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Compilation of strategies for the environmentally sound management of banks of ozone-depleting substances

Note by the Secretariat

The annex to the present note contains a compilation of strategies by Parties to the Montreal Protocol for the environmentally sound management of banks of ozone-depleting substances. The strategies have been reproduced as received, without formal editing.

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Annex



Australian Government

Department of the Environment, Water, Heritage and the Arts

Australia's approach to disposal and destruction of ozone depleting substances

Submission to the Ozone Secretariat in line with Decision XX/7

Summary

Australia has developed a robust and functioning product stewardship programme for the management of ozone depleting substances and synthetic greenhouse gases, which ensures the proper handling of these substances from their import into Australia through to their eventual disposal and destruction. It functions on the "polluter pays" principle, with industry funding the scheme through a levy imposed on imports of bulk gases and gas contained in refrigeration and air-conditioning equipment. Fees from issuing licences also assist the Australian Government in administering the various licence schemes connected to the consumption of ozone depleting substances and synthetic greenhouse gases. In recent decades, the Australian Government has been implementing a highly effective national strategy for the recovery, management and disposal of halons.

Introduction

Australia has been Party to the Vienna Convention for the Protection of the Ozone Layer and Montreal Protocol on Substances that Deplete the Ozone Layer since their inception in the 1980's, and has consistently met or exceeded its obligations to phase-out the production and consumption of ozone depleting substances.

Australia meets it obligations through implementation of the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*, which is administered by the Ozone and Synthetic Gas Team of the Department of the Environment, Water, Heritage and the Arts.

This Act and its associated regulations allow Australia to meet its obligations through imposing controls on the manufacture, import and export of ozone depleting substances (ODS) in bulk and in product form. It also has established a faster reduction in Australia's consumption of ODS than required, allows Australia to meet its reporting obligations for synthetic greenhouse gases (SGGs) under the United Nations Framework Convention on Climate Change and sets in place controls to minimise impacts of ODS and SGGs on the atmosphere.

The approach of the Australian Government to the recovery and destruction of ODS and SGGs may change over the coming years with the introduction of the Carbon Pollution Reduction Scheme

(CPRS), a market-based mechanism for reducing the emissions of greenhouse gases covered under the Kyoto Protocol (including HFCs, PFCs and SF_6).

Product Stewardship requirements for the refrigeration and air-conditioning sector

All imports of ODS and SGGs into Australia must be licensed, including those contained in refrigeration and air conditioning equipment. One of the conditions of an import licence requires importers to manage ODS and SGGs at the end of their life and to be a member of an approved product stewardship scheme. At this time, there is only one approved product stewardship scheme, Refrigerant Reclaim Australia (RRA). This scheme was established in 1993 to recover waste ODS and is operated primarily by the refrigeration and air-conditioning industry, which consumes over 90% of all ODS and SGGs imported into Australia. The RRA program was expanded in 2003 to include SGGs and the gas incorporated in refrigeration and air-conditioning equipment, to avoid market distortions and to ensure consistent treatment of all fluorocarbon refrigerants by technicians.

RRA charges a levy on all imports of ODS and SGG refrigerants, in bulk and in equipment, on a per kilogram basis to cover the costs of recovery and destruction. RRA makes payments to technicians that recover refrigerant and return it to the wholesalers, who then transport the refrigerant to RRA for disposal and /or destruction. The import levy currently covers the cost of the transport, storage and destruction of used ODS and SGG in Australia.

The Act and its regulations also regulate the sale, purchase, use, storage and disposal of ODS and SGG in Australia. Refrigerants and fire extinguishing agents can only be acquired by a licensed business holding a trading authorisation and all technicians that handle the gas must hold an appropriate handling licence. This licence obliges technicians to have minimum skills, to abide by relevant codes of practice and to meet appropriate Australian standards. Technicians are required to recover refrigerants during installation, servicing and decommissioning and to return used and unwanted refrigerant to an approved disposal facility.

Technicians wishing to dispose of used refrigerant firstly obtain a ‘recovery cylinder’ from a refrigerant wholesaler for use in recovery of used and contaminated refrigerant during the maintenance and decommissioning of systems. The technician then returns full cylinders to the refrigerant wholesaler, and the wholesaler weighs the refrigerant and pays a credit to the technician. The large majority of refrigerant recovered is from the commercial refrigeration and air conditioning industry, with increasing quantities coming from the mobile air-conditioning industry.

Conditions of refrigerant handling licenses include requirements that:

- only refillable containers are used for the storage of refrigerant;
- refrigerant recovered from RAC equipment (except halon) are surrendered to the holder of a refrigerant trading authorisation or to the operator of an approved refrigerant destruction facility;
- records are kept on refrigerant bought, sold and recovered each quarter;

- equipment preventing avoidable emissions is operating correctly; and
- adequate amounts of equipment are available and cylinders regularly leak checked.

Holders of refrigerant handling licenses must also have in place a risk management plan for the storage and handling of refrigerant and must ensure that destruction of any refrigerant is only carried out by the operator of an approved refrigerant destruction facility. Destruction facilities must be approved by the Minister for the Environment, Heritage and the Arts and be listed by the Montreal Protocol as an approved technology. Holders of refrigerant trading licences are also required to accept any surrendered refrigerant that appears to be intended for use in refrigeration or air-conditioning equipment.

Any discharge of scheduled substances, which is not in accordance with the regulations, is an offence under section 45B of the Act.

Disposal and destruction of ODS and SGGs in Australia

The Act allows for the establishment of refrigerant destruction facilities in Australia. Currently one facility has been approved and is operational (BCD Technologies). The Act requires that any destruction facility approved must operate consistently with Montreal Protocol obligations and that a destruction efficiency of at least 99.999% is achieved.

RRA uses the Australian developed plasma-arc technology located at a plant owned and operated in Melbourne by BCD Technologies to destroy refrigerants. This transforms fluorocarbon refrigerants to salty water, with higher than 99.999% efficiency, in accordance with Montreal Protocol obligations. This facility effectively eliminates various waste types such as PCBs, pesticides, ODS, SGGs and halons. RRA has facilitated the recovery of approximately 2000 tonnes of ozone depleting and synthetic greenhouse gas refrigerants since the program began in 1993.

RRA and the Australian Refrigeration Council (ARC) also conduct educational activities to educate the commercial refrigeration and air conditioning sector on best practices. In 2008, a high profile public education campaign was conducted by the ARC to educate consumers on the importance of using licensed technicians and of having refrigeration and air-conditioning systems regularly serviced.

The issue of recycling or reusing ODS is a decision for commercial businesses to make and, generally, refrigerant is reused by the technician or premises if it isn't contaminated. All refrigerant currently recovered at end of life is sent for disposal and/or destruction. In the late 1990s some CFCs were reprocessed by National Halon Bank back to specification due to dwindling availability. At present, neither RRA nor BCD Technologies purify recovered refrigerant for re-use.

Of the recovered refrigerant, each year approximately 80% is destroyed, 7% is used as feedstock, 7% is reclaimed, and 5% is stored. To date, the program has prevented the emission of sufficient ozone depleting refrigerant to destroy 7.5 million tonnes of stratospheric ozone (see graphs at the end of this paper).

Halon recovery, management and disposal in Australia

Australia finalised its Halon Management Strategy in February 2000. It outlines Australia's commitment to the effective management of halon stocks until a complete phase out of the use of halon can be achieved. Under the Act, Australia ceased importation of halons from 31 December 1992, for all but essential uses.

Critical to the success of this Strategy is the ongoing operation and development of the National Halon Bank (the Bank) as a regional environmental facility for the safe management of surplus and essential use stocks of halon. The Bank was established in 1993 and is one of the largest halon depositories in the world.

Australia takes account of its international obligations when deciding whether to destroy or recycle halon. Such considerations include the finding by the Montreal Protocol's Halon Technical Options Committee that very few halon 1211 applications are essential uses and stocks contained in existing equipment provide a more than adequate supply to meet these essential use applications. Australia has destroyed in excess of 1,200 tonnes of halon 1211 to date.

Halon held at the Bank originated from industry and government agencies following the decommissioning of non-essential halon fire protection systems. A service charge, sufficient to fund the collection, storage and disposal of the halon was levied on deposits of halon 1211 and some deposits of halon 1301. Private individuals and small businesses have been able to surrender their halon at no cost.

The Bank currently operates as a:

- disposal facility for halon remaining in the community;
- commercial storage facility for halon held on behalf of domestic and international clients;
- storage facility for Australia's reserve of halon;
- service facility for users of halon; and a
- host facility for the operation of the BCD owned PLASMA Plasma Arc facility owned by BCD Technologies and its associated activities.

The Bank continues to provide a disposal service for halon 1211 and halon 1301 that is surrendered. The Bank contract provides for a "free call" service to arrange collection of halon. A disposal network, based on the metropolitan and country fire brigades enables members of the public to dispose of their unwanted extinguishers in a controlled environment. A similar service is provided for fire protection companies. This halon is mainly in the form of halon 1211 fire extinguishers and runs to about 10 tonnes per annum.

The collection is at no cost to the public. Halon fire extinguishers are still in use in the community despite intensive publicity for over 15 years. Cessation of the disposal service may result in the emission of the halon to the atmosphere through the inappropriate disposal of the gas or the systems.

The Bank also assists with the commercial disposal of halon 1211 and halon 1301 from businesses, or from overseas. The fee for disposal is negotiated on a case by case basis. Revenue from the sale of surplus halon and other commercial activities of the Bank is returned in full to ozone protection

activities, including costs associated with the management of the Bank. The Bank also holds bulk gas and various cylinders for RRA and others on a commercial basis. The fees are negotiated on a case by case basis.

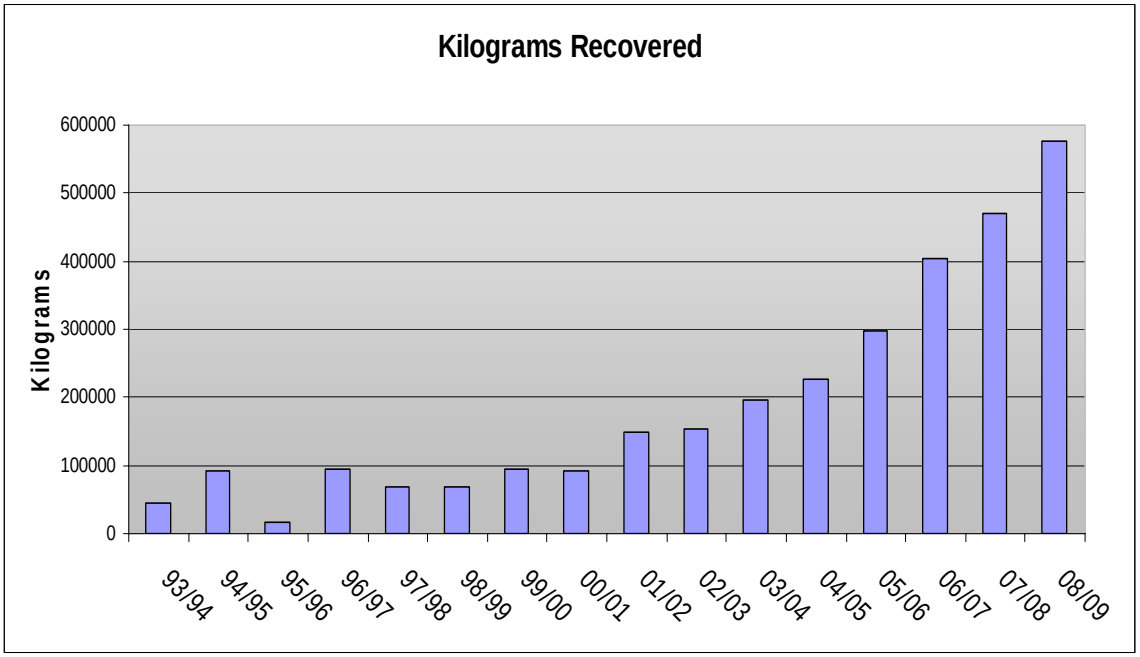
Material recovered from surrendered halon is available for sale or re-use for essential uses to help meet the cost of the service.

The Bank holds 200 tonnes of halon 1301 and 70 tonnes of halon 1211 to meet Australia's estimated needs to 2030. The size of the reserve was established following an operational review by a consultancy in 1998 and reviewed in 2003.
The halon 1301 stock is stored in 500 kg cylinders and is subject to a structured leak monitoring regime.

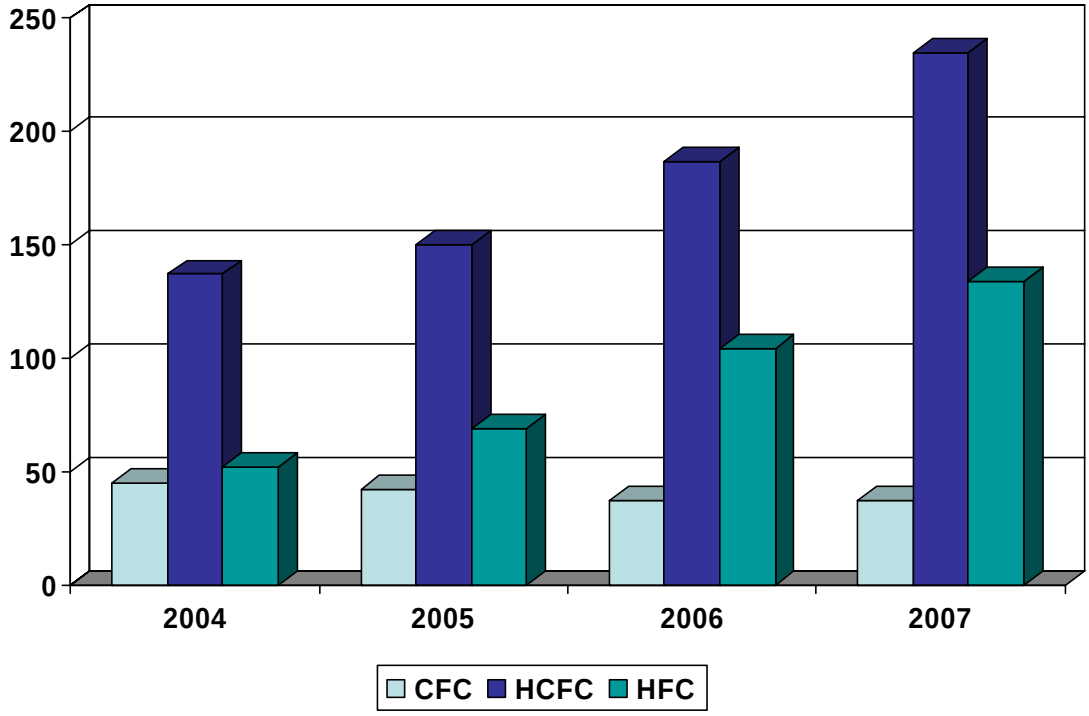
The Bank has developed recovery and reclamation units which can be used to safely transfer and recover halon. The Bank provides repackaging services to users and holders of halon. These services are required, for example, when cylinders need to be pressure tested and the halon has to be temporarily stored while the test facility carries out its work.

The Bank also operates a laboratory for quality assurance of stock and to provide information on the material being destroyed. The laboratory has been accredited by the National Association of Testing Authorities, Australia to assist in compliance and enforcement activities associated with the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* in relation to halons. The laboratory is available to certify purity of halon on a cost recovery basis.

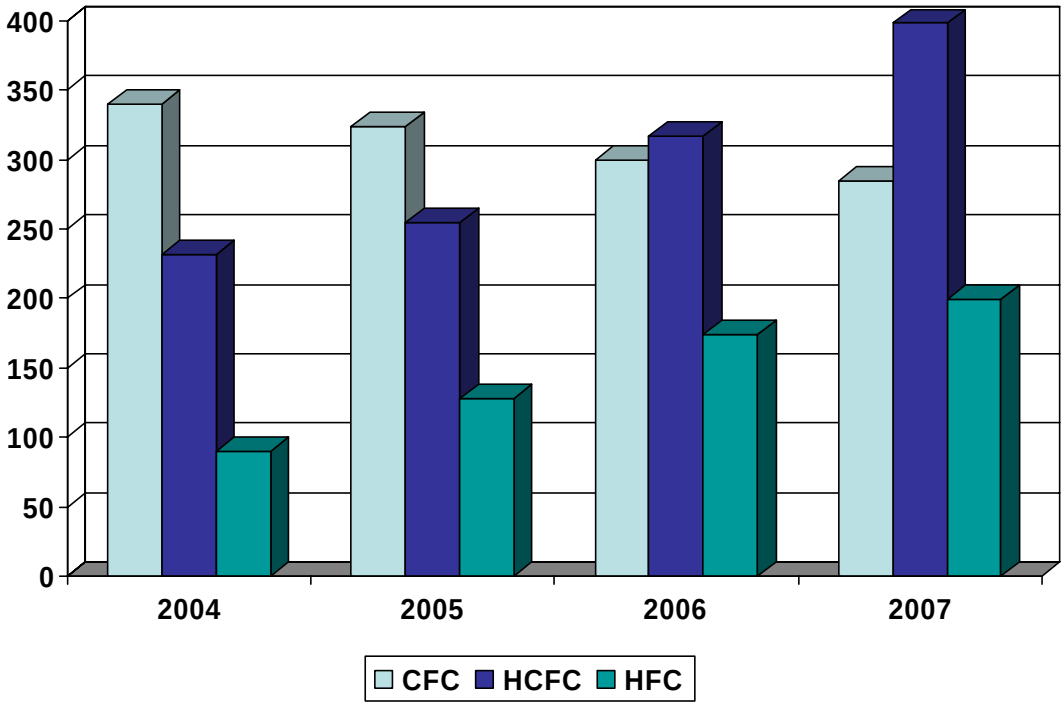
Refrigerant recovered by RRA (tonnes)



Type of refrigerant covered (ODP tonnes) 2004-2007



Recovered Refrigerant CO2e ‘000’s Tonnes By Species 2004 – 2007



ODS DESTRUCTION IN THE UNITED STATES OF AMERICA AND ABROAD

(May 2009)

Prepared by ICF International for
U.S. EPA's Stratospheric Protection Division

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Acronyms

CAA	Clean Air Act
CEMS	Continuous Emission Monitoring System
CFC	Chlorofluorocarbon
CMS	Continuous Monitoring System
CO	Carbon Monoxide
CPT	Comprehensive Performance Test
DRE	Destruction and Removal Efficiency
EPA	United States Environmental Protection Agency
HCFC	Hydrochlorofluorocarbon
HWC	Hazardous Waste Combustor
ICFB	Internally Circulated Fluidized Bed
ICRF	Inductively Coupled Radio Frequency
MACT	Maximum Achievable Control Technology
NESHAP	National Emission Standards for Hazardous Air Pollutants
ODS	Ozone Depleting Substance
PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzodioxins
PCDFs	Polychlorinated Dibenzofurans
PIC	Product of Incomplete Combustion
POHC	Principal Organic Hazardous Constituent
RCRA	Resource Conservation and Recovery Act
SVOC	Semi-Volatile Organic Compounds
TEAP	Technology and Economic Assessment Panel
TFDT	Task Force on Destruction Technologies
THC	Total Hydrocarbons
TRI	Toxics Release Inventory
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compound

Executive Summary

In 1988 the United States ratified the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). By ratifying the Montreal Protocol and its subsequent adjustments and amendments the U.S. committed to a collaborative, international regime to control and phase out ozone-depleting substances (ODS), including chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

Ratification of the Montreal Protocol led to amendment of U.S. law in 1990 and new provisions titled Title VI, "Stratospheric Ozone Protection," were added to the U.S. Clean Air Act (CAA). Title VI authorizes the U.S. Environmental Protection Agency (U.S. EPA) to manage the phase out of ODS in the United States.

Among the regulations established by U.S. EPA under Title VI are the "National Recycling and Emissions Reduction Program" (Section 608 of Title VI of the U.S. Clean Air Act Amendments (CAAA)). The U.S. EPA Section 608 regulations establish requirements for the safe handling of ODS and prohibit knowingly venting or releasing ODS into the atmosphere. As ODS are phased out in the United States, surplus ODS recovered from older equipment are being sent for destruction, often after being recycled, reclaimed, or stockpiled. Properly destroying surplus ODS prevents emissions into the atmosphere.

This report examines the state of ODS destruction in the U.S. and abroad, including the following topics:

- U.S. facilities that destroy ODS, and the amounts of ODS destroyed in the past by U.S. facilities;
- The future amounts of ODS potentially available for destruction and the capacity of U.S. facilities to destroy ODS;
- The costs associated with the destruction and transportation of ODS;
- U.S. regulations relevant to the destruction of ODS;
- The ability of U.S. facilities to meet the recommended criteria for ODS destruction established by the Montreal Protocol; and
- Destruction facilities and relevant regulations abroad.

Major Findings:

- The Montreal Protocol has established criteria for the destruction of ODS. Specifically, destruction and removal efficiency (DRE) should be at least 99.99%, and maximum emissions are set for polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/PCDFs, or dioxins and furans), hydrochloric acid (HCl), chlorine (Cl_2), hydrofluoric acid (HF), hydrobromic acid (HBr), bromine (Br_2), particulate matter (PM), and carbon monoxide (CO). (Decision XV/8 and Annexes I,II,III and IV)
- In the United States, approximately 20 facilities were identified that accept ODS waste from outside sources for commercial destruction (EPA 2006c).[1]
- All U.S. destruction facilities identified (except for the newly constructed plasma arc facility in Ohio), are permitted under the U.S. law for combustion of hazardous wastes (RCRA-permitted hazardous waste combustors (HWCs)). These RCRA-permitted hazardous waster combustors must meet the U.S. EPA regulatory standards for maximum achievable combustion technology (MACT standards), including the minimum DRE of 99.99% for hazardous waste including ODS that are classified as hazardous waste.

[1] This estimate includes all facilities with reported destruction capabilities as of 2004, except those characterized as carrying out incidental creation or byproduct destruction. It should be noted that because some facilities may transship ODS materials received to another commercial destruction facility, the actual number of facilities destroying ODS could be less than 20. On the other hand, there may be other facilities that are regulatory permitted to accept ODS for destruction and capable of ODS destruction but that have not reported doing so.

- Overall, it should be noted that U.S.-based hazardous waste combustors are highly regulated entities, subject to regulation under both the CAA and RCRA, as well as associated state statutes and regulations. Further, hazardous waste combustors in the U.S. have been subjected to site-specific human health and environmental risk assessments (SSRAs) that demonstrate on a facility-specific basis that air emissions from those facilities do not pose a significant risk to human health and the environment.
- The MACT standards (Maximum Achievable Control Technology) and associated Title V Operating Permit limits for HWCs operating in the U.S. establish highly individualized, site-specific emission limits and associated monitoring, reporting, and recordkeeping requirements.
- Concerning emissions, most types of emissions covered by the Montreal Protocol criteria are also regulated under U.S. EPA's MACT standards. Most emissions limitations under the U.S. MACT standards are equal to or more stringent than the Montreal Protocol criteria.
- The Montreal Protocol criteria for combustion operations for ODS were established for facilities world-wide, many of which are not subject to any regulations and may not employ any air emissions control systems. The Montreal Protocol criteria are designed as generic standards applicable to ODS destruction facilities.

Introduction

In 1988 the United States ratified the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). By ratifying the Montreal Protocol and its subsequent adjustments and amendments the U.S. committed to a collaborative, international regime to control and phase out ozone-depleting substances (ODS), including chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

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Among the regulations established by U.S. EPA under Title VI is the "National Recycling and Emissions Reduction Program" (Section 608 of Title VI of the U.S. Clean Air Act Amendments (CAAA)). The U.S. EPA Section 608 regulations establish requirements for the safe handling of ODS and prohibit knowingly venting or releasing ODS into the atmosphere. As ODS are phased out in the United States, surplus ODS recovered from older equipment are being sent for destruction, often after being recycled, reclaimed, or stockpiled. Properly destroying surplus ODS prevents emissions into the atmosphere.

This report explores the state of ODS destruction in the United States (Part 1) and looks at the technologies used to destroy ODS throughout the world (Part 2). The objective of this report is to answer the following questions and related issues:

- What type and quantity of ODS are destroyed in the US and, as available, worldwide?
- How are ODS destroyed in the US and worldwide?
- What destruction criteria (e.g., regulations, standards, etc.) are employed?
- What are the potential costs and benefits to ODS destruction?
- What is the future potential for destruction of ODS in the US?

The report is organized as follows:

Part I: **ODS Destruction in the United States**

- **Section 1** provides a list of U.S. companies that destroy ODS and the destruction technology used and discusses the potential capacity of these facilities to destroy additional ODS
- **Section 2** summarizes the total quantities of ODS destroyed in the past based on questionnaires and reported data
- **Section 3** estimates the amounts of ODS that will be available for destruction in the future
- **Section 4** discusses the costs to destroy and transport ODS
- **Section 5** assesses whether U.S. destruction facilities meet Montreal Protocol criteria

Part II: ODS Destruction Abroad

- **Section 6** presents a list of countries with technologies for destroying ODS outside the United States

Appendix A presents detailed descriptions of destruction technologies

Appendix B discusses halon chemistry

Appendix C presents the ODS destruction data from the US Toxics Release Inventory

Appendix D presents data on ODS potentially recoverable at EOL and available for destruction

Appendix E presents the US regulatory requirements for ODS destruction facilities

Appendix F discusses the specific emission limits and performance testing requirements for hazardous waste combustors that destroy ODS in the US

PART I: ODS DESTRUCTION IN THE UNITED STATES

1. ODS Destruction Facilities

This section describes the known commercial ODS destruction facilities operating in the United States, including their location, technology, reported DRE, and capacity.

1.1 Known Destruction Facilities in the U.S.

In total, **approximately** 20 facilities were identified that accept ODS waste from outside sources for commercial destruction (EPA 2006c).[2]

In accordance with the 1990 Pollution Prevention Act, waste management activities, including the treatment and/or destruction of hazardous waste, are reported to the Toxics Release Inventory (TRI), a database established to provide communities with information about toxic chemical releases in accordance with the Emergency Planning and Community Right-to-Know Act of 1986.

Based on data submitted to TRI in 2003, over 60 companies that destroyed ODS hazardous waste were identified. Many of these facilities are chemical manufacturing plants that "incidentally" destroy ODS that is generated on site or used on site in a chemical production process.[3] EPA sent questionnaires to the 60 companies reporting ODS destruction under the TRI requesting further information.

The responses to the questionnaires, as well as additional internet and personal communication were used to determine which facilities accept commercially-generated ODS waste for disposal.

Example: Collecting and Destroying ODS in the U.S.

Types of ODS collected for reclamation or destruction: About half of the ODS received by one company is halon, while the remaining half is split between various types of refrigerants and solvents—about 80 percent of which is HCFC-22 (implying that in total, they receive about 40% HCFC-22).

Process for collecting used ODS: The majority of the refrigerants and solvents received by the company are mixtures; technicians typically mix different ODS into the same collection tank, unless a special effort is made to set aside valuable ODS, such as halons or CFC-12.

What is reclaimed vs. destroyed?: When the ODS is received, they conduct a number of tests to identify the types of ODS included and the level of contamination. If the mixture contains halons, CFC-12, HFC-134a, and/or HFC-227ea, those ODS are separated out of the mixture using distillation towers, and set aside for reclamation. Because all other ODS types, especially HCFC-22, still have a relatively low market value, reclamation is not economically practical, so these ODS are destroyed. Conversely, another company reclaims around 99.5 percent of the refrigerant supplied to them, including R-22.

How are ODS transported?: Before building their facility, the company sent its ODS waste to the a incineration destruction facility. To ship bulk ODS, they used pressure rated ISO tanks, which are generally rated up to 250 psi. They also have a few specialty ISO tanks which are rated to a higher pressure to hold halons. Although the incineration facility destroyed a small amount of halon, they no longer accept halons for destruction because of cost and equipment maintenance concerns.

Process for Destroying ODS: When ODS arrives at a destruction site, it is typically stored for a week to a month before it can be fed into the destruction unit. Several facilities provided information indicating that the average rate at which ODS can be fed into a unit is around 500 pounds per hour (as compared to the maximum waste feed rate at one facility of 42,410 pounds per hour). For a typical shipment of ODS (around 30,000 pounds), this would result in a total destruction time of about 60 hours.

[2] This estimate includes all facilities with reported destruction capabilities as of 2004, except those characterized as carrying out incidental creation or byproduct destruction. It should be noted that because some facilities may transship ODS materials received to another commercial destruction facility, the actual number of facilities destroying ODS could be less than 20. On the other hand, there may be other facilities that are regulatory permitted to accept ODS for destruction and capable of ODS destruction but that have not reported doing so.

[3] These facilities generally use fume/vapor incinerators or other types of air emissions control devices to destroy ODS.

Table 1 summarizes destruction facilities that accept commercially-generated ODS by location, technology type, and reported DRE. The facilities can be categorized as incinerators (including rotary kilns, fixed hearth, liquid injection, and gas/fume oxidation), cement kilns, lightweight aggregate kilns, sulfuric acid recovery units, and plasma arc units.[4] All commercial facilities listed, with the exception of one plasma arc unit, are permitted hazardous waste combustors (HWCs) under U.S. EPA's regulations in accordance with legislative provisions of the Resource Conservation and Recovery Act (RCRA). As a RCRA-permitted HWC a facility must meet all regulatory requirements discussed in Appendix E. The plasma arc facility has an operating permit from the Ohio EPA and has indicated that they are meeting all criteria established by TEAP when destroying ODS.

Table 1: Known Commercial ODS Destruction Facilities in the United States

Technology Used	Location	DRE (%)
Rotary Kiln Incinerator	Cincinnati, OH	NA
Cement Kiln (2 units)	Foreman, AR	NA
Rotary Kiln Incineration (2 units)	Deer Park, TX	99.99
Fluidized Bed Incinerator	Kimball, NE	99.9999
Rotary Kiln with Liquid Injection Unit Afterburner	Aragonite, UT	99.99
Cement Kiln	Hannibal, MO	99.9985
Cement Kilns (2 units)	Logansport, IN	99.996
Cement Kiln	Artesia, MS	99.99
Cement Kiln	Holly Hill, SC	99.99
Cement Kiln	Clarksville, MO	99.99
Cement Kiln	Fredonia, KS	99.9977
Cement Kiln (2 units)	Paulding, OH	NA
Plasma Arc	Bowling Green, OH	99.999999
Sulfuric Acid Recovery Furnace	Hammond, IN	99.99
Liquid Injection Incineration (2 units)	Baton Rouge, LA	99.99
Rotary Kiln Incineration with Thermal Oxidation Unit	Grafton, OH	99.99
Lightweight Aggregate Kiln (2 units)	Arvonia, VA	99.99
Rotary Kiln Incineration with Single Thermal Oxidation Unit (2 units) and Rotary Kiln Incineration with Secondary Combustion Chamber	El Dorado, AR	99.99
Cement Kiln	Midlothian, TX	99.99
Rotary Kiln Incineration	East Liverpool, OH	99.99997

Source: EPA (2002, 2006c), Arkansas DEQ (2002, 2006), Utah DEQ (2003), Illinois EPA (2003), Ohio EPA (2003, 2004), Virginia DEQ (2001), and ICF calls to industry conducted in 2002, 2005, and 2006.
NA = Not available.

In addition to those facilities that destroy ODS commercially, Table 6 lists destruction companies and/or facilities that destroyed ODS on site in 2003 and/or 2004, either as a by-product of fluorochemical manufacture or when it is used as raw material in a manufacturing process. The technologies used by many of these facilities are classified as air emissions control systems (e.g., fume/vapor incineration) and not as HWCs. Because these facilities are not receiving or combusting commercial waste, but only processing workplace or industrial process exhaust gas streams, they are not regulated as HWCs.

[4] A description of these destruction technologies is provided in Appendix A.

Table 2: Facilities that Destroy Byproduct or Raw Material ODS in the United States (Non-Commercial)

Location	Technology Used
Calvert City, KY	Liquid Injection Incineration
Leland, NC	Catalytic Oxidation
	Gas/Fume Oxidation
Belle, WV	Gas/Fume Oxidation
Gregory, TX	Gas/Fume Oxidation
Washington, WV	Thermal Incineration
Romulus, MI	Solvent Recycling Facility/Fume/Vapor Incineration
Ingleside, TX	Gas/Fume Oxidation
	Liquid Injection Incineration/Gas/Fume Oxidation (Unit #1)
	Liquid Injection Incineration/Gas/Fume Oxidation (Unit #2)
Wichita, KS	Gas/Fume Oxidation
Geismar, LA	Gas/Fume Oxidation
	Liquid Injection Incineration/ Gas/Fume Oxidation
La Porte, TX	Gas/Fume Oxidation (Unit #1)
	Gas/Fume Oxidation (Unit #2)
Deer Park, TX	Liquid Injection Incineration/ Gas/Fume Oxidation (Unit #1)
	Liquid Injection Incineration/ Gas/Fume Oxidation (Unit #2)
Lake Charles, LA	Liquid Injection Incineration/ Gas/Fume Oxidation (Unit #1)
	Liquid Injection Incineration/ Gas/Fume Oxidation (Unit #2)
Connersville, IN	Solvent recycling facility/ Fume/Vapor Incineration
East Palo Alto, CA	None
Chandler, AZ	Lacquer Thinner Recycling Facility / Fume/Vapor Incineration
East Chicago, IN	Oil/Solvent Recycling Facility/ Waste-Fired Boiler (Industrial Furnace)
Thorofare, NJ	Liquid Injection Incineration
St. Gabriel, LA	Gas/Fume Oxidation
Memphis, TN	Liquid Injection Incineration
Geismar, LA	Fume/Vapor Incinerator

1.2 Capacity of U.S. Destruction Facilities

RCRA-Permitted Commercial HWCs

The capacity for hazardous waste incineration at U.S. commercial HWC facilities varies greatly, from about 0.5 MT/hr to about 14 MT/hr. On an annual basis, total destruction capacity for a single facility can be upwards of 40,000 MT of material per year. However, this capacity does not translate directly into the potential capacity to destroy ODS because all facilities (with the exception of the plasma arc facility) process ODS as a small part of a much larger variety of hazardous wastes. The ODS destruction capacity of any one facility depends on the amount of other hazardous wastes being supplied to the facility at any given time and the operating conditions of the facility (including feed rate, flame temperature, fuel composition, oxygen content).

Other factors serve to limit the amount of ODS that commercial HWCs can accept for destruction. Apart from permit limits for maximum total feed rate of chlorine to the unit, discussed in Appendix E, commercial HWCs can only combust limited amounts of fluorinated and brominated compounds, due to the corrosive nature of the acid gases (HF and HBr) that result from their incineration. The production of acid gases, especially HF, requires expensive upgrades to the HWC unit in order to prevent damage to downstream equipment caused by corrosion. This equipment includes:

- upgraded bag material in the bag house;
- HF-resistant refractory lining and binder in the combustion chambers through the quench area; and
- specially-lined, corrosion-resistant, fiberglass-reinforced plastic (FRP) in the scrubbing system.

According to one industry representative, the total capital costs to install the necessary equipment can exceed $1 million. In addition, increased operations and maintenance costs generally follow such upgrades; therefore, operators of HWCs generally perform site-specific calculations to assess the maximum feed rates of fluorinated and brominated compounds they can accept without causing corrosion concerns.

Feed rates are also restricted because fluorinated and brominated compounds must be destroyed with an increased level of hydrogen to promote the formation of HF and HBr over F_2 and Br_2. During the destruction of halon, additional oxygen must also be present to prevent the halon from affecting the stability of the combustion flame, as halons by nature act as fire suppressants. All of these factors would serve to restrict the amount of ODS waste that facilities could feed into their HWCs at any given time (EPA 2006a).

In 2003, 3,657,026 metric tons (MT) of hazardous waste was destroyed in the U.S. (EPA 2003).[5] However, according to industry estimates, commercial HWCs are currently operating at only about 70% of total capacity (EPA 2006a). Assuming that these units can operate continually at full capacity, it can be estimated that an additional 156,730 MT of capacity can be made available for hazardous waste destruction. This suggests that **total U.S. destruction capacity was about 3.8 million metric tons** in 2003. However, this additional capacity cannot be directly translated into destruction capacity for ODS, as many facilities would have to make equipment upgrades to accept additional amounts of ODS for destruction, and the supply of ODS for destruction, or the current market for ODS destruction might not warrant the costs to make these changes.

Conversion of ODS into Useful Products

In order to explore alternatives to ODS destruction, the U.S. EPA has sponsored an investigation of the process of converting ODS to useful products (e.g., conversion of Halon 1211 and Halon 1301 to difluoroethylene). Research on this process has been conducted at the University of Newcastle, Australia, and other institutions. One recent study provided a design of a process for conversion of Halon 1211 and Halon 1301 to difluoroethylene (VDF), a feedstock for the production of polyvinylidene fluoride, commercially known as Viton®. Research indicates that these processes could be operated commercially at a profit as an alternative to ODS destruction. (AFRL 2006; Kennedy and Dlugogorski 2003).

The plasma arc unit is the only destruction facility in the U.S. currently dedicated to destroying ODS, including CFCs, HCFCs, and halons, but they have also investigated using the unit to destroy other wastes. The capacity of the plasma arc unit ranges from 295 to 318 MT per year of a 100% ODS feed, and they have indicated that additional units could be added to meet requirements for additional capacity.

Non-Commercial Facilities

Facilities that incidentally destroy ODS generally do not have the capacity, infrastructure, or permitting to accept ODS wastes generated offsite. Some of these facilities reported that they do accept offsite waste

[5] This includes hazardous waste that was destroyed by the following management methods: Incineration (H040), defined as "thermal destruction other than use as a fuel (includes any preparation prior to burning)"; Energy Recovery (H050), defined as "used as fuel (includes on-site fuel blending before energy recovery)"; and Fuel Blending (H061), defined as "waste generated either on site or received from offsite" according to U.S. EPA's National Biennial RCRA Hazardous Waste Report.

for destruction, but only wastes generated at other facilities operated by the same entity. ODS destruction units at these facilities may have additional capacity available to destroy ODS generated by other entities, but the facilities may not have adequate hazardous waste storage and handling infrastructure or the appropriate regulatory permits to do so.

Non-MACT Compliant Facilities

Non-MACT-compliant waste combustion facilities could also potentially be used to destroy ODS that are not categorized as RCRA hazardous wastes. (The description of Maximum Achievable Control Technology (MACT) regulatory standards is found below in Appendix E.) When the U.S. Clean Air Act Amendments (CAAA) regulatory standards called MACT were proposed for HWCs, a number of existing hazardous waste destruction facilities assessed the cost of upgrading their facilities in order to comply with the proposed MACT Standards and, based on that analysis, declined to pursue operating permits under the MACT Standards. These facilities are no longer regulated as HWCs and are no longer permitted to combust hazardous wastes generated outside the facility.

Under existing regulations, non-MACT compliant facilities could still pursue operating permits issued by a State, such as Ohio, to combust non-hazardous wastes, including ODS that are not categorized as hazardous wastes. Such facilities could also be permitted for use as fume/vapor incinerators (i.e., air emission control devices) to destroy chemical process byproducts generated on site. The number of such facilities that have acquired permits to combust non-hazardous waste and their potential capacity to accept non-hazardous waste ODS for destruction is unknown.

Non-Permitted Facilities

Another category of facilities that could potentially be used to destroy either hazardous waste ODS or non-hazardous waste ODS are combustion facilities that are similar in process to facilities that are currently destroying ODS (e.g., cement kilns, sulfuric acid furnaces) but that have never obtained permits to combust hazardous wastes and have never reported destruction of ODS. For example, there are more than 100 cement kilns in the U.S., only 13 of which appear on the list of ODS destruction facilities.

Cement kilns operate at kiln temperatures in excess of 2,000 °F in order to make cement clinker; cement kilns that are destroying ODS would not operate at significantly different kiln temperatures than cement kilns that are not destroying ODS, since the kiln temperature is inherent to the process of making cement clinker. Cement kilns and other combustion facilities that are similar in process to facilities that are currently destroying ODS could pursue the appropriate permits to combust hazardous waste and/or non-hazardous waste ODS, and thereby increase the ODS destruction capacity in the U.S. There are costs associated with pursuing such permits, including costs to modify the facility operating permits and the cost to conduct performance testing. A decision by a combustion facility to pursue the appropriate permits to combust non-hazardous waste ODS would involve significantly less cost than a decision to pursue the appropriate permits to combust hazardous waste ODS. Of the approximately 100 cement kilns in the United States, less than 20% are permitted to receive hazardous waste.

It should be noted that the Montreal Protocol did not approve cement kilns for halon destruction, due to insufficient evidence available to the TFDT to demonstrate that cement kilns used to destroy halons could meet the Montreal Protocol criteria. However, this does not mean that appropriate technologies could not be implemented to allow cement kilns to destroy halons effectively while meeting the necessary criteria.

2. Amount and Type of ODS Commercially Destroyed

Table 3 presents the total reported quantity of ODS (by type) destroyed in the U.S. for the years 2003 and 2004. Data is only presented for those facilities destroying ODS commercially that provided responses to questionnaires. Several other companies reported sending ODS to other off-site destruction facilities, but these data were not included due to their incomplete nature. Therefore, the data presented are *not inclusive of all commercial ODS destruction* that occurred in the U.S. in 2003 and 2004. Quantities of ODS destruction as reported in the TRI database, are presented in Appendix C.

Table 3: Reported Kilograms of ODS Destroyed by Type and Associated Emissions Avoided

ODS Type	2003	2004
Class I		
CFC-11	58,846	109,884
CFC-12	23,709	62,364
CFC-113	305,254	46,782
CFC-114	464	4,044
CFC-115	4,401	6,737
Halon 1301	3	6,487
Halon 2402	41	5,400
CFC-13	153	182
CFC-112	67,252	68,327
Carbon Tetrachloride	2,523,547	1,608,251
Methyl Chloroform	1,460,762	1,234,257
Methyl Bromide	36,815	63,334
CFC-11	58,846	109,884
Class II		
HCFC-123	40,171	923
HCFC-124	1,208	391
HCFC-131	944	21
HCFC-132b	760	1,109
HCFC-133a	1,621	2,433
HCFC-141b	6,039	16,217
HCFC-142b	236,024	5,893
HCFC-21	31,929	14,341
HCFC-22	87,922	5,890
HCFC-225ca	765	951
HCFC-225cb	1,094	1,248
HCFC-233	2,609	3,959
HCFC-253fb	342	1,268
Emissions Avoided (ODP-weighted metric tons)		
Total	3,366	2,318

Source: EPA (2006c).

Destruction of Imported ODS

ODS waste can be imported to the United States for commercial destruction. EPA developed a shipment-by-shipment petition process for importing used ODS in 40 CFR Part 82, including the import of ODS for the sole purpose of destruction. ODS importers are required to submit quarterly reports on the quantity of class I substances imported for in-house or second-party destruction. This information is then entered into EPA's Tracking System.

At this time, ODS import data from the ODS Tracking System is not readily available for review. However, there is a known case of ODS import for destruction. The ODS refrigerant waste (including CFCs, HCFCs, and HCFC blends) was imported into the United States due to the limited destruction capacity in Canada. As of July 2004, 27 tons of refrigerant waste were shipped to a fixed hearth incinerator in the U.S. for destruction.

Whether the ODS waste destroyed was from stockpiles or serviced/retired equipment is not known. Additional analysis is needed to determine the source of the ODS, including in-depth research on U.S. stockpiles.

3. Projections of Future Amounts of ODS for Destruction

This section presents projections of the amount of ODS refrigerant in the U.S. potentially available for destruction through 2050, based on three recovery scenarios (high, medium, low), and also makes a

comparison between the estimated potential quantities of ODS for destruction and the actual (known) amount of ODS destroyed in 2003 and 2004.

The U.S. EPA Vintaging Model (VM)[6] was used to develop all estimates presented. The VM estimates consumption and emissions from six industrial sectors: refrigeration and air-conditioning, foams, aerosols, solvents, fire extinguishing, and sterilization. The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The VM makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. For the purpose of projecting the use and emissions of chemicals into the future, the available information about probable evolutions of the end-use market is incorporated into the model.

3.1 ODS Potentially Available for Destruction in the United States

ODS may be made available for destruction from both equipment and product banks and existing stockpiles, as discussed below.

3.1.1 ODS Recoverable From Equipment and Products

ODS refrigerant from refrigeration/AC equipment is typically easier to recover, making the refrigeration/AC sector one of the largest accessible banks. In the fire protection sector, halons may also be recovered, including halon 1211, which is most commonly found in hand-held extinguishers, and halon 1301, commonly used in built-in flood systems (NFPA 2008).[7] In this section, only accessible ODS from the refrigeration/AC and fire protection sectors are estimated.

The amount of ODS potentially available for destruction in any given year will be a portion of the total inventory of ODS contained in equipment and products. ODS can be recovered during equipment servicing events and at equipment end-of-life (EOL). The amount of refrigerant recovered during servicing events is much less than that recovered at EOL and is not estimated in this analysis.[8]

The actual amount of refrigerant that is recovered at equipment EOL depends on a number of factors, including (a) the refrigerant charge remaining at time of disposal, (b) losses during the recovery process, and (c) residual refrigerant remaining in the system ("heel"). Because there is great uncertainty regarding the actual amount of refrigerant recoverable at EOL, this analysis considered three recovery scenarios:

- **High recovery**: assumes that 90% of the original equipment charge is recovered at EOL.
- **Medium recovery**: assumes that 50% of the original equipment charge is recovered at EOL.
- **Low recovery**: assumes that 10% of the original equipment charge is recovered at EOL.

These percentages were applied to the original charge of equipment estimated to be retired in each year to determine the upper, middle, and lower bound amounts of recovered refrigerant potentially available for

[6] *U.S. EPA Vintaging Model*. IO version 4.2 (10.07.08)

[7] However, because Halons have a more active reuse market, the amount that is available for destruction (particularly 1301) may be limited; this was, for example, the experience of the United Kingdom and Germany (MLF 2008).

[8] According to industry sources, refrigerant recovered during service events primarily originates from commercial and industrial equipment (Home Energy Center 2006, Airgas 2006). Refrigerant is rarely recovered during the servicing of small equipment in the residential sector because these units tend not to be overcharged or leaking (Home Energy Center 2006).

destruction (or reuse).[9] In other words, potential annual supply was determined by multiplying the number of units of equipment retired in a given year by the full charge size and the respective recovery rates.

Table 4 presents the upper, middle, and lower bound quantities of CFC and HCFC refrigerants and halons potentially available for destruction from retired equipment through 2050. Years 2003 and 2004 are presented to allow for comparison with actual data on U.S. ODS destroyed (in Section 3.2). Data on CFC, HCFC, and halon potentially recoverable by end use is provided in Appendix D.

Table 4: Quantity of ODS Potentially Recoverable from Retired Equipment at EOL and Available for Destruction (in MT, ODP-weighted MT, and GWP-weighted MT)

	Upper Bound			Middle Bound			Lower Bound		
Year	CFC	HCFC	Halon	CFC	HCFC	Halon	CFC	HCFC	Halon
METRIC TONS									
2003	13,888	21,486	1,679	7,716	11,937	933	1,543	2,387	187
2004	12,654	22,307	1,384	7,030	12,393	769	1,406	2,479	154
2005	9,131	23,457	1,180	5,073	13,032	656	1,015	2,606	131
2010	2,353	29,137	1,821	1,307	16,187	1,012	261	3,237	202
2015	2,265	39,297	1,087	1,258	21,831	604	252	4,366	121
2020	140	38,281	857	78	21,267	476	16	4,253	95
2025	0	10,904	695	0	6,058	386	0	1,212	77
2030	0	4,546	538	0	2,526	299	0	505	60
2035	0	1,194	435	0	663	242	0	133	48
2040	0	1,247	410	0	693	228	0	139	46
2045	0	1,320	406	0	733	225	0	147	45
2050	0	1,401	419	0	778	233	0	156	47
ODP-WEIGHTED METRIC TONS									
2003	13,228	1,178	12,887	7,349	654	7,159	1,470	131	1,432
2004	11,859	1,222	11,121	6,588	679	6,178	1,318	136	1,236
2005	8,351	1,286	9,896	4,639	714	5,498	928	143	1,100
2010	2,340	1,597	18,147	1,300	887	10,081	260	177	2,016
2015	2,251	2,154	9,633	1,251	1,197	5,352	250	239	1,070
2020	137	2,089	7,200	76	1,160	4,000	15	232	800
2025	0	581	5,776	0	323	3,209	0	65	642
2030	0	233	4,652	0	130	2,585	0	26	517
2035	0	48	3,901	0	27	2,167	0	5	433
2040	0	50	3,569	0	28	1,983	0	6	397
2045	0	53	3,305	0	29	1,836	0	6	367
2050	0	56	3,215	0	31	1,786	0	6	357
MILLONS OF METRIC TONS OF CARBON DIOXIDE EQUIVALENT									
2003	141	39	6	79	21	3	16	4	1
2004	127	40	5	71	22	3	14	4	1
2005	89	42	5	49	23	3	10	5	1
2010	21	52	10	11	29	5	2	6	1
2015	17	70	5	10	39	3	2	8	1
2020	1	67	3	1	37	2	0	7	0

[9] In practice, the amount of ODS recoverable from equipment at disposal varies by equipment and gas type, ranging from about 90% of the original charge recovered at disposal for large equipment such as chillers or cold storage to about 65% recovered for small equipment like small retail food units (e.g., display coolers and freezers), according to assumptions in the Vintaging Model.

	Upper Bound			Middle Bound			Lower Bound		
Year	CFC	HCFC	Halon	CFC	HCFC	Halon	CFC	HCFC	Halon
2025	0	18	3	0	10	2	0	2	0
2030	0	6	2	0	3	1	0	1	0
2035	0	0	2	0	0	1	0	0	0
2040	0	0	2	0	0	1	0	0	0
2045	0	0	2	0	0	1	0	0	0
2050	0	0	1	0	0	1	0	0	0

Source: *U.S. EPA Vintaging Model.* IO version 4.2 (10.07.08)

Figure 1 presents the breakdown of total CFCs available for destruction (in MT) by end use through 2050, using the 50% recovery rate estimate (middle bound). In 2010, CFCs potentially available for destruction are expected to come only from the retirement of equipment in three end uses: commercial refrigeration, industrial process refrigeration, and stationary AC. By 2025, no CFCs are expected to be available for recovery for destruction.

Figure 1. CFC Refrigerant Potentially Available for Destruction at EOL by End Use, using Middle Bound, from 2000-2050, in Metric Tons

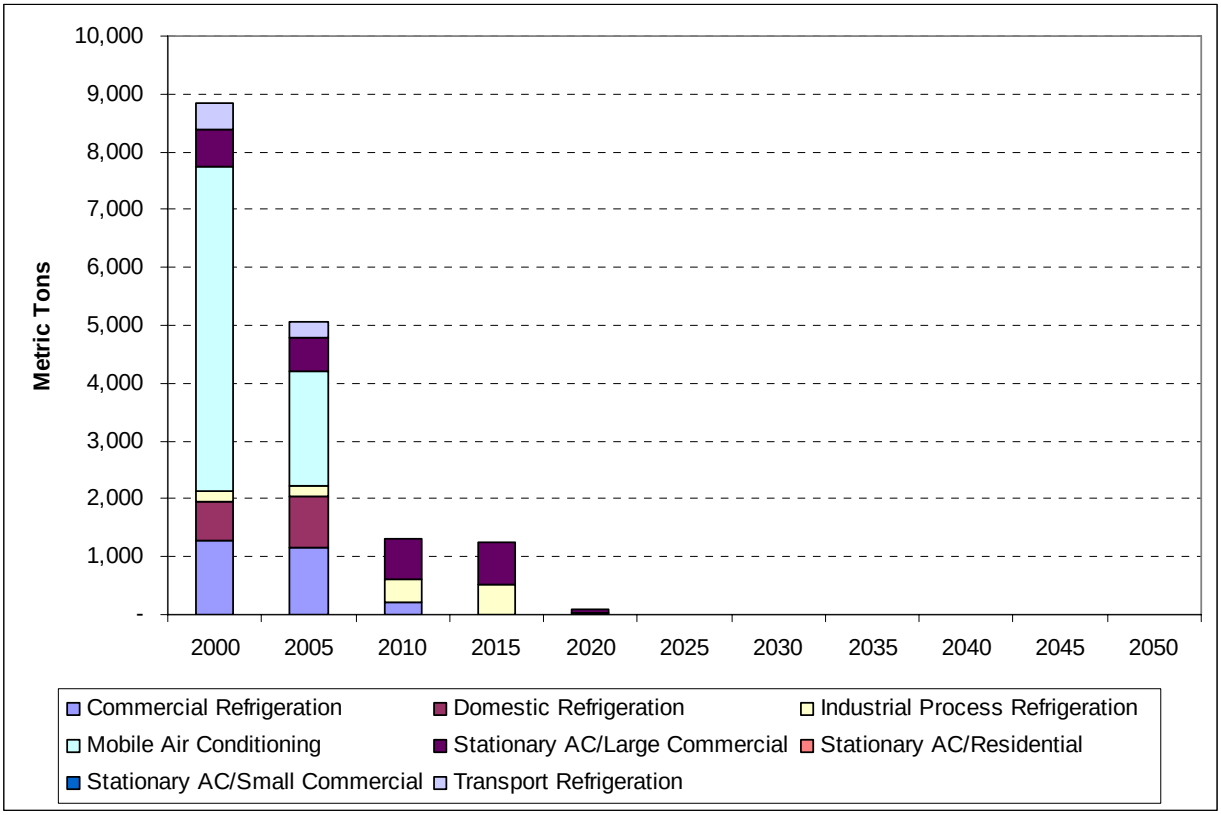
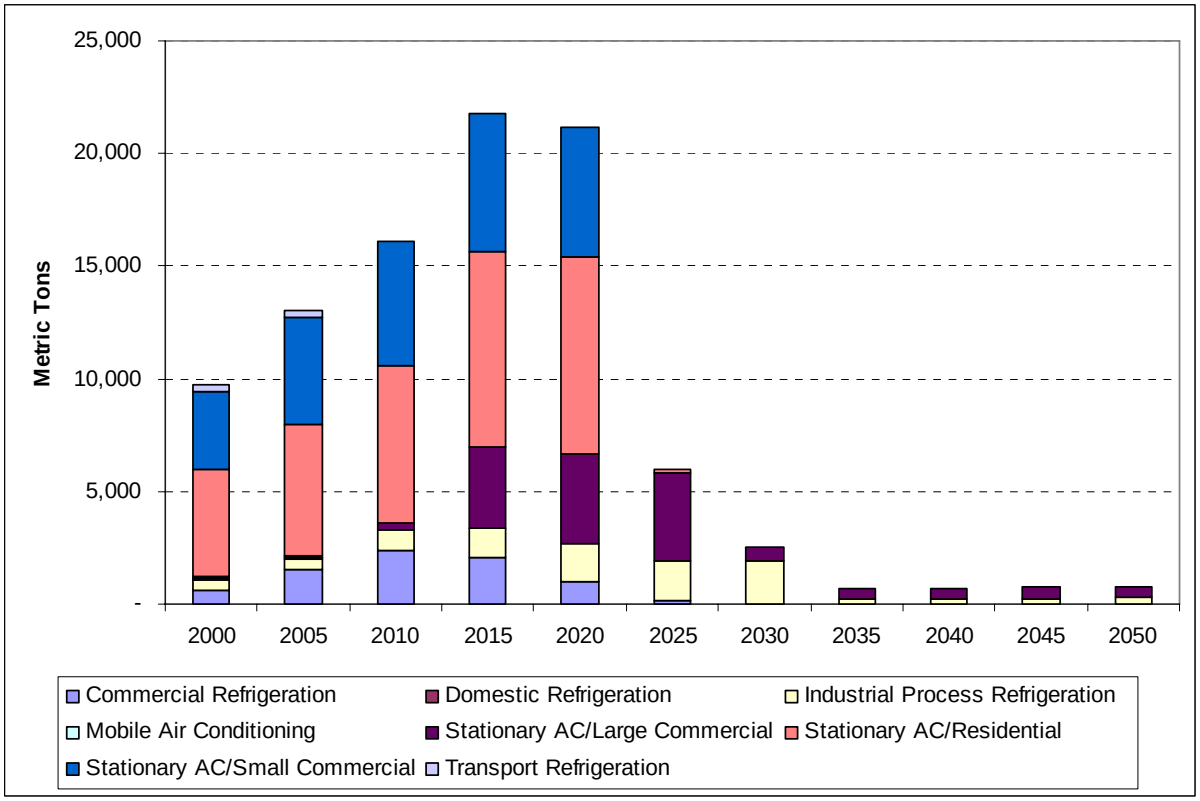


Figure 2 presents the breakdown of total HCFCs available for destruction (in MT) by end use through 2050, using the 50% recovery rate estimate (middle bound). In 2010, most of the HCFCs potentially available for destruction will come from the retirement of stationary AC equipment (residential and commercial), as well as some from industrial process refrigeration and commercial refrigeration. Stationary AC and industrial process refrigeration equipment types remain the dominant end uses from which HCFC refrigerants may be potentially available for destruction at equipment EOL through 2050.

Figure 2. HCFC Refrigerant Potentially Available for Destruction at EOL by End Use, using Middle Bound, from 2000-2050, in Metric Tons



In practice, the amount of ODS available for destruction would be slightly less than the recoverable amounts since some emissions occur between recovery and destruction. These emission points include (ICF 2006):

- Leakage during storage (0.025% to 3% per year depending on the storage container used);
- Emissions during the transfer of ODS into a pressurized container (1% to 3%);
- Emissions during transfer into a non-pressurized container for transportation (0.0004% to 5% depending on whether closed loop transfer/vapor line equalization and dry break couplings are used);
- Emissions from remaining heel (5% if heel is not evacuated; 0.014% if it is);
- Emissions during transfer of ODS into the destruction unit (1% to 3%);[10] and
- Destruction unit emissions (0.01% or less).

If best practices are employed, emissions can be as small as about 2% to 3%, and in those cases, the amount of ODS recoverable at EOL is considered a good approximation of the total amount of ODS potentially available for destruction.

[10] ICF (2006). This emission rate is based on the emission factor for transfers into pressurized containers since specific information on emissions resulting from transfer of ODS into a destruction unit was not available.

3.1.2 Availability of Stockpiles

The above estimates of ODS potentially available for destruction do not account for any stockpiles. Currently, there is little information available on current or future ODS stockpiles. Preliminary research indicates that the likelihood of ODS users having large stockpiles for which future planned use is not imminent is quite low because of the extra costs required to store surplus ODS and the current demand for most ODS. The most likely holders of surplus ODS are service companies that possess "empty" cylinders of ODS that were used to service equipment and still contain a "heel" of up to 5% of the original contents (Remtec 2006, ICF 1998). Further, there is potential to stockpile virgin ODS for future servicing needs (e.g., R-22 prior to 2020), but such stockpiling may be a risky business practice due to the costs associated with storing containers and the uncertainty associated with market trends. Industry experts do not expect future stockpiling of virgin ODS to be significant.

3.2 Comparison of Potential and Actual ODS Destruction Amounts (2003-2004)

Based on data provided through Section 114 questionnaire responses, a comparison can be made between actual (reported) quantities of CFCs/HCFCs destroyed in 2003 and 2004 and the VM projections of ODS potentially available for destruction in those years. Table 5 presents this comparison. It should be noted, however, that these quantities are not directly comparable because destruction was not a substantial practice for recovered ODS as of 2004.[11]

Table 5. Comparison of Actual ODS Destroyed vs. Potential ODS Available for Destruction in 2003 and 2004 (ODP Weighted MT)

Year	Actual (Reported) Amount of ODS Destroyed		Estimated Potential Amount of ODS Available for Destruction from Equipment Servicing and Retirement					
			Upper Bound		Middle Bound		Lower Bound	
	CFC	HCFC	CFC	HCFC	CFC	HCFC	CFC	HCFC
2003	397.3	24	13,228	1,178	7,349	654	1,470	131
2004	286.3	4	11,859	1,222	6,588	679	1,318	136

Source: EPA (2006c), and *U.S. EPA Vintaging Model.* IO version 4.2 (10.07.08)

As shown, the estimated potential amount of ODS available for destruction far exceeds actual ODS quantities destroyed This is not surprising given that recovered refrigerant can either be sent for destruction *or* for reclamation (for eventual reuse). According to one industry representative, the majority of recovered refrigerant in the U.S. (including HCFCs) is reclaimed, not destroyed (Airgas 2006).

4. Destruction and Transportation Costs

This section presents a discussion of reported costs to destroy and transport various types of ODS. Information was received through personal communication with destruction companies.

4.1 ODS Destruction Costs

The price of ODS destruction depends on the type of ODS, composition/purity, quantity, and the type of container the ODS is stored in. In general, costs are greater to destroy ODS delivered in smaller versus

[11] Further, the VM estimates of ODS potentially available for destruction consider only destruction of CFC and HCFC refrigerants contained in existing equipment, while the Section 114 data could include quantities of CFCs/HCFCs destroyed from other sources (e.g., stockpiles).

large containers (e.g., cylinders versus ISO tanks). Additionally, if a destruction facility has a large amount of refrigerant to destroy in a given week, prices may increase or the facility may even refuse to accept the waste (EPA 2002). In general, destruction costs in the U.S. range from $0.70 to $6.00 per pound (MLF 2008). Table 6 presents estimates of destruction costs for specific destruction technologies. These costs do not include transportation.

Table 6: U.S. Destruction Costs for Different Types of ODS

Destruction Technology	Destruction Cost Estimate (per pound)
Hazardous waste combustor	$1.00
Plasma arc	$5.00
Cement kiln	$0.70
General range in U.S.	$0.70 to $6.00

These estimates assume a 99.99% DRE for ODS destruction.
Source: MLF 2008.

It should be noted that the marginal cost of destroying ODS at a hazardous waste combustor is nearly negligible. These facilities destroy hazardous at high rates, with small amounts of ODS mixed in. For example, one facility in Arkansas is known to have a capacity of 55,000 lbs. per hour for mixed hazardous waste (MLF 2008). As a result, the addition of ODS makes very little difference in the combustor operating costs.

4.2 ODS Transportation Costs

Costs associated with transporting ODS to a destruction facility can vary greatly depending on distance and quantity, and whether the transport is within or beyond State borders. Bulk quantities in-State are the most economical to transport. According to one destruction company, a railcar carrying 190,000 pounds of waste-containing ODS costs approximately $800 for in-state shipments (about $0.42 per 100 pounds of ODS); these costs approximately double for out-of-state shipments. The same source estimates that a tank truck carrying 42,000 pounds of waste can cost as much as $700 for in-state shipments ($1.67 per 100 pounds); corresponding prices for out-of-state shipments were not provided by the source, as they are highly variable. Another company charges $4.00 per mile for transport in a pressurized ISO tanker, or the tanker can be leased (with a minimum 1-year lease) for $1,000 per month. Another destruction company reported the cost to transport waste refrigerant varies from $0.15 to $0.30 per pound, depending on the refrigerant type.

In addition, there are other costs associated with the management of used ODS. These costs are also associated with ODS being sent for destruction and should be factored into the total cost of destruction. ODS must be collected from service technicians who have removed the ODS from equipment, or from bulk customers. There also may be a need to buy-back unused refrigerant, if it has market value. Once ODS has been collected, it must be consolidated to a central location, and/or into larger containers - usually in a central storage area. Before being transported to a destruction facility, manifests must be completed and the contents of each tank identified through gas chromatography or other verifiable means.

5. Assessment of U.S. Technologies: Are They Meeting the Montreal Protocol Criteria?

At the Fifteenth Meeting of the Parties to the Protocol, Decision XV/9 was agreed upon, which updates the list of approved destruction technologies for ODS (Annex II), adopts a Code of Good Housekeeping for the transport, storage, and eventual destruction of ODS (Annex III), and reiterates the suggested substances that should be used when monitoring and declaring destruction technologies (Annex IV)

(UNEP 2003). This section assesses whether U.S. destruction facilities destroying ODS are meeting the recommended criteria established by the Parties. More detail on U.S regulatory requirements for ODS destruction and emissions associated with destruction by HWCs is provided in Appendix E and F, respectively.

5.1 Comparison of Montreal Protocol Criteria, MACT Standards, and Measured DREs and Emissions

The destruction efficiency criterion set by the Montreal Protocol ensures that only a maximum of 0.01% of the ODS feed to the unit is emitted. The air emissions criteria assure that the efficiency of air emissions systems used by facilities destroying ODS around the world suitably minimize the emissions of other harmful pollutants. To determine whether U.S. ODS destruction facilities are meeting the criteria established by the Montreal Protocol, Table 7 summarizes the Montreal Protocol criteria as well as the U.S. MACT standards for HWCs and compares them to (a) actual DRE and emissions values cited in the TEAP report for ODS destruction facilities, and (b) actual DRE and emissions values obtained from trial burns at hazardous waste combustors in the United States. All values that exceed the Montreal Protocol criteria are shown in bold text. Note that the trial burn data presented for each U.S. facility were collected from multiple test burns conducted over the course of several years with a number of different principal organic hazardous constituents (POHCs), including those listed in the "ODS Type" column. Not all tests measured all types of emissions or used all POHCs listed in the "ODS Type" column. Note also that the performance tests for the commercial HWCs shown in Table 7 were obtained from trial burn tests conducted in the 1990s, prior to the implementation of the current MACT standards. Some of the facilities that were tested have since implemented stricter emissions controls or implemented other operating modifications in order to comply with the new standards (if they are still operating). Therefore, the trial burn data are not fully representative of the current operating performance of the facilities. For this reason, performance test results for these facilities that are in excess of the MACT standards are not shown in the table.

Table 7: Comparison of Montreal Protocol Criteria for ODS Destruction Units and Hazardous Waste Combustor Subpart EEE Standards for Hazardous Waste Combustors with Reported Values*

Criteria/Combustor Type	DRE	PCDD/Fs	HCl/Cl_2	HF	HBr/Br_2	PM[a]	CO	ODS Type[b]
	(%)	(ng/m^3)	(mg/m^3)					
Criteria/Standard Limits								
Montreal Protocol Criteria								
All ODS Destruction Technologies	99.99	0.2	100	5	5	50	100	Any
HWC MACT Standard[c,d]								
Incinerators	99.99	0.2[e]	21[f]	NA	NA	30	87	NA
Cement Kilns	99.99	0.2[e]	81[g]	NA	NA	64	87	NA
Lightweight Aggregate Kilns	99.99	0.2[h]	403	NA	NA	57	87	NA
HCl Production Furnaces[i]	99.99	NA[j]	101[k]	NA	NA	NA[l]	87	NA
Reported Values								
TEAP[m]								
Reactor Cracking	>99.999	<0.010	<100	<0.1	NA	<10	<50	CFCs
Gas/Fume	>99.999[n]	0.032	3	0.5	2	22	40	CFCs/Halons
Rotary Kiln	>99.9999	0.03-0.15[o]	3	0.5	4	10	50	CFCs/Halons
Liquid Injection	>99.99	0.52[p]	<10	<1.0	NR	NR	<10	CFCs/Halons
Cement Kilns	>99.99	0.040	<1	0.4	NA	10	100	CFCs
Argon Plasma Arc	>99.9998	0.006	2	0.2	<4	<10	96	CFCs/Halons
ICRF Plasma	>99.99	0.012	5	2.4	2	5	5	CFCs/Halons
Microwave Plasma	>99.99	0.001	2	0.7	NA	11	4	CFCs
Nitrogen Plasma Arc	99.99	0.044	2	0.6	NA	9	26	CFCs

Criteria/Combustor Type	DRE	PCDD/Fs	HCl/ Cl_2	HF	HBr/ Br_2	PM[a]	CO	ODS Type[b]
	(%)	(ng/m^3)	(mg/m^3)					
Superheated Steam Reactor	>99.99	0.041	<3	<0.8	NA	NR	<11	CFCs
Gas Phase Catalytic Dehalogenation	>99.99	<0.010	1	<0.5	NA	2	13	CFCs
U.S. Hazardous Waste Combustors (Trail Burn Data)[q]								
Rotary Kiln (Chemical Waste Management)	99.99989 99.99973 99.9997	0.007 0.01 0.006	2 2 0	NA	NA	13 16 5	9 7 3	Carbon Tetrachloride
Fluidized Bed (Clean Harbors Environmental Services)	99.99922 99.9982 99.99928 99.99947	0.175 0.057	4 6 5 30	NA	NA	6 8 10 7	64 16 29 47	Carbon Tetrachloride Methyl Chloroform
Cement Kiln (ESSROC Cement)	99.99977 99.99525 99.9999 99.998 99.99943 99.9999	[q]	14 50	NA	NA	68 162	[q]	Carbon Tetrachloride Methyl Chloroform CFC-113
Sulfuric Acid Recovery Unit (Rhodia)	99.99986 99.99999 99.999997 99.99999	0.053 0.021	1 0.4 15 8	NA	NA	3 4 1 1	46 65 15	Carbon Tetrachloride Methyl Chloroform
Rotary Kiln (WTI)	99.9989 99.9963 [q]	0.067 0.019	0.6 6 3 1	NA	NA	6 6 4 7	39 74 42	Carbon Tetrachloride

Source: UNEP (2002), 70 FR 59410, 70 FR 59557, EPA (2006d)

[*] All values that exceed the Montreal Protocol criteria are shown in bold text.

NA = not applicable; NR = not reported.

[a] According to 71 FR 14665, the particulate matter (PM) MACT standards for incinerators, cement kilns, and liquid-fueled boilers are currently under review by EPA and may change.

[b] The ODS type listed for the data reported in the TEAP report represents the type of ODS shown to be destroyed by the technology. The ODS type listed for the trail burn data represents the ODS POHCs used during the trial burns.

[c] The MACT standard emissions limits for total chlorine were converted from ppmv to mg/m^3 using the molecular weight for HCl, as this is the most abundant constituent of total chlorine emissions.

[d] Sources may elect to comply with either the CO or an HC standard set at 10 ppmv for incinerators, 20 ppmv for lightweight aggregate kilns, 20 ppmv for cement kilns without a bypass, and 10 ppmv for cement kilns with a bypass/mid-kiln sampling system.

[e] Or 0.40 and temperature control < 400°F at air pollution control device inlet.

[f] Under the MACT standards, HWCs incinerators can also meet a risk-based standard for total chlorine emissions of 77 ppmv (~52 mg/m^3) (70 FR 59557).

[g] Under the MACT standards, HWCs cement kilns can also meet a risk-based standard for total chlorine emissions of 130 ppmv (~87 mg/m^3) (70 FR 59557).

[h] Or rapid quench < 400°F at kiln exit.

[i] Includes Sulfuric Acid Recovery Furnaces.

[j] CO, HC, and DRE standards are surrogates for the PCDD/PDCF standard for this source.

[k] Or 99.923% system removal efficiency for chlorine.

[l] Total chlorine standard is surrogate for particulate matter standard.

[m] The data presented in the TEAP report are measured data for specific facilities located around the world.

[n] Only 99.99% DRE reported for halon destruction.

[o] Some rotary kilns that reported emission for the TEAP analysis indicated PCDD/F emission greater than 0.3 ng/m^3.

[p] Although the particular data provided for the TEAP report did not meet the required levels for PCDD/F emissions, it is expected that liquid injection systems could meet the required levels with the proper pollution control mechanisms.

[q] Because the trial burn data presented was taken before the updated MACT standards were implemented, several of the measured values for DRE, PCDD/F, PM, and/or CO emissions are above the current allowable limits. These data points were not included as they are no longer applicable or allowable under the updated standards.

As shown in Table 7, the CAAA MACT Standards for HWCs are, for the most part, equivalent to or more stringent than the Montreal Protocol criteria. The following points should be taken into account when reviewing Table 7:

- Each permitted hazardous waste combustor is subject to facility-specific emission limits for each pollutant specified in the MACT standard, and can be subject to additional limits for other hazardous air pollutants (such as HF), as determined at the discretion of the state agency permit writer. These facility-specific emissions limits—which are contained in the Title V Operating Permit for the facility—may be based on evaluation of the types, quantities, and compositions of the hazardous wastes being destroyed, the location of the unit, and/or air emissions dispersion modeling. Therefore, the emission limits and performance standards in facilities' individual Title V Operating Permits can be more stringent than the minimums required under the MACT standards.
- Limits on emissions of other compounds, such as HBr, can be identified in the CAAA Title V Operating Permit for the HWC, based on site-specific human health and environmental risk assessments (SSRA). The need for an SSRA is evaluated by the permitting agency on a case-by-case basis in accordance with EPA SSRA policy, and could be required by the presence of any conditions that the agency determines could lead to increased human health or environmental risk, such as changes in the types, quantities, and characteristics of the wastes accepted for destruction. For example, if an existing HWC facility wishes to accept quantities of fluorinated or brominated ODS for destruction, but the facility had not previously been evaluated or permitted with respect to combustion of such waste, then the RCRA Part B permit and Title V Operating Permit for that facility could be reevaluated by the state permitting agency in order to ensure that the facility is permitted to receive such waste (i.e., that it is designed and operated to properly combust fluorinated or brominated ODS).
- Hazardous waste combustors generally operate well below their permitted emission levels because any excursion beyond the limits may result in a fine or other regulatory enforcement action. Also, as discussed above, operation of the unit outside of its permit limits for monitored parameters (e.g., combustion temperature) could initiate an automatic waste feed cutoff and shutdown of the unit.
- U.S.-based hazardous waste combustors are highly regulated entities, subject to regulation under both the CAA and RCRA and associated state statutes and regulations; conversely, the Montreal Protocol criteria were established for facilities world-wide, many of which are not subject to any regulations and may not employ any air emissions control systems. Also, hazardous waste combustors in the U.S. have been subjected to SSRAs that demonstrate on a facility-specific basis that air emissions from those facilities do not pose a significant risk to human health and the environment. In other words, the Montreal Protocol criteria are designed as generic standards applicable to ODS destruction facilities, while the CAAA MACT standards and associated Title V Operating Permit limits for HWCs operating in the U.S. establish highly individualized, site-specific emission limits and associated monitoring, reporting, and recordkeeping requirements.
- Even before the stricter MACT standards were implemented, which is when the trial burn data presented in Table 7 was taken, most commercial facilities for which data are available were already exceeding the minimum DRE of 99.99 and meeting air emissions limits corresponding to the current MACT standards.

5.2 Conclusions for CFC/HCFC Destruction

DRE

All known commercial ODS destruction facilities operating in the U.S. (with the exception of Remtec)[12] are permitted hazardous waste combustor facilities; therefore, they are required to meet the HWC MACT standards for DRE and emissions of dioxins/furans, particulate matter, total chlorine (HCl and Cl_2), and CO when destroying ODS that are also listed hazardous wastes, including most CFCs. Additionally, because HCFCs are easier to destroy than CFCs, these standards will be met for HCFC destruction as well (UNEP 2002).

Air Emissions

The HWC MACT standards for HWCs are at or below the Montreal Protocol criteria for air emissions of HCl/Cl_2, particulate matter, carbon monoxide, and PCDDs/PCDFs, with few exceptions. The particulate emission limits in the MACT standards for cement kilns and lightweight aggregate kilns exceed the Montreal Protocol criteria, as do the total chlorine MACT standard for lightweight aggregate kilns. Note that the particulate matter MACT standards for cement kilns and lightweight aggregate kilns are currently being reevaluated by U.S. EPA. Also, while the total chlorine MACT standard for lightweight aggregate kilns is approximately four times the Montreal Protocol criteria (and the standards for PM are slightly above the Montreal Protocol criteria), it is likely that facilities will generally operate well below this level and any emissions will be limited by permit conditions to levels below those that would present a risk to human and/or environmental health, as discussed in the bullet points above.[13]

Also, the incineration of fluorinated substances would result in the production of HF, a hazardous air pollutant that is not addressed in the HWC MACT standards. However, if fluorinated compounds are being combusted and significant emissions of HF are expected from a hazardous waste combustor, it is expected that state permit writers would establish site-specific feed rate limits for total fluorine and site-specific emissions limits for HF, and that acid gas control systems in place to control HCl emissions will also be designed and operated to control HF emissions.

5.3 Conclusions for Halon Destruction

DRE

Because halons are not listed as RCRA-hazardous wastes, permitted hazardous waste combustors are not required to meet the MACT standards for their destruction, and therefore, it cannot be guaranteed with certainty that the minimum DRE is being met for halon destruction in hazardous waste combustors. Indeed, the TEAP only recommended technologies for halon destruction based on actual trials of ODS destruction units using halons—i.e., a technology deemed acceptable to destroy CFCs was not necessarily also deemed acceptable to destroy halons if that technology was not actually tested using halons. Thus, the only way to be completely certain that the DRE is being met for halon destruction in hazardous waste combustors would be for U.S. facilities to conduct performance testing using halons as POHCs to directly determine the DRE achieved for each of these compounds.

However, based on available performance data and the chemical properties of halons, one can establish a *degree of confidence that the 99.99% DRE is in fact being met for halons*, which would suggest that testing of each non-hazardous waste ODS is not needed. In particular:

[12] As described above, Remtec has an operating permit from the Ohio EPA.

[13] In general, state agencies can require a SSRA in the event that the agency concludes that emissions from a hazardous waste combustor may pose a significant risk to human health or the environment.

- *Findings based on existing trial burn data:* While performance data for halon destruction in U.S. HWCs could not be found, performance data for other ODS—including carbon tetrachloride, CFC-11, and CFC-113—demonstrate that conventional incineration technologies (e.g., rotary kilns) have in practice achieved DREs far greater than the 99.99% standard (on the order of 99.9999%), even when destroying chlorinated organic compounds that have very high thermal stability (e.g., monochlorobenzene). The fact that HWCs have demonstrated performance greater than the minimum DRE standard provides a substantial margin of operation with respect to the incineration of halons. Unless the thermal stability of halons is far greater than that of monochlorobenzene and other difficult to incinerate compounds, it would be expected that HWCs that could incinerate these other compounds to a DRE of 99.9999% could also incinerate halons to a DRE of at least 99.99%. Furthermore, similar international technologies analyzed in the TEAP report were shown to meet the minimum DRE when destroying both CFCs and halons.

Air Emissions from the Destruction of Brominated Compounds

In the destruction of halons and other brominated compounds, Br_2 tends to form over HBr when reducing conditions are present, and Br_2 is much harder to remove from exhaust gas than HBr (UNEP 2002). In combustion systems burning chlorinated and brominated compounds, the ratio of Br_2 to HBr is much higher than the ratio of Cl_2 to HCl—generally 10% Cl_2 and 90% HCl (see Table 7 on trial burn data for ODS destruction in HWCs) (Lemieux, et al. 1996). Theoretical calculations indicate that there would be more Br_2 formed than Cl_2 in combustion systems where chlorine and bromine are present in equal amounts, which is attributed to the lower oxidation potential of bromine than chlorine (Sonderstrom and Marklund 2002). If there is the potential for elemental Br_2 to form in the combustion system, these emissions can be mitigated by introducing a reducing agent into the combustion unit air emission control system (Vehlow, et al. 2003). By ensuring that Br_2 generation is reduced, emissions of Br_2 would thereby be minimized.

- *Findings based on halon chemistry:* The incinerability of halons can be estimated based on their chemical composition, and it is expected that halons would react relatively easily at the very high temperatures at which HWCs operate (see Appendix D for more information). Indeed, the Material Safety Data Sheets (MSDS) for halons indicate that Halon 1301 decomposes at fire temperatures above 1,562 °F, and that Halon 1211 can decompose at fire temperatures above 900 °F.[14] As these temperatures are lower than the combustion temperatures at which HWCs generally operate (i.e., above 1,800 °F),[15] it is expected that halons will be easily destroyed to the minimum DRE in U.S. HWCs.

Air Emissions

The incineration of halons and other brominated compounds (e.g., methyl bromide) would result in the release of an additional acid gas, HBr, that is not formed during the incineration of CFCs/HCFCs and for which there is no MACT standard. Again, it is expected that if brominated compounds such as halons are being combusted and significant emissions of HBr are expected, state permit writers would establish site-specific feed rate limits for total bromine and site-specific emissions limits for HBr, and that the air emissions control systems in place to control HCl emissions will also be designed and operated to control HBr emissions.[16]

[14] See <www.ansul.com/AnsulGetDoc.asp?FileID=13402> for MSDS for Halon 1211, and <http://msds.dupont.com/msds/pdf/EN/PEN_09004a2f8000768d.pdf> for MSDS for Halon 1301.

[15] According to the U.S. performance test data available, the lowest afterburner (secondary combustion chamber) operating temperature is 1,610 °F, which is higher than the threshold temperatures needed to decompose both Halon 1211 and 1301.

[16] Similarly, it is expected that measures will be taken to prevent the formation of Br_2 instead of HBr.

PART II: ODS Destruction Abroad

6. Destruction Facilities Overseas

As of 2008, about 147 destruction facilities were known to operate in 25 countries around the world, including Argentina, Australia, Austria, Brazil, Canada, Estonia, Finland, France, Germany, Indonesia, Japan, Spain, Sweden, the United Kingdom, and Venezuela (MLF 2008).

Table 8 lists countries other than the U.S. with destruction facilities, as well as the type of technologies they use, their capacities to destroy ODS, destruction costs in US dollars, and DREs. Those facilities listed as commercial destruction facilities on UNEP's Division of Technology, Industry, and Economics OzonAction Branch website as of 2006 are identified in bold text (UNEP 2006). Data on the amounts of ODS destroyed in past years outside of the U.S. were not readily available.

Table 8: ODS Destruction Companies Outside the U.S.

Country	Number of Known ODS Destruction Facilities in Operation	Technologies Utilized	ODS Destruction Capacity (except where indicated)	Destruction Costs (US$)	DRE (%)
1. Argentina	NA	NA	NA	NA	NA
2. Australia	1	Argon Plasma Arc	600 MT/year	$7/kg	99.9998
3. Austria	1	NA	NA	NA	NA
4. Belgium	2	Rotary Kiln	NA	NA	NA
5. Brazil	NA	Rotary Kiln	NA	NA	NA
6. Canada	1	Rotary Kiln	5 kg/hour (~40 MT/year, assuming 6,000 hours of operation/year)	$12/kg	99.9999
7. Czech Republic	1	Rotary Kiln	40 MT/year	NA	NA
8. Denmark	4	NA	NA	NA	NA
9. Estonia	1	NA	NA	NA	NA
10. Finland	1	Rotary Kiln	545 MT/year	NA	NA
11. France	2	NA	NA	NA	NA
12. Germany	6	▪ Hazardous Waste Incinerator ▪ Reactor Cracking	1,600 MT/year[b] (reactor cracking)	NA	NA
13. Hungary	5	▪ Rotary Kiln ▪ Liquid Injection Incineration	▪ 13 MT/year (liquid injection incineration) ▪ 75 MT/year[a] (rotary kiln)	NA	NA
14. Indonesia	1	Cement kiln	100 kg/hour (~ 600 MT/yr, assuming 6,000 hours of operation/year)	NA	NA
15. Italy	12	NA	NA	NA	NA

Country	Number of Known ODS Destruction Facilities in Operation	Technologies Utilized	ODS Destruction Capacity (except where indicated)	Destruction Costs (US$)	DRE (%)
16. Japan	80	▪ Cement Kilns/Lime Rotary Kilns (7) ▪ Nitrogen Plasma Arc (8) ▪ Rotary Kiln Incineration/ Municipal Solid Waste Incinerators (24) ▪ Liquid Injection Incineration (7) ▪ Microwave Plasma (5) ▪ Inductively Coupled Radio Frequency Plasma (1) ▪ Gas-Phase Catalytic Dehalogenation (1) ▪ Superheated Steam Reactors (25) ▪ Solid-Phase Alkaline Reactor (1) ▪ Electric Furnace (1)	▪ 36 MT/yr (one catalytic facility) ▪ 2,600 MT/year[b] (one incinerator)	▪ Rotary kilns: $4/kg ▪ Superheated steam: $5/kg ▪ Plasma arc: $9/kg ▪ Reactor cracking: $4-6/kg ▪ Gas Phase Catalytic Dehalogenation: $5-7/kg	▪ Cement Kilns: 99.99 ▪ Inductively Coupled Radio Frequency Plasma: >99.99 ▪ Liquid Injection Incineration: >99.99 ▪ Microwave Plasma: >99.99 ▪ Rotary Kiln Incineration: 99.75
17. Netherlands	6	NA	NA	NA	NA
18. Poland	1	NA	NA	NA	NA
19. Slovakia	1	NA	NA	NA	NA
20. Spain	1	NA	NA	NA	NA
21. Sweden	4	Air Plasma, among others	100 MT/year (air plasma)	NA	Air plasma: >99.999
22. Switzerland	> 4	Rotary Kiln, among others	▪ 910 MT/year[b] (rotary kiln) ▪ > 320 MT/year (others)	NA	NA
23. United Kingdom	2	High-Temperature Incineration	NA	NA	NA
24. Venezuela	NA	NA	NA	NA	NA

NA= Not available.

[a] Number represents approximate ODS destruction capacity based on known overall plant capacity and typical ODS feed rates for rotary kilns.

[b] Capacity is not specific to ODS; value shown refers to capacity for all hazardous wastes and/or other types of wastes.

Source: MLF 2008, UNEP (2002), UNEP (2006), EPA (2002), Scanarc Plasma Technologies AB (2005), Earth Tech (2005), DASCEM Pty. Ltd. (2003), Ekokem (2006).

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Appendix A: Description of ODS Destruction Technologies

This section provides brief descriptions of each of the ODS destruction technologies found environmentally acceptable by the TEAP Destruction Taskforce. Three additional technologies not evaluated by the TEAP Task Force are also described, which are believed to be suitable for ODS destruction and are known to be in use.

Incineration Technologies

Incineration technologies utilize "a controlled flame to destroy ODS in an engineered device" (UNEP 2002: 42). There are seven different types of incinerators in use in the United States and abroad, as described below.

Reactor Cracking

CFCs and HCFCs (as well as HFCs) are broken down, or "cracked," into HF, H_2O, HCl, CO_2, and Cl_2 in a 2,000°C reaction chamber by the reactor cracking process. After to products are cracked, they are moved to the absorber for cooling. The entire process results in waste gases consisting mainly of CO_2, O_2, water vapor, and technical grade quality HF and HCl. The reactor cracking process results in few emissions due to the fact that hydrogen and oxygen are used as the fuel and oxidant, which results in a reduced volume of flue gas. The reactor cracking process is only designed to destroy fluorocarbons and cannot destroy foams or halons (UNEP 2002; HUG Engineering 2004).

Hoechst AG originally patented the reactor cracking process in 1986. SolvayFluor, a fluorocarbon manufacturing company, obtained Hoechst's fluorocarbon business and the reactor cracking destruction facility near Frankfurt, Germany in 1996. While the facility is mainly used to treat waste gas from the production of HCFCs and HFCs, SolvayFluor has also offered CFC destruction services in the past (UNEP 2002).

Gas/Fume Incineration

The gas/fume incineration process destroys CFCs, HCFCs, halons, and other wastes in a heat-resistant combustion chamber using fume steam at temperatures around 1,000°C. An external fuel such as natural gas or fuel oil is used to heat the steam (UNEP 2002). There are three common types of fume incinerators, including direct flame, recuperative, and regenerative, with direct flame incinerators being the most common type of gas/fume incinerator (EPA 2002).

Research conducted in 2000 indicated that Degussa-Huls Corporation operated a gas/fume incinerator to destroy carbon tetrachloride in the U.S. (EPA 2002). Outside the U.S., the fluorochemicals production company Ineos Fluor in Japan (previously known as ICI-Teijin Fluorochemicals Co., Ltd.) uses gas/fume incineration to destroy ODS. In general, most gas/fume incinerators are associated with fluorochemical production plants which do not offer destruction services to outside parties (UNEP 2002, Ineos Fluor 2005).

Rotary Kiln Incineration

Rotary kilns utilize a rotating cylinder to destroy hazardous wastes such as CFCs, halons, other ODS, and ODS-containing foams. The cylinder is set at an incline to allow the ash/molten slag to fall out. The afterburner uses temperatures around 1,000°C to ensure the breakdown of all the exhaust gases. Rotary kiln incinerators are not specifically designed to destroy ODS, so the feed must be regulated to prevent an excess of fluorine from harming the equipment (UNEP 2002; USACE 2002).

Rotary kiln incineration is the most common technology used to commercially destroy ODS in the United States, used by the following companies (among others):[17] (EPA 2002, 2006a)

- Teris LLC (formerly ENSCO, El Dorado, AR)
- Von Roll WTI (East Liverpool, OH)
- Clean Harbors Environmental Services, Inc. (Deer Park, TX and Aragonite, UT)
- Ross Incineration Services, Inc. (Grafton, OH)
- Veolia Environmental Services (formerly Onyx, Sauget, IL)

Outside the U.S., rotary kilns are used to destroy ODS by: (EPA 2002; UNEP 2002; UNEP 2006)

- SPOVO Ostrava s.r.o. (Czech Republic)
- INDAVER N.V. (Belgium)
- TdB Incineração Ltda (Brazil)
- Dowa Clean Technological Service (Japan)
- Ems-Dottikon AG (Switzerland)
- Service Industriel de Genève (Switzerland)
- Valorec Services AG (Switzerland)
- Cleanaway Ltd. (United Kingdom)
- Ekokem Oy Ab (Finland)
- Onyx Magyarország Ltd. (Hungary)
- Earth Tech Canada Inc., Swann Hills Treatment Centre (Canada)
- Sensor Environmental Services Ltd (Canada).

Liquid Injection Incineration

Liquid injection incinerators inject either liquid or vapor wastes into a chamber, where they are broken down into fine droplets, converted into a gas, and then combusted (UNEP 2002, USACE 2002). These types of incinerators are most typically used to destroy wastes such as oils, solvents, and wastewater at manufacturing sites.

Three U.S. companies, Teris (El Dorado, AR), Clean Harbors Environmental Services, Inc. (Aragonite, UT), and Von Roll WTI (East Liverpool, OH) are known to use liquid injection incinerators for commercial ODS destruction (EPA 2002 and 2006). These units are operated in conjunction with rotary kiln incinerators. Rhodia operates a sulfuric acid recovery furnace, which is similar to liquid injection incineration, in Baton Rouge, LA, that burns hazardous waste including ODS for energy recovery. Additionally, an Onyx subsidiary (Sarp Industries) facility in Hungary and Asahi Glass Company's Chiba plant in Japan use liquid injection incineration to destroy ODS (UNEP 2002).

Cement Kilns

Cement kilns are primarily used to produce clinker, which is then combined with calcium silica, alumina, iron, and other materials to make cement. Due to the intense heat of a cement kiln (up to 1,500°C), some cement kilns are also used to destroy organic compounds, such as ODS. However, the fluorine and chlorine content of the raw material fed into the kiln must be monitored and controlled in order not to affect the quality of the clinker. Cement kilns consist of tilted, rotating cylinders that are heated on one end. The raw material is fed into the higher, cooler end of the kiln and falls down towards the heated end. The heated gases used to convert the raw materials into clinker rise up the cylinder and are emitted out of the higher end of the kiln after passing though a pollution control device that removes the particulate matter in the gases (UNEP 2002; Richardson 1995; CKRC 2004).

[17] Arkema (formerly Total Petrochemicals/Atofina) and Ciba Specialty Chemicals Corporation operate rotary kilns but do not offer commercial destruction for outside parties (Webbolt 2006, Alabama Department of Environmental Management 2006).

Cement kilns are widely used throughout the world to destroy ODS. In the U.S., Ash Grove Cement (Foreman, AR), Holcim (Artesia, MS; and Holly Hill, SC), LaFarge (Fredonia, KS; and Paulding, OH) Continental Cement (Hannibal, MO), Texas Industries (Midlothian, TX), and ESSROC Cement (Logansport, IN) uses cement kilns to destroy ODS, as does Taiheiyo Cement Corporation in Japan, (EPA 2002 and 2006, UNEP 2002). A cement kiln in Indonesia has also been retrofitted to accept ODS, with the help of the Japanese Ministry of Environment (Japan MOE 2008).

Internally Circulated Fluidized Bed (ICFB) Incineration

An ICFB incinerator consists of a vertical chamber with a bed of a heated, inert material such as sand or wood chips on the perforated bottom. Air is blown up through bottom of the chamber, creating a fluidized environment which heats up the wastes and breaks them down. When ODS are destroyed, the resultant HCl and HF are neutralized with calcium carbonate, which is added to the incinerator (EPA 2002; Taboas 2004).

ICFB incinerators are typically utilized to destroy sewage sludge, but Clean Harbors Environmental Services, Inc.(Kimball, NE) reported the use of a fluidized bed incinerator to destroy ODS (EPA 2006b).

Fixed Hearth Incinerator

Fixed hearth incinerators function similarly to rotary kiln incinerators but utilize fixed combustion chambers to destroy liquid wastes at temperatures ranging from 1,400-1,800°F. Solid wastes are placed in the primary combustion chamber where they are burned; the residue ash is removed from the primary chamber, and the by-product gases move into the secondary combustion chamber for further destruction. While fixed hearth incinerators are typically utilized to incinerate sewage sludge, medical wastes, and pathological waste, they can also be used to destroy ODS (EPA 2002; Bungay 1994).

Veolia Environmental Services operates the only known fixed hearth incinerators, located in Sauget, IL and Port Arthur, TX, used to destroy ODS in the United States. Based on the usual function of fixed hearth incinerators, it is likely that Veolia is destroying ODS as part of other wastes and not pure ODS waste (EPA 2002).

Plasma Technologies

Plasma technologies utilize plasma, which produces intense heat, to destroy ODS. Plasma is created when a gas interacts with an electric arc or magnetic field in an inert atmosphere (e.g., argon) at temperatures ranging from 4,726ºC to 19,727ºC and is subsequently ionized. Plasma destruction units are generally designed to be relatively small, compact, and transportable. They consume a large amount of energy in order to generate the plasma, but tend to have very high destruction efficiencies and low gas emissions (EPA 2002; UNEP 2002). Five different types of plasma technologies are described below.

Argon Plasma Arc

Argon plasma arc technology uses the patented PLASCON™ torch is used to created a 10,000ºC plasma arc in the presence of argon to destroy ODS. The ODS are almost instantaneously broken down through a heat-degradation process called pyrolysis, during which the molecules are broken down into their constituent atoms and ions. The cause the ODS to be converted into an ionized gas, which then moved into a reaction chamber or flight tube, located below the PLASCON™ torch, in order to be cooled to below 100 ºC with water. The final solid and liquid by-products of the process are halide salts and water, which can be released into the municipal sewage system. The final gaseous by-products include carbon dioxide and argon, which are both released into the atmosphere (DASCEM 2003).

The PLASCON™ torch was jointly developed by SRL Plasma Ltd. and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. In Australia, the Department of Administrative Services Centre for Environmental Management (DASCEM), which currently manages the Australian National Halon Bank, uses argon plasma arc technology to destroy both halons and CFCs. DASCEM Europe also operates a PLASCON™ unit in Peterlee, County Durham, United Kingdom, which is being used to destroy the remaining halon in the EU (UNEP 2002). In 2006, Remtec International began destroying ODS in the first plasma arc facility located in the U.S., in Bowling Green, KY This facility is meeting the Montreal Protocol criteria and is achieving a DRE of 99.99999% to 99.999999% (Remtec 2006).

Nitrogen Plasma Arc

Similar to argon plasma arc technology, nitrogen plasma arc technology utilizes nitrogen plasma created by a plasma torch to break down liquefied fluorocarbon gases into CO, HF, and HCl. The CO is then combined with air to form CO_2 and HCl, and HF that are absorbed by a calcium hydroxide solution (UNEP 2002).

The nitrogen plasma arc destruction process was developed in Japan by Gunma University, ShinMaywa Auto Engineering, and Daihen Corporation. Currently ShinMaywa Auto Engineering sells the commercial systems, and there are five such units known to be commercially destroying ODS in Japan. Because of their compact size (9 m x 4.25 m), these units can be used as mobile destruction facilities (UNEP 2002).

Inductively Coupled Radio Frequency Plasma (ICRF)

ICRF plasma technology uses 10,000ºC plasma created using an inductively coupled radio frequency torch to destroy ODS. Gaseous ODS and steam are placed into the destruction unit through the plasma torch, heated, and then moved into a reactor chamber where the gases are broken down. The gases are then cooled and cleaned with a caustic solution to remove the acid gases (UNEP 2002).

A consortium of stakeholders known as the Ministry of International Trade and Industry (MITI) operates an ICRF plant in Ichikawa City, Japan (UNEP 2002). This is the only ICRF plasma destruction facility known to be in operation in the world.

Microwave Plasma

Microwave plasma technology uses 6,000K plus plasma, which is created using argon and microwave energy, to break down CFCs into HCl, HF, CO and CO_2. The final by products of the destruction process that are released into the atmosphere consist only of halide salts and CO_2, as the acid gases are removed by a scrubber and the CO is combusted with air in order to convert it to CO_2 (UNEP 2002).

The microwave plasma process was developed by Mitsubishi Heavy Industries, Ltd. of Japan, which has been commercially destroying CFCs since 2000 (UNEP 2002).

Air Plasma

Air plasma technology destroys CFC and HCFCs by injecting them into a reaction chamber filled with air, LPG, and water. The air is heated to about 1,300ºC in a plasma generator, and the CFCs and HCFCs are broken down into H_2, H_2O, CO, CO_2, HCl, and HF. These resulting gases are cooled by water injection once they leave the reaction chamber and scrubbed in a spray tower. The acids are washed out of the gases as calcium chloride and fluorspar by adding calcium hydroxide to the mixture. The gas is washed a second time in a packed bed to ensure that all acids are removed.

The gas is released through a stack after passing through a wet electrostatic precipitator, the fluorspar is removed as sludge in a settling tank, and the calcium chloride solution is either used for dust reduction on gravel roads or is disposed (ScanArc Plasma Technologies 2005a).

ScanArc Plasma Technologies operates an experimental air plasma destruction facility in Sweden that destroys CFC-11, CFC-12, and HCFC-22 at a rate of about 300 kg per hour (Scanarc Plasma Technologies AB 2005a, 2005b). This is the only known air plasma facility.

Other Non-Incineration Technologies

Superheated Steam Reactor

The superheated steam reactor destroys CFC, HCFCs, and HFCs in a reactor with walls that are electrically heated to 850-1,000ºC. The fluorocarbons are first mixed with steam and air and preheated to about 500ºC before being placed in the reactor. The by products of the process, HF, HCl, and CO_2 are quenched with a calcium hydroxide solution to neutralize the acid gases and minimize dioxin and furan emissions. Because of their compact size, superheated steam reactors can be used as mobile destruction facilities (UNEP 2002).

The superheated steam reactor technology was developed by the Japanese company Ohei Development Industries Co., Ltd, and there are 11 known units in operation in Japan (UNEP 2002).

Gas Phase Catalytic Dehalogenation

The gas phase catalytic dehalogenation process destroys CFCs at a lower temperature (400ºC), which requires less energy consumption. The process emits no dioxins or furans and very small amounts of other pollutants (UNEP 2002).

The gas phase catalytic dehalogenation process was developed by the Japanese company Hitachi Ltd. (UNEP 2002). It is unknown whether this technology is currently in use for commercial ODS destruction.

Appendix B: Halon Chemistry and Destruction

An inherent characteristic of halons is that they undergo chemical reaction when exposed to flame. Considering the chemistry of halons in fire extinguishing applications, it is expected that a similar chemical reaction would occur if halons were exposed to flame and a burning fuel-air mixture in an incinerator. Specifically, halon would produce HBr and Br^- and remove hydrogen and oxygen from the combustion process in the incinerator. Also, considering that the halon decomposition and the HBr/Br^- reaction occurs at relatively low flame temperatures in fire extinguishing applications, it is expected that halon would also react relatively easily at the much higher temperatures at which incinerators operate. Indeed, the MSDS indicate that Halon 1301 decomposes at fire temperatures above 1,562 °F, and that Halon 1211 can decompose at fire temperatures above 900 °F—well below the combustion temperatures at which HWCs generally operate. According to the U.S. performance test data available, the lowest afterburner (secondary combustion chamber) operating temperature is 1,610 °F, which is higher than the threshold temperatures needed to decompose both Halon 1211 and 1301.

To compare the difficulty of destroying ODS—including halons—an incinerability index (as shown in Appendix E below) was developed by Dellinger *et al.* for the U.S. EPA, measuring relative difficulty of destruction via oxygen-starved high-temperature reactions. (It is also referred to as a thermal stability index.) It was developed as a direct result of RCRA requirements regarding the destruction of organic compounds. The incinerability index is especially of use in determining if halons are being destroyed sufficiently at HWCs. As halons are not RCRA-hazardous waste, there are no MACT regulations specifically for halon incineration. Neither special monitoring nor stack testing is required for halon incineration. Thus, by determining the incinerability values for halons, effective destruction can be assumed if tests at each HWC combust a compound with a lower incinerability value.

For halons, incinerability can be theoretically calculated using pseudo-first order kinetics. Halons 1301, 1211, and 2402 were shown to be relatively easy to destroy. For all halons, however, there is a slim possibility that incineration can form products of incomplete combustion that are highly indestructible, high global warming potential (GWP) gases. These possibilities require further research (Dellinger *et al.* 2008).

Appendix C: ODS Destruction Data from the U.S. Toxic Release Inventory

On November 1, 2005, ICF submitted the original revised draft of this report to EPA. This report contained data on ODS destruction facilities and the amounts of ODS destroyed by these facilities from EPA's Toxic's Release Inventory (TRI). Because the TRI database includes companies that destroy ODS commercially and that "inadvertently" destroy ODS that is generated on site or used on site in a chemical production process, EPA sent questionnaires to these companies, as permitted under Section 114 of the CAA, requesting further information on their destruction process and the amount of ODS destroyed in 2003 and 2004. The responses to these questionnaires, as well as additional internet and personal communication research conducted by ICF, were used to update the list of destruction facilities and the amount of ODS destroyed as presented in the above report. This appendix presents the data obtained from TRI as presented in the ODS Destruction report delivered in 2005.

ODS Destruction Facilities that Report to the Toxic Release Inventory (TRI)

Table 9 lists all companies known to destroy ODS in the U.S., based on TRI data from 2003.

Table 9: Companies Known to Destroy ODS in the United States Based on TRI Data for the Year 2003

Company/Facility	Primary Technology	Efficiency[a]
3M Pharmaceuticals Northridge, CA[b]	NR	NR
Arvesta Perry, OH	Fume/Vapor	98.8%
Atofina Calvert City, KY	Liquid Injection	99.99%
Bayer Kansas City, MO	Fume/Vapor	100%
BP Amoco Decatur, AL	Other Incineration/Thermal Treatment	97.3%
BP Amoco Channahan, IL	Fume/Vapor	97.5%
	Fume/Vapor	99.6%
BP Amoco Wando, SC	Other Incineration/Thermal Treatment	99%
Citgo Lake Charles, LA	Flare	98%
Clean Harbors Environmental Service, Inc. Deer Park, TX	Rotary Kiln with Liquid Injection Unit	99.99%
Clean Harbors Environmental Service, Inc. Grantsville, UT	Rotary Kiln with Liquid Injection Unit	99.99%
Clean Harbors Environmental Service, Inc. Kimball, NE	Fluidized Bed	99.99%
Continental Cement Hannibal, MO	Rotary Kiln with Liquid Injection Unit	99.99%
DAK Americas LLC Leland, NC	Fume/Vapor	98%
	Industrial Boiler	NA
DOW Chemical Co. Freeport, TX	Other Incineration/Thermal Treatment	99.99%
DOW Chemical Co. Plaquemine, LA	Rotary Kiln with Liquid Injection Unit	99.99%
	Other Rotary Kiln	99.99%
	Other Incineration/Thermal Treatment	99.99%
	Liquid Injection	99.99%
	Industrial Boiler	NA
DOW Chemical Co. Pittsburg, CA	Other Incineration/Thermal Treatment	99.99%
DuPont Belle, WV	Fume/Vapor	99.8%
DuPont Gregory, TX[b]	NR	NR

Company/Facility	Primary Technology	Efficiency[a]
DuPont Richmond, VA	Other Incineration/Thermal Treatment	99% (CFC-11)
DuPont Washington, WV	Other Incineration/Thermal Treatment	99.9% (CFC-114)
Eastman Chemical Kingsport, TN	Other Incineration/Thermal Treatment	99%
	Rotary Kiln with Liquid Injection Unit	99.99%
	Other Incineration/Thermal Treatment	99.99%
	Industrial Furnace	NA
	Industrial Boiler	NA
Eastman Chemical West Columbia, SC	Other Incineration/Thermal Treatment	97%
	Industrial Boiler	NA
Envirotrol Inc Darlington, PA	Other Air Emission Treatment	99.99%
EQ Resource Recovery Romulus, MI[b]	NR	NR
Essroc Cement Logansport, IN	Other Rotary Kiln	99.99%
FMC Baltimore, MD	Industrial Kiln	NA
	Liquid Injection	99.99%
Formosa Plastics Baton Rouge, LA	Other Incineration/Thermal Treatment	99.99%
	Fume/Vapor	
Formosa Plastics Point Comfort, TX	Fume/Vapor (with Stripping – Steam)	100%
	Industrial Boiler	NA
GB Biosciences Houston, TX	Fume/Vapor	99.9%
GE Burkville, Al[b]	NR	NR
Geismar Vinyls Co. Geismar, LA	Fume/Vapor	99.92%
Georgia Gulf Plaquemine, LA	Fume/Vapor	99.76% (methyl chloroform)
	Fume/Vapor	99.77% (CCl_4)
Georgia Gulf Westlake, LA	Fume/Vapor	99.99% (CCl_4)
Holcim Artesia, MS	Industrial Kiln	NA
Honeywell Carville, LA	Other Incineration/Thermal Treatment	99% (CFC-113)
	Other Incineration/Thermal Treatment	99.99% (CFC-115, CFC-114)
Honeywell El Segundo, CA[b]	NR	NR
Lafarge/Systech Fredonia, KS	Other Rotary Kiln	99.99%
	Industrial Kiln	NA
LWD Calvert City, KY	Rotary Kiln with Liquid Injection Unit	99.99%
	Liquid Injection	99.99%
Lyondell Westlake, LA	Other Incineration/Thermal Treatment	99.99%
	Liquid Injection	99.99%
Occidental Gregory, TX	Fume/Vapor	99.99%
	Liquid Injection	99.99%
Onyx Port Arthur, TX	Rotary Kiln with Liquid Injection Unit	99.99%
Onyx Sauget, IL	Fixed Hearth	99.99%
	Rotary Kiln with Liquid Injection Unit	
Oxy Vinyls 851 Tidal Rd. Deer Park, TX	Liquid Injection	100%
	Fume/Vapor	
Oxy Vinyls 1000 Tidal Rd. Deer Park, TX	Fume/Vapor	99.7%
Oxy Vinyls La Porte, TX	Fume/Vapor	99.99%
PPG Westlake, LA	Liquid Injection	100%
	Fume/Vapor	100%
	Fluidized Bed	100%

Company/Facility	Primary Technology	Efficiency[a]
Reclaimed Energy Connersville, IN	Fume/Vapor	95%
Rhodia Hammond, IN	Other Incineration/Thermal Treatment	99%
Rhodia Baton Rouge, LA	Liquid Injection	99.99%
Romic East Palo Alto, CA[b]	NR	NR
Ross Grafton, OH	Rotary Kiln with Liquid Injection Unit	99.99%
Safety Kleen East Chicago, IN	Industrial Furnace	NA
Solite Corp. Arvonia, VA	Industrial Kiln	NA
Solvay Thorofare, NJ	Liquid Injection	99.99%
	Fume/Vapor	99.99%
Syngenta Saint Gabriel, LA	Other Rotary Kiln	99.99%
	Rotary Kiln with Liquid Injection Unit	99.99%
	Fume/Vapor	96.5%
Teris El Dorado, AR	Industrial Boiler	NA
	Rotary Kiln with Liquid Injection Unit	99.99%
Veliscol Memphis, TN[b]	NR	NR
Von Roll East Liverpool, OH	Rotary Kiln with Liquid Injection Unit	99.99%
Vulcan Geismar, LA	Liquid Injection	99.99%
	Fume/Vapor	99.72%
Vulcan Sedgwick, KS	Fume/Vapor	99.5%
Westlake Calvert City, KY	Other Incineration/Thermal Treatment	99.9%

Source: TRI (2005).
NA = Not available.
NR = Not reported; this facility did not specify a destruction technology or associated efficiency in the sequence of waste treatment methods to account for the destruction of the reported quantities.
[a] The percentage of the toxic chemical removed from the waste stream through destruction, biological degradation, chemical conversion, or physical removal.
[b] Due to reporting ambiguities in the TRI database, it is possible that quantities of ODS reportedly destroyed by this facility were in fact destroyed off-site.

Amount and Type of ODS Destroyed: TRI Data

The TRI database was established to provide communities with information about toxic chemical releases in accordance with the Emergency Planning and Community Right-to-Know Act of 1986. Waste management activities are reported to TRI in accordance with the 1990 Pollution Prevention Act. Substances destroyed at a facility are reported as *Treated On-Site, Energy Recovery On-Site, or Energy Recovery Off-Site.* These terms are defined as follows:

- *Treated On-Site* includes only the amount of the toxic chemical actually treated (destroyed) by processes at the facility, not the total amount of the toxic chemical present in waste streams sent to those processes (TRI 2005).
- *Energy Recovery On-Site* includes only the amount of the toxic chemical actually combusted in the unit, not the total amount of the toxic chemical in the waste stream sent for energy recovery (TRI 2005).
- *Energy Recovery Off-Site* includes all amounts of the toxic chemical that were intended to be recovered for energy and were sent off-site for that purpose (TRI 2005).
- *Treated Off-Site* includes the total amount of the toxic chemical intended to be treated (destroyed) and sent off-site for that purpose, not the amount of the toxic chemical actually treated (destroyed) by off-site processes (TRI 2005).

Table 10 presents the total reported quantity of ODS (by type) destroyed in the U.S. for the years 1991 to 2003. Quantities reported to TRI as *Treated Off-Site* may include quantities destroyed but are not included in Table 3 because it is not certain that those amounts have in fact been destroyed (as explained in the definition provided above). When a quantity is reported as *Treated Off-Site*, the facility to which it was transferred is reported in Section 6.2 of an individual facility's Form R as a *Transfer to Treatment*. This designation includes waste management practices such as *solidification/stabilization*, *wastewater treatment*, and *transfer to waste broker*, which may not include actual destruction; and information about the subsequent destruction of this quantity at the destination facility is not provided (TRI 2005). Therefore, at the risk of underreporting, quantities reported as *Treated Off-Site* are not included in Table 10. All information is based on reported data obtained from the TRI database for individual destruction facilities.

Table 10: Reported Kilograms of ODS Destroyed by Type, as Reported in TRI (1991 – 2003)

Year	Methyl Chloroform	Carbon Tetrachloride	CFC-11	CFC-12	CFC-13	CFC-113	CFC-114	CFC-115	Methyl Bromide[a]	Total
1991	7,454,523	9,569,841	113,976	237,154	0	393,931[b]	15,876	27,669	264,227	18,077,198
1992	3,180,240	9,027,809	370,249	176,447	0	108,534[b]	108,862	8,618	53,953	13,034,711
1993	2,790,630	9,140,041	107,167	136,982	0	140,065[b]	82,513	30,019	47,205	12,474,623
1994	2,746,573	6,552,825	498,114	89,370	0	141,528[b]	103,899	47,046	84,956	10,264,310
1995	2,379,484	24,029,522	359,844	242,734	0	164,035	729,594	116,800	2,257,735	30,279,749
1996	1,093,951	19,231,111	86,051	7,756	0	244,273	739,976	31,132	300,431	21,734,681
1997	1,447,214	19,533,938	148,766	6,217	0	54,970	643,759	1,747	562,872	22,399,484
1998	3,439,784	5,700,372	440,555	108,263	0	603,283	463,977	1,423	323,943	11,081,601
1999	3,560,439	8,658,388	876,319	132,768	0	420,706	17,609	2,124	634,830	14,303,184
2000	3,645,941	9,953,482[c]	372,685	92,750	25,927	395,740	31,720	1,873	611,938	15,106,128
2001	2,640,980	8,092,232	272,812	51,931	16,012	499,593	728,888	81,950	1,145,955	13,514,342
2002	3,130,470	9,828,631	63,099	127,005	17,659	347,045	758,137	96,687	4,713,595	19,064,670
2003	1,903,611	9,368,657	103,995	38,599	52,267	1,186,521	1,085,015	314,143	2,237,757	16,238,298

Source: TRI (2005).

[a] In the early 1990s, some of the methyl bromide that was destroyed was due to overproduction by manufacturers; however, since 1993, the methyl bromide destroyed appears to represent recovered material. It is assumed that any recovered methyl bromide is destroyed because the available recycling technologies are complex, expensive, and require a high level of technical competence to operate that is not normally found at most fumigation facilities.

[b] These quantities have been revised according to personal communication with Honeywell International Technical Center, Chesterfield, VA. This facility did not destroy any CFC-113 in 1991 through 1994 although they have reported it to TRI (Honeywell, 2005).

[c] This quantity has been revised according to personal communication with DOW Chemical, Louisiana division. They have reported a quantity higher than the actual one (DOW Chemical, 2005).

It should be noted that several limitations are associated with the data gathered from the TRI database. In particular:

- Companies are not required to report the processing of less than 25,000 lbs (11,340 kg) of a non-PBT substance to TRI, as described in Section B.4 of the TRI Forms & Instructions Document.
- Quantities reported as *Treated Off-Site* include quantities destroyed but have not been accounted as "destroyed" because their destruction is not guaranteed.
- In gathering data for this report, cases of misreporting were found in the TRI database. Specifically, ICF identified two facilities with uncharacteristically high quantities of reported ODS destruction. After following up with these facilities, it was determined that these were reporting errors made on the part of companies (not the TRI staff) (DOW 2005; Honeywell 2005).

Appendix D: End Use Data on ODS Potentially Available for Destruction in the U.S.

This appendix provides additional detail on the estimated amount of ODS potentially recoverable from refrigeration/AC and fire protection equipment at end-of-life (EOL) for destruction from 2010 through 2050. These estimates have been developed using the U.S. EPA's Vintaging Model (IO version 4.2 10.07.08), applying the assumption that 50% of the original equipment charge is recovered at EOL.

Table 11: ODS Potentially Recoverable at End-of-Life from Refrigeration/AC and Fire Protection Equipment, 2010-2050 (ODP-weighted MT)

Sector/ End Use	CFC-11	CFC-12	CFC-114	CFC-115	HCFC-22	HCFC-123	HCFC-124	Halon 1211	Halon 1301
2010									
Refrigeration/AC*									
Transport	0	0	0	0	3	0	0	0	0
Stationary AC	423	208	59	0	12,659	141	0	0	0
Cold Storage/IPR	14	358	0	18	944	0	0	0	0
Retail Food	0	227	0	0	2,354	0	0	0	0
MVACs	0	0	0	0	28	0	0	0	0
Appliances	0	0	0	0	0	0	0	0	0
Fire Protection									
Total Flooding	0	0	0	0	0	0	0	0	669
Streaming	0	0	0	0	0	58	0	343	0
2020									
Refrigeration/AC*									
Transport	0	0	0	0	0	0	0	0	0
Stationary AC	0	60	0	0	18,086	404	0	0	0
Cold Storage/IPR	0	14	0	4	1,567	134	4	0	0
Retail Food	0	0	0	0	994	0	0	0	0
MVACs	0	0	0	0	1	0	0	0	0
Appliances	0	0	0	0	0	0	0	0	0
Fire Protection									
Total Flooding	0	0	0	0	0	0	0	0	191
Streaming	0	0	0	0	0	77	0	286	0
2030									
Refrigeration/AC*									
Transport	0	0	0	0	0	0	0	0	0
Stationary AC	0	0	0	0	129	450	0	0	0
Cold Storage/IPR	0	0	0	0	1,775	172	0	0	0
Retail Food	0	0	0	0	0	0	0	0	0
MVACs	0	0	0	0	0	0	0	0	0
Appliances	0	0	0	0	0	0	0	0	0
Fire Protection									
Total Flooding	0	0	0	0	0	0	0	0	132
Streaming	0	0	0	0	0	0	0	167	0

Sector/ End Use	CFC-11	CFC-12	CFC-114	CFC-115	HCFC-22	HCFC-123	HCFC-124	Halon 1211	Halon 1301
2040									
Refrigeration/AC*									
Transport	0	0	0	0	0	0	0	0	0
Stationary AC	0	0	0	0	0	473	0	0	0
Cold Storage/IPR	0	0	0	0	0	220	0	0	0
Retail Food	0	0	0	0	0	0	0	0	0
MVACs	0	0	0	0	0	0	0	0	0
Appliances	0	0	0	0	0	0	0	0	0
Fire Protection									
Total Flooding	0	0	0	0	0	0	0	0	103
Streaming	0	0	0	0	0	0	0	125	0
2050									
Refrigeration/AC*									
Transport	0	0	0	0	0	0	0	0	0
Stationary AC	0	0	0	0	0	497	0	0	0
Cold Storage/IPR	0	0	0	0	0	281	0	0	0
Retail Food	0	0	0	0	0	0	0	0	0
MVACs	0	0	0	0	0	0	0	0	0
Appliances	0	0	0	0	0	0	0	0	0
Fire Protection									
Total Flooding	0	0	0	0	0	0	0	0	65
Streaming	0	0	0	0	0	0	0	168	0

Source: *U.S. EPA Vintaging Model.* IO version 4.2 (10.07.08)
Note: CFC-113, HCFC-141b, HCFC-142b, and HCFC-225 are not included in this table because no quantities were modeled as recoverable in this analysis.

Appendix E: U.S. Regulatory Requirements

The destruction of ODS is regulated under the authority of both the CAA and the Resource Conservation and Recovery Act (RCRA).[18] This section describes the stratospheric ozone protection regulations under the CAA, which apply to all controlled substances (i.e., ODS). Additionally, because some ODS are classified as hazardous wastes, facilities that handle these ODS are regulated under RCRA. Hazardous waste combustors (HWCs, e.g., incinerators) that destroy ODS classified as hazardous waste are also regulated by the Maximum Achievable Control Technology (MACT) standard under the CAA.

Stratospheric Ozone Protection Regulations

Under the authority of the CAA, the stratospheric ozone protection regulations (40 CFR Part 82, Subpart A) establish the following definitions relating to the destruction of controlled substances:[19]

- "*Destruction* means the expiration of a controlled substance to the destruction efficiency actually achieved, unless considered completely destroyed as defined in this section. Such destruction does not result in a commercially useful end product and uses one of the following controlled processes approved by the Parties to the Protocol:
    (1) Liquid injection incineration;
    (2) Reactor cracking;
    (3) Gaseous/fume oxidation;
    (4) Rotary kiln incineration;
    (5) Cement kiln;
    (6) Radio frequency plasma; or
    (7) Municipal waste incinerators only for the destruction of foams."
- "*Completely destroy* means to cause the expiration of a controlled substance at a destruction efficiency of 98 percent or greater using one of the destruction technologies approved by the Parties."

In other words, the stratospheric ozone protection regulations require the use of one of the technologies approved by the Parties, as listed in Appendix A: Description of ODS Destruction Technologies, when destroying a controlled substance. Additionally, if the substance is to be considered "completely destroyed" as defined in the regulations, it must be destroyed to a 98 percent destruction efficiency (DE). Unlike the TEAP recommendations, which include a DRE limit of 99.99 percent, the U.S. regulations include a DE limit of 98 percent. According to the TEAP, DE is a more comprehensive measure of destruction than DRE as it includes emissions of undestroyed chemical from all points (e.g., stack gases, fly ash, scrubber, water, bottom ash), while DRE includes emissions of undestroyed chemical from the stack gas only. However, "because of the relatively volatile nature of ODS and because, with the exception of foams, they are generally introduced as relatively clean fluids, one would not expect a very significant difference between DRE and DE" (TEAP 2002:31).

[18] Although the destruction of ODS is not regulated under the Toxic Substances Control Act (TSCA), hazardous waste combustors that destroy PCBs must be permitted under TSCA and achieve a DRE of 99.9999 percent. These facilities could be used to destroy ODS (although if they were to destroy ODS classified as hazardous waste, they would also need to be RCRA permitted). See the text box in Section Maximum Achievable Control Technology Standards (MACT) for further discussion of PCB incinerators.

[19] According to 40 CFR 82.3, "the inadvertent or coincidental creation of insignificant quantities of a listed [ODS] during a chemical manufacturing process, resulting from unreacted feedstock, from the…use [of ODS] as a process agent present as a trace quantity in the chemical substance being manufactured, or as an unintended byproduct of research and development applications, is not deemed a controlled substance."

Resource Conservation and Recovery Act (RCRA)

In addition to the stratospheric ozone protection regulations for ODS under the CAA, several ODS that are classified as hazardous wastes are also regulated under RCRA. Therefore, the regulations that apply to facilities that handle these hazardous wastes apply to facilities in the U.S. that destroy hazardous waste ODS. Generally, RCRA requires facilities that operate hazardous waste storage tanks, manage hazardous waste containers, and operate hazardous waste treatment units to have RCRA permits, which regulate what specific hazardous waste codes the facilities are permitted to receive and store, and in what quantities. In addition, the Land Disposal Restrictions program (40 CFR Part 268) sets concentrations of hazardous constituents or methods of treatment for hazardous wastes, which must be achieved before the wastes, or waste treatment residues, are land disposed.

According to 40 CFR Part 261, Subpart D, ODS (or ODS-containing waste) may be classified as hazardous wastes if they fall under one of the following waste categories:

- Wastes from non-specific sources (Code F);
- Commercial chemical products (Code U);
- Characteristic wastes (Code D); or
- Wastes from specific sources (Code K).

However, according to 40 CFR 261.4(b)(12), refrigerants that meet the following definition are exempt from classification as hazardous wastes: "used chlorofluorocarbon refrigerants from totally enclosed heat transfer equipment, including mobile air conditioning systems, mobile refrigeration, and commercial and industrial air conditioning and refrigeration systems that use chlorofluorocarbons as the heat transfer fluid in a refrigeration cycle, provided the refrigerant is reclaimed for further use".[20] According to 56 FR 5913, this exemption includes CFC and HCFC refrigerants.
The remainder of this section discusses the circumstances in which ODS may be considered hazardous wastes under Codes F, U, D, and K.

Code F (Wastes from Non-Specific Sources)

ODS may be classified under hazardous waste codes F001 or F002 if they meet one of the following definitions listed under 40 CFR 261.31:[21]

- **F001**—Applies to the following spent halogenated solvents used in degreasing: tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; all spent solvent mixtures/blends used in degreasing containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
- **F002**—Applies to the following spent halogenated solvents: tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, trichlorofluoromethane, and 1,1,2-trichloroethane; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those listed in F001, F004, or F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.

[20] Reclamation is defined in 40 CFR 82.152 as "to reprocess refrigerant to all of the specifications in appendix A to 40 CFR Part 82, Subpart F…that are applicable to that refrigerant and to verify that the refrigerant meets these specifications using the analytical methodology prescribed in Section 5 of Appendix A of 40 CFR Part 82, Subpart F."
[21] Waste codes F024 and F025 also apply to hazardous wastes that could contain ODS; however, these would not be considered controlled substances as they are byproducts of manufacturing processes.

In short, carbon tetrachloride, methyl chloroform, and all CFCs and HCFCs may be classified as Code F hazardous wastes if they have been used as solvents prior to disposal. The generator of the waste is responsible for determining whether the waste is to be classified as hazardous versus non-hazardous and if hazardous, assigning as waste code. Additionally, any destruction facility receiving waste is responsible for verifying that the waste is correctly identified (EPA 2006a).

Code U (Commercial Chemical Products)

ODS may be classified as Code U hazardous wastes (as defined in 40 CFR 261.33) if they are commercial chemical products or manufacturing chemical intermediates that are discarded or intended to be discarded (i.e., abandoned by being disposed of; burned/incinerated; or accumulated, stored, or treated but not recycled before or in lieu of being abandoned by being disposed of, burned, or incinerated, see 40 CFR 261.2(a) and (b)). A commercial chemical product/manufacturing chemical intermediate is defined in 40 CFR 261.33(c) and (d) as:

- a chemical substance that is manufactured or formulated for commercial or manufacturing use which consists of the commercially pure grade of the chemical;
- any technical grades of the chemical that are produced or marketed;
- all formulations in which the chemical is the sole active ingredient; and
- any residue remaining in a container or in an inner liner removed from a container that has held any commercial chemical product or manufacturing chemical intermediate named in this section of the regulations.[22]

Thus, while carbon tetrachloride, methyl chloroform, methyl bromide, trichlorofluoromethane (CFC-11), and dichlorodifluoromethane (CFC-12) have designated U waste codes—U211, U226, U029, U121, and U075 respectively—this code is limited to container residues and products that were manufactured but never used. Therefore, refrigerants removed from equipment (which are not classified as hazardous wastes) and used solvents (some of which do fall under waste Code F) *would not* fall under hazardous waste Code U; a controlled substance that was manufactured and never used *would* be considered a Code U waste if it was discarded or intended to be discarded.

Code K (Wastes from Specific Sources)

ODS-contaminated wastes which may be generated from specific sources, such as the production of carbon tetrachloride, may be classified under several K waste codes (e.g., K016, K018, K021, K028, K029, K073, K095, K096, K131, K132, K150). However, because these waste codes apply mainly to wastes/residues from the production of various chemicals, they will not apply to controlled substances being sent for destruction.

Code D (Characteristic Wastes)

Code D includes wastes that exhibit any of the four characteristics—ignitability (D001), corrosivity (D002), reactivity (D003), and toxicity (D004 through D043)—as described in 40 CFR 261.21 to 261.24. The most likely characteristic to apply to ODS waste is the toxicity characteristic (TC). Carbon tetrachloride is designated under waste code D019; thus, if an extract from a representative sample of a solid waste contains a concentration of carbon tetrachloride equal to or greater than the regulatory threshold level of 0.5 mg/L, it is considered a hazardous waste.[23] Additionally, used ODS contaminated with any of the other Code D chemicals are considered hazardous wastes if an extract contains any of the contaminants listed in 40 CFR 261.24 at a concentration equal to or greater than the specified values.

[22] Unless the container is empty, as defined in 40 CFR 261.7(b). According to this section, "a container that has held a hazardous waste that is a compressed gas is empty when the pressure in the container approaches atmospheric." Therefore, any heels in containers that held ODS would most likely not be considered hazardous waste.

[23] A waste extract is obtained using a specific test method called the Toxicity Characteristic Leaching Procedure (TCLP).

The Mixture and Derived-From Rules

According to 40 CFR 261.3(a)(2)(iv), any combination of a listed hazardous waste with non-hazardous waste is defined as a listed hazardous waste. Even if a small amount of listed waste is mixed with a large quantity of non-hazardous waste, the resulting mixture bears the same waste code and regulatory status as the original listed component of the mixture. The mixture rule applies differently to listed and characteristic wastes. A mixture involving characteristic wastes is hazardous only if the resulting mixture itself exhibits a characteristic. Once a characteristic waste no longer exhibits one of the four regulated properties, it is no longer regulated as hazardous. However EPA places certain restrictions on the manner in which a waste can be treated (see the Land Disposal Restrictions regulations in 40 CFR Part 268).

Furthermore, hazardous waste treatment, storage, and disposal processes often generate waste residues (i.e., "derived-from" wastes). Residues produced from the treatment of listed hazardous wastes are generally still considered hazardous wastes under the RCRA derived-from rule (see 40 CFR 261.3(c)(2)), which states that any material derived from a listed hazardous waste is also a listed hazardous waste. For example, ash created by burning a hazardous waste is considered derived-from that hazardous waste. Thus, such ash bears the same waste code and regulatory status as the original listed waste, regardless of the ash's actual properties.

RCRA Waste Code Summary

Table 12 summarizes the RCRA hazardous waste codes that may apply to controlled substances (i.e., not including ODS byproducts or ODS-containing wastes from chemical manufacture).

Table 12: RCRA Hazardous Waste Codes for Selected ODS

Chemical Name	Hazardous Waste Codes			
	U[a]	F	D	K
CFC-11 (Trichlorofluoromethane)	U121	F001, F002	-	-
CFC-12 (Dichlorodifluoromethane)	U075	F001	-	-
Other CFCs and HCFCs	-	F001	-	-
Carbon Tetrachloride	U211	F001	D019	-
Methyl Chloroform (1,1,1-trichloroethane)	U226	F001, F002	-	-
Methyl Bromide	U029	-	-	-

[a] Code U only applies to the controlled substances listed above if they were manufactured and subsequently disposed of without ever being used.

While all known ODS destruction undertaken in the U.S. has occurred at RCRA-permitted HWCs with the exception of one facility, the possibility remains that non-hazardous waste ODS could be destroyed at non-RCRA regulated facilities, as the majority of ODS likely to be destroyed are not classified as hazardous wastes. Therefore, the regulations that apply to permitted HWCs, as discussed further below, would not apply to the destruction of non-hazardous waste ODS. See Appendix F for further discussion of the possibility of non-permitted facilities destroying ODS.

Maximum Achievable Control Technology Standards (MACT)

RCRA-permitted hazardous waste facilities that operate HWCs are also required by the MACT standard under the CAA to obtain a Title V Operating Permit as a hazardous air pollutant (HAP) emission source. Title V Operating Permits contain emission limits for the release of air pollutants, including HAPs, from the combustion of hazardous wastes to ensure the protection of human and environmental health. Three ODS are listed HAPs under the CAA:[24]

[24] Title V Operating Permits do not necessarily identify specific emission limits for each CAA HAP. Rather, the Title V Operating Permit may instead set a total emission limit for all CAA HAPs (e.g., 10 tons per year), so there may not be specific emission limits in the Title V Operating Permit for the three ODS that are also HAPs.

- Carbon tetrachloride;
- Methyl bromide; and
- Methyl chloroform.

On October 12, 2005, EPA issued a Final Rule (70 FR 59402, codified in 40 CFR Part 63, Subpart EEE) for National Emission Standards for Hazardous Air Pollutants (NESHAP) emitted by HWCs.[25] The standards were issued under Section 112(d) of the CAA as a MACT standard.[26] The Final Rule, effective December 12, 2005, applies to hazardous waste burning (a) incinerators, including rotary kilns, fluidized bed units, liquid injection units, and fixed hearth units, which are used primarily for waste destruction; and (b) boilers and industrial furnaces (BIFs), including cement kilns, lightweight aggregate kilns, industrial/commercial/institutional boilers and process heaters, and hydrochloric acid production furnaces, which are used primarily for energy and material recovery. This Final Rule, as well as the NESHAP finalized on September 30, 1999, rendered existing RCRA stack emission standards inapplicable upon demonstration of compliance with the MACT standards to avoid unnecessary duplication with the MACT standards.[27] Permits under the CAA Title V Operating Permit Program contain emission limits for HAPs and other pollutants set by these MACT standards.

Under the MACT standards, when hazardous wastes are to be destroyed by way of combustion, the combustion unit must adhere to a minimum 99.99 percent DRE and also meet the air emission limits listed in 40 CFR 63.1216 – 63.1221. The air emission limits relevant to ODS destruction include limits for dioxins and furans, PM, total chlorine (HCl and Cl_2), and CO. (See Section 5 for a comparison of the MACT standard limits to the TEAP recommendations.) Additional operating limitations for HWCs, including maximum hazardous waste feed rates and ranges of hazardous waste composition (e.g., maximum feed rate of chlorine to the unit), are established on a unit-specific basis by the Title V Operating Permit writers based on a review of the unit design, waste characterization data, and performance test results.

Comprehensive Performance Tests (CPT)

According to 40 CFR 63.1206 and 63.1207, HWCs must document compliance with emission limits (including DRE) and demonstrate performance of their continuous monitoring systems (CMS) by conducting comprehensive performance tests (CPT) every five years. During a CPT, one or two difficult-to-combust compounds referred to as POHCs are fed into the unit along with wastes that have been formulated to be representative of the typical wastes fed into the system, and specific parameters are monitored (including temperature, feed rate, and air emissions).[28] Prior to conducting a CPT, a test plan must be submitted to the permitting agency for review, public comment, and approval. A test plan must contain an analysis of each feedstream to the unit (including the identification of any hazardous wastes and organic HAPs present in the feedstream) and the proposed performance test methods (including the selected POHCs). For each hazardous waste identified in the feedstream, the plan also must include (a) the ranges of the hazardous waste feed rates for each waste feed system; (b) the feed rates of other fuels and feedstocks to the unit as appropriate (e.g., for cement kilns); (c) a determination of the combustion residence time; and (d) the identification of any other relevant parameters that may affect the ability of the HWC to meet the emission standards.

[25] The Federal Register Notice and Final Rule are available at the following EPA website: http://www.epa.gov/epaoswer/hazwaste/combust/toolkit/links.htm#hwc. Related information concerning the Final Rule is available at the following EPA website: http://www.epa.gov/epaoswer/hazwaste/combust/toolkit/index.htm.

[26] The MACT standards are industry-specific, technology-based standards designed to reduce HAP emissions.

[27] Final standards for Phase 1 sources (i.e., incinerators, cement kilns, and lightweight aggregate kilns) were originally promulgated on September 30, 1999 and established the framework for making existing RCRA stack emission standards inapplicable for the Phase 1 sources once they demonstrated compliance with the MACT standard. The October 12, 2005 final rule made the remaining RCRA stack emission standards for Phase 2 sources (i.e., boilers and HCl Production Furnaces) inapplicable upon demonstration of compliance with the MACT standard.

[28] A company must also submit reports if it performs modifications to the source/destruction process in a manner that could affect its ability to achieve the DRE standard. Most HWCs are also required to conduct confirmatory performance testing every 2.5 years to demonstrate compliance with the dioxin and furan emission standard.

Principal Organic Hazardous Constituents (POHCs)

Based on the design of the combustion unit and the specific characteristics of the hazardous wastes being combusted by the unit (including their concentrations in the feedstream), POHCs that are the most difficult to combust when compared to the other wastes being destroyed by the unit are selected from the CAA list of HAPs (which include three ODS—carbon tetrachloride, methyl bromide, and methyl chloroform). POHCs may be volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), or solids, depending upon the specific characteristics of the hazardous wastes being combusted.

The difficulty-of-combustion, or "incinerability," of organic compounds are established using a quantitative thermal stability ranking system included in Appendix D of the *Guidance on Setting Permit Conditions and Reporting Trial Burn Results*, which was developed based on pilot and full scale test burn data (EPA 1989). The ranking scale ranges from 1, representing the most difficult-to-combust compound, to 320, representing the least difficult-to-combust compound.

Performance Testing for PCB Incinerators

Under 40 CFR Part 761, Subpart D, facilities wishing to destroy polychlorinated biphenyls (PCBs) must apply for a permit and demonstrate compliance with several combustion criteria through performance tests. Most units permitted to incinerate PCBs under 40 CFR Part 761 are also permitted to incinerate hazardous wastes under 40 CFR Part 63; however, most facilities that commercially destroy ODS are not permitted to destroy PCBs.

Performance test requirements of PCB incinerators are similar in concept to performance test requirements for HWCs. Because PCB wastes may be semivolatile organic compounds (SVOCs), solid compounds, or articles (e.g., PCB-contaminated capacitors), the POHCs chosen to test the units are SVOCs or solids. The facility operator is required to monitor operating conditions during the trial burn test, including the concentration of PCBs, CO, and oxygen in the exhaust gas and the rates and quantities of PCBs fed to the incinerator. The operator is also required to demonstrate that the temperature of the incinerator is maintained above 1,200°C for a 2-second residence time or above 1,600°C for a 1.5-second residence time, and that the DRE for the PCB compounds is 99.9999 percent or greater. (EPA 2004)

Compounds are ranked based on the temperature required to achieve 99% destruction in two seconds. A score of 1 represents the most difficult substance to combust, and 320 indicates the easiest. The incinerability ratings of many common ODS are presented in the table below. During the testing of a HWC under the MACT standards, a difficult-to-combust compound is incinerated and the DRE is evaluated. If the incinerator has passed this test, it can then be assumed that the incinerator can destroy compounds that are easier to incinerate to a satisfactory DRE. The compound with the lowest score that is suitable for testing cycles is monochlorobenzene, ranked with a thermal stability of 19. (Most of the lower-ranked compounds are extremely toxic [e.g., cyanides, pyrenes] and therefore present occupational safety issues for use in performance testing.) Other difficult-to-combust compounds used as POHCs include:

- 1,2,4,5-tetrachlorobenzene (thermal stability rank 20);
- 1,2-dichlorobenzene (thermal stability rank 23-24);
- trichlorobenzene (thermal stability rank 26);
- tetrachloroethylene (thermal stability rank 36); and
- carbon tetrachloride (thermal stability rank 136-140).

Table 13 lists the thermal stability rankings of the ODS included in the ranking scale.

Table 13: Thermal Stability Ratings of Several ODS

ODS	Thermal Stability Rating	Difficulty to Destroy
Methyl Bromide	31-33	Most Difficult ↑
CFC-113	85-88	
CFC-12	85-88	
CFC-11	89-91	
Halon 1301	116	
Halon 2402	131	
HCFC-22	133	
Carbon Tetrachloride	136-140	
Halon 1211	143	
CFC-21	154-157	↓ Least Difficult
Methyl Chloroform	201	

Source: Dellinger 2008.

As shown in Table 13, all ODS for which data are available are less difficult to destroy than monochlorobenzene (rank 19), a widely used POHC for testing DRE in trial burns.

Comprehensive Performance Test Process

During the performance test, each representative POHC and the other surrogate wastes are fed into the HWC at a known and fixed feed rate, and the concentration of each POHC is monitored in the exhaust gas of the HWC.[29] The DRE is determined by the difference between the amount of the POHC fed into the HWC and the amount of the POHC emitted in the exhaust gas.[30] The operating conditions of the HWC are also monitored during the performance test, including the total hazardous waste feed rate, combustion temperature, exhaust gas oxygen and CO concentrations, and other parameters. Exhaust gas flow rate is monitored as a surrogate for the retention time of the combustion unit.

If the CPT results demonstrate that the HWC achieved the applicable DRE (e.g., 99.99 percent for hazardous wastes or 99.9999 percent for PCBs and certain chlorinated dioxin/furan-containing hazardous wastes) for the difficult-to-combust POHCs, it is then presumed that the HWC will also destroy organic compounds that are less difficult to combust to at least the same DRE, assuming that the HWC is operated within the permitted range of operating parameters under which the CPT was conducted (e.g., waste feed rate, waste composition, combustion temperature, exhaust gas flow rate). For example, several state agency permit writers indicated that monochlorobenzene, one of the most difficult compounds to combust, was specified as one of the POHCs for performance tests of HWCs under their purview (Missouri Department of Natural Resources 2005, Ohio EPA 2005). Therefore, these facilities could destroy any organic compound that is less difficult to destroy, including all ODS compounds listed as hazardous wastes.

The presumption that the performance of the unit in destroying difficult-to-combust POHCs will be representative of the performance of the unit in destroying less difficult-to-combust compounds is established as a concept in the HWC regulations (see e.g., 40 CFR 63.1220(c)(3)(ii)), explicitly stated in the performance test requirements for chlorinated dioxin and furan incineration (see e.g., 40 CFR 63.1219(c)(2)), and reflected in how permit conditions for performance testing and operation of HWCs are written in Title V Operating Permits.

[29] See Appendix F for further information on the costs of conducting a CPT.
[30] The formula used to calculate DRE for hazardous waste incinerators, for example, is provided in 40 CFR 63.1219(c)(1).

Monitoring, Recordkeeping, and Reporting Requirements

Monitoring and recordkeeping/reporting requirements for HWCs are contained in 40 CFR 63.1209 and 40 CFR 63.1211, respectively. Facilities that destroy ODS must also meet the recordkeeping and reporting requirements listed in 40 CFR Part 82, Subpart A on protection of stratospheric ozone. These requirements are described in this section.

Hazardous Waste Combustors Monitoring and Reporting

Under 40 CFR 63.1209, hazardous waste combustors are required to continuously monitor (a) total hydrocarbon (THC) or CO emissions in exhaust gas using a continuous emission monitoring system (CEMS) and (b) the waste feed rate into the unit.[31] As an indicator of gas residence time, a facility operator must establish and comply with a limit on the maximum flue gas flow rate, the maximum production rate, or another parameter that is documented in the site-specific performance test plan as an appropriate surrogate for gas residence time. Facility operators are also required to measure the temperature of each combustion chamber at a location that best represents bulk gas temperature in the combustion zone and establish a minimum combustion chamber temperature for permitted operation. In the event that operating parameters fall outside of the permitted range, facility operators are required to file a report to the permitting agency.

Under 40 CFR 62.1211, facility operators are required to maintain information on site to document and maintain compliance with MACT standard Subpart EEE regulations (including data recorded by CMS) and make the operating records available for on-site inspection by the permitting agency. Facility operators are also required to develop a Documentation of Compliance that must identify the applicable emission standards under Subpart EEE and the limits on the unit operating parameters under 40 CFR 63.1209 that will ensure compliance with those emission standards.

There are no explicit regulatory requirements in Subpart EEE to monitor and record the amount of ODS being combusted in HWCs. However, RCRA-permitted facilities are required to monitor and record the types and amounts of hazardous wastes (including ODS classified as hazardous wastes) accepted in order to determine that the types and amounts of wastes accepted are in accordance with what the facility is permitted to accept under its RCRA permit. For ODS that are classified as hazardous wastes, information concerning the types and quantities accepted could be determined from the Waste Characterization Data for the facility. However, ODS that are not classified as hazardous wastes may not be identified in the RCRA permit or in the Waste Characterization Data.

ODS Destruction Facilities Reporting

According to the stratospheric ozone protection regulations (40 CFR Part 82, Subpart A), all facilities that destroy controlled ODS must submit to EPA a one-time report detailing the following:

- the destruction unit's destruction efficiency;
- the methods used to record the volume destroyed;
- the methods used to record destruction efficiency; and
- the names of other relevant federal or state regulations that may apply to the destruction process.

If there are changes in a facility's DE and/or methods used to record the volume destroyed or used to determine DE, the facility must submit a revised report to EPA within 60 days of the change.
Where controlled ODS were originally produced without expending allowances, ODS destruction facilities must provide a destruction verification document, which documents that the materials received will be destroyed, to the producer/importer from whom they purchased/received the ODS. This verification document must include:

[31] Facility operators must implement a waste feed analysis plan that specifies the parameters that will be analyzed for each feed stream to ensure compliance with operating parameter limits in the regulations including applicable waste feed rate limits.

- the identity and address of the person intending to destroy controlled substances;
- an indication of whether those controlled substances will be "completely destroyed" or less than completely destroyed, in which case they must provide the DE;[32]
- the period of time over which the person intends to destroy the controlled substances; and
- the signature of the verifying person.

Additionally, those facilities that destroy ODS that submitted a destruction verification to a producer and/or importer are required to report annually to EPA the names and quantities of ODS destroyed during the control period (i.e. one calendar year).

[32] "Completely destroy," as defined in 40 CFR 82.3, means "to cause the expiration of a controlled substance at a destruction efficiency of 98 percent or greater, using one of the destruction technologies approved by the Parties."

Appendix F: Destruction of ODS in U.S. Hazardous Waste Combustors

This section discusses the potential emissions resulting from the destruction of ODS, outlines the limits on air emissions from HWCs destroying ODS, discusses performance testing conducted on HWCs using ODS, and presents information from several operating permits for HWCs that are known to destroy ODS.

Emissions Associated with ODS Destruction

The incineration of CFCs and HCFCs produces air emissions including carbon dioxide, HF, HCl and Cl_2. The incineration of halons and other brominated ODS (e.g., methyl bromide) also produces HBr and Br_2. CO, hydrocarbons (HC), organic acids, and other products of incomplete combustion (PICs) and dioxins and furans are also produced from the combustion of chlorinated ODS including CFCs, HCFCs, and halons. Acid gases are generally removed using gas scrubbing systems, such as Venturi scrubbers, packed bed scrubbers, or plate scrubbers (TEAP 2002).[33]

ODS Products of Incomplete Combustion

In the early to mid 1990s, a substantial amount of research was conducted by EPA and academic researchers into products of incomplete combustion (PIC) formation from the combustion of ODS. One study monitored PICs, including carbon tetrachloride, methyl chloroform, and CFC-11, in the flue gas during the combustion of CFC-12 in a bench scale incinerator (EPA 1993). PIC generation rates for the ODS ranged from non-detectable to about 0.5 to 10 micrograms per gram of CFC-12 feed, equivalent to 0.001 percent of the feed. Another study measured methyl chloroform PIC emissions of 170 micrograms per cubic meter at a high CFC feed rate and did not measure any "target" PIC emissions at the low CFC feed rate (EPA 1993). A 1996 EPA study reported results from combustion of CFC-11, CFC-12, and HCFC-141b in a pilot-scale incinerator; concentrations of VOCs (volatile PICs) were reported as being "very low" in all tests conducted (EPA 1996). The formation of PICs that are also ODS is limited by the requirements to monitor THC emissions from facilities; additionally, CPT results for HWCs include monitoring of VOC and SVOC PIC emissions, which could include ODS (e.g., carbon tetrachloride). For example, performance data that were reported for a sulfuric acid recovery unit show PIC emissions of CFC-11 of 0.0003 lb/hr when operating at a total hazardous waste feed of 4,500 lb/hr and a combustion temperature of 1800°F; and of 0.0024 lb/hr when operating at a total hazardous waste feed rate of 6,400 lb/hr and a combustion temperature of 1700°F. (EPA 2006b)

Limitations on ODS Emissions from Hazardous Waste Combustors

Title V Operating Permits for HWCs may or may not have explicit limits for feed rates and emissions of *individual* ODS compounds. However, the units are required to achieve, at a minimum, a 99.99 percent DRE for each RCRA hazardous waste—including all ODS that are classified as hazardous wastes—fed into the unit. The maximum feed rates and emissions of ODS from HWCs are limited by the permit limitations on unit operating conditions. For example, Title V Operating Permits typically establish maximum chlorine feed rates, which for one facility is established at 1,582 pounds per hour (EPA 2006a).

Additionally, the combustion temperature, exhaust gas flow rate, and hazardous waste feed rate are continuously monitored and recorded. Therefore, instances in which the units fall outside of the permitted range of any monitored parameter are recorded and reported. Remedial actions specified in the permit conditions and in the regulations are implemented if an excursion is detected.

[33] The production of acid gases, especially HF, also requires specific equipment—which is not necessarily standard at incineration facilities—to prevent damage to the unit caused by corrosion. This equipment includes upgraded bag material in the bag house; HF-resistant refractory lining and binder in the combustion chambers through the quench area; and specially-lined, corrosion-resistant, fiberglass-reinforced plastic (FRP) in the scrubbing system.

Additionally, HWC operating permits typically include automatic feed cutoff limits and combustors are equipped with waste feed cutoff systems set to these limits. In the event that a monitored operating parameter (e.g., waste feed rate, combustion temperature) falls outside of the permitted range (i.e., the range within which the applicable DRE was demonstrated to be achieved during the CPT) the waste feed cutoff system activates and blocks any further waste feed to the combustor. Therefore, hazardous wastes cannot continue to be fed to the combustor if the unit is operating outside of the operating parameters that have been demonstrated to achieve the applicable DRE (Missouri Department of Natural Resources 2005; Ohio EPA 2005).

In summary, because the DRE being achieved by an HWC generally cannot and is not required by regulation to be monitored continuously, facility operators and permitting agencies determine that the HWCs are achieving the applicable DRE by determining that the units are being operated within the permitted range of operating parameters. This permitted range of parameters is developed based on the conditions under which performance tests for the HWC were conducted. *Hazardous waste combustors that are used to destroy ODS that are classified as hazardous wastes would be required by regulation to meet the applicable DRE for those ODS, and the HWC would be determined to be achieving the applicable DRE through monitoring of the operating parameters established in the HWC operating permit* (Missouri Department of Natural Resources 2005; Ohio EPA 2005).

Comprehensive Performance Testing Using ODS

EPA published summaries of performance test data for HWCs in support of the recently-finalized MACT standards (EPA 2006b). The summary data include pollutant-specific emissions and hazardous waste feed rates, combustion temperature, DRE, HAP emissions, chlorine feed rates, and stack gas conditions. Because most of these performance tests were conducted in the 1990s, before the new MACT standard was implemented, it is likely that facilities have since implemented stricter emissions controls in order to comply with the new standards. *Therefore, these performance test data may not reflect the current status of emissions from the facilities.*

Some of the performance tests were conducted using ODS (i.e., carbon tetrachloride, methyl chloroform, CFC-11, and CFC-113) as POHCs. There were no performance test data identified in the database for halons or other ODS that are not classified as hazardous wastes. The performance test data using ODS as POHCs are presented in Table 7 in Section 5. DREs greater than 99.999 percent were reported for most HWCs using carbon tetrachloride or methyl chloroform as POHCs.

Review of Selected Title V Operating Permits: Comparison of Performance and Monitoring Requirements

To understand the performance and monitoring requirements of U.S. facilities known to have destroyed ODS, selected publicly available Title V Operating Permits were reviewed for three companies operating a range of hazardous waste combustors: (1) rotary kilns, (2) cement kilns, and (3) lightweight aggregate kilns.[34] Each of the facilities—whose company names are not disclosed—has reportedly incinerated ODS or used blended waste containing ODS as fuel. While most Title V Operating Permits cite the underlying MACT standards relevant to the facility, at times state implementation plans or other state regulations can require the establishment of source-specific HAP limits in the Title V Operating Permit.

The Title V Operating Permit for Facility A—a commercial hazardous waste treatment facility that operates two **rotary kilns**, one secondary combustion unit, and one waste-fired boiler—reflects the underlying MACT

[34] Note that permits were reviewed as of 2005; because operating permits are updated approximately every five years, permitting conditions may have changed from what is presented here.

standard emission limits for incinerators as listed in 40 CFR 63.1203.[35] The permit includes a maximum waste feed rate and a limit on VOC emissions; it also requires continuous emission monitoring systems for combustion chamber temperature, exhaust gas flow rate, hazardous waste feed rate, THC, and CO to demonstrate compliance with the MACT standard. Additionally, the following emission limits for the three ODS HAPs are specified in the permit: (Arkansas DEQ 2002)

- Maximum Carbon Tetrachloride Emissions: 0.43 lbs/hr
- Maximum Methyl Bromide Emissions: 0.43 lbs/hr
- Maximum Methyl Chloroform Emissions: 0.43 lbs/hr

The Title V Operating Permit for Facility B, which operates two wet process **cement kilns,** reflects the underlying MACT standard emission limits for cement kilns as listed in 40 CFR 63.1204.[36] Performance testing is required to include continuous monitoring of kiln temperature, oxygen concentration, and kiln feed rate. The facility is also required to conduct continuous monitoring and recording of THC concentration in the exhaust gas. However, this permit does not list specific emission limits for the ODS HAPs (Indiana DEM 2003).

The Title V Operating Permit for Facility C, which operates two **lightweight aggregate kilns**, reflects the underlying MACT standard emission limits for lightweight aggregate kilns listed in 40 CFR 63.1205 or 40 CFR 63.1221, as applicable. Monitoring conditions and performance test requirements included are similar to the monitoring and performance test requirements for Facility A's rotary kilns. As with the permit for Facility B, this permit does not list emission limits for individual ODS HAPs (Virginia DEQ 2006).

Based on the three Title V Operating Permits described above, it is apparent that the level of detail of the permit conditions can vary. For example, the Title V Operating Permit for Facility A's rotary kilns explicitly identifies maximum emission limits, in units of pounds per hour, for the three ODS HAPs The Title V Operating Permits for the other two facilities do not contain explicit maximum emission limits for individual ODS. Overall, however, the performance testing, monitoring, and reporting requirements for the three facilities are similar.

Costs of Comprehensive Performance Testing (CPT)

The cost of conducting a CPT, which must be done every five years, can vary depending on the type and size of the facility conducting the test, the POHCs and other wastes burned during the test, and the types of sampling and analysis conducted. In general, the source of the costs can be roughly broken down as follows: 50 percent for the sampling and analytical costs, 25 percent for the purchase of any POHCs needed for the trial burns and/or additional wastes needed to obtain wastes with the correct metal content, and 25 percent for the destruction time lost during the performance of the test (Ullrich 2007). Estimates of the total costs to conduct a CPT range from $150,000 to $500,000. However, these costs could be significantly reduced if the only desired result was to determine the DRE for a specific ODS. If an ODS was added as a POHC to an already scheduled CPT, the additional analytical costs would range from $1,000 to $3,000, plus the cost to purchase the volatile chlorinated compound needed to conduct the test. Alternatively, a separate, DRE-specific performance test would cost around $50,000 (Ullrich 2007).

[35] Note that 40 CFR 63.1203 lists the interim standards, as full compliance with the final standards listed in 40 CFR 63.1219 is not required until October 2008.

[36] Note that 40 CFR 63.1204 lists the interim standards, as full compliance with the final standards listed in 40 CFR 63.1220 is not required until October 2008.