations for destruction, as hazardous waste imports are allowed in a recycling scenario.

Table 15 Cross-comparison of destruction scenarios

Parameters	Stage 1A	Stage 1B	Stage 2
Technical performance			
Demonstration Project status	Not executed	Completed in 2016	Completed in 2017
Project location	Ohio and Texas, USA.	Monterrey, Mexico.	Colima, Mexico
Technology	Ohio: Argon plasma arc Texas: Rotary kiln incinerator	Argon plasma arc	Cement kiln
Technology status	Both commercial	Commercial.	Commercial.
Availability of facilities	There are currently seven commercial available ODS destruction facilities referenced by EPA, while many others are authorized to destroy hazardous waste	1 Argon plasma arc facility	34 cement facilities, only one currently authorized for ODS destruction [a]
Environmental performance			
ODS destruction performance	>99.99%	>99.99%	>99.99%
ODS actually destroyed in Demonstration Project (tonnes)	0	74	39
CO_2 emission reduction from ODS destruction (Thousand tCO_2e)	0	351	153
Emissions to the atmosphere	NA	CO	Dust and particles
Economic performance [b]			
Total implementation cost (USD/kg ODS)	11.0 (proposed but not implemented cost)	9.2	8.0
Destruction-only cost (USD/kg ODS)	NA	7.5	6.0
Cost-effectiveness (USD/tCO_2e) – Total costs	NA	1.9	2.0
Cost-effectiveness	NA	1.6	1.5

Parameters	Stage 1A	Stage 1B	Stage 2
Technical performance			
(USD/tCO_2e) – Destruction-only costs			
Current market	Large, including imports	Currently reduced	Currently reduced for ODS but large for other waste
Legal considerations			
License availability	There are currently seven commercial available ODS destruction facilities referenced by EPA, while many others are authorized to destroy hazardous waste	1 facility currently licensed to destroy unwanted ODS (Quimobásicos)	1 facility currently licensed to co-process unwanted ODS (Holcim Mexico)
ODS import destruction feasibility		Not possible in Mexico as hazardous waste imports are not allowed in case of incineration without thermal recovery	Possible in Mexico as hazardous waste imports are allowed in case of recycling or co-processing

[a] Cement manufacturing facilities in Mexico. A detailed assessment is needed to determine feasibility of ODS destruction in each plant.

[b] Cost-effectiveness depends not only of the amount of ODS destroyed but its actual types and concentrations. Each CFC, HCFC and HFC features different GWP values, which in turn determines the climate impact of the achieved reductions.

5 Dissemination Activities

Considering the Demonstration Project was a first-of-its-kind in Mexico and one of the first unwanted ODS disposal projects supported by MLF, it was very relevant to produce outreach materials that demonstrated the impact and benefits achieved.

To start communication activities, at the beginning of 2016, SEMARNAT and UNIDO arranged a closing event of the first stage of the project which took place at Quimobásicos plant located in Monterrey, Nuevo Leon. The purpose of the event was to disseminate the results of the project and announce that Mexico had developed national capacities to handle and destroy ODS in an environmentally responsible manner.

Figure 16 Representatives of France, Mexico, Ozone Secretariat, UNIDO and Quimobásicos during closure event

Source: SEMARNAT.

Regarding the second stage of the project, Holcim Mexico promoted its corresponding outcomes at national and international level. Consequently, in 2017 the company and its subsidiary Geocycle, were both recognized with the Environmental Excellence Award for the mitigation actions carried out in the context of this project.

Figure 17 Representatives of Holcim Mexico and Geocycle during award ceremony

Source: PROFEPA.

In addition to the dissemination activities previously mentioned, in order to share with other countries the project outcomes, transfer results, challenges and lesson learned, in August 2017, one study tour to the Holcim facilities was arranged by SEMARNAT and UNEP. Representatives of LAC region such as Guatemala, El Salvador, Chile, Colombia, Honduras, Panama, Costa Rica, Dominican Republic, Peru, Ecuador and Uruguay attended the visit.

Figure 18 Ozone and Customs officers of LAC during Holcim visit

Source: SEMARNAT.

Finally, three videos on the following topics were produced and published:

- Unwanted ODS handling and destruction in Mexico
- Destruction in Argon plasma arc at Quimobásicos
- Destruction in cement kiln at Holcim Mexico

Videos are available on Youtube Channels of UNIDO and SEMARNAT.

Given the limited funds of the projects for this component, it is important to highlight that activities associated with the videos were financed through Institutional Strengthening Project.

6 Conclusions

Project implementation

- Mexico´s Demonstration Project has proved, for the first time among high-volume-consume Article 5 countries, the destruction of unwanted ODS banks in a MLF-supported project. However, original destruction targets were not achieved due to underestimation of the collection, training, handling, and transportation costs.
- Project implementation timeline increased two years due to unexpected barriers, mainly related to higher implementation costs of the preparatory activities, time-lag derived from licensing and permit authorizations, effectiveness at consolidating unwanted ODS banks, and lack of awareness on project benefits among stakeholders.
- As it was seen from unfinished Stage 1A implementation, intended exportation of unwanted ODS stockpiles, turned out more expensive than originally estimated. It is therefore recommended to destroy unwanted ODS at local facilities whenever sufficient legal framework, destruction facilities that comply with environmental criteria are available. ODS destruction via export to Mexico is an option in cases in which these conditions cannot be guaranteed.

Technical-related aspects

- Unwanted ODS are classified as hazardous waste in Mexico. Infrastructure built along the country for handling and transportation of ODS stockpiles was a key element of the project execution. In spite of the efforts made previously by the national authorities on this topic, it was acknowledged that further training and infrastructure strengthening to recover unwanted ODS was required in order to implement a project of such a scale.
- Argon plasma arc is a cutting-edge destruction technology. Currently its application market is reduced in Mexico and related costs are also higher than other approved technologies. However, it is no-doubt the cleanest technology of the two tested and implemented during the Demonstration Project, with close to zero waste by-products. For its performance, this technology can be used to destroy other hazardous waste such as PCBs.
- Cement kiln proved to be the most cost-effective ODS destruction technology in Mexico´s Demonstration Project. Moreover, several cement manufacturing facilities are available through, in general, they exhibit state-of-the-art kilns and emissions control and monitoring devices. This industry has long experience in handling hazardous waste, other than unwanted ODS. Certain provisions must be taken for monitoring of emissions as not all of cement facilities feature Continuous Emissions Monitoring Systems (CEMS). Furthermore, cement kiln technology allows for recycling and co-processing of hazardous waste in a sustainable sound manner.
- The Project stimulated the first facilities in LAC region to obtain license authorizations to incinerate and co-process unwanted ODS, while proving the feasibility of ODS destruction using two different technologies available in Mexico: Argon plasma arc and Cement kiln.

Policy and regulatory issues

- Existing policies and regulations in Mexico were robust and sufficient for the implementation of an unwanted ODS disposal project, whether ODS are destroyed at local facilities or exported to a foreign location. Nevertheless, in order to smoothly implement the legal framework, it is necessary to raise awareness among authorities as ODS destruction had not taken place before in the country.
- Transboundary movements of unwanted ODS for their disposal is an alternative for countries where no destruction facilities are available, or when policy frameworks and environmental criteria are uncertain. As proved in Stage 1A of Mexico's Demonstration Project, cost-effectiveness of waste exportation can become a barrier, particularly if there is no access to carbon credits. Legal requirements are also relevant, as in the Mexican, no importation of waste is admitted, unless it is intended for recycling or co-processing, which is applicable to cement kiln destruction but no to Argon Plasma Arc.

Economic and Environment performance

- Second stage destructions costs were lower than first one, while proposed costs for unfinished Stage 1A proved that exportation of unwanted ODS is not the most economically feasible alternative. It was further acknowledged that the existence of more than one destruction technology and facility increases competitiveness and creates market incentives, while decreasing overall implementation costs.
- Project´s second stage revealed that co-financing of stockpiles transportation is feasible and improves its cost effectiveness. Material scrapping and recycling activities, as performed by R&R Centers in Mexico, are key to support financial balance of these companies. Furthermore, such a scheme increases overall environmental benefits of the project.
- Being a first-of-its-kind project in Mexico, its implementation path involved the testing of two destruction technologies from two different implementers, which certified that clean and safe disposal of ODS banks was feasible and, under adequate policies, cost-efficient within the region. Among most relevant outcomes, the Demonstration Project proved the necessity to strengthen regulatory framework on ODS waste management in order to encourage recycling centers to use a portion of the revenues from scrap sales to finance ODS waste destruction.
- Mexico´s pilot project will facilitate the development of better financing schemes for future projects within the LAC region. As it was witnessed here, encouraging the availability of technological alternatives can lead into relevant cost reductions. This project further allowed to try co-financing schemes with ODS stockpiles generators which, for instance, enabled significant costs drops on handling and transportation.
- Environmental impacts of the project are very significant. The co-benefits generated through its implementation contribute to harmonize the efforts made in the Montreal Protocol, with the commitments established by Mexico in terms of climate change, while promoting the use of energy efficient programs encouraging the pursue of sustainable development goals.

7 Lessons learned

- The implementation of the Demonstration Project deferred from the originally proposal after the decision of the Executive Committee to restrict the possibility of carbon credit yield, which in turn modified the original scope and objectives of the project which were more ambitious; nevertheless, the core aim of the project was sustained as legal and technical feasibility was proven, capacity building was created and financial schemes were tested. These outcomes are likely to be translated into future ODS destruction activities either which could be financed via national carbon markets or legislation strengthening.
- The substances being destroyed, and their respective compositions and amounts, were only exactly known at the moment of their final disposal at the destruction facilities, not during the collection chain.
- Unwanted ODS banks stockpiled could contain important quantities of CFC blended with HCFC and HFC, therefore training on identification and handling of unwanted ODS generators is essential to consolidate ODS banks properly. Consequently, in the future, whenever a destruction activity aims at destroying a specific substance, it is recommended taking into account that waste-refrigerants are in from of multiple blended with ODSs and HFC and other substances that cannot be separated prior destruction.
- Capacity building formed in the context of NPP and HPMP in terms of technicians training, recycling centers and customs training, is essential to facilitate project implementation.
- Preparatory activities focused on technical and legal aspects are crucial to guarantee the correct project implementation, timeline should consider activities such as training, equipment, legal diagnostics, handling and transportation issues, pilot tests and licensing, MRV, as well as socialization.
- Awareness of government areas involved in the management of unwanted ODS should be highlighted in order to familiarize them with such kind of projects. First project certifications will most likely take longer.
- It is better to destroy ODS at local facilities. However ODS destruction via export is still an option for countries where no ODS destruction facilities are available, or when performance and environmental criteria are not guaranteed.
- It is recommended to create incentives so that more than one facility could destroy ODS. This will potentially lead to reduce destruction associated costs.
- Both ODS destruction technologies proven outstanding technical performance and environmental compliance.
- Cement kiln is the most cost-effective ODS destruction technology. Such facilities in Mexico also have long experience in handling other type of hazardous waste. However, provisions must be taken for optimum monitoring of air emissions. In Mexico not all of cement facilities have CEMS installed.
- Argon plasma arc is a cutting-edge technology. Currently its application market is reduced in Mexico. Its related costs are also higher than cement kiln destruction. However, it is the cleanest technology of the two tested in this project.
- Imports of ODS for destruction are only feasible at cement facilities and not at Argon plasma arc facility, as hazardous waste imports are only allowed for recycling.

- Adequate funding for demonstration ODS destruction projects should consider costs associated with handling, transportation and dissemination activities.
- HFC phase-out Plans should consider one specific component for ODS disposal.
- Project outcomes will contribute to develop cost-effective financing schemes that enable the destruction of additional amounts of Unwanted ODS, whilst the lessons accumulated during its implementation will help relieve associated barriers to implement future unwanted HFC disposal projects in Article 5 countries.
- It was moreover identified additional market incentives such as carbon markets and tax incentives can encourage ODS destruction in the future, it is expected that once Mexico´s carbon trading program enters in operation, ODS destruction projects will get further stimulated.

8 References

1. Climate Action Reserve. (2015). 2015 Annual Report.
2. Climate Action Reserve. (2017). Projects. Available from View Projects: https://thereserve2.apx.com/myModule/rpt/myrpt.asp
3. EPA. (2017a). ODS Phase-out. Available from Importing Ozone-Depleting Substances: https://www.epa.gov/ods-phaseout/importing-ozone-depleting-substances
4. EPA. (2017b). ODS Phase-out. Available from ODS Destruction Technologies: https://www.epa.gov/ods-phaseout/ods-destruction-technologies
5. ICF International. (2009). ODS Destruction in the United States of America and Abroad. Available at: http://unep.ch/ozone/data_reporting/USA-Decision-XX-7-ODS-Destruction.pdf
6. IPCC (2007). Fourth Assessment Report: Climate Change 2007. Working Group I: The Physical Science Basis. Direct Global Warming Potentials. Table 2.14 Lifetimes, radiative efficiencies and direct (except for CH4) GWPs relative to CO2. Available at: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.
7. IPCC/TEAP. (2005). Safeguarding the Ozone Layer and the Global System. Issues Related to Hydrofluorocarbons and Perfluorocarbons. Summary for Policy makers and Technical Summary. Intergovernmental Panel on Climate Change (IPCC) and the Technology and Economic Assessment Panel (TEAP).
8. Ley General para la Prevención y Gestión Integral de los Residuos (last version published in DOF, 22-05-2015)
9. NORMA Oficial Mexicana NOM-002-SCT-2011, Listado de las substancias y materiales peligrosos más usualmente transportados (published in DOF, 27-01-2012)
10. NORMA Oficial Mexicana NOM-003-SCT-2008, Características de las etiquetas de envases y embalajes, destinadas al transporte de substancias, materiales y residuos peligrosos (published in DOF, 15-08-2008
11. NORMA Oficial Mexicana NOM-040-SEMARNAT-2002, Protección ambiental – Fabricación de cemento hidráulico – Niveles Máximos Permisibles de emisión a la atmósfera (published in DOF, 18-12-2002)
12. NORMA Oficial Mexicana NOM-052-SEMARNAT-2005, Que establece las características, el procedimiento de identificación, clasificación y los listados de los residuos peligrosos (published in DOF, 23-06-2006)
13. NORMA Oficial Mexicana NOM-098-SEMARNAT-2002, Protección ambiental – Incineración de residuos, especificaciones de operación y límites de emisión de contaminantes (published in DOF, 01-10-2014).
14. NORMA Oficial Mexicana NOM-161-SEMARNAT-2011, Que establece los criterios para clasificar a los Residuos de Manejo Especial y determinar cuáles están sujetos a Plan de Manejo; el listado de los mismos, el procedimiento para la inclusión o exclusión a dicho listado; así como los elementos y procedimientos para la formulación de planes de manejo (published in DOF, 01-02-2013).
15. Pandey, A. (2012). Disposal of ODS Collected from Refrigerator and Air Conditioners under

the Mexican Efficient Lighting and Appliances Program.

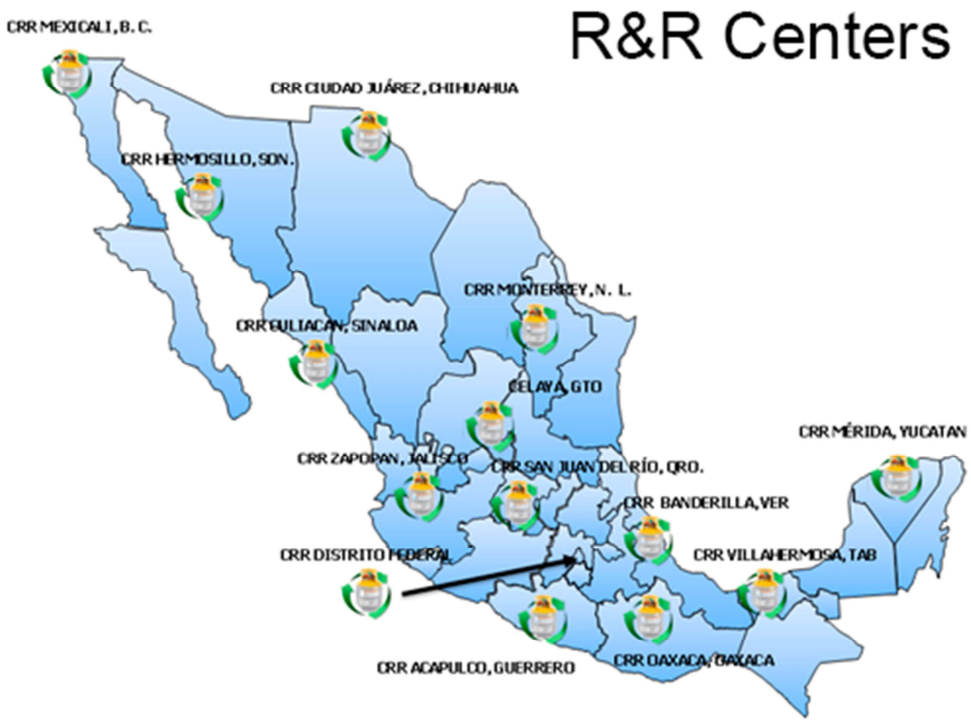
16. Reglamento de la Ley General para la Prevención y Gestión Integral de los Residuos (last version published on DOF, 31-10-2014)
17. SEMARNAT. (2005). Sistema de Información y Seguimiento de Sustancias Agotadoras de la Capa de Ozono. Available at: http://apps2.semarnat.gob.mx:8080/sissao/index.jsp
18. SEMARNAT. (n.d.). Guía para la importación y exportación de residuos en México. Secretaría de Medio Ambiente y Recursos Naturales.
19. The World Bank. (2016). Implementation Completion and Results Report (IBRD-7996 TF-98062 TF-098465).
20. UNEP/TEAP. (2002). Report of the Technology and Economic Assessment Panel. Volume 3B Report of the Task Force on Collection, Recovery and Storage. United Nations Environment Programme.

Annexes

Annex I. Description of R&R Centers in Mexico

The 14 R&R centers in Mexico that were created by the NPP and operated as part of the ODS destruction project are geographically depicted in Figure 18, while a brief description of each is presented below.

Figure 18 Location of Recovery and Recycling Centers



Source: SEMARNAT.

1. **Recycling Center Celaya, Guanajuato. Ecofrigo.** Ecofrigo Company is dedicated to fridges scrapping and refrigerant gas center, it has installed an efficient system to increase the performance in the refrigerant gas recovery up to 150 g per equipment.
2. **Recycling Center Mexico City. Control Ambiental Profesional del Norte, S.A. de C.V.** The company operated a recycling center and it had a center for collection and destruction of refrigerators.
3. **Recycling Center Mexicali, Baja California. ING Servicios Profesionales, S.A. de C.V.** Since the installation of the recycling center in 2007, the company has been collecting and storing gases for destruction, currently is working in close coordination with others two centers (Veracruz and Tabasco) in order to get carbon credits. The company operated a recycling and FIDE centers within Baja California, it mainly dedicates to sell air conditioning equipment such as minisplits, cassette units and window units.

4. **Recycling Center Villahermosa, Tabasco. Martín Alejandro Ramón.** From the beginning of the operations, the recycling center has been collecting and storing ODS contaminated for destruction from 7 FIDE Centers.
5. **Recycling Center Xalapa, Veracruz. Ingeniería en Construcción y Soluciones Ambientales, S.A. de C.V**. The company was founded in Veracruz in 2004; its main services included the collection of gases from the equipment replacement at the FIDE centers. The company operated a recycling center and 5 FIDE centers within Veracruz. According to the SISSAO and FIDE, after Ecofrigo, this center had the highest recovery rates in the program.
6. **Recycling Center Acapulco, Guerrero. Trade Supply Integral S.A de C.V.** A company based in the south of the country. During the last 15 years the company has been involved in the commercial air conditioning business and recovery and recycling market of HCFC-22 covering part of Guerrero, Morelos, Chiapas, Campeche and Mexico City.
7. **Recycling Center Ciudad Juárez, Chihuahua. Radiorefrigeración.** It is the second center located in the north of the country, near of the border with the United States, it is mainly dedicated to the sale of commercial refrigeration machines and distribution of refrigerant gas.
8. **Recycling Center Zapopan, Jalisco. Jorge Medina Álvarez.** Previously operated by Importaciones Cortez Company (from 2007 to 2011), the recycling center of Jalisco began operations in April 2011. Based in the metropolitan area of Guadalajara, Jorge Medina Company has 20 years of experience in the field of handling, sale and distribution of refrigerant gases.
9. **Recycling Center Hermosillo, Sonora. Refriequipos de Sonora**. It was founded over 20 years ago in the north of the country, it was the second recycling center near of the border with the United States, the company was involved in buying and selling parts, accessories, conditioning air equipment and distribution of refrigerant gases covering Sonora and Baja California. In the recovery and recycling concerns, the center worked significantly in the HCFC-22 market for air conditioners.
10. **Recycling Center Monterrey, Nuevo León. Instalaciones y servicios de refrigeración, S.A de C.V.** A Mexican company founded 20 years ago, it was based in the north of the country, the third center installed near of the border with the United States, and the company was involved on vending machines sales and distribution of refrigerant gas.
11. **Recycling Center San Juan del Río, Querétaro. Refrigerantes del Bajío.** A Mexican company founded 10 years ago, it is located in the center of the country and has with 10 branches. They are involved in de commercial and air conditioning business as well the center offers maintenance service in all sectors. The company operated a recycling center and it had a center for collection and destruction of refrigerators (FIDE).
12. **Recycling Center Oaxaca. Refri-Hogar.** It was a company founded 35 years ago, located in the southwest of Mexico, involved in selling parts and accessories for refrigeration equipment, fridges, and minisplits and as a part of the integral service it provided maintenance for refrigeration and conditioning air equipment. The company operated a recycling center and it had a center for collection and destruction of refrigerators (FIDE). This center had one of the highest recovery rates in the FIDE centers, in average 50 g per appliance. From 2007 the recycling center has been collecting and storing refrigerant gases for destruction, currently the company has stockpiled already collected to be sent for destruction.

13. **Recycling Center Culiacan, Sinaloa. Taller el Capule, S.A. de C.V.** It was located in the northwest of the country, in the capital of Sinaloa, the company has over 30 years of experience on the sale of refrigeration and air conditioning equipment, parts and distribution of refrigerant gases as well as offering recovery services. This center received and stored gas for destruction from 8 FIDE centers of the region and other stakeholders.
14. **Recycling Center Mérida, Yucatán. Refrimart de México, S.A. DE C.V.** Refrimart de Mexico was based in the southeast of the country, in the capital of Yucatán State, the company was involved in the sale of refrigeration and air conditioning equipment, accessories and distribution of refrigerant gases as well as offering recovery services. This center is received and stored gas for destruction from 7 FIDE centers of the region and other stakeholders.

As part of the NPPR&R training programme, each center was trained and equipped with the below items:

Table 16 R&R Centers equipment

Description	Units
Reclaiming Machine for CFC, HCFC and HFC	1
Recovery machine	1
Vacuum pumps	1
Refrigerant Identifying Kit	1
Liquid refrigerant transfer kit	1
Programmable Electronic Charging Scale	1
Service two way manifold for R-12, R-22 and R-502 with hoses	1
Service two way manifold for R-134a, R-404A and R-407C with hoses	1
Recovery cylinders (50 pound)	20
Recovery Tanks (1,000 pounds)	3
Dehydrator Filter	10
Valve core set (piercing valves) in box	2
Digital balances	1
Portable electronic leak detector	1
Contamination detector Kit	1
Stock of spare parts to operate for one year	1

Source: SEMARNAT.

Annex II. Intended ODS destruction costs in the USA

Though not fully implemented[33] due to underestimation of the implementation costs, the indented economic costs for Stage 1A ODS destruction at two facilities in the USA are summarized in Table 17.

Table 17 Proposed cost structure of ODS destruction project in the USA

Project component	Cost (USD)
Staff and travel expenses	30,000
Transportation within Mexico	42,000
Aggregation and centralization	58,000
International transportation (2 facilities)	60,000
Documentation and permits	20,000
ODS Destruction (2 facilities)	428,064
MRV	62,500
Project management	21,403
Technical workshop	55,000
Total Destruction Project Implementation	**776,967**
ODS banks to be destroyed (kg)	**74,000**
Unit costs (USD/kg)	**10.5**

Source: UNIDO.

[33] Only Transportation within Mexico, Aggregation and Centralization were implemented.

Annex III. ODS destruction pilot test results in Argon plasma arc

ODS destruction pilot test at Quimobásicos Argon plasma arc took place from August 27th to 30th, 2013. As per the test protocol approved by SEMARNAT, 480 kg of ODS were supplied in four test cycles as seen in Table 18.

Table 18 ODS composition of samples used during pilot test in Argon Plasma Arc

Test cycle	ODS tested	Composition	Quantity (kg)
1	HFC-134a	100%	120
2	HFC-134a	100%	120
3	HFC-134a /HCFC-22	85%/15%	120
4	HFC-134a /HCFC-22	85%/15%	120
Total			**480**

Source: Quimobásicos.

The results of the destruction tests showed that average destruction efficiency was 99.9994%. Five samples were tested, as one of the cycles (August 28th) was interrupted due to issues in one of the equipment components. ODS destruction efficiency was analyzed by a certified laboratory from the US.

Table 19 ODS destruction efficiency results during pilot test in Argon Plasma Arc

Date	Operation time (h)	ODS tested	Destruction Efficiency
August 27th	4.09	100% HFC-134a	99.9994%
August 28th	4.45	100% HFC-134a	99.9994%
August 29th	4.05	85% HFC-134a / 15% HCFC-22	99.9998%
August 29th	4.02	85% HFC-134a / 15% HCFC-22	99.9983%
August 30th	4.03	100% HFC-134a	99.9999%
Mean value			**99.9994%**

Source: Quimobásicos.

Annex IV. ODS destruction pilot test results in cement kiln

ODS destruction pilot test at Holcim Mexico facilities took place on May 19 and 20th, 2015 in the cement kiln 1 of Tecomán plant. 2,050 kg of recovered unwanted ODS contained in three cylinders of varying compositions of HFC-134a, CFC-12 and HCFC-22 were supplied through SEMARNAT (Table 20). A dedicated feeding pipe with instrumentation was installed in order to supply the ODS into the main burner´s primary air inlet. ODS handling was performed by Geocycle (formerly Ecoltec), while Holcim staff supervised the flow of gases supplied into the cement kiln.

Table 20 ODS composition of samples used during pilot test in cement kiln

	Cylinder 1	Cylinder 2	Cylinder 3
HFC-134a (%)	35.6	23.8	30.5
CFC-12 (%)	52.6	53.2	10.2
HCFC-22 (%)	10.8	23.0	59.4
Gross weight (kg)	1320	1290	550
ODS net weight (kg)	**840**	**810**	**150**

Source: Holcim Mexico/Geocycle.

In each test, samples of fuels supplied in the cement kiln were analyzed (Table 22). Results are shown in Table 21. It is relevant to mention that between 12 and 21% of alternative fuels were supplied in the kiln, including tire and sludge residues.

Table 21 Results of analysis performed to fuels supplied during the pilot test in cement kiln

Parameter	Units	Solids	Tires	Liquids	Sludge
Moisture	%	17.30	2.36	93.6	89.90
Chlorine	%	0.31	≤ 0.03	0.15	0.18
Caloric value	MJ/kg	25.8	30	0	6.0
Sulfur	%	0.42	1.6	1.2	0.48
Na_2O	%	0.30	0.02	1.88	0.18
K_2O	%	0.18	0.05	0.02	0.05
pH	%	7.90	8.1	4.05	4.67
Ashes	%	17.90	NA	1.09	6.97

Source: Holcim Mexico/Geocycle.

Table 22 Amount and type of fuels supplied into the cement kiln during the pilot test

Test date	Tire chips (tonnes)	Solids (tonnes)	Liquids (tonnes)	Sludge (tonnes)	% Alternative fuels
May 20th	21.7	16.3	6.5	13.8	12.2
May 21st	38.6	26	0	24.8	20.7

Source: Holcim Mexico/Geocycle.

Combustion gases were analyzed through the CEMS installed in the stack of line number one, which consists of a dust analyzer and a gas analyzer, according to NOM-040-SEMARNAT-2002

requirements. CEMS allow the measurement of NO_x, SO2, HCl, CO, Particles and Hydrocarbons. Other parameters, including Dioxins and Furans, heavy metals and ODS, were point measured by third party laboratories.

Operating conditions of the pilot tests are summarized in the Table 23.

Table 23 Cement kiln pilot test operating conditions in 2015

Test date	Average gas flow (kg/h)	Maximum gas flow (kg/h)	Gas feed period (h)	Gas fed (kg)
May 20	43	52	23	980
May 21	153	277	7	1070

Source: Holcim Mexico/Geocycle.

The results of the emission parameters measured through the CEMS are shown in Table 24. It must be noticed that CO emissions are expected be high as alternative fuels, such as tires and sludge, were supplied to the kilns. Nevertheless, these emissions are kept well below NOM-040-SEMARNAT-2002 specifications as seen below.

Table 24 Continuous monitoring results of emission parameters regulated by NOM-040-SEMARNAT-2002

Parameter	Emission limits [a]	Units	Test date	
			May 20th	May 21st
CO	4,000	mg/m^3	340.71	585.93
SO_2	1,200	mg/m^3	0.88	0.08
NO_x	1,200	mg/m^3	480.81	454.67
THC	70	mg/m^3	24.08	28.47
HCl	70	mg/m^3	10.34	5.92

[a] Emission limits set as per NOM-040-SEMARNAT-2002

Source: Holcim Mexico/Geocycle.

Moreover, the results of point measurements to regulated emission parameters is depicted in Table 25.

Table 25 Point measurement results of emission parameters regulated by NOM-040-SEMARNAT-2002 and TEAP

Parameter	Emission limits [a]	Test date	
		May 20th	May 21st
Sb, As, Se, Ni, Mn	0.70 mg/m^3	< 0,0770	< 0,073 2
Cd	0.07 mg/m^3	0,0015	~ 0,000 6
Hg	0.07 mg/m^3	< 0,0023	~ 0,003 5
Pb, Cr, Zn	0.70 mg/m^3	~ 0,0463	~ 0,039 8
Dioxins and Furans	0.2 (ng ITEQ/m^3)	0,0010	0,001 4
Particles (TSP)	26.7 kg/h	0,1910	0,242

[a] Emission limits set as per NOM-040-SEMARNAT-2002, except for Dioxins and Furans, which are set according to UNEP/TEAP (2002).

Source: Holcim Mexico/Geocycle.

Finally, the results of analysis performed to combustion gases on ODS composition is summarized in Table 26.

Table 26 ODS concentration in combustion gases during pilot tests

ODS	May 20th			May 21st		
	Sampling time	Gas flow (kg/h)	Concentration (mg/m^3)	Sampling time	Gas flow (kg/h)	Concentration (mg/m^3)
CFC-12	13:35-14:06	50	< 0.0243	10:05-10:54	200	< 0.0240
	14:07-14:21	50	< 0.0265	11:00-11:30	240	< 0.0253
	14:22-14:46	50	< 0.0249	11:48-12:40	277	< 0.0251
HCFC-22	13:35-14:06	50	~ 0.0577	10:05-10:54	200	< 0.0142
	14:07-14:21	50	< 0.0157	11:00-11:30	240	< 0.0150
	14:22-14:46	50	< 0.0148	11:48-12:40	277	< 0.0149
HFC-134a	13:35-14:06	50	< 0.0193	10:05-10:54	200	< 0.0191
	14:07-14:21	50	< 0.0148	11:00-11:30	240	< 0.0200
	14:22-14:46	50	< 0.0198	11:48-12:40	277	< 0.0199

~ Results are between detection limit (DL) and quantification limit (QL).
< Results are below the detection limit (DL).

Source: Holcim Mexico/Geocycle.

According to pilot test performance results it was concluded that ODS destruction is feasible without increasing toxic and regulated emissions, and without impacting the quality of the clinker produced.

A maximum gas feed flow of 277 kg/h was achieved in 7 hours of test during the second day. This feed flow was attained by supplying the gases through the primary airline of the main burner. The destruction efficiency reached was 99.99865%.

All the measured parameters complied with the regulations established in NOM-040-SEMARNAT-2002 and the UNEP/TEAP (2002). It was further noticed that during the tests a reduction of 16% of NO_x was accomplished in comparison to 2014 average value.

The applied operation and safety measures allowed to ensure that unwanted ODS destruction:

1. Safety of workers and community is not put at risk

2. Emissions limits set by NOM-040-SEMARNAT-2002 and TEAP are not exceeded.

3. No disturbances are introduced into the process or quality of cement produced.

4. Destruction of unwanted ODS is compatible with clinker manufacturing.