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The objective of this project is to compile data and analyses for the Air Resources Board (ARB) that will allow the Board and its staff to understand and assess the full range of issues regarding emissions of stratospheric ozone-depleting compounds (ODCs) and their control. The ODCs of interest in this study are the fully halogenated chlorofluorocarbons (CFCs); the partially-halogenated chlorofluorocarbons (HCFCs); the bromine-containing halon compounds; methyl chloroform; and carbon tetrachloride. These compounds are currently the focus of national and international control efforts.

This report presents: (1) U.S. and California ODC emissions inventoris for 1990 and 2005 that reflect current and expected future restrictions on ODC production, use and emissions; (2) detailed descriptions of the technologies available for reducing ODC use and emissions; and (3) summaries of current federal, state, and local legislations affecting ODC use and emissions.

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FINAL REPORT
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ABSTRACT

The objective of this project is to compile data and analyses for the Air Resources Board (ARB) that will allow the Board and its staff to understand and assess the full range of issues regarding emissions of stratospheric ozone-depleting compounds (ODCs) and their control. The ODCs of interest in this study are the fully halogenated chlorofluorocarbons (CFCs); the partially-halogenated chlorofluorocarbons (HCFCs); the bromine-containing halon compounds; methyl chloroform; and carbon tetrachloride. These compounds are currently the focus of national and international control efforts.

This report presents: (1) U.S. and California ODC emissions inventories for 1990 and 2005 that reflect current and expected future restrictions on ODC production, use and emissions; (2) detailed descriptions of the technologies available for reducing ODC use and emissions; and (3) summaries of current federal, state, and local legislation and regulations affecting ODC use and emissions.

Key conclusions drawn from the study include the following:

Future Emissions: Over time, U.S. ODC emissions will be eliminated by the ODC production phaseout mandated under the 1990 Clean Air Act Amendments and international agreements. Although U.S. production will be phased out in 1996, ODCs will continue to be emitted from products that contain them for at least 20 or more years after that time.

Control Measures: There are a large number of control measures for reducing ODC use and emissions. New chemical substitutes and processes are anticipated to be available for all new air conditioning and refrigeration systems. Alternative blowing agents are available for most types of foam production. Proven alternatives are available for all solvent cleaning needs, in particular the printed circuit board and electronics cleaning industries that are important in California.

Enforcement: In addition to phasing out the production of ODCs, federal rules being promulgated under the CAAAs cover a wide range of services and products found throughout the country. Local initiatives could assist in enforcing these requirements.

The Need for a Market in Recycled ODCs: A market for recycled ODCs is needed. While the production of ODCs is phased out, existing air conditioning and refrigeration equipment will require ODCs for servicing. "Drop-in" substitutes are not expected to be available, and the retrofits required to accept the new refrigerants appear to be costly. Consequently, ODCs recovered from equipment being disposed must be made available to enable existing ODC-based equipment to be used for its expected useful life. The CAAAs require ODC recovery and recycling at both service and disposal. These requirements will help to create a supply of recycled ODCs.

Potential Control Gaps: Over the next 10 to 15 years, steps should be taken to ensure that the remaining available ODCs are used most effectively. By doing so, emissions will be

minimized and the usefulness of existing ODC-based equipment will be maintained. The market for recycled ODCs should be monitored to assess whether interventions are needed to ensure the maximum possible recovery of ODCs during product servicing and disposal. In the event that the supply of recycled ODCs does not develop as currently expected, low-cost options for maintaining the usefulness of existing ODC-based equipment will require increased attention.

Additional Research Needs: By phasing out the production of ODCs, all ODC emissions will be eliminated. Currently, however, there are no provisions for preventing all the ODCs that were produced from being emitted eventually. In particular, ODC-based foams in buildings and appliances are expected to continue to emit ODCs slowly over many years. No cost-effective method of capturing these ODCs, even during product disposal, is currently available.

It is possible that recycled ODCs will remain available after ODC-based equipment is retired. In the event that more recycled ODCs are available than required, options for safely disposing of the chemicals may need to be developed. Over the long term, replacements for the transitional HCFCs will also be required. Demonstration projects for innovative cooling systems may be particularly valuable, as a variety of new chemical and process options are under development.

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ICF thanks the California Air Resources Board project manager, Marla Mueller, for her direction and assistance.

* In the State of California, ICF Incorporated does business as ICF Consulting Associates, Incorporated.

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prepared under the auspices of the United Nations Environment Programme (UNEP) which summarize technologies for reducing ODC use and emissions. Additionally, several reports have been prepared specifically for California (CEC, 1990 and ARB, 1990).

The analytic tools and data available from this literature form the primary basis for the material presented in this report. To perform the emissions inventory for 1990, these data were supplemented with new information in two areas:

1. The available data form the basis for estimating 1990 emissions for the entire U.S. Data were obtained that describe activity levels in California so that the national emissions estimate could be tailored to the state.

2. As the result of concern over ozone depletion, regulatory requirements, and increases in the price of ODCs, substantial shifts in ODC use and emissions have occurred in the last several years. The published available data do not reflect these recent shifts. New data were obtained based on contacts with industry representatives and ODC producers to quantify these shifts.

These new data help to ensure that the 1990 emissions inventory is as accurate as possible.

A similar approach was used to perform the 2005 emissions inventory. By the year 2005, most of the current ODCs will be phased out. Therefore, the 2005 emissions inventory is heavily influenced by the anticipated use of emission-reducing technologies, including substitute chemicals and products. Recent analyses performed for the U.S. Environmental Protection Agency (EPA) of the complex factors affecting future use and emissions in the U.S. were used as the basis for the 2005 inventory.

Considerable data on technologies for reducing use and emissions of ODCs are available from published sources. This project focused on organizing these data into a readily accessible format and summarizing the control options in terms of costs and effectiveness.

The updated review of federal, state, and local regulations and ordinances was prepared by contacting and interviewing federal, state, and local government representatives.

1.3 THE SCOPE OF THIS REPORT

This report covers all the ODCs and their expected substitute compounds listed in Exhibit 1. ODCs are used in the eight major end use sectors also listed in Exhibit 1. Each end use sector was examined in detail to estimate the current and expected future use and emissions of each compound. The results of this study can be used to describe how the various ODCs are used and emitted by end use sector.

Exhibit 1: ODCs and End Use Sectors

ODCs Currently In Use[a]	Candidate Substitutes[a]
Fully-halogenated CFCs: CFC-11: CCl_3F CFC-12: CCl_2F_2 CFC-113: CCl_2FCClF_2 CFC-114: $CClF_2CClF_2$ CFC-115: $CClF_2CF_3$ Halons: Halon 1211: $CBrClF_2$ Halon 1301: $CBrF_3$ Others: HCFC-22: $CHClF_2$ Methyl Chloroform: CH_3CCl_3 Carbon Tetrachloride: CCl_4 HFC-152a:[b] CH_3CHF_2	Chlorine-containing Compounds: HCFC-123: $CHCl_2CF_3$ HCFC-124: $CHClFCF_3$ HCFC-141b: CH_3CCl_2F HCFC-142b: CH_3CClF_2 Others: HFC-125: CHF_2CF_3 HFC-134a CH_2FCF_3 HFC-143a: CH_3CF_3

Major End Use Sectors

Refrigeration: ODCs are used as refrigerants in industrial, commercial, and residential refrigeration systems.

Air Conditioning: ODCs are used as refrigerants in commercial, residential, and mobile (i.e., automobile and truck) air conditioning systems.

Solvent Cleaning: ODCs are used to clean metal and electronic parts in a variety of applications.

Foam Production: ODCs are used in the production of polyurethane and non-urethane foams.

Sterilization: ODCs are used in commercial and hospital-based sterilization systems.

Fire Extinguishing: ODCs (halons) are used in fire extinguisher systems used to protect electronic equipment.

Chemical Intermediates: ODCs are used as chemical intermediates in the production of other compounds.

Miscellaneous: ODCs are used in a variety of miscellaneous categories including aerosol products and other devices.

a The chemical formulae are read as follows:

C = Carbon Cl = Chlorine F = Fluorine H = Hydrogen Br = Bromine

b HFC-152a does not contain chlorine or bromine, and hence does not deplete stratospheric ozone. HFC-152a is used in conjunction with other ODCs.

Similarly, technical controls were evaluated in detail for each end use sector, including: chemical substitutes; product substitutes; process substitutes; recycling and reuse; and disposal. The resulting summaries are intended as a compendium of options, and are organized as a reference volume. These data can be used to identify candidate options for reducing use and emissions by end use sector.

The review of regulatory and statutory efforts covers all recent activities in the U.S. The summaries highlight the objectives and implementation strategies of the various efforts. These data provide an overview of the variety of steps that have been taken at all levels of government to control ODC use and emissions.

1.4 REPORT ORGANIZATION

This report is organized as follows:

- Section 2 presents an overview of the ODCs and the steps currently underway to control emissions.
- Section 3 presents the emissions inventory for 1990.
- Section 4 presents the emissions inventory for 2005.
- Section 5 presents the control measure descriptions and evaluations.
- Section 6 summarizes the statutory and regulatory initiatives.

Appendices are included at the end of the report to present additional detailed data on specific topics.

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2. OVERVIEW OF OZONE-DEPLETING COMPOUNDS

This section presents a general overview of ozone depletion and the ozone-depleting compounds. The major ODCs and their uses are discussed. More detailed descriptions of the manner in which ODCs are used are presented in Section 3.

2.1 WHAT ARE THE OZONE-DEPLETING COMPOUNDS (ODCs)?

2.1.1 Stratospheric Ozone Depletion

Ozone is a trace constituent in the stratosphere, which is approximately 10 to 45 kilometers above sea level. The ozone molecule is comprised of three oxygen atoms (O_3), and is continuously created and destroyed in the stratosphere by natural processes. The equilibrium amount of ozone in the stratosphere (i.e., the "thickness" of the ozone layer) is controlled by the relative rates of ozone creation and destruction. If ozone is created faster, the layer will be "thicker;" if ozone is destroyed faster, the layer will be "thinner."

In 1974, Molina and Rowland (1974) hypothesized that CFCs would release chlorine in the stratosphere and increase the rate of ozone destruction. The increased rate of ozone destruction would reduce the equilibrium amount of ozone in the stratosphere, leading to ozone depletion.

Since 1974 the Molina and Rowland hypothesis has been verified. Compounds released from human activities are releasing chlorine and bromine into the stratosphere. The increasing atmospheric concentrations of the compounds and of chlorine and bromine are being monitored (WMO, 1989). These increasing concentrations are now associated with observed reductions in the amount of ozone in the stratosphere.

Although the observation of substantial reductions in Antarctic ozone during springtime (the ozone "hole") focused world attention on ozone depletion in the polar regions, widespread depletion has been confirmed (NASA, 1988; WMO, 1989). Exhibit 2 summarizes published estimates of trends in stratospheric ozone at the northern latitudes for which data are available. Because 17 years of data are available, the trend estimates are not sensitive to the influence of two natural sources of ozone variation: radiation fluctuations due to the 11-year solar cycle and changes in wind patterns associated with the Quasi-Biennial Oscillation (WMO, 1989). Therefore, these observed trends are believed to be caused by ODC emissions from human activities.

As shown in the exhibit, ozone depletion per decade ranges from about 0.4 percent to nearly 4.0 percent depending on latitude and season. More recent analyses based on satellite data have revised these estimates upward (Appenzeller, 1991). In the range of 30-39°N, Exhibit 2 shows that winter depletion may be about 0.9 to 1.7 percent per decade with smaller trends reported for summer (California falls in the range of about 33-42°N).

It is also well known that significant ozone loss is experienced in September and October over the Antarctic. This recurring "ozone hole" represents a loss of about 50 percent of the ozone over the continent. Much smaller losses have been detected over the Arctic. It is currently believed that the large rates of polar depletion are caused by heterogeneous chemical reactions occurring on the surface of polar stratospheric clouds (PSCs). Conditions necessary for these reactions to take place exist primarily in the polar regions, and are considered less important factors in the observed widespread depletion.

Exhibit 2: Observed Trends in Stratospheric Ozone Percent Reduction Per Decade (±2 std error limits)

Latitude (Range)	Winter (December-March)	Summer (May-August)
35°N (30-39°N)	-0.9% to -1.7% (±0.9) (±0.9)	-0.4% to -1.1% (±0.9) (±0.9)
45°N (40-52°N)	-2.0% to -3.0% (±0.8) (±1.7)	-0.7% to -1.1% (±0.6) (±0.8)
55°N (53-64°N)	-2.5% to -3.7% (±1.9) (±1.8)	-0.1% to -0.7% (±0.9) (±0.8)

Source: WMO (1989).

Concern about ozone depletion has arisen because stratospheric ozone shields the Earth's surface from ultraviolet (UV) radiation. The UV radiation blocked by the ozone layer is known to be harmful to human health and the environment. EPA (1987) provides a comprehensive review of the risks of increased UV radiation reaching the Earth's surface as the result of ozone depletion. The major impacts from increased exposure to UV radiation include: increased risks of skin cancer, cataracts and actinic keratosis (pre-cancerous skin lesions) in humans; suppression of the immune system in humans; crop damage; damage to polymer-based materials; and disruption of aquatic ecosystems (EPA, 1987). Additionally, increased UV radiation is expected to enhance the formation of ground-based ozone, which is a component of urban "smog."

2.1.2 Ozone Depleting Compounds

For purposes of this study, ozone depleting compounds (ODCs) are trace gases emitted from human activities that release chlorine or bromine into the stratosphere. To release chlorine or bromine into the stratosphere, the compounds must have two characteristics. First, they must

be sufficiently stable so that they do not break down in the lower atmosphere. If they were to break down in the lower atmosphere, they would not reach the stratosphere. Second, when they reach the stratosphere, the compounds must break down and release their chlorine and bromine atoms.

Exhibit 1 (above) lists the major ODCs currently in use in the U.S. As shown in the exhibit, all the compounds contain one or more chlorine or bromine atoms, and are divided into three main groups:[2]

- Fully-halogenated CFCs are the primary chlorofluorocarbons used today. These compounds contain chlorine and are called "fully-halogenated" because they have no hydrogen atoms.

- Halons are compounds with one or more bromine atoms. Halon 1211 and 1301 are the two halons used in the U.S.

- Other ODCs include: HCFC-22 and methyl chloroform which are partially-halogenated compounds (they contain hydrogen); and carbon tetrachloride.

This report focuses on these compounds that are solely emitted by human activities.

Of note is that recent analyses have suggested that methyl bromide (CH_3Br) may also be an important source of stratospheric bromine. Methyl bromide is not as stable in the lower atmosphere as the other compounds, and has significant natural sources (WMO, 1989). However, evidence of increased atmospheric concentrations of methyl bromide is prompting analyses of current industrial uses of the compound. Very little data are available on methyl bromide at this time, and consequently it is not included in this report.

2.1.3 The Relative Potency of the ODCs

The consideration of policy actions to control ODCs prompted the development of estimates of the relative potency of the ODCs for depleting stratospheric ozone. These estimates are referred to as "ozone depleting potentials" or ODPs.

Traditionally, the ODPs have been defined as the estimated steady state ozone depletion per kilogram of emissions relative to the depletion per kilogram of CFC-11 (WMO, 1989). For example, an ODP of 0.5 means that the compound will result in one-half as much ozone depletion per kilogram from a continuous release as would the same continuous release of CFC-11. This definition of the ODP can be expressed as follows:

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[2] HFC-152a, listed in Exhibit 2, is used in conjunction with ODCs but does not contain chlorine or bromine.

$$ODP = \frac{\dfrac{\text{Calculated Steady State depletion due to Compound X}}{\text{Emissions rate of Compound X}}}{\dfrac{\text{Calculated Steady State depletion due to CFC-11}}{\text{Emissions rate of CFC-11}}}$$

ODPs of this type are estimated using data on the physical characteristics of the ODCs and global atmospheric models. Because ozone depletion is a non-linear process, emission rates for each compound are selected to produce ozone depletion values of approximately one percent when the ODP calculations are conducted. While various uncertainties in the processes and models exist, model inter-comparisons show general agreement in the ODP estimates for the ODCs.

Exhibit 3 lists the ODPs for the ODCs recently published by WMO (1989) based on Fisher et al. (1989). As shown in the exhibit, ranges are reported based on the results of various atmospheric models. The point estimates shown were selected for use in this report. In some cases these estimates differ from the ODPs adopted in the original Montreal Protocol because estimates of the factors influencing the ODP values have changed over time.

A key aspect of the ODP estimates shown in the exhibit is that they rely on estimates of steady state ozone depletion. It is well known that the fully-halogenated CFCs are not near steady-state conditions because they are extremely stable in the atmosphere. Therefore, alternative measures of the relative impacts of the various compounds have been proposed that reflect the non-steady-state nature of the compounds.

Hoffman and Gibbs (1988) proposed that stratospheric chlorine loading over time be used as an indicator of relative impacts of the CFCs, and a similar concept of chlorine loading potentials was presented in WMO (1989). To illustrate the importance of non-steady-state conditions on the relative impacts of equivalent releases of the ODCs, the relative atmospheric chlorine loading from each ODC is listed in Exhibit 3 for periods of 10, 25, and 100 years of emissions. Equivalent emissions are assumed for each compound to permit inter-comparison. The longer the time period examined, the closer the conditions will be to steady state.

As shown in the exhibit, the relative chlorine loading values track the ODP values for the CFCs fairly well. By the time 100 years has elapsed, the relative chlorine loadings nearly match the steady-state ODP. The reason that these values match well is that the CFCs all approach steady-state at roughly similar rates.

Larger differences are evident, however, for HCFC-22 and methyl chloroform. In the near term (e.g., over the next 10 to 25 years) the relative impact of these two compounds is much larger than is indicated by their steady-state ODPs. For example over a 10 year period, the relative chlorine loading for HCFC-22 is estimated at about 0.5, which is 10 times larger than its ODP. The reason for these large differences is that HCFC-22 and methyl chloroform reach

steady state much faster than does CFC-11. Therefore, the full impacts of HCFC-22 and methyl chloroform are felt relatively quickly, while it takes many years for the full impacts of CFC-11 to be realized. Chlorine loadings are not estimated for Halon 1211 because it also contains bromine and are not estimated for Halon 1301 because it does not contain chlorine.

Exhibit 3: ODP and Chlorine Loading Estimates

ODC	ODP	Relative Chlorine Loading		
		10 Yrs	25 Yrs	100 Yrs
CFC-11	1.0	1.0	1.0	1.0
CFC-12	1.0 (0.9-1.0)	0.8	0.8	1.0
CFC-113	0.8 (0.8-0.9)	0.7	0.7	0.8
CFC-114	0.6 (0.6-0.8)	0.6	0.6	0.7
CFC-115	0.5 (0.3-0.5)	0.3	0.3	0.5
HCFC-22	0.05 (0.04-0.05)	0.5	0.4	0.2
Methyl Chloroform	0.11 (0.1- 0.16)	0.6	0.4	0.1
Carbon Tetrachloride	1.1 (1.0-1.2)	1.2	1.2	1.1
Halon 1211	3.0 (2.2-3.5)	(NE)	(NE)	(NE)
Halon 1301	10 (7.8-16)	(NE)	(NE)	(NE)

Source of ODP estimates: WMO (1989).

Source of Chlorine Loading Estimates: ICF Consulting Associates, Inc. estimate.

All estimates relative to CFC-11, which is assigned a value of 1.0.

NE = not estimated.

The implication of the chlorine loading values is that switching from the CFCs to HCFC-22, methyl chloroform, or similar compounds does not provide as large a benefit in the near term as would be indicated by the traditional ODP values. Because ozone depletion is now known to be widespread, near term impacts on the chlorine loading of the atmosphere should be considered along with the traditional ODP-based impact estimates when control actions are assessed.

2.2 HOW ARE ODCs USED AND EMITTED?

Since their invention in the early 1900s, CFC use grew consistently until the middle 1970s in the U.S. and globally. Initially used as refrigerants in both refrigerators and air conditioners, CFCs were found to have many desirable properties that made them useful for a variety of applications. Over time, new uses for CFCs were developed, including as aerosol propellants, foam blowing agents, sterilant gases, solvents, and chemical intermediates. By the early 1970s, CFCs were commodity chemicals, produced and traded internationally.

Exhibit 4 summarizes the manner in which the CFC-11 and CFC-12 were used in the U.S. in the mid-1970s and early 1980s. Aerosol propellant uses dominated both CFC-11 and CFC-12 use in 1975. By 1980, however, the U.S. had banned the use of the fully-halogenated CFCs in non-essential aerosol applications. As shown in the exhibit, aerosol use declined to a very low level by 1983.

Throughout the 1980s the non-aerosol uses of the CFCs continued to grow. CFC-113 use for cleaning electronic components grew significantly. In the late 1980s another significant restructuring of the CFC market was initiated in response to the ratification of the Montreal Protocol and the promulgation of regulations by the U.S. EPA and others to control CFC use and emissions.

In the last several years CFC production and use in the U.S. has declined approximately 40 percent relative to production levels in the mid- to late 1980s, and all production will be eliminated before the end of the century. Most of the reductions to date have occurred in the use of CFCs for manufacturing various types of plastic foams and in solvent applications. In some cases, HCFC-22 has emerged as a substitute chemical, and its use has increased in some areas. These recent significant shifts in use and emissions are discussed more fully in the context of the 1990 emissions inventory in Section 3.

Compared to CFCs, the market for methyl chloroform has developed more recently. Used principally as a solvent in a variety of applications, methyl chloroform use began to grow in the late 1960s when it was viewed as a favorable alternative to trichloroethylene, a suspected carcinogen. In addition to its solvent uses, methyl chloroform is used in aerosol products, and in inks, adhesives, and coatings.

The halons are used exclusively as fire extinguishing agents. Halons are valuable fire extinguishing agents because they are very effective at extinguishing a fire and preventing/suppressing explosions, while also: being electrically nonconductive; dissipating quickly; leaving no residue; and posing little harm from human exposure (UNEP, 1991). As a consequence, halons are used to protect computers and other sensitive equipment from fire.

Based on testing performed in the 1940s, halon 1301 was selected for military fire protection applications in the U.S. (UNEP, 1991). Halon 1301 became the halon of choice for total flooding fire extinguishing systems, and its use has grown significantly since 1966 when it started to be used to protect computer rooms and command and control centers. Total flooding

systems are designed to "flood" an entire room or area rapidly with the fire extinguishing agent. In this case, halon 1301 is flooded into the room to extinguish the fire.

Halon 1211 was also recognized as a suitable fire extinguishing agent in the late 1940s. Halon 1211 has become the halon of choice for portable fire extinguishers, and is found in military and various commercial applications in museums, art galleries, and computer rooms.

Exhibit 4: Historical CFC Use in the U.S.

ODC Year	Distribution Across Major Uses (%)			
	Aerosol Propellant	Foam Production	Refrig. Air Cond.	Misc.
CFC-11				
1975	60%	29%	3%	8%
1980	13%	68%	6%	13%
1983	5%	78%	7%	10%
CFC-12				
1975	53%	6%	28%	13%
1980	4%	14%	52%	30%
1983	4%	14%	52%	30%

Source: ICF Consulting Associates, Inc. estimate for EPA (1988).

2.3 STEPS UNDERWAY TO CONTROL ODC EMISSIONS

ODC use and emissions were first controlled in the late 1970s in the U.S. Since then, two international agreements, the Vienna Convention of 1985 and the Montreal Protocol of 1987, were negotiated and ratified. Most recently, the U.S. enacted the Clean Air Act Amendments of 1990 authorizing EPA to promulgate regulations to fulfill the U.S. obligations under the Montreal Protocol and its subsequent revisions agreed to in London in 1990 (the London Agreements). Throughout this period, various state and local regulations and ordinances have also been promulgated and enacted. The following is a brief history of these events. Section 7 presents a complete review of national, state, and local regulations and ordinances.

In 1978, the U.S. Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) banned the use of CFCs as propellants in non-essential aerosol products

(43 FR 11301; March 17, 1978). The Consumer Product Safety Commission (CPSC) issued regulations requiring that exempted aerosol products bear a warning label identifying the product as containing CFCs, which may deplete ozone. Several other nations also controlled the use of CFCs as propellants in aerosol products.

In the 1977 Amendments to the Clean Air Act, Congress strengthened EPA's regulatory authority for actions to protect stratospheric ozone. In 1980, EPA issued an Advance Notice of Proposed Rulemaking (ANPRM), "Ozone-Depleting Chlorofluorocarbons: Proposed Production/Restriction" (45 FR 66726; October 7, 1980) that called for limits on non-aerosol uses of CFCs. The Agency announced its objective to freeze current emissions of ozone-depleting compounds.

In 1984, the Natural Resources Defense Council (NRDC) brought suit against the EPA, arguing that the ANPRM constituted a finding of a reasonable threat to the stratosphere, which required the Agency either to issue regulations or to formally withdraw the ANPRM. In 1985, EPA and NRDC were joined by the Alliance for Responsible CFC Policy in filing a joint settlement motion calling for a proposed regulatory decision by May 1, 1987 and a final decision by November 1, 1987. This consent decree was extended in 1987 with deadlines set for December 1, 1987 and August 1, 1988 for proposal and final action, respectively.

Concerted international efforts at protecting stratospheric ozone had begun in 1981 under the auspices of the United Nations Environment Programme (UNEP). In 1982, the UNEP Governing Council established the Ad Hoc Working Group of Legal and Technical Experts, which began negotiating a global framework for a convention to protect the ozone layer. Negotiations in 1985 under the auspices of UNEP resulted in the adoption of the Vienna Convention for Protection of the Ozone Layer. This convention set no specific targets for CFC restrictions, but established a framework for further international negotiations to develop such limits, and required member nations to submit CFC production and use data to UNEP.

Under the auspices of the Vienna Convention, and consistent with EPA's consent decree, a series of domestic and international workshops were held to set forth the technical data that could be used to negotiate an international agreement to control CFCs. Following a series of negotiations in late 1986 and early 1987, a final Diplomatic Conference was held in Montreal, Canada in September 1987 that concluded negotiations for an international protocol. This historic international agreement called for a freeze of CFCs 11, 12, 113, 114, and 115 production at 1986 levels in 1989, followed by a 20 percent reduction in 1993 and a 50 percent reduction in 1998. Halons 1211, 1301, and 2402 were to be frozen at 1986 levels in 1992.

The agreement also called for periodic assessment and review of the international control measures and set trade restrictions on countries that were not parties to the protocol. Developing countries with low levels of use per capita were permitted to delay their compliance with the Protocol for up to 10 years. The Parties to the Protocol also agreed to assist developing countries to make expeditious use of environmentally-safe alternative substances and technologies.

The U.S. implemented its obligations under the Montreal Protocol by restricting the production and import of CFCs and halons using a quota system (53 FR 30566, August 12, 1988). At the same time, EPA published an advance notice of proposed rulemaking to consider further efforts to protect stratospheric ozone (53, FR 30604, August 12, 1988).

In response to new scientific evidence developed since the Protocol was negotiated, a number of countries, including the U.S., called for further actions to protect the ozone layer by expanding the provisions of the Montreal Protocol. In April 1989, 70 nations met in Helsinki, Finland at the First Meeting of the Parties to the Montreal Protocol and agreed to a non-binding resolution calling for a complete phaseout of CFCs and halons and for reductions in other ozone-depleting chemicals as soon as feasible.

In July 1990, the parties to the Montreal Protocol met in London to discuss possible agreements on more stringent control measures in light of the new scientific findings on stratospheric ozone depletion. The parties in London agreed to amendments calling for a phaseout of all fully halogenated CFCs, halons, and carbon tetrachloride by the year 2000, and for a phaseout of methyl chloroform by the year 2005. In addition, the parties agreed to a resolution calling for a phaseout of HCFCs by the year 2020 if feasible, and no later than 2040.

In November 1990, the U.S. enacted new Clean Air Act (CAA) amendments that include provisions for stratospheric ozone protection. These amendments continue the federal role in the control of production and imports of ODCs. The amendments require a faster phaseout in the U.S. of ozone-depleting compounds than was specified in the international agreement in London. CFCs, halons, and carbon tetrachloride are to be phased out by the year 2000. Methyl chloroform is to be phased out by the year 2002 -- three years earlier than the international agreement. HCFC production is to be frozen in the year 2015 and phased out by the year 2030. In addition to the control of imports and production, the Clean Air Act amendments also give EPA the authority to issue controls on individual ODC uses.

Given the strong U.S. and international policy initiatives of 1990, it is clear that the production of CFCs will be phased out over the next 10 to 15 years. Recent announcements indicate that CFCs and MC may be phased out within the next five years. HCFCs are now generally considered to be "transition" chemicals, playing a role to help eliminate CFCs, but themselves being controlled and phased out in the long term.

Considerable uncertainty remains regarding the best way to conduct the transition away from CFCs and, eventually, HCFCs. With the exception of the non-essential aerosol propellant ban, to date the international treaties and federal U.S. role have been solely to limit production and imports of the controlled chemicals. Restrictions on specific uses or requirements for specific technologies have not been adopted at the federal or international levels, and the state and local prerogatives in this area have not been preempted.

Because federal regulations did not preempt state or local authority to put specific use limits or requirements in place, numerous initiatives have been undertaken at the state and local level. With the enactment of the Clean Air Act amendments, the federal role will shift significantly.

The EPA is implementing a program to control emissions from mobile air conditioners and other refrigeration and air conditioning equipment. Additionally, the EPA has authority to control other specific uses (see Section 6).

2.4 THE RELATIONSHIP BETWEEN OZONE DEPLETION AND GLOBAL WARMING

Stratospheric ozone depletion and global warming are two global environmental problems associated with trace gas emissions from human activities. While these two issues are closely related and frequently discussed together, they are in fact quite different.

As discussed above, stratospheric ozone depletion is caused by chlorine and bromine released into the stratosphere. Global warming is caused by a completely separate mechanism: the build up of trace gases in the atmosphere that "trap heat." The fact that water vapor, carbon dioxide, methane, and other trace gases trap heat and warm the Earth has been know for over a century. In fact, without the natural warming effects of water vapor and other trace gases in the atmosphere, the Earth would be about 33°C colder on average than observed today, which would be too cold to support life as we know it.

Although the atmospheric abundances of carbon dioxide and methane have been relatively stable for many thousands of years, comprehensive global measurements show that the concentrations of these two most important greenhouse gases have been increasing over the last 200 years. Best estimates indicate that the increase in carbon dioxide abundance is being caused by the burning of fossil fuels and shifts in land use, principally deforestation. Similarly, methane concentration increases appear to be the result of increased emissions from its various anthropogenic sources, including fossil fuel production and use, landfills, rice cultivation, and animal husbandry. Because methane and carbon dioxide also have large natural sources and because their atmospheric abundances are controlled by complex bio-geochemical cycles, the precise causes of the observed increases in concentrations cannot be proved definitively.

The ODCs, and in particular the fully-halogenated CFCs, also trap heat in the atmosphere, and consequently also contribute to global warming. Ozone depletion itself also affects the Earth's ability to trap heat, and consequently also is a factor to be considered as part of the global warming issue.

Exhibit 5 lists the manner in which the ODCs and their substitutes affect global warming and the manner in which carbon dioxide and methane affect stratospheric ozone depletion. As shown in the exhibit, the fully-halogenated CFCs, halons, and partially-halogenated HCFCs contribute to both stratospheric ozone depletion and global warming. Of note is that recent scientific studies indicate that ozone depletion itself may cause a significant global cooling. If these analyses are verified, the net impact of the ODCs on global warming may be quite small as the ozone depletion-related cooling offsets the additional heat trapped by the ODCs themselves.

Exhibit 5: Stratospheric Ozone and Global Warming Impacts

Trace Gas	Impact on Stratospheric Ozone	Impact on Global Warming
Fully-halogenated CFCs, carbon tetrachloride, and halons	Release chlorine and bromine which deplete stratospheric ozone.	Contribute to warming by trapping heat. Ozone depletion causes cooling.
Partially-halogenated HCFCs and methyl chloroform	Release chlorine which depletes stratospheric ozone.	Contribute to warming by trapping heat. Contribute to warming by increasing the lifetime of methane in the atmosphere (this is a minor effect). Ozone depletion causes cooling.
Partially-halogenated HFCs (ODC substitutes)	No direct impact on stratospheric ozone depletion. Contribute to stratospheric ozone depletion by increasing the lifetimes of the HCFCs in the atmosphere (this is a minor effect).	Contribute to warming by trapping heat. Contribute to warming by increasing the lifetime of methane in the atmosphere (this is a minor effect).
Carbon Dioxide	Reduces the rate of stratospheric ozone depletion by cooling the stratosphere. May promote ozone depletion, however, by promoting the formation of stratospheric clouds which are implicated in the stratospheric chemistry causing the ozone hole.	Contributes to warming by trapping heat. CO_2 is the most important greenhouse gas accounting for over 50% of expected future global warming.
Methane	Reduces the rate of stratospheric ozone depletion by cooling the stratosphere. May be an important factor causing increased ozone depletion because methane may contribute to stratospheric water vapor, which has been implicated in the heterogeneous chemistry causing the ozone hole. Also contributes to stratospheric ozone depletion by increasing the lifetimes of the HCFCs in the atmosphere.	Contributes to warming by trapping heat. CH_4 is the second most important greenhouse gas, accounting for about 15 to 20% of expected future global warming. Also contributes to warming by promoting the formation of ground-based ozone and increasing the atmospheric lifetimes of HCFCs and HFCs.

Also shown in the exhibit is that the ODC substitutes that do not contain chlorine or bromine have no direct impact on stratospheric ozone depletion. These compounds may have a slight impact on stratospheric ozone by increasing the atmospheric lifetimes of the partially-halogenated HCFCs, thereby enhancing the ability of the HCFCs to inject chlorine into the stratosphere. This indirect impact is small, however, due to the relatively small amount of ODC substitutes that will likely be emitted.

The partially-halogenated ODC substitutes do contribute to global warming directly, however, because they are able to trap heat. Because these ODC substitutes do not deplete

stratospheric ozone, they may have a larger impact on global warming than the ODCs they replace if the ozone-depletion-cooling caused by the ODCs is significant.

Carbon dioxide is well known to be the principal trace gas contributing to anthropogenically-induced global warming. It has been believed that the carbon dioxide build up helps to slow the rate of ozone depletion by cooling the stratosphere. More recently, however, it has been asserted that stratospheric cooling may contribute to the formation of stratospheric clouds, which are associated with the formation of the ozone hole. The net impact of carbon dioxide on stratospheric ozone is ambiguous at this time.

Following carbon dioxide, methane is the second most important greenhouse gas. It traps heat directly and contributes to warming indirectly by promoting the formation of ground based ozone (which traps heat) and increasing the atmospheric lifetimes of the HFCs and HCFCs (which will then trap more heat). As with carbon dioxide, methane's impact on stratospheric ozone is ambiguous.

As with the ODPs discussed above, Global Warming Potentials (GWPs) have been developed for the various ODCs and other trace gases. The GWPs express the relative ability of the trace gases to trap heat and contribute to the greenhouse effect. Because there are uncertainties in the processes that cause global warming, there is also uncertainty in the GWPs. For example, to date the GWPs for the ODCs do not take into account the ozone-depletion-cooling that may offset the ODCs' heat trapping ability. Additionally, as with the ODPs, the GWPs can be calculated over various time horizons, such as 20 or 100 years.

Exhibit 6 presents recently published estimates of GWPs for the major ODCs. The steady state GWPs are estimated using a procedure similar to the procedure used to estimate the steady-state ODPs. As shown in the exhibit, HCFC-22 has a relatively low steady-state GWP relative to CFC-11, while its near term GWP (20 years) is much higher. A similar effect is seen with methyl chloroform.

This brief review of the relationship between these two issues demonstrates that efforts to address one problem will have various impacts on the other. In some cases, scientific investigations are only now uncovering important relationships among the ODCs, ozone depletion and global warming.

Exhibit 6: Steady-State and Time-Dependent GWPs				
ODC	Steady-State GWP	Time-Dependent GWP		
		20 Yrs	100 Yrs	500 Yrs
CFC-11	1.0	1.0	1.0	1.0
CFC-12	2.7-3.4	1.6	2.1	3.0
CFC-113	1.3-1.4	1.0	1.2	1.4
CFC-114	3.7-4.1	1.3	2.0	3.7
CFC-115	7.5-7.6	1.2	2.0	4.9
HCFC-22	0.34-0.37	0.91	0.43	0.34
Methyl Chloroform	0.022-0.026	0.08	0.03	0.02
Carbon Tetrachloride	0.34-0.35	0.42	0.37	0.31
Halon 1211	(not estimated)	(not estimated)	(not estimated)	(not estimated)
Halon 1301	(not estimated)	1.3	1.7	2.1

Source of steady-state GWP estimates: WMO (1989).

Source of time-dependent GWP values: IPCC (1990).

All estimates relative to CFC-11 which is set to 1.0. Estimates do not include cooling associated with ozone depletion.

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3. EMISSIONS INVENTORY FOR 1990

3.1 INTRODUCTION

This section presents the ozone depleting compound (ODC) emissions inventory for the State of California for 1990. The emissions inventory is based on: (1) emissions factors developed from a model of the use and emissions of ODCs in the United States; and (2) state-specific activity levels for the major ODC applications. Because ODC use and emissions have been changing rapidly in response to federal restrictions on ODC production, emissions inventories from the mid- to late-1980s are no longer applicable. This section presents an emissions inventory for the most recent year for which data are available, 1990. Additionally, near term trends in emissions are discussed.

3.2 METHODOLOGY

The general approach for developing the 1990 emissions inventory was to apply emissions factors for the key ODC applications to activity levels for those applications. A large volume of information exists on ODC use and the mechanisms that lead to emissions in these uses. In addition to drawing in this available information, the emissions estimates presented in this section reflect information collected on the recent changes in ODC use and California-specific data on activity levels.

The emissions inventory for 1990 was developed using the following four steps.

1. Source Characterization. The applications in which ODCs are used were identified. Each application was characterized in terms of which ODCs are used and the manner in which each is used. The substantial available data on the ODC applications in the U.S. were used to perform this task.[3] New ODC applications have not been developed in the past several years, consequently the available information is a good representation of the ODC sources in the U.S. Additionally, all the sources are known to exist in the State of California, so this body of information is a good basis for source characterization within the state.

The amount of ODCs used and emitted from the applications has shifted significantly as the result of federal controls. Therefore, the available published information on the pattern of total U.S. ODC use and emissions is no longer current. Thus, the available information was used principally to identify and characterize the applications.

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[3] Published reports on ODC applications in the U.S. include: EPA (1979, 1980, 1987, 1988, 1990) and Hammitt et al. (1986).

2. Emissions Algorithms. Emissions algorithms were developed to model the full life-cycle emissions from the ODC applications. The algorithms describe how ODCs are emitted during each phase of the product life-cycle, including: manufacturing; operation; servicing; and disposal.

ODCs are used in many refrigeration and cooling applications which emit from each of these life-cycle phases. A detailed simulation model developed for the U.S. EPA, the Vintaging Analysis Framework (VAF), was used to represent the emissions algorithms for these applications. This model: (1) describes the equipment used in each application in terms of its "vintage" or age; and (2) simulates the events that lead to emissions from each vintage. For example, the likelihood of requiring service varies with the "vintage" or age of the equipment. The VAF simulates the expected frequency of servicing and estimates ODC use and emissions based on estimates of the ODC requirements of each service event. The emissions events modeled vary with the application. For example, emissions associated with automobile accidents are included in the analysis of mobile air conditioners (MACS).

Because the VAF is capable of representing the emissions events in significant detail, and because it has been benchmarked to independent estimates of ODC usage in the U.S., it is a good tool for representing the emissions algorithms for this emissions inventory. The VAF is described in more detail in Appendix A.

Other ODC applications have relatively simple emissions profiles. For example, ODCs have been used in the production of flexible polyurethane foams. The ODCs are emitted immediately when the foam is produced. Because there are no operation, servicing or disposal emissions, the emissions from flexible foams in a year are equal to the quantity of ODC used to produce the foams in that year. The emissions algorithms used in each application are described in more detail below.

3. Activity Levels. Activity levels describe the "sizes" of the applications in various ways, and consequently provide the basis for estimating ODC use and emissions. For applications that have emissions throughout their life-cycle, the preferred approach for defining the activity level is in terms of the "stock" of equipment in use and the production of equipment that is being added to the stock. For example, the activity level for home refrigerators is defined as the number of home refrigerators in use in 1990 by vintage, and the number of refrigerators produced in 1990. Emissions due to servicing and disposal events are associated with the stock of refrigerators, while manufacturing emissions are associated with the refrigerators produced in 1990.

For applications that only have emissions during production, the activity levels can be defined simply as the production quantity. For example, the activity level for flexible polyurethane foam is the quantity of foam produced in 1990, or the quantity of CFC used to produce the foam.

Detailed activity levels have been developed at the national level in previous work for the U.S. EPA. In some cases analogous California-specific data were obtained so that the California activity levels were comparable to the national data collected previously. However, in most cases

detailed California-specific data were not readily available. In these cases more aggregated data were used. For example, although a good estimate of the total home refrigerator stock in California was available, a reliable estimate of the age distribution of home refrigerators in the state was not. Consequently, the home refrigerator age distribution was assumed to be the same as the age distribution for the nation as a whole.

In some cases, even aggregate California-specific data comparable to the national activity data could not be obtained. In these cases, proxies were used for the activity levels. For example, in previous work, data were obtained on the number of cooling units used in the chemical industry. Because similar estimates were not available for California, data on number of establishments in the industry nationally and in the state were obtained. These data were used as proxies for the detailed activity levels.

While preparing the emissions inventory, emphasis was placed on collecting the most detailed activity level data possible for those ODC applications with the largest emissions. Less emphasis was placed on the minor applications, which generally resulted in the use of more proxy data for the minor uses.

4. Emissions Estimates. Using the data developed above, the 1990 emissions were estimated for each application. The following computations were performed:

- Based on the source characterizations, the emissions algorithms, and the national activity levels, 1990 emissions for the U.S. were estimated for each application and each ODC. These estimates start with the pattern of ODC use and emissions in the mid-1980s, and adjust them to reflect the recent shifts in ODC use as a consequence of federal controls.

- Emissions factors were estimated by dividing the U.S. 1990 emissions for each application by national activity levels for which comparable California-specific information is available.

- California emissions were estimated for each application by multiplying the emissions factor based on the national data by the California-specific activity levels. In several cases these emissions estimates were adjusted slightly to reflect California-specific factors that have not been modeled at the national level.

This procedure produced estimates of ODC emissions for each application. The emissions by ODC were estimated by summing across the applications.

3.3 EMISSIONS ESTIMATES

3.3.1 Mobile Air Conditioning

End Use Description. Mobile air conditioners (MACs) refer to air conditioners used to cool the passenger compartments of vehicles including automobiles (cars) and light trucks. MACs use CFC-12 exclusively as the refrigerant because it is thermodynamically suitable, chemically stable, non toxic, non flammable, and non corrosive. The design and production of MACs are controlled by the automobile manufacturers. However, MACs are serviced at thousands of automobile repair shops throughout the state.

Currently, approximately 92 percent of new passenger vehicles in the U.S. have MACs installed in the automobile manufacturing plants. Overall, approximately 90 percent of the passenger cars and 55 percent of the light trucks in service in 1990 have MACs. All manufacturers supplying the U.S. market plan to phase out CFC-12 in MACs by the end of the 1995 model year, and will install air conditioners containing an alternative refrigerant in all new vehicles by that time. At this time, HFC-134a is anticipated to be the replacement refrigerant.

Unfortunately, there is no drop-in substitute refrigerant for existing MACs. HFC-134a and other substitutes can only be used in existing systems after retrofitting the system at substantial cost. Consequently, CFC-12 will be required to service the existing MACs through their remaining useful lives. Recognition of this need has led to the implementation of federal CFC-12 recycling requirements during MAC servicing. Various state and local recycling programs have also been initiated. The MAC recycling programs, and ODC recycling in general from other applications, will play an important role in supplying CFC-12 for MAC servicing in the future.

Emissions Algorithm. The Vintaging Analysis Framework (VAF) was used to model the emissions from MACs. The following events were modeled as causing emissions in 1990:

- Manufacturing: a small amount of CFC-12 is emitted when MACs are installed.
- Normal Leakage: during normal use, CFC-12 leaks out very slowly as the result of permeation through hoses and around fittings.
- Abnormal Leakage: poor-fitting or worn hoses or fittings can result in larger than normal leakage during normal use.
- Accident: a portion of accidents result in the rupture of the MAC system, and consequently a release of CFC-12.
- System Failure with a Rupture: occasionally the MAC system ruptures and fails, releasing CFC-12; a broken hose may result in this type of system failure.

- System Failure without a Rupture: occasionally the MACS system fails without rupturing and releasing CFC-12; this event prompts the need for servicing. A failed compressor is an example of this type of system failure.

- Servicing: servicing is modeled to occur when normal or abnormal leakage results in degraded system performance. Servicing is also performed as the result of system failures and accidents. Emissions during servicing result from the venting of the CFC-12 remaining in the system (if applicable) and leakage during servicing activities.

- Disposal: if CFC-12 remains in a MAC at the time of disposal it is routinely vented when the MAC is salvaged or the vehicle destroyed.

Because recycling programs are now being put into place, emissions associated with servicing and disposal are expected to decline relative to the estimates for 1990. In 1990, recycling was not significant at the national level, however, several communities in California adopted recycling requirements in 1990 or the beginning of 1991 (see Section 6). Consequently, a small amount of recycling was probably taking place in 1990 in California, making the emissions estimates based on the national data biased upward. As discussed below, the California emissions estimate was adjusted downward slightly to address this bias.

It has been suggested that the national estimates of the frequency of MAC servicing may not be appropriate for MACs in California because of differences in climate or miles driven. To date there is no evidence that miles driven has an impact on the need to service a MAC or expected emissions. Although there may be differences in the likelihood of accidents, which could lead to differences in emissions, accident-induced emissions are a relatively small portion of total MAC emissions (less than 10 percent), so potential biases associated with differential accident rates are not expected to be serious.

Similarly, climate differences have not been demonstrated to play a role in emissions. Although MACs may be utilized more hours per year in California, leakage rates are not modeled as a function of hours of operation. In fact, the mild winters and more frequent MAC usage in the state may help reduce leakage by keeping valves and fittings well lubricated. Consequently, the national data are used to model the emissions from MACs.

Activity Levels. Exhibit 7 presents the national and state-specific activity level data used in the analysis. As shown in the exhibit, data were collected for four vintage categories: pre-1976; 1976-1980; 1981-1984; and 1985-1990. The data indicate that overall the cars in use in California are about 11.5 percent of the cars in use nationally; the figure for light trucks is about 6.8 percent. However, the percentages are not constant by vintage; California has a larger proportion of older cars and the percentage of light trucks varies for the vintages. Because MAC emissions vary with vehicle age, the differences in the ages of the U.S. and California cars and trucks affect the California emissions estimates.

Exhibit 7: Activity Levels for MACs

	Numbers of Vehicles in Use in 1990 by Vintage (Thousands)				Total
	Before 1976	1976-1980	1981-1984	1985-1990	
U.S. Passenger Cars	11,720	26,076	28,944	56,427	123,167
U.S. Light Duty Trucks	8,862	11,259	9,864	25,879	55,864
California Passenger Cars	1,715	3,045	3,581	5,850	14,191
California Light Duty Trucks	496	887	1,033	1,365	3,781
CA Passenger Cars as % of U.S.	14.6%	11.7%	12.4%	10.4%	11.5%
CA Light Duty Trucks as % of U.S.	5.6%	7.9%	10.5%	5.3%	6.8%

Sources: U.S. data reported for cars in operation in MVMA (1991). California data reported as registered cars in operation from EMFAC output provided by ARB (1991).

More detailed activity level data were desired for California, including: estimates of the portion of cars that are domestic versus import; and estimates of the portion of cars and trucks equipped with MACs. Data collection efforts did not identify these estimates in published sources. Consequently, the national estimates for these proportions were used. Using the national proportions may bias the emissions estimates by an unknown amount because:

- It is anticipated that California cars have a larger proportion of imports than the national average. Because import cars have had smaller air conditioners, their emissions per car tend to be lower than the emissions from domestic cars. Consequently, using the national proportion of import cars may bias the emissions estimate upward.

- It is likely the proportion of cars and trucks in California with MACs is larger than the national average because of the hot climate in many parts of the state. Using the national average data may bias the emissions estimates downward.

In the absence of better information, the magnitudes of these potential biases cannot be determined. However, the biases are not anticipated to be large because the differences in emissions per MAC from domestic and import cars is small and the national estimate of the proportion of cars with MACs is about 90 percent.

Emissions Estimate. The VAF was used to estimate U.S. emissions from MACs in 1990. California emissions were estimated using the national and state-specific activity levels presented above. Exhibits 8 and 9 present the emissions estimates for cars and light trucks respectively. As shown in the exhibits, total national emissions are about 61 million kilograms, and California emissions are about 6.3 million kilograms, or about 10 percent of the national total. Over 80 percent of the emissions are associated with cars, with the remainder associated with light trucks.

About one-third of emissions originate from the newest vintage of cars and trucks (1985-1990) for both California and the U.S., even though these vehicles make up 40 to 45 percent of the total population of vehicles. As shown in the exhibits, the newest vehicles have below average emissions per vehicle. The oldest vehicles also have below average emissions per vehicle, principally because the portion of older vehicles with MACs is lower.

Exhibit 8: Emissions Estimates for MACs from Cars

	CFC-12 Emissions in 1990 by Vintage				
	Before 1976	1976-1980	1981-1984	1985-1990	Total
U.S. Estimates (thousands of kilograms)					
Manufacturing Emissions	na	na	na	900	900
Normal and Abnormal Leakage	341	1,941	2,769	4,963	10,014
Accidents, System Failure and Servicing	1,027	7,082	7,220	13,538	28,867
Disposal	1,625	5,202	2,429	992	10,249
Total	2,993	14,226	12,418	20,394	50,030
California Estimates (thousands of kilograms)					
Manufacturing Emissions	na	na	na	93	93
Normal and Abnormal Leakage	50	227	342	515	1,134
Accidents, System Failure and Servicing[a]	143	786	848	1,334	3,111
Disposal	238	608	301	103	1,249
Total	430	1,620	1,491	2,045	5,587
Average Annual Emissions per Vehicle Based on U.S. Data (kilograms)					
Cars	0.26	0.55	0.43	0.36	0.41

a Estimates reflect a 5% reduction relative to national data due to California recycling requirements. See text.
Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 9: Emissions Estimates for MACs from Light Trucks

	CFC-12 Emissions in 1990 by Vintage				
	Before 1976	1976-1980	1981-1984	1985-1990	Total
U.S. Estimates (thousands of kilograms)					
Manufacturing Emissions	na	na	na	234	234
Normal and Abnormal Leakage	253	508	560	1,346	2,667
Accidents, System Failure and Servicing	863	1,840	1,406	2,965	7,073
Disposal	392	430	101	28	951
Total	1,508	2,777	2,067	4,573	10,924
California Estimates (thousands of kilograms)					
Manufacturing Emissions	na	na	na	12	12
Normal and Abnormal Leakage	14	40	59	70	183
Accidents, System Failure and Servicing[a]	46	138	140	147	470
Disposal	22	34	11	1	68
Total	82	212	209	231	733
Average Annual Emissions per Vehicle Based on U.S. Data (kilograms)					
Light Trucks	0.17	0.25	0.21	0.18	0.20

a Estimates reflect a 5% reduction relative to national data due to California recycling requirements. See text.
Source: ICF Consulting Associates, Incorporated estimates.

Because recycling requirements became effective in portions of California in 1990 and the beginning of 1991, the California estimates for accidents, system failure, and servicing were reduced by 5 percent relative to the national estimates. A large portion of the emissions from these events is associated with venting and other emissions during servicing. A modest reduction in emissions is therefore included for this category for the 1990 emissions inventory. As recycling during servicing becomes mandatory throughout the state by 1993 under federal regulation (see Section 6), the emissions associated with these events will decline further.

Several factors contribute to the uncertainty in these emissions estimates for MACs. The underlying national data on the frequency of the emissions events and the emissions associated with each are uncertain. In particular, estimates of CFC use based on these data obtained from

industry surveys and repair statistics underestimate total CFC use in the application reported by producers by about 20 percent. Consequently, the estimates of CFC use (and emissions) are increased in the accident, system failure, and servicing category to compensate. Further uncertainty is added to the California estimates because only aggregate activity level data are available and because the effect of recycling in 1990 could not be evaluated precisely.

Despite these uncertainties, MACs are among the largest single emitters of ODCs in California. Given current and impending federal recycling regulations, these emissions will be reduced substantially. Additionally, because automakers are switching to HFC-134a in MACs, emissions of CFC-12 will decline substantially in the long term.

3.3.2 Process Refrigeration

End Use Description. Process refrigeration refers to refrigeration equipment used during the manufacture of products and for other industrial applications. It is used primarily in the chemical, pharmaceutical, petrochemical, oil and gas, metallurgical and industrial ice making industries. (Refrigeration for cold storage warehouses is discussed below under commercial refrigeration.)

Process refrigeration equipment includes a broad spectrum of designs. Equipment is not standardized but is typically designed and manufactured to specification. There are, however, several key characteristics of the process refrigeration sector:

- The number of process refrigeration units is comparatively low, and the amount of refrigerant used in each (the "charge") is typically large, often in the range of several thousand tons.
- The equipment has a 25 to 30 year lifetime.
- There is generally no public access to the systems; and
- System reliability and energy efficiency are important concerns because of the high cost and the direct link to industrial production.

Ammonia, hydrocarbons, HCFCs and CFCs are the most common types of refrigerants used, with CFC-based systems comprising only about 15 to 20 percent of the total sector. The choice of refrigerant depends primarily on the temperature range needed. The major portion of industrial cooling is required for moderately low temperatures of approximately -20°C and above. CFC-500[4] is typically used for the low temperature region (-70°C to -45°C); ammonia and HCFC-

[4] CFC-500 is a mixture of 74 percent CFC-12 and 26 percent HFC-152a (by weight).

22 and some CFC-502[5] is used above -45°C; CFC-12 is mostly used for -30°C and above; and CFC-11 is used for water chilling in the range of 5-10°C.

Although CFCs are the most expensive refrigerant, they are used for process refrigeration primarily because they are safe, easy to handle, nontoxic and nonflammable. However, as a result of the specialized needs in the process refrigeration sector, system availability, energy consumption and refrigerant price are more important concerns than hazards from toxicity and flammability.

Emissions Algorithm. CFCs are emitted from process refrigeration equipment during use and disposal. During use, emissions result from normal leakage, leakage as a result of system damage, and scheduled and unscheduled servicing. Unscheduled servicing occurs as a result of system failure or external damage. Because process equipment is typically charged on site after installation, emissions at installation are estimated and emissions during manufacture are not of concern. It is estimated that from one to two thirds of emissions occur during servicing, either by deliberate venting or accidental loss.

The VAF was used to estimate the emissions from process refrigeration equipment at the national level. The emissions events modeled were: installation; normal leakage; leakage due to damage; servicing (scheduled and unscheduled); and disposal. During installation, HCFC-22 is routinely used as a leak-test gas to test the integrity of the system. Consequently, the HCFC-22 emissions associated with leak test at installation is tracked separately.

Exhibit 10 lists the types of process refrigeration equipment modeled. As shown in the exhibit, three industry segments are included: chemical industry; refineries; and pharmaceutical industry. Two types of systems are included: Built-Up, which are constructed on site; and Packaged, which are assembled off-site and brought to the site for installation. The two main types of compressors, centrifugal and reciprocating are listed along with the various refrigerants used. The number of units in use in the U.S. were estimated from industry and refrigeration manufacturer data.

Based on data obtained there is no indication that emissions vary with equipment age. Consequently, the age of the equipment was not used in modeling the frequency of the emissions events or the amount of emissions per event.

Activity Levels. Exhibit 10 lists estimates of the number of each type of unit in use in the U.S. These detailed estimates, prepared for the U.S. EPA from industry data, were not available for the State of California. Consequently, the number of establishments was used as proxy data as shown in Exhibit 11. The number of establishments was used because the number of refrigeration units is expected to vary most closely with the number of manufacturing or processing locations. Exhibit 11 shows that these proxy data indicate that California has about 12 to 15 percent of the national total establishments in these industries. These values are a

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[5] CFC-502 is a mixture of 49 percent HCFC-22 and 51 percent CFC-115 (by weight).

larger proportion than would be indicated by the state and national population, which is expected because California has a large concentration of these industries.

Emissions Estimates. The VAF was used to estimate emissions at the national level. The national emissions were used to estimate California emissions using the activity level data in Exhibit 11. Exhibit 12 presents the resulting emissions estimates. As shown in the exhibit, the chemical industry has the largest emissions of the three segments.

Exhibit 10: Process Refrigeration Systems: U.S. - 1990

System Type	Compressor Type	Refrigerant	Number of Units
Chemical Industry			
Built-Up	Centrifugal	CFC-11	376
Built-Up	Centrifugal	CFC-12	548
Built-Up	Centrifugal	HCFC-22	128
Built-Up	Centrifugal	CFC-500	112
Built-Up	Reciprocating	CFC-12	55
Built-Up	Reciprocating	HCFC-22	1,155
Packaged	Centrifugal	CFC-11	413
Packaged	Reciprocating	CFC-12	133
Packaged	Reciprocating	HCFC-22	1,403
Packaged	Reciprocating	CFC-502	224
Refineries			
Built-Up	Centrifugal	CFC-12	26
Pharmaceutical Industry			
Packaged	Centrifugal	CFC-11	200
Packaged	Reciprocating	CFC-12	100
Packaged	Reciprocating	HCFC-22	100

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 11: Process Refrigeration Systems - 1990			
Industry	**U.S. Number of Establishments**	**California Number of Establishments**	**California as a Percent of the U.S.**
Chemical Industry	12,039	1,423	11.8%
Refineries	194	30	15.5%
Pharmaceutical Industry	1,356	206	15.2%
Source: Chemical Industry and Pharmaceutical Industry data from U.S. Department of Commerce (1990). Refinery data from Oil and Gas Journal (1991).			

Exhibit 12: Process Refrigeration Emissions - 1990					
Industry	**Refrigerant (Thousands of Kilograms)**				
	CFC-11	**CFC-12**	**CFC-115**	**HCFC-22**	**HFC-152a**
U.S. Estimates					
Chemical Industry	307.5	412.1	4.8	2,365.6	11.9
Refineries	na	13.9	na	<0.1	na
Pharmaceutical Industry	79.9	7.8	na	8.0	na
California Estimates					
Chemical Industry	36.3	48.7	0.6	279.6	1.4
Refineries	na	2.1	na	<<0.1	na
Pharmaceutical Industry	12.1	1.2	na	1.2	na
Source: ICF Consulting Associates, Incorporated estimates.					

Various factors contribute to uncertainty in these emissions estimates. The national emissions estimates rely on equipment and servicing data obtained from industry. The detailed modeling of the emissions events is limited by the unique nature of each refrigeration unit. Because a complete census of all the units was not performed, the emissions characteristics are necessarily based on "average" or "typical" conditions which may not be appropriate in many cases. Additionally, the activity level data for California are very aggregate, and do not take into account potential state-specific conditions in these systems. Because the emissions from process refrigeration systems are relatively small compared to the state and national totals, these uncertainties do not have a large impact on the uncertainty in the total emissions of all ODCs in the U.S. and the state.

3.3.3 Commercial Refrigeration

End Use Description. Commercial refrigeration equipment is primarily used for food storage and display. The major applications are in supermarkets, other retail food establishments, refrigerated warehouses, and refrigerated transportation equipment (primarily trucks, rail cars, and ships). The equipment ranges in type from self-contained stand alone equipment display cases to walk-in cold storage rooms.

There are a few standard sizes or designs in the equipment used in retail food establishments. Most of the equipment is factory assembled and installed at the job site, often with a multi-stage compressor and inter-connecting piping. The equipment is commonly used in areas of high occupancy, or in close proximity to areas of high occupancy, in buildings generally intended for public occupancy.

The three common temperature ranges in this sector are high (0 to 13 degrees Celsius), medium (-15 to 2°C), and low (-18 to -32°C), and very low (down to -45°C). The refrigerants most commonly used are CFC-12 for the medium and high temperature ranges (-15 to 15 °C), HCFC-22 for low temperature (down to -37°C), and CFC-502 for the very low temperatures. Design of equipment and refrigerants used depend on desired operating temperatures.

Cold storage warehouse facilities most often use ammonia as the refrigerant, primarily due to its lower cost. Less than 20 percent of warehouses use either CFC-12, CFC-502 and HCFC-22. CFC refrigerants are often used when the facility is in a populated area and potential exposure to ammonia is a concern.

Transport refrigeration includes road transport (trucks and trailers), rail cars, ships (mostly refrigerated cargo ships), and inter-modal containers for the transport of refrigerated cargoes. Whereas retail food and warehouse applications have units with hundreds or thousands of pounds of refrigerant, transportation units usually have less than 50 pounds per unit. Refrigerated rail cars use CFC-12 systems, which are most suitable because of the wide range

of ambient temperatures encountered. Refrigerants CFC-12 and CFC-502 are used in trucks with all sizes of units, and some HCFC-22 is now used in newer truck trailer units.

In marine applications, CFC-12 is universally used in refrigerated containers. HCFC-22 is used in most central cargo refrigeration, fish freezers and fishing boat refrigerated storage. It is also used for liquid gas tanker re-liquefaction plants. CFC-502 is used only very seldom for low temperature refrigeration requirements.

ODCs are also used in several minor commercial refrigeration applications including the following:

- Ice machines are used in hotels, restaurants, and industrial processes. CFC-12 is used as the refrigerant.

- Water coolers, vending machines and dehumidifiers are used in commercial buildings and hotels. CFC-12 is used almost exclusively in this application, with CFC-502 in some specialized uses.

- Ice rinks use CFC-12, HCFC-22 and CFC-502 systems.

- Liquid fast freezing uses CFC-12 to rapidly freeze fruits, vegetables, and meats by bringing the food in direct contact with the refrigerant.

Emissions Algorithm. The VAF was used to estimate emissions from these applications. Emissions were modeled from manufacturing/installation, leakage, servicing, and disposal. The hermetically sealed equipment (such as vending machines) were modeled to have much lower leakage rates and service requirements than the other major equipment types. Detailed estimates of the number of units by type and the frequency of emissions events were estimated for the U.S. EPA based on industry-supplied data.

Activity Levels. Detailed estimates of the number of units by type could not be obtained for California. Consequently, the proxy data shown in Exhibit 13 were used. For the major applications, proxies were selected that related to the specific uses. The number of supermarkets in California tracks well with the relative sizes of the U.S. and California populations. The reason for the relatively smaller percentages for other stores (which are principally convenience stores) and refrigerated warehouse space is not known. Data from NACS (1991) was used to check the other store estimate, and an even lower percentage was computed from that source, 5.6 percent.

The values for refrigerated warehouse space in California (11.3 percent of the national total) and refrigerated transport (11.5 percent) is reasonable, although higher estimates may have been expected given the large amount of agriculture in the state. Unfortunately, no data were available on the use of CFC-based systems versus ammonia-based systems in warehouses.

Exhibit 13: Commercial Refrigeration Activity Level Data - 1990

Industry	U.S. Estimate	California Estimate	California as a Percent of U.S.	Units	Source
Retail Food: supermarkets	302,612	34,454	11.4%	Number of establishments in SIC 54, food stores	Dun's (1991)
Retail Food: other stores	58,749	4,339	7.4%	Number of establishments in SIC 541102, convenience stores	Dun's (1991)
Cold Storage Warehouse	2,570	290	11.3%	Millions of square feet of warehouse space	USDA (1990)
Refrigerated Transport	160	18.5	11.5%	Thousands of refrigerated trucks and vans	U.S. Bureau of the Census (1987)[a]
Ice Rinks	336	21	9.5%	Ice skating and curling rinks listed in SICs 79990601/2	Dun's (1991)
Ice makers, vending machines, liquid fast freezing, other	249.8	29.2	11.7%	Population	U.S. Bureau of Economic Analysis (1990)

a The data from the Census Bureau were used to estimate the portion of the fleet of trucks that have refrigeration in the California fleet and the total U.S. fleet. These percentages were applied to the number of trucks registered in California and the U.S. in 1990 to estimate the number of refrigerated trucks in 1990. Data on 1990 truck registrations were obtained from MVMA (1991).

Data for ice rinks was available and used as shown in Exhibit 13. For the other minor uses, population was used as a proxy for the activity levels. The California population in 1990 was estimated at 11.7 percent of the total U.S. population.

Emissions Estimates. Emissions estimates are presented in Exhibit 14. As shown in the exhibit, the emissions associated with retail food refrigeration equipment are the largest in this category. Although HCFC-22 emissions are relatively large, the ODP of HCFC-22 is small, thereby reducing the importance of these emissions.

Because most of the equipment used in retail food applications is standardized, the emissions estimates for these categories are relatively reliable. The most uncertain estimates are for HCFC-22, in particular in the refrigerated warehouse category. The data used in the VAF do not produce estimates of HCFC-22 use and emissions that are consistent with total national use

Exhibit 14: Commercial Refrigeration Emissions Estimates				
Industry	**1990 ODC Emissions (Thousands of Kilograms)**			
	CFC-12	**CFC-115**	**HCFC-22**	**HCF-152a**
U.S. Estimates				
Retail Food: supermarkets	2,622	820	6,364	na
Retail Food: other stores	8,984	2,677	2,706	na
Cold Storage Warehouses	81	50	10,340	na
Refrigerated Transport	2,006	102	97	41
Miscellaneous Uses[a]	4,409	46	172	na
California Estimates				
Retail Food: supermarkets	299	93	725	na
Retail Food: other stores	664	198	200	na
Cold Storage Warehouses	9	6	1,167	na
Refrigerated Transport	231	12	11	5
Miscellaneous Uses[a]	515	5	17	na

a Includes ice rinks, ice makers, vending machines, liquid fast freezing, and other.

Source: ICF Consulting Associates, Incorporated estimates.

estimated from industry production statistics. Consequently, the VAF national use and emissions estimates for HCFC-22 are increased in several applications to make up this short fall, including

refrigerated warehouses. Primarily, additional use and emissions are allocated to servicing activities, which are the least well characterized of the emissions sources.

While the estimate of HCFC-22 use in the refrigerated warehouse sector is very uncertain, the total use and emissions of HCFC-22 nationally are relatively well known from industry production statistics. Because HCFC-22 is used overwhelmingly in refrigeration and air conditioning applications, the principal uncertainty is in the appropriate manner in which to allocate use. Estimates of total emissions are certain because the HCFC-22 air conditioning and refrigeration systems have similar release characteristics.

3.3.4 Residential Refrigeration

End Use Description. Domestic refrigerators and freezers are used primarily for food preservation and storage. During the past 50 years, manufacturers have developed high efficiency systems using the basic vapor compression refrigeration cycle. Compressors and other system components have been optimized to be compatible with CFC-12, the existing refrigerant.

For the domestic refrigeration sector, the most important properties of CFC-12 are its non-toxic and non-flammable characteristics. The household refrigerator is also unique from other commercial refrigeration equipment in the U.S. in that energy efficiency standards have been developed and implemented for this sector. Any substitute technology or alternative refrigerant must be equally or nearly as energy efficient as CFC-12.

The majority of emissions from refrigerators and freezers occur at the point of disposal. Until recently, appliances were typically disposed similarly to other metal wastes, and refrigerant charges were emitted as the appliance was stripped of parts or crushed. Refrigerants are also emitted during servicing, which accounts for the second largest category of emissions from these products. Residential refrigerators and freezers are designed to be a closed non-leaking system. Typically, they do not have to be serviced during their expected lifetime of 10 to 15 years, and can last as long as 30 years. It is estimated that only about 1.5 percent of refrigerators and freezers are serviced each year.

Emissions Algorithm. The VAF was used to model emissions from residential refrigerators and freezers. The national stock of refrigerators and freezers by vintage was modeled because the amount of CFC-12 per unit varies with age. Exhibit 15 summarizes the national stock data estimated using the VAF.

As shown in Exhibit 15, there are about 122 million refrigerators in the U.S., which is consistent with the expectation of approximately one refrigerator per household. The average amount of CFC-12 in refrigerators (the average charge size) has been declining in recent years as energy efficiency has improved. A similar pattern in charge size is seen in the data for freezers. Of interest is that there is a "bulge" in the stock of freezers manufactured during the period 1971-1975. This bulge is confirmed in freezer production statistics from that time.

Exhibit 15: National Stock of Refrigerators and Freezers - 1990				
Vintage	Refrigerators		Freezers	
	Number (Thousands)	Ave. Charge (Kilograms)	Number (Thousands)	Ave. Charge (Kilograms)
1986-1990	38,505	0.19	5,832	0.31
1981-1985	32,202	0.21	6,676	0.29
1976-1980	27,546	0.28	8,300	0.37
1971-1975	19,390	0.33	11,491	0.44
pre-1971	4,661	0.33	2,052	0.44
Total	122,304	--	34,351	--
Source: ICF Consulting Associates, Incorporated estimates based on analysis of industry-supplied data.				

Emissions events modeled for this stock of freezers include the following:

- Manufacturing emissions are 6.4 percent of the initial charge of refrigerators and freezers produced in 1990.
- Leakage emissions are 0.2 percent of the remaining charge in the entire stock of equipment.
- Service emissions are estimated assuming that the remaining charge in the unit is vented during service and that about 1.5 percent of the units are serviced each year.
- Disposal emissions are estimates assuming that the remaining charge is released at disposal. Retirement curves based on industry data are used to model disposal. These curves imply that the lifetimes of refrigerators and freezers are about 19 and 21 years respectively.

This emissions algorithm does not include any CFC recycling at time of service or disposal. Federal recycling requirements will soon mandate such recycling, and consequently emissions associated with these events will soon be reduced.

Activity Levels. Exhibit 15 presents the national activity level data collected for the U.S. EPA based on industry data. The California Energy Commission (CEC) provided detailed

estimates of the stock of refrigerators and freezers based on data collected from the six major utility service planning areas in the state. These data were scaled upward slightly using population data because the utility statistics only cover 96 percent of the state population.

Unfortunately, reliable data on the vintage of refrigerators and freezers in the state were not available from the CEC or others. Consequently, the age distribution of the national stocks of refrigerators and freezers was used in the analysis. Because California has experienced rapid growth in the 1980s, the stock of refrigerators and freezers in the state may be younger than the national average. Consequently, disposal emissions may be over-estimated.

Exhibit 16 displays the activity level data used to estimate emissions in California. As expected, the refrigerator estimate for California is about 10 percent of the national total, which is close to the 11.7 percent figure for state population as a percentage of national population. The number of freezers is less than expected based solely on state and national population. This result is not unexpected because the largest period of freezer sales occurred in the early 1970s prior to California's recent high population growth rates.

Exhibit 16: California Activity Levels for Refrigerators and Freezers - 1990

	Refrigerators	Freezers
U.S. Estimates (Thousands)	122,304	34,351
California Estimates (Thousands)	12,339	2,108
California Estimates as a Percentage of the U.S.	10.1%	6.1%

Sources: ICF Consulting Associates, Incorporated estimates based on industry data for the U.S. and CEC data for California.

Emissions Estimates. The VAF was used to estimate emissions for the national stock of refrigerators and freezers. These estimates were then used to estimate California emissions using the activity level data in Exhibit 16. Exhibit 17 presents these estimates by source of emissions. As shown in the exhibit, emissions associated with disposal are the largest single source, and emissions associated with service are the next largest.

While residential refrigerators and freezers are highly visible and often mentioned sources of ODC emissions, the emissions from the refrigerant in this equipment are relatively small. The major uncertainty in the estimates are associated with the emissions associated with servicing. The frequency of servicing and the emissions associated with this event are based on industry data. Because this category of emissions is small, this uncertainty does not contribute significantly to the uncertainty in total emissions.

Exhibit 17: Refrigerator and Freezer Emissions Estimates -1990					
	Emissions of CFC-12 by Source				
	Manufacturing	Service	Leakage	Disposal	Total
U.S. Estimates (Thousands of Kilograms)					
Refrigerators	94	622	52	1,863	2,630
Freezers	23	280	23	712	1,038
California Estimates (Thousands of Kilograms)					
Refrigerators	9	63	5	188	265
Freezers	1	17	1	44	64
Emissions per Unit (Kilograms)					
Refrigerators	0.77	5.08	0.42	15.23	21.50
Freezers	0.68	8.14	0.66	20.72	30.20
Source: ICF Consulting Associates, Incorporated estimates.					

3.3.5 Residential and Light Commercial Air Conditioning

End Use Description. Residential and light commercial air conditioning systems can be divided into three major types: window units; unitary systems; and packaged terminal systems. All three types use HCFC-22 almost exclusively because it: meets all toxicity and flammability requirements; is thermodynamically suited for the temperature ranges typically encountered; and is compatible with all common construction materials and nearly all commonly used lubricants.

Window units, or "room" air conditioners consist of a single factory-made encased assembly designed for window or wall mounting. The unit delivers conditioned air into a room without the use of ducts. In addition to cooling the air, it generally dehumidifies the air and may perform other ventilating or heating functions.

Unitary systems are air conditioners and heat pumps which are commonly referred to as "central air systems." Unitary systems consist of one or more factory-made assemblies which normally include an evaporator or cooling coil, a compressor and a condenser. The conditioned air is typically distributed through the use of ducts. Unitary systems may provide heating as well as cooling.

Packaged terminal air conditioners and heat pumps are self-contained units commonly used in office buildings and hotels. Similar to window units, these units typically include both

heating and cooling components, and are only mounted through walls. Packaged terminal systems generally have a higher capacity than window units, but also are designed to serve a single room.

Emissions Algorithm. The VAF was used to model emissions from manufacturing, leakage, service, and disposal. For window units and packaged terminal units, servicing is seldom performed, and consequently the majority of emissions are associated with disposal. Unitary units require servicing more often, and it is believed that significant amounts of HCFC-22 are used and emitted during these service activities. For example, in many cases HCFC-22 is used as a compressed gas to clean condensing coils and other system components during servicing. Consequently, use and emissions exceed the quantities needed to recharge the units.

Exhibit 18 lists the national emissions estimated for each of the equipment types. As shown in the exhibit, unitary systems make up the majority of systems and account for the majority of the emissions. The estimate for the largest single source of emissions from this category, servicing of unitary systems, is particularly uncertain because these emissions result from the service practices of thousands of service technicians. To date, these practices have not been well characterized in terms of their emissions. The emissions estimate reported for this category in Exhibit 18 is derived, in part, by allocating a portion of national HCFC-22 use to this category.[6]

Activity Levels. A variety of sources were consulted to obtain data on the number of window, packaged terminal and unitary systems in California. Unfortunately, these data do not exist from either manufacturers or utility companies. Consequently proxy data were used.

Data from the 1980 Census of Housing (U.S. Bureau of the Census, 1983) and the 1989 American Housing Survey (U.S. Bureau of the Census, 1991) were used to estimate the fraction of the total U.S. air conditioned residential housing units that are in California. Residential data were used as the proxy because residential units are the majority of the units in this end use.

The 1980 data are available for California, the Western Region, and the total U.S. The 1989 data are available only for the Western Region and the total U.S. (The Western Region includes Washington, Oregon, California, Alaska, Hawaii, Idaho, Nevada, Montana, Wyoming, Utah, Colorado, Arizona, and New Mexico.) In order to use the latest data, the Western Region estimate for 1989 was used to estimate a 1989 value for California as follows:

1. In 1980, California had 69.5 percent and 61.2 percent of the room and centrally air conditioned residential housing units in the Western Region. Also in 1980 California had 54.8 percent of the population in the Western Region.

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[6] There is a discrepancy between the estimate of total U.S. HCFC-22 use based on the best available data for estimating use and the reported HCFC-22 production that is sold annually as HCFC-22. A portion of this discrepancy is allocated to the service category.

Exhibit 18: Residential and Light Commercial Cooling					
Equipment Type	Number of Units (Thousands)	1990 U.S. Emissions by Source (Thousand of Kilograms)			
		Manufacturing	Leakage	Service	Disposal
Window Units	29,350	72	167	636	5,722
Packaged Terminal Units	2,932	3	8	31	64
Unitary Systems	49,087	287	727	25,114	8,480
Total	81,369	362	902	25,781	14,266
Source: ICF Consulting Associates, Incorporated estimates.					

2. In 1990, California had 55.3 percent of the Western Region population. Using the data from 1980, it is estimated that in 1990 California had 70.1 percent and 61.7 percent of the room and centrally air conditioned residential housing units in the Western Region.[7]

3. In 1990 the Western Region had 8.4 percent and 15.3 percent of the national room and centrally air conditioned residential housing units. Consequently, California is estimated to have 5.9 percent and 9.4 percent of the national totals.[8]

These activity factors of 5.9 percent and 9.4 percent of the national totals are used to estimate California emissions from this end use: 5.9 percent is used for window and packaged terminal units; and 9.4 percent is used for unitary systems.

Emissions Estimates. Exhibit 19 presents the resulting emissions estimates for California. The California activity levels were applied to the U.S. emissions to estimate state emissions. As with the national emissions, service emissions associated with unitary systems dominate. Because recycling requirements during servicing will soon be implemented on the national level, these emissions are expected to decline. However, these estimates could be improved with better assessments of actual service practices.

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[7] The 1990 values were calculated as: 55.3% x (69.5%÷54.8%) = 70.1% and 55.3% x (61.2%÷54.8%) = 61.7%.

[8] The California percentages are computed as: 8.4% x 70.1% = 5.9% and 15.3% x 61.7% = 9.4%.

Exhibit 19: Residential and Light Commercial Cooling Emissions Estimates

	1990 Emissions of HCFC-22 by Source				
	Manufacturing	Leakage	Service	Disposal	Total
U.S. Estimates (Thousands of Kilograms)					
Window Units	72	167	636	5,722	6,596
Packaged Terminal Units	3	8	31	64	106
Unitary	287	727	25,114	8,480	34,608
Total	362	902	25,781	14,266	41,311
California Estimates (Thousands of Kilograms)					
Window Units	4	10	37	336	387
Packaged Terminal Units	0	0	2	4	6
Unitary	27	68	2,363	798	3,256
Total	31	78	2,402	1,138	3,649

Source: ICF Consulting Associates, Incorporated estimates.

3.3.6 Commercial Chilling

End Use Description. Chillers are large air conditioning units used primarily for commercial and industrial buildings. Unlike the unitary systems discussed in the previous section, chillers cool water (or a water/glycol mixture) which is then passed through a heat exchanger to cool and dehumidify the air being conditioned.

There are two basic types of water chillers, categorized by compressor types: positive displacement compressors and centrifugal compressor systems. Positive displacement compressors (reciprocating and screw) cover the smaller end of the capacity range of commercial chillers. Some positive displacement chillers use CFC-12 but most use HCFC-22. As CFCs are phased out, it is expected that HCFC-22 positive displacement chillers will predominate.

Centrifugal compressor systems are usually larger in capacity and primarily use CFC-11 as the refrigerant. CFC-11 is a low pressure refrigerant and is suitable for centrifugal systems only. Some CFC-12 is used in systems that cover a broad range of capacities. Some centrifugal chillers designed for CFC-12 are charged with CFC-500 in order to broaden their capacity range.

Very large chillers are often charged with HCFC-22. CFC-114 is used for chilling aboard submarines because it is capable of being used with reduced levels of vibration.

Nearly all chillers are expected to be in service for many years, usually 25 years or more. They are generally large pieces of equipment with high capital costs. Chillers are used to cool areas of high occupancy (such as office buildings), but are usually operated in a relatively remote locations, such as the roof or a dedicated floor for mechanical equipment.

Emissions Algorithm. CFCs are emitted from chillers during use and disposal. During use, emissions result from normal leakage, leakage as a result of system damage, and scheduled and unscheduled servicing. Unscheduled servicing occurs as a result of system failure or external damage. Because this equipment is typically charged on site after installation, emissions at installation are estimated and emissions during manufacture are not of concern.

The VAF was used to estimate the emissions from chilling equipment at the national level. The emissions events modeled were: installation; normal leakage; servicing (scheduled and unscheduled); and disposal. Exhibit 20 lists the types of chillers modeled and the estimated 1990 U.S. emissions. As shown in the exhibit, HCFC-22 has the largest emissions, and is emitted principally from reciprocating and screw compressor equipment. Because HCFC-22 has a low ODP, the CFC-11 emissions are actually larger on an ODP-weighted basis.

Exhibit 20: U.S. Emissions from Commercial Chillers

Equipment Type	1990 U.S. Emissions by Compound (Thousands of Kilograms)				
	CFC-11	CFC-12	CFC-114	HCFC-22	HFC-152a
Centrifugal Compressors	7,313	1,422	88	2,616	142
Reciprocating and Screw Compressors	na	314	na	12,830	na
Total	7,313	1,736	88	15,446	142

Source: ICF Consulting Associates, Incorporated estimates.

The majority of the emissions are associated with servicing. In particular, HCFC-22 use and emissions are allocated to service events. Servicing emissions will decline as recycling requirements are implemented. These estimates for 1990 assume that no recycling is taking place.

Activity Levels. The national stock of chilling equipment was used in the VAF to estimate national emissions in 1990. These detailed data were not available for the state of California so proxy data were used.

Data on the total square feet of commercial air conditioned floorspace were obtained from the Department of Energy (U.S. DOE, 1991). These data indicate that nationally in 1989, 51.8 billion square feet of office space had some level of air conditioning. This source also reports that the Pacific Division had about 5.9 billion square feet, or about 11.4 percent of the national total.[9] Because there is no comparable California-specific estimate, the California value is estimated from the Pacific Division data using the ratio of the California population to the division population, which is 74.4 percent. Therefore, California is estimated to have 8.5 percent of the national total commercial chilling equipment (74.4 percent times 11.4 percent).

Data from the CEC were also reviewed to estimate this activity level (CEC, 1991). These data indicate that there is about 3 billion square feet of air conditioned commercial space in the state in 1990. The estimate from the U.S. DOE data indicate a total of about 4.4 billion square feet. Because the estimate for California must be compared to a comparable national estimate in this analysis, it was decided that the U.S. DOE data, which have both national and regional data, are preferred.

Emissions Estimates. The 8.5 percent activity level figure was applied to the national emissions shown in Exhibit 20 to estimate emission in the state. These estimates are shown in Exhibit 21. As with the national emissions, the HCFC-22 emissions are the most uncertain.

3.3.7 Solvent Applications

End Use Description. CFC-113 and methyl chloroform (MC) are widely used as solvents to clean electronics assemblies, delicate instruments and surfaces, and metal parts. These substances are also used in a number of countries for the dry cleaning of clothing, but this use is not significant in the U.S. The three main types of solvent cleaning in the U.S. are:

- Electronics cleaning: Solvents are used extensively in electronics cleaning primarily to remove flux residue which is left on printed circuit boards after components have been attached to the board by a soldering operation.

- Metal cleaning: Metal cleaning applications of solvents usually consist of the removal of oil and grease from large metal parts such as automobile components. These parts often do not require a high level of cleanliness.

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[9] The Pacific Division includes Washington, Oregon, California, Alaska, and Hawaii.

- Precision cleaning: Precision cleaning is performed on products that require an extremely fine level of cleanliness, including computer disk drives, gyroscopes, and other high-technology devices.

Exhibit 21: California Emissions from Commercial Chillers

Equipment Type	1990 California Emissions by Compound (Thousands of Kilograms)				
	CFC-11	CFC-12	CFC-114	HCFC-22	HFC-152a
Centrifugal Compressors	622	121	7	223	12
Reciprocating and Screw Compressors	na	27	na	1,092	na
Total	622	148	7	1,314	12

Source: ICF Consulting Associates, Incorporated estimates.

CFC-113 and MC are two common solvents among a variety of chlorinated and aqueous solvents in use. In general, the solvents clean by dissolving and/or washing away the grease, dirt, or solder flux from the parts being cleaned. Various types of equipment are used, including:

- Conveyorized Vapor Degreasers in which the parts being cleaned are on a conveyor belt that moves through a solvent spray, bath, or vapor zone.
- Open Top Vapor Degreasing in which the parts being cleaned are brought in contact with heated solvent or heated solvent vapors.
- Cold Cleaning in which the parts are placed in a solvent bath or sprayed with solvent.

These three types of equipment can be designed and used in a variety of configurations, and consequently there are a very wide variety of systems in use.

The solvents are seldom used in their pure form, but are mixed with various stabilizers to improve performance. In many cases equipment is used to prevent the emissions of solvent vapors. Because some solvents are considered volatile organic compounds (VOCs), emission control requirements have been implemented to limit emissions. These requirements generally exempt CFC-113 and MC, which are not considered VOCs.

Solvent recycling has recently become increasingly popular as the cost of used solvent storage and disposal have increased. Recycling is performed on site if large quantities are used. More commonly, off site recycling is more cost effective.

Emissions Algorithm. When newly-produced CFC-113 and MC are used as solvents they are generally emitted within the year in which they are used. Even with the increased use of recycling equipment, newly-produced CFC-113 and MC are required to replace the amounts of the solvents that are emitted. Because virtually no MC is destroyed (e.g., chemically or through incineration), MC emissions from solvent uses are approximately equal to MC sales for this use. It has been estimated that about 15 percent of CFC-113 is destroyed or sequestered as part of disposal (EPA, 1988), therefore, CFC-113 emissions are approximately equal to 85 percent of its annual sales for solvent uses.

Various studies have been performed to estimate the portion of CFC-113 and MC sales that is devoted to solvent uses. With the exception of small specialty uses, nearly all of CFC-113 production is used in solvent applications each year (EPA, 1988). Consequently, CFC-113 solvent-related emissions can be estimated relatively well.

MC is used in a variety of miscellaneous applications (which are discussed below). Solvent applications are estimated to account for about two-thirds of total sales in the U.S. (Chem Systems, 1989). While this estimate is somewhat uncertain, the emissions characteristics from virtually all MC use is the same. Consequently, this uncertainty does not influence total emissions significantly, although it affects the estimates of emissions by end use.

Activity Levels. The use of CFC-113 and MC is described in terms of CFC-113 and MC production and sales. These production and sales statistics are not published routinely in government reports, consequently industry data and reports are used to estimate national use.

EPA (1988) estimated CFC-113 use in 1985 and expected increases in use in the absence of specific measures to control CFC-113 use and emissions. During the early 1980s CFC-113 use was increasing rapidly due to increases in the production of computers, military equipment, and other electronic equipment. EPA (1988) estimated that by 1990 CFC-113 emissions from solvent applications would reach about 88.6 million kilograms.

Since the signing of the Montreal Protocol and the implementation of federal regulations to restrict CFC production, CFC-113 use has declined substantially from its expected levels. It is estimated that as of 1990 about 50 percent of national CFC-113 solvent use has been replaced with alternative cleaning processes or solvents including: "no-clean" production processes that do not require solvent cleaning; aqueous solvents; and terpene solvents. Consequently, a 1990 national emissions estimate of 44.3 million kilograms is used as the national activity level for CFC-113.

Similar estimates of CFC-113 use in California are not available. The toxic emissions inventory compiled by the California EPA reports emissions in 1990, but these figures are believed to be a substantial underestimate of total emissions due to limited reporting

requirements. Consequently, state emissions are estimated from the national estimates based on proxy activity level data.

Solvents are used in several major manufacturing industries. Data obtained on the number of establishments in four key industries are shown in Exhibit 22. As shown in the exhibit, California has about 16 to 22 percent of the nation's establishments in these industries. This percentage is larger than the state's share of the national population, which is expected due to the large number of electronics firms in the state. For purposes of estimating state emissions of CFC-113, an activity level of 18.1 percent of the national total emissions is used (see Exhibit 22).

Exhibit 22: Activity Levels for Solvent Emissions - 1990

SIC	Industry	# of Establishments U.S.	# of Establishments California	California as a % of U.S.
35	Industrial Machinery	99,358	15,950	16.1%
36	Electronic and Electric Mach.	35,815	7,738	21.6%
37	Transportation Equipment	22,523	4,735	21.0%
38	Instruments and Related Equip.	24,948	4,577	18.4%
	Total	182,644	33,000	18.1%

Source: Dun's (1991).

U.S. MC use and emissions in the late 1980s were estimated in Chem Systems (1989). Based on expected growth in use, total solvent use and emissions of MC in the U.S. are estimated at about 203 million kilograms in 1990. Because MC production and use were not controlled in 1990, nor was control expected to be imminent at that time, MC solvent use in 1990 is consistent with expectations from the late 1980s. Consequently, state MC emissions are estimated from this national estimate of MC emissions.

MC is used as a solvent in the same industries that use CFC-113. Consequently, the activity data in Exhibit 22 is also used to estimate MC emissions. The California EPA also reports MC emissions from its toxic emissions inventory. As with CFC-113, the reported data are believed to be an underestimate of total state emissions due to limited reporting requirements.

Emissions Estimates. The state CFC-113 and MC emissions estimates for solvent uses are presented in Exhibit 23. The principal uncertainty in the estimates is the allocation of national emissions to the state. Although the activity levels seem reasonable, the California estimates may be biased downward if, for example, CFC-113 and MC have been used preferentially in the state as a result of controls on VOC emissions. As mentioned above, other chlorinated solvents are VOCs, and California establishments may have used CFC-113 and MC to reduce VOC emissions.

The national estimate of CFC-113 use reductions in response to federal controls is implicitly applied to the state as well. These reductions are consistent with information obtained in telephone conversations with electronics manufacturers in California as part of this project.

Exhibit 23: Solvents Emissions Estimates - 1990

	CFC-113 (Thousands of Kilograms)	Methyl Chloroform (Thousands of Kilograms)
U.S. Estimate	44,300	203,197
California Estimate	8,004	36,714

ICF Consulting Associates, Incorporated estimates.

3.3.8 Foam Production

End Use Description. CFCs have been used to make a variety of different types of foams. CFCs are used primarily as blowing agents, which cause the expansion of the resin or other materials from which the foam is made. As a result of this expansion, bubbles or "cells" are created in the resin that hardens to form the foam material. CFCs also serve other important functions, such as increasing the foam's insulating properties, softening the foam, absorbing some of the heat generated during production so that the foam does not scorch or burn, and reducing the foam's density.

Foams are used to produce a variety of foam plastic products, including building and appliance insulation, cushioning materials, packaging, and flotation devices. CFC-11, CFC-12, CFC-113 and CFC-114 are used in the manufacture of the four main types of foam:

- Flexible Polyurethane Foam is made from a polyurethane resin and is primarily used in cushioning products such as furniture, carpet padding, and packaging. CFC-11 is used to produce this foam.

- Rigid Polyurethane Foam is made from a polyurethane resin in a manner that produces a very stiff material. This foam can be factory-produced as boards with

laminated sealants on the outside for use as building insulation. This foam can also be sprayed or poured onto surfaces or into molds. Rigid polyurethane foam is currently used in the walls of refrigerators and freezers to supply both structural strength and insulation. CFC-11 and CFC-12 are used to produce this foam.

- Extruded polystyrene (EPS) foam is produced in two forms: sheet and boardstock. EPS sheet has been used for food service and packaging applications. EPS boardstock has been used almost exclusively for insulation in buildings. EPS has been produced primarily with CFC-12.

- Other Foam Products include polyolefin foams made from polypropylene or polyethylene resins and phenolic foams made from phenol-based resins. These foams are used in a wide variety of products, including building insulation, flotation devices, aircraft seating, automotive bumper systems, packaging, and other applications. CFC-11, CFC-12, CFC-113, and CFC-114 are used in the production of these foams.

Since the signing of the Montreal Protocol and the implementation of federal regulations restricting CFC production, the use of CFCs in making foam has declined significantly. Restrictions on the use of CFCs in foam production in some states and localities have also played a role (see Section 6). HCFC-22 is being used in increasing amounts as a substitute blowing agent in many foam formulations. Additionally, MC is being used in some areas, as are alternative foam production systems and non-foam substitute products.

Emissions Algorithm. EPA (1987 and 1988) present estimates of the rate at which CFCs are emitted from the various types of foams. There are two basic types of emissions rates from foams:

- Prompt emitters release their CFCs during or shortly following foam production. CFCs are not stored in these foams for an extended period of time.

- Delayed emitters store CFCs in the foam material, for example to enhance the insulating properties of the foam. These CFCs are released slowly over a period of many years.

Flexible polyurethane foam, EPS sheet, and other foam products are prompt emitters. For these foams, emissions in each year are equal to the amount of CFCs used in the production of the foams in the year. Rigid polyurethane foams and EPS board store CFCs for a range of 12 to 30 years.

A variety of studies have been performed on the rate of CFC release from the delayed emitting foams. The emissions rate is very variable depending on how the foam was manufactured, sealed (if at all) and used. The release rate tends to be on the order of 2 to 5 percent per year. However, these foams are used in a variety of products, and the point at which

the product is disposed often determines when the bulk of the CFCs are released. In all cases, the CFCs will be emitted eventually.

To estimate the emissions from the delayed emitters, data describing the historical production and use of these foams are required. Based on these data, the 1990 emissions from foams produced over the past 30 years are estimated. Exhibit 24 summarizes the release rate data used to model the emissions from the various types of foam. As shown in the exhibit, the release rates from the prompt emitters are 100 percent in the year of manufacture. The year of product disposal is not relevant in these cases. The delayed emitters have very low annual release rates, but are assumed to emit their remaining CFCs when the products are disposed.

Exhibit 24: Foam Emissions Characteristics

Foam Type	Product	Emissions Rate (% per year)	Year of Product Disposal
Flexible Polyurethane Foam	Cushioning products such as furniture, carpet padding, packaging	100% in year of manufacture	na
Rigid Polyurethane Foam	Building insulation from boardstock, poured in place, and sprayed in place	4.5%	30
	Industrial insulation from boardstock, poured in place, and sprayed in place	4.5%	20
	Insulation in refrigerators and freezers	4.5%	19
	Packaging foams	100% in year of manufacture	na
	Other rigid polyurethane products, such as automobile parts and furniture parts	4.5%	12
EPS Boardstock	Insulation	1.7%	20
EPS Sheet	Packaging, fast food containers	100% in year of manufacture	na
Other Foams	Various	100% in year of manufacture	na

ICF Consulting Associates, Incorporated estimates based on EPA (1988) and industry data.

The primary uncertainty in the release data is the release rate from building insulation. Foam insulation was originally produced without a laminated sealant. Such a sealant was used in later years to improve the insulating properties of the foam which degraded over time due to CFCs being released. The assumptions used here assume that the bulk of CFC-blown building insulation that is still emitting was produced with the laminated sealants.

Activity Levels. EPA (1988) estimated the use and emissions of CFCs from foam products based on historical data on foam production. These data have been extended to 1990 in three steps as follows:

1. The trend in foam production in the 1980s was extended to 1990 to estimate total production and expected CFC use and emissions.

2. The use of CFCs in foam production of foam was reduced to reflect the large shifts to alternative blowing agents and products that have occurred.

3. The use and emissions of MC and HCFC-22 were estimated to increase to reflect the switching away from CFCs in some foam production applications.

The slow leakages from the delayed emitters in 1990 were not influenced by the shifts in CFC use that were occurring at that time because the shifts only apply to the current use of CFCs in the production of foam. Exhibit 25 summarizes the national emissions estimates.

The top portion of Exhibit 25 lists the CFC emissions that would have been anticipated based on growth rates and use patterns in the 1980s. The middle portion of the exhibit lists the manner in which use and emissions have changed as a result of CFC restrictions. The bottom portion of the exhibit lists the emissions estimates for 1990 that reflect the shifts in use. Based on telephone contacts with foam producers in California, the national estimates of shifts in CFC use shown in Exhibit 25 are also applicable to foam producers in California, with one exception discussed below.

As shown in the exhibit, although CFC use in rigid polyurethane foam production is estimated to have declined by 30 percent from previous expectations, the emissions only decline by about 5 to 7 percent because most of the emissions come from foam in place in buildings, appliances, and other applications. Similarly, most of the emissions from EPS boardstock are not affected by the recent 50 reduction in use. Also shown are areas in which HCFC-22 use and emissions have increased as the result of reductions in CFC use.

Similar estimates of foam production and use in California are not available. For most types of foam uses, use per capita in California should be similar to use per capita in the U.S. Consequently, as a proxy for activity levels the ratio of California population to U.S. population was used, 11.7 percent. Because California experienced rapid growth in construction in the 1980s, the emissions from delayed emitting rigid polyurethane insulation foams in California may exceed the value expected solely based on the ratio of California to U.S. population. Although

Exhibit 25: U.S. 1990 Foam Emissions

Foam Type	1990 Emissions (Thousands of Kilograms)				
	CFC-11	CFC-12	CFC-113	CFC-114	Substitute
U.S. Estimates Based on the Trends in Production in the 1980s					
Flexible PU Foam	25,000	na	na	na	na
Rigid Foam	33,900	2,500	na	na	na
EPS Foam	na	13,363	na	na	na
Other Foam	2,800	3,236	1,900	5,100	na
Modifications in Use and Emissions due to Federal CFC Restrictions					
Flexible PU Foam	90% reduction in use and emissions	na	na	na	no chemical substitution nationally -- MC being used in CA[a]
Rigid PU Foam	30% reduction in use -- no reduction in emissions from foam in place		na	na	no chemical substitution
EPS Foam	na	50% reduction in use -- no reduction in emissions from boardstock in place emissions	na	na	substitution of HCFC-22 for reduced CFC use
Other Foam	50% reduction in use and emissions				substitution of HCFC-22 for reduced CFC use
U.S. Estimates Reflecting Changes in CFC Use due to Federal Restrictions					
Flexible PU Foam	2,500	na	na	na	na
Rigid PU Foam	31,576	2,389	na	na	na
EPS Foam	na	7,578	na	na	5,785 HCFC-22
Other Foam	1,400	1,618	950	2,550	6,517 HCFC-22

a Non-ODC chemical substitutes are being used. In California, MC is being used as a substitute. See text.

ICF Consulting Associates, Incorporated estimates.

data on foam use in California were not available, data were collected on construction expenditures in the state and nationally from 1979 through 1990. As shown in Exhibit 26, California accounted for an average of 18 percent of total construction dollars during this period. Consequently, the emissions from rigid polyurethane foam are estimated at 18 percent of the national value.

Exhibit 26: California and U.S. Construction Expenditures (Thousands of Current Dollars)

Year	U.S. Expenditures	California Expenditures	California as a Percent of the U.S.
1979	107,450,733	18,083,905	16.8%
1980	101,947,454	16,558,118	16.2%
1981	103,720,143	16,391,398	15.8%
1982	98,389,606	15,002,783	15.2%
1983	132,908,072	21,738,576	16.4%
1984	154,932,725	27,075,131	17.5%
1985	171,890,704	31,438,783	18.3%
1986	184,212,461	36,326,880	19.7%
1987	185,991,746	35,017,518	18.8%
1988	195,551,796	40,521,571	20.7%
1989	193,793,807	41,456,493	21.4%
1990	175,823,875	33,421,729	19.0%
		Average Percentage:	18.0%

Source: CIRB (1991).

Emissions Estimates. California emissions were estimated by applying the proxy activity level data to the national emissions estimates. As shown in Exhibit 27, CFC-11 emissions from rigid polyurethane foams account for the majority of emissions from this application. Although it is estimated that HCFC-22 is being used to substitute for CFCs that are being phased out, these emissions remain fairly small. Based on conversations with foam manufacturers in California, Exhibit 27 also shows MC emissions as a result of substitution for CFC-11 in flexible foams. This substitution occurred in California, but is not believed to be commonly occurring in the U.S. This MC use is expected to be transitory as MC production is being phased out.

The uncertainties in the estimates of these emissions are primarily associated with: (1) the emissions from the delayed emitting insulating foams; and (2) the extent to which HCFC-22 has substituted for fully-halogenated CFCs. The estimates in Exhibit 27 assume that HCFC-22 is being used extensively as a replacement in the production of EPS sheet and other

foams. Actual emissions of HCFC-22 may be less than indicated in Exhibit 27 if alternative foam production techniques are being used.

Exhibit 27: California 1990 Foam Emissions

Foam Type	1990 Emissions (Thousands of Kilograms)				
	CFC-11	CFC-12	CFC-113	CFC-114	Substitute
Flexible PU Foam	292	na	na	na	1,751 MC
Rigid PU Foam	5,684	430	na	na	na
EPS Foam	na	887	na	na	677 HCFC-22
Other Foam	164	189	111	298	762 HCFC-22

ICF Consulting Associates, Incorporated estimates.

3.3.9 Sterilization

End Use Description. CFC-12 with ethylene oxide (EO) is widely used for sterilization of medical equipment and devices by medical device manufacturers and contract sterilization services, as well as by hospitals. EO, the main cleaning ingredient of sterilization solutions, is used for its ability to penetrate a wide variety of packaging materials to destroy microorganisms on medical products and devices. Due to the high flammability and explosion risk associated with EO, it is often diluted with CFC-12 to a mixture of 12 percent EO and 88 percent CFC-12 (by weight), a combination commonly referred to as "12/88".

Emissions Algorithm. When CFC-12 is used in sterilization equipment it is routinely vented to the atmosphere. The material to be sterilized is first placed in the sterilization equipment. The sterilization equipment is pressurized with the 12/88 mixture. Following a specified period of time, the equipment is vented. Due to the toxicity of EO, the equipment exhaust is usually vented to the outside through dedicated ducts. Given the manner in which the sterilization equipment is used, emissions in a year are equal to the total amount of CFC-12 used in that year.

Activity Levels. National emissions of CFC-12 were estimated based on the number of sterilizers in use in hospitals and other establishments. As shown in Exhibit 28, nationally there are about 5,600 sterilizers in use in hospitals and about 400 in use in other establishments, including contract sterilization firms. While hospitals use relatively small equipment, contract sterilizers have large equipment that uses considerably more 12/88 per year. Consequently, as shown in the exhibit, the emissions per sterilizer are much smaller for the sterilizers in hospitals.

Detailed data on the number of sterilizers in California were not available. As a proxy, the numbers of hospitals in the U.S. and the state were used as the activity levels. The number of hospitals is a good proxy because the hospital sterilizers are associated with the number of hospitals and the sterilizers at other establishments are used principally to sterilize medical products. The proxy activity level data are shown in Exhibit 28.

Emissions Estimate. California emissions were estimated by applying the proxy activity level data to the national emissions estimates. As shown in Exhibit 29, CFC-12 emissions from sterilizers in California are about 959,000 kilograms. The uncertainties in the estimates of these emissions are primarily associated with the national estimates of CFC-12 use and emissions in this application. The use and emissions estimates are based on a national assessment of CFC-12 use (EPA (1988) and estimates of the numbers of various types of sterilizers in use provided by industry sources. Although shifts in CFC-12 use in sterilization are anticipated in response to federal limits on CFC production, no shifts are assumed for the 1990 estimates.

Exhibit 28: Activity Level Data for Sterilization - 1990	
U.S. Sterilizer Data	
Number of Hospital Sterilizers	5,625
Number of Other Sterilizers	407
Annual CFC-12 Emissions per Hospital Sterilizer (kg)	891
Annual CFC-12 Emissions per Sterilizer in Other Establishments (kg)	15,960
Hospital Data	
Number of U.S. Hospitals	6,720
Number of California Hospitals	560
California Hospitals as a Percent of the U.S.	8.3%
Sources: Hospital data from AHA (1990). U.S. sterilizer data are ICF Consulting Associates, Incorporated estimates.	

3.3.10 Miscellaneous Uses

End Use Description. ODCs are used in a variety of miscellaneous applications, including the following.

- Adhesives. Methyl chloroform (MC) is used as an adhesive solvent because it is nonflammable, dries rapidly, and performs well in many applications, particularly

foam bonding. Adhesives are used in a very wide range of industries and consumer applications.

- Coatings and inks. MC is used alone or combined with other solvents in coatings and inks applications and is preferred for its low flammability and its fast evaporation rate. In coatings, MC can be used to solubilize a binding substance due to its good solvency power. These properties also make MC especially favorable in the manufacture of inks which are used to print items such as wallpaper and beverage bottles or cartons.

Exhibit 29: U.S. and California CFC-12 Emissions from Sterilization - 1990	
U.S. Emissions (Thousands of kilograms)	
Emissions from Hospital Sterilizers	5,010
Emissions from Other Sterilizers	6,496
Total U.S. Emissions	11,507
California Emissions (Thousands of kilograms)	
Emissions from Hospital Sterilizers	417
Emissions from Other Sterilizers	541
Total California Emissions	959
Sources: ICF Consulting Associates, Incorporated estimates.	

- Aerosols. MC, CFC-11, and CFC-12 are used in aerosol product applications. MC functions principally as a solvent in these products. CFCs can be used as propellants or as active ingredients. In the U.S., the use of CFCs in nonessential aerosol propellant applications was banned in 1978. Some medical devices were found to be essential and were exempt from the ban, as were aerosol products in which CFCs were an active ingredient.

- Other Miscellaneous Uses. CFCs and MC are used in a variety of other applications and products. For example, CFC-12 is used in warning devices, boat horns, pressurizes blowers, and drain cleaners (Hammitt et al., 1986). MC is used in semi-conductor fabrication, film cleaning, and fabric manufacturing applications.

Emissions Algorithm. When ODCs are used in these miscellaneous applications they are generally emitted in the year in which they are used. For example, the MC used in adhesives, coatings, and inks evaporates quickly, leading to emissions. Similarly, the ODCs placed in

aerosol products are emitted within one or two years of manufacture. Although some small pressurized devices may retain their ODCs for a period of years, emissions from the miscellaneous applications are assumed to be equal to use in that year.

Activity Levels. EPA (1988) estimated the use and emissions of CFCs in these miscellaneous applications as of 1985. Based on trends in these uses, 1990 use and emissions were estimated. However, shifts in use are known to have occurred as the result of federal restrictions on CFC production. CFC-11 and CFC-12 use in exempted aerosol applications have declined by about 50 percent from levels anticipated in the absence of controls. Similarly, CFC-12 use in other miscellaneous uses has declined by as much as 90 percent.

MC use is also starting to decline in some of these applications. However, because MC production and use were not controlled in 1990, nor was control expected to be imminent at that time, MC use did not decline in 1990 relative to expectations from the late 1980s. Therefore, no adjustment is made to the estimate for MC emissions.

Detailed use and emissions estimates for California are not available for this set of applications. Consequently, proxy data were used for the activity levels. For aerosol products and other miscellaneous uses the California population as a fraction of the total U.S. population (11.7 percent) was used. For adhesives the number of establishments in SIC 289102 (Adhesives) was used as the proxy, and for coatings and inks the number of establishments in SIC 2851 (paints) and SIC 2893 (printing inks) was used. Exhibit 30 summarizes these data.

Emissions Estimate. California emissions were estimated by applying the proxy activity level data to the national emissions estimates. As shown in Exhibit 31, the largest emissions are associated with MC use. Smaller amounts of the other ODCs are emitted.

3.3.11 Fire Extinguishers

End Use Description. Halons are used in specialized fire extinguisher applications. Halons are very effective in fire fighting and explosion prevention/suppression and have valuable characteristics including: (1) they are electrically nonconductive; (2) they dissipate quickly and leave no residue; and (3) they are relatively safe for human exposure (UNEP, 1991).

Halon 1301 is used principally in total flooding systems to protect electronic equipment rooms. Upon detection of a fire, the total flooding system discharges halon 1301 very rapidly, extinguishing the fire. The total flooding systems are designed to produce a sufficient concentration of halon in the room in order to be effective in fighting the fire. Total flooding systems are also used in areas where flammable liquids are stored or handled, in military applications, and other miscellaneous situations.

Halon 1211 is used principally in portable fire extinguishers. These systems are used to protect the same types of areas that use total flooding systems, with electronic equipment and military applications being the largest uses. Halon 1211 hand-held fire extinguishers have also

Exhibit 30: Activity Levels for Miscellaneous Uses

U.S. 1990 Emissions Estimates (Thousands of kilograms)

	CFC-11	CFC-12	HCFC-22	MC
Aerosols	3,250	4,350	na	41,527
Adhesives	na	na	na	31,066
Coatings/Inks	na	na	na	20,605
Miscellaneous	na	2,430	2,890	20,605

U.S. and California Proxy Activity Level Data (Number of establishments) - 1990

Industry	U.S.	California	California as % of U.S.
Adhesives (SIC 289102)	833	107	12.8
Paints (SIC 2851) and Printing Ink (SIC 2893)	3,086	390	12.6%

na = Not Applicable

Sources: 1990 U.S. emissions estimates are ICF Consulting Associates, Incorporated estimates based on EPA (1988). SIC data from Dun's (1991).

Exhibit 31: California Emissions Estimates for Miscellaneous Uses

	1990 Emissions (Thousands of Kilograms)			
	CFC-11	CFC-12	HCFC-22	MC
Aerosols	380	509	na	4,859
Adhesives	na	na	na	3,990
Coatings/Inks	na	na	na	2,604
Miscellaneous	na	284	338	2,410

na = Not Applicable

Source: ICF Consulting Associates, Incorporated estimates.

been marketed to consumers for home use. A small amount of halon 1301 is used in portable systems, and small amounts of both halon 1211 and 1301 are used in locally applied systems which are similar to total flooding systems, but only are effective in a portion of the room.

The 1970s and early 1980s were periods of rapid growth in halon use in the U.S. and globally. Fire protection codes required or recommended their use for protecting against electrical fires and in areas where flammable liquids are stored or handled. Additionally, halon systems have been used to meet flight certification requirements for civilian aircraft and in a variety of military aviation applications.

In response to concerns about stratospheric ozone depletion, extensive reviews of options for reducing or eliminating halon emissions have been performed. A variety of steps have been initiated to reduce emissions immediately and to enable the existing halon-based systems to remain in service for their remaining useful lives.

Halon 2402 is an ODC covered by the Montreal Protocol. This halon has not been manufactured or used in the U.S. Consequently, it is not discussed further in this report.

Emissions Algorithm. Halons are emitted as the result of several emissions events, including the following.

- Manufacturing and Installation. Halons are emitted when total flooding system containers and portable devices are filled. Additionally, when total flooding systems are installed, a discharge test is required to ensure that adequate levels of halon are reached and maintained within the protected area. This discharge test results in large emissions, and has recently been modified to enable alternative testing procedures to be employed.

- Discharge During a Fire. Halons are emitted when released to fight a fire. Only a small portion of the halon is decomposed by the fire (about 10 percent).

- Unwanted Discharge. Halons are emitted when a total flooding system discharges accidentally due to a detector malfunction or operator error. In some cases unwanted discharges occur from portable systems as well.

- Leakage and Servicing. Small leaks from both total flooding and portable systems result in emissions. Servicing leaking systems also produces emissions, although improved servicing procedures are being developed that reduce the service-related losses.

- Training. Halon systems are used in civilian and military training courses. Until recently these emissions were substantial. Recently, training guidelines have been modified to reduce these emissions substantially.

- Disposal. Total flooding systems produce only small amounts of disposal emissions as nearly all the halon 1301 in de-commissioned systems is recycled. Some portable halon 1211 systems have been produced that do not include the valves and connections necessary to recycle their contents, and consequently

some emissions occur at disposal of these systems. Recycling is now emphasized in halon system products.

The frequency of these emissions events and their associated emissions were quantified in EPA (1988). Subsequent updates of these estimates have confirmed the overall values and led to some refinements (e.g., UNEP, 1991).

Activity Levels. National emissions estimates have been developed based on estimates of the inventory of halon systems in use and installed annually. Exhibit 32 summarizes the estimated inventory of equipment. As shown in the exhibit, there are about 150,000 total flooding systems and over 6.5 million portable systems in the U.S. Similar data are not available for California, consequently proxy data are used. To estimate California emissions, the ratio of California to U.S. population is used to estimate emissions from civilian uses (11.7 percent). The ratio of California to U.S. active duty and civilian military personnel is used to estimate emissions from military/government uses (13.8 percent).[10]

Emissions Estimates. The U.S. emissions were estimated for each of the emissions events for the inventory of fire extinguisher systems. These emissions estimates were multiplied by the proxy activity levels to estimate emissions in California. The U.S. emissions estimates are summarized in Exhibit 33. As shown in the exhibit, the total flooding systems have about 1.5 million kilograms of emissions nationally. The majority of these emissions are associated with installation, fire fighting, and unintended release emissions. As mentioned above, steps are currently underway to reduce emissions associated with installation and unintended releases. The estimates in Exhibit 33 for 1990 do not include the effects of these reduction strategies.

The emissions from the portable and locally applied systems are somewhat smaller than the emissions from the total flooding systems. The training-related emissions dominate the emissions from these systems. Training practices are currently being changed to reduce these emissions significantly. The estimates for 1990 do not reflect the reductions anticipated from these changes. Exhibit 34 presents the emissions estimates for California.

3.3.12 ODC Manufacturing

Fugitive emissions from manufacturing facilities may result in ODC emissions. Only carbon tetrachloride (CT) emissions from this source have been estimated to date. Rand (1986) estimates that 30 and 34 kilograms of CT are emitted per metric ton of CFC-11 and CFC-12 produced, respectively. This estimate is based on the stoichiometric requirements for CFC production and actual CT usage in the process. Based on total estimated 1990 U.S. CFC-11 and CFC-12 production, these emissions rates imply 1990 CT emissions of 5.3 million kilograms.

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[10] Total U.S. active duty and civilian military personnel in 1990 were 2,116,000. Personnel in California in 1990 were 293,000 or 13.8 percent of the total (DOD, 1990).

Exhibit 32: U.S. Activity Levels for Fire Extinguishers - 1990		
Application	**Halon 1211**	**Halon 1301**
U.S. Estimates of the Number of Systems in Use (Thousands)		
Civilian Total Flooding Systems	na	131
Military/Government Total Flooding Systems	na	20
Locally Applied Systems	3	1
Civilian Portable Systems	5,505	na
Military/Government Portable Systems	1,120	244
Source: ICF Consulting Associates, Incorporated estimates.		

Exhibit 33: U.S. Fire Extinguisher Emissions Estimates for 1990							
System Type	**Emissions Type (Thousands of kilograms)**						
	Mfg/Ins	**Fire**	**Unwant**	**Ser/Lk**	**Train**	**Disp**	**Total**
Halon 1301 Total Flooding Systems							
Civilian Systems	454	341	288	135	7	0	1,225
Military/Government Systems	78	72	61	29	1	21	261
Local Application Systems							
Halon 1211	2	6	0	2	12	0	22
Halon 1301	4	2	2	1	4	0	13
Portable Systems							
Civilian Halon 1211 Systems	73	214	46	58	321	8	721
Military Systems: Halon 1211 Halon 1301	 20 30	 72 18	 0 15	 20 7	 142 0	 45 3	 299 74
Mfg/Ins = emissions from manufacturing and installation. Fire = emissions during use to fight fires. Unwant = unwanted or accidental discharge. Ser/Lk = emissions from servicing and leakage. Train = emissions from training. Disp = emissions from disposal. Source: ICF Consulting Associates, Incorporated estimates.							

Exhibit 34: California Fire Extinguisher Emissions Estimates for 1990

System Type	Emissions Type (Thousands of kilograms)						
	Mfg/Ins	Fire	Unwant	Ser/Lk	Train	Disp	Total
Halon 1301 Total Flooding Systems							
Civilian Systems	53	40	34	16	1	0	143
Military/Government Systems	11	10	8	4	0.2	3	36
Local Application Systems							
Halon 1211	0.2	0.7	0	0.2	1.5	0	2.6
Halon 1301	0.4	0.3	0.2	0.1	0.5	0	1.5
Portable Systems							
Civilian Halon 1211 Systems	9	25	5	7	38	1	84
Military Systems:							
Halon 1211	3	10	0	3	20	6	41
Halon 1301	4	3	2	1	0	0.4	10

Mfg/Ins = emissions from manufacturing and installation. Fire = emissions during use to fight fires. Unwant = unwanted or accidental discharge. Ser/Lk = emissions from servicing and leakage. Train = emissions from training. Disp = emissions from disposal.

Source: ICF Consulting Associates, Incorporated estimates.

Fugitive emissions of the CFCs, halons, and MC themselves also likely occur during the manufacture of the chemicals. These fugitive emissions have not been estimated, but are likely to be in the range of about 0.1 to 1.0 percent of total production. A 0.5 percent figure is used in this analysis.

Based on industry sources, CFCs and MC are manufactured in California, and halons are not. For purposes of this inventory, the fugitive emissions associated with the use of ODCs in California are estimated, even though all, or a portion, of these ODCs may be produced elsewhere. Similarly, emissions from ODCs produced in the state that are used elsewhere are excluded. Exhibit 35 summarizes the emissions estimates for the state.

3.3.13 Large Point Sources of Emissions

Data were reviewed and industry representatives were contacted to identify potential large sources of ODC emissions. Emissions from most ODC applications are very dispersed. For example, emissions from MACs are the result of small leaks from millions of cars and servicing

practices at thousands of service locations. Emissions from refrigeration, sterilization, fire extinguishing, and miscellaneous applications are similarly dispersed.

Exhibit 35: California Emissions from ODC Manufacturing - 1990 (Thousands of kilograms)

CFC-11	CFC-12	CFC-113	CFC-114	CFC-115
11	39	41	2	1
HCFC-22	**MC**	**Halon 1211**	**Halon 1301**	**CT**
32	262	<1	1	396

Source: Estimated assuming that fugitive emissions are 0.5 percent of ODC use in California. CT estimates also include fugitive emissions during CFC-11 and CFC-12 manufacturing.

Solvent and some foam applications are the most likely candidates for large point sources of emissions. These industries can have large facilities that can use significant quantities of ODCs in one location. Solvent applications use CFC-113 and MC. In California it is reported that MC is being used in place of CFC-11 in flexible foam manufacturing. CFC use in foam production is declining rapidly, and consequently was not examined.

The 1989 and 1990 state SARA Title 313 reports compiled by the California EPA include reports of emissions from the relevant manufacturing industries that use and emit CFC-113 and MC from solvent and foam blowing applications. These reports are expected to include the largest emitters and consequently are anticipated to be a good source of data for identifying the largest point sources of emissions in the state.

Exhibit 36 presents the five largest emitters reported in the state SARA Title 313 data for CFC-113 and MC in 1989 and 1990. As shown in the exhibit, the largest CFC-113 emissions are on the order of 100,000 kilograms per year or less. The sum of the top five emitters in 1990 is less than four percent of total CFC-113 emissions estimated for the state. Although the emissions of MC from the five largest emitters are larger, these emissions are also less than four percent of total emissions. Based on these data and contacts with industry, no individual sources of emissions were identified that account for a large portion of total emissions.

Exhibit 36: Reported SARA Title 313 Emissions (Thousands of Kilograms)

CFC-113		Methyl Chloroform	
Company	**Emissions**	**Company**	**Emissions**
1989 Data			
Airesearch, L.A. Div. of Allied Signal	136	General Motors	731
General Dynamics	130	Rohr Industries (Chula Vista)	387
IBM Corp.	105	Chase Packaging	281
DuPont Antioch Plant	84	American Brass and Iron Foundry	259
Sola/Barnes-Hind	83	Rohr Industries (Riverside)	245
1990 Data			
Sola/Barnes-Hind	90	Great Western Foam Products,	726
Allergan Medical Optics	62	CMC Printed Bag Co.	262
General Dynamics	60	General Dynamics	236
Hughes Aircraft Co.	52	Rohr Industries (Chula Vista)	231
Lockheed Missiles and Space Co.	51	Hickory Springs of California, Inc.	225

Source: California EPA SARA Title 313 Emissions Reports for 1989 and 1990.

3.3.14 Disposal Related Emission from Consumer Products

An informal survey was performed to characterize emissions during the disposal of consumer products containing ODCs. The survey focused on the disposal of refrigerators, freezers, and window air conditioning units (see Appendix C). Based on detailed telephone conversations, the public and private entities involved in the chain of disposal activities and potential emission points were identified.

Exhibit 37 displays a flow chart of the disposal process. The process begins with a consumer who is disposing of a product. The consumer may transfer the product to one of various entities including:

- Retail Stores often agree to take away an old appliance (such as refrigerator) when a new one is delivered.
- Non-Profit Resell Organizations, such as Salvation Army and Goodwill, provide free curbside pick-up of appliances and other items. These organizations resell the items through thrift shops or auction off the ones they cannot sell or repair.
- Other Consumers may purchase the appliance directly.
- Public Sanitation Departments often offer curbside pick up of large appliances.
- Consumers may take the appliances directly to landfills.

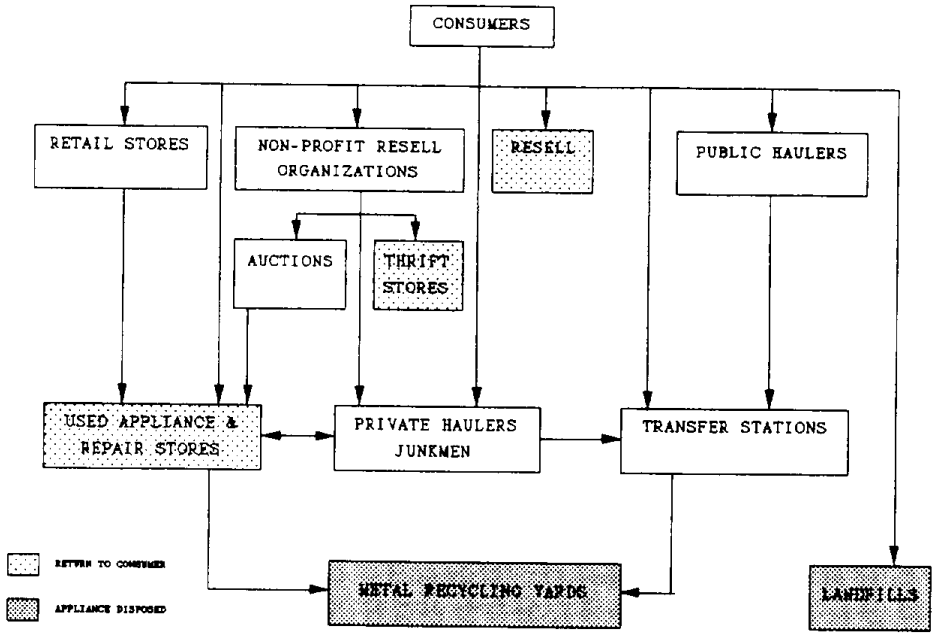
As shown in the exhibit, many appliances are resold through used appliance stores, thrift stores, or by the consumers themselves. Those appliances that cannot be resold generally end up at metal recycling facilities. A very small number of appliances may be disposed of in landfills, but this practice is not common in the areas of California we contacted.

Prior to reaching a metal recycling yard most appliances are handled by used appliance stores, non-profit resell organizations, private haulers/junkmen, and transfer stations. If an appliance is not able to be resold, these entities will generally remove any usable parts before shipping or taking the appliance to the metal recycler. In fact, most metal recyclers will not accept appliances that have not been stripped of certain unacceptable parts, including motors and transformers. All but one metal recycler contacted said that they only accept refrigerators, freezers, or air conditioners that have been stripped and do not contain CFC refrigerants.

Based on the survey, it appears that by the time appliances reach metal recyclers their CFC refrigerants have already been released. The CFCs in the insulating foams, however, are expected to remain largely intact until the material is crushed. It was not possible to quantify precisely the relative amounts of appliances that were handled by the various entities. However, it appeared that a significant portion of major appliances, perhaps as much as 50 to 75 percent, passed through a used appliance dealer on the way to disposal. Private haulers/junkmen and public sanitation departments accounted for most of the remainder.

The used appliance stores contacted also service appliances. Consequently, they use the parts they strip from disposed appliances to repair appliances or prepare used appliances for sale. Under the Federal Clean Air Act Amendments, regulations will soon be promulgated that require all CFCs to be recycled during the servicing and disposal of all refrigeration and air conditioner equipment (see Section 6). Based on this survey, used appliance stores will be an important CFC recycling point.

Exhibit 37: Flowchart of Appliance Disposal



Source: ICF Consulting Associates, Incorporated survey.

Because appliances are generally stripped before they reach metal recyclers, CFC recycling may not be common at these locations. For those appliances that do not pass through used appliance stores, transfer stations may be the point at which recycling is required. It is clear, however, that private haulers/junkmen are unlikely to have the resources and expertise necessary to recycle CFCs. If these entities are permitted to continue to strip appliances for parts, the CFC refrigerants in the stripped appliances will not likely be recycled.

3.4 SUMMARY OF 1990 EMISSIONS INVENTORY

Exhibit 38 presents a summary of the U.S. and California 1990 emissions by end use and ODC. As shown in the exhibit, MACs are the largest source of CFC emissions in both the U.S. and California. CFC-113 solvent applications and CFC-11 foam applications are the next largest

sources of CFC emissions. While CFC-113 emissions are associated with the current use of the chemical for cleaning electronic and metal parts, CFC-12 emissions from MACs are principally due to leakage and servicing-related activities. Because CFC-11 use in all types of foam production have decline substantially in the past few years, the CFC-11 emissions from foams are driven principally by emissions from insulating foams currently in place in buildings and appliances.

MC emissions are the largest of the ODCs. MC is used principally in solvent and other miscellaneous applications. In California MC is also replacing CFC-11 in the manufacture of flexible polyurethane foams. Halon use is limited to fire extinguishing applications, and emissions are relatively modest. CT emissions are only estimated for fugitive emissions associated with CFC manufacturing. Other uses of CT are extremely small. Emissions of HFC-152a are shown because this chemical is used in conjunction with CFC-12 in some refrigeration applications. HFC-152a contains no chlorine, and consequently does not contribute to stratospheric ozone depletion.

Exhibit 38 also shows California emissions as a percentage of U.S. emissions. Due to various activity level patterns, the California emissions range from about 8.5 percent to nearly 18 percent of the U.S. figures.

Exhibit 39 presents the summary emissions estimates weighted by ODP. As shown in the exhibit, MACs account for nearly 23 percent of total weighted emissions nationally. Solvents are the second largest source of emissions, followed by foams. Because of its high ODP and widespread use, CFC-12 accounts for over 40 percent of total weighted emissions nationally. Despite its large emissions from solvent uses and other applications, ODP-weighted MC emissions are only about 13 percent of the national estimate. Despite their high ODPs, halon emissions remain a relatively small portion of the total weighted emissions nationally.

The California ODP-weighted emissions show a pattern similar to the U.S. emissions, however solvent emissions are the largest. Based on national and state-specific activity level data, California is estimated to account for a disproportionately large share of national solvent emissions. Of note is that the estimates in Exhibit 39 use the steady-state ODP values discussed in Section 2. If shorter-term chlorine loading potential were used, the MC ODP would increase and the relative importance of MC emissions and solvent applications would increase further.

Exhibit 40 presents the emissions estimates weighted by their global warming potentials (GWPs). Nationally, CFC-12 is again the most important. Relative to the ODPs, the GWPs give more significance to HCFC-22, which accounts for nearly 10 percent of the GWP-weighted emissions. MACs have the largest GWP-weighted emissions. Because the GWP for MC is low, the relative importance of solvent-related emissions is also low. Foam emissions, in particular from delayed emissions, account for a significant portion of emissions nationally. The GWP-weighted California emissions show a similar pattern. Again MACs are the single largest emitter. Solvent and foam applications are the next largest sources in the state.

Exhibit 38: Summary of U.S. and California 1990 ODC Emissions (Thousands of Kilograms)

U.S. Estimates

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A
Mobile AC	0	60,954	0	0	0	0	0	0	0	0	0
Process Refrigeration	387	434	0	0	5	2,374	0	0	0	0	12
Commercial Refrig.	0	18,102	0	0	3,695	19,679	0	0	0	0	41
Res. Refrig. & Freezers	0	3,668	0	0	0	0	0	0	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	41,311	0	0	0	0	0
Commercial Chillers	7,313	1,736	0	88	0	15,446	0	0	0	0	142
Solvents	0	0	44,300	0	0	0	203,197	0	0	0	0
Foams	35,476	11,586	950	2,550	0	12,303	0	0	0	0	0
Sterilization	0	11,507	0	0	0	0	0	0	0	0	0
Miscellaneous	3,250	6,780	0	0	0	2,890	113,803	0	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	1,043	1,574	0	0
ODC Manufacturing	89	390	226	13	12	324	1,585	3	6	3,812	1
Total	46,516	115,156	45,476	2,651	3,712	94,327	318,585	1,046	1,580	3,812	195

California Estimates

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A
Mobile AC	0	6,320	0	0	0	0	0	0	0	0	0
Process Refrigeration	48	52	0	0	1	281	0	0	0	0	1
Commercial Refrig.	0	1,717	0	0	314	2,119	0	0	0	0	5
Res. Refrig. & Freezers	0	329	0	0	0	0	0	0	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	3,649	0	0	0	0	0
Commercial Chillers	622	148	0	7	0	1,314	0	0	0	0	12
Solvents	0	0	8,004	0	0	0	36,714	0	0	0	0
Foams	6,140	1,506	111	298	0	1,440	1,751	0	0	0	0
Sterilization	0	959	0	0	0	0	0	0	0	0	0
Miscellaneous	380	793	0	0	0	338	13,864	0	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	128	191	0	0
ODC Manufacturing	11	39	41	2	1	32	262	0	1	396	0
Total	7,202	11,862	8,156	307	315	9,174	52,590	129	192	396	18
Percent of U.S.	15.5%	10.3%	17.9%	11.6%	8.5%	9.7%	16.5%	12.3%	12.2%	10.4%	9.3%

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 39: Summary of ODP-Weighted U.S. and California 1990 ODC Emissions (Thousands of Weighted Kilograms)

U.S. Estimates

ODP	1.00	1.00	0.80	0.60	0.50	0.05	0.11	3.00	10.00	1.10	0.00	
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A	% of Total
Mobile AC	0	60,954	0	0	0	0	0	0	0	0	0	23.1%
Process Refrigeration	387	434	0	0	2	119	0	0	0	0	0	0.4%
Commercial Refrig.	0	18,102	0	0	1,848	984	0	0	0	0	0	7.9%
Res. Refrig. & Freezers	0	3,668	0	0	0	0	0	0	0	0	0	1.4%
Res. & Light Com'l AC	0	0	0	0	0	2,066	0	0	0	0	0	0.8%
Commercial Chillers	7,313	1,736	0	53	0	772	0	0	0	0	0	3.7%
Solvents	0	0	35,440	0	0	0	22,352	0	0	0	0	21.9%
Foams	35,476	11,586	760	1,530	0	615	0	0	0	0	0	18.9%
Sterilization	0	11,507	0	0	0	0	0	0	0	0	0	4.4%
Miscellaneous	3,250	6,780	0	0	0	145	12,518	0	0	0	0	8.6%
Fire Extinguishing	0	0	0	0	0	0	0	3,128	15,739	0	0	7.1%
ODC Manufacturing	89	390	181	8	6	16	174	10	56	4,193	0	1.9%
Total	46,516	115,156	36,381	1,590	1,856	4,716	35,044	3,138	15,795	4,193	0	100.0%
Percent of Total	17.6%	43.6%	13.8%	0.6%	0.7%	1.8%	13.3%	1.2%	6.0%	1.6%	0.0%	100.0%

California Estimates

ODP	1.00	1.00	0.80	0.60	0.50	0.05	0.11	3.00	10.00	1.10	0.00		
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A	% of Total	% of U.S.
Mobile AC	0	6,320	0	0	0	0	0	0	0	0	0	18.1%	10.4%
Process Refrigeration	48	52	0	0	0	14	0	0	0	0	0	0.3%	12.2%
Commercial Refrig.	0	1,717	0	0	157	106	0	0	0	0	0	5.7%	9.5%
Res. Refrig. & Freezers	0	329	0	0	0	0	0	0	0	0	0	0.9%	9.0%
Res. & Light Com'l AC	0	0	0	0	0	182	0	0	0	0	0	0.5%	8.8%
Commercial Chillers	622	148	0	4	0	66	0	0	0	0	0	2.4%	8.5%
Solvents	0	0	6,403	0	0	0	4,038	0	0	0	0	29.9%	18.1%
Foams	6,140	1,506	89	179	0	72	193	0	0	0	0	23.4%	16.4%
Sterilization	0	959	0	0	0	0	0	0	0	0	0	2.7%	8.3%
Miscellaneous	380	793	0	0	0	17	1,525	0	0	0	0	7.8%	12.0%
Fire Extinguishing	0	0	0	0	0	0	0	385	1,914	0	0	6.6%	12.2%
ODC Manufacturing	11	39	32	1	0	2	29	1	7	435	0	1.6%	10.9%
Total	7,202	11,862	6,525	184	158	459	5,785	386	1,920	435	0	100.0%	
Percent of Total	20.6%	34.0%	18.7%	0.5%	0.5%	1.3%	16.6%	1.1%	5.5%	1.2%	0.0%	100.0%	

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 40: Summary of GWP-Weighted U.S. and California 1990 ODC Emissions (Thousands of Weighted Kilograms)

U.S. Estimates

100 Year GWP	1.00	2.10	1.20	2.00	2.00	0.43	0.03	NA	1.70	0.37	0.03	
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A	
Mobile AC	0	128,004	0	0	0	0	0	0	0	0	0	31.2%
Process Refrigeration	387	911	0	0	10	1,021	0	0	0	0	0	0.6%
Commercial Refrig.	0	38,015	0	0	7,390	8,462	0	0	0	0	1	13.1%
Res. Refrig. & Freezers	0	7,702	0	0	0	0	0	0	0	0	0	1.9%
Res. & Light Com'l AC	0	0	0	0	0	17,764	0	0	0	0	0	4.3%
Commercial Chillers	7,313	3,646	0	175	0	6,642	0	0	0	0	4	4.3%
Solvents	0	0	53,160	0	0	0	6,096	0	0	0	0	14.5%
Foams	35,476	24,330	1,140	5,100	0	5,290	0	0	0	0	0	17.4%
Sterilization	0	24,164	0	0	0	0	0	0	0	0	0	5.9%
Miscellaneous	3,250	14,238	0	0	0	1,243	3,414	0	0	0	0	5.4%
Fire Extinguishing	0	0	0	0	0	0	0	0	2,676	0	0	0.7%
ODC Manufacturing	89	818	272	26	24	139	48	0	9	1,410	0	0.7%
Total	46,516	241,827	54,572	5,301	7,424	40,561	9,558	0	2,685	1,410	6	100.0%
Percent of Total	11.3%	59.0%	13.3%	1.3%	1.8%	9.9%	2.3%	0.0%	0.7%	0.3%	0.0%	100.0%

California Estimates

100 Year GWP	1.00	2.10	1.20	2.00	2.00	0.43	0.03	NA	1.70	0.37	0.03		
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301	CT	HFC-152A		% of U.S.
Mobile AC	0	13,272	0	0	0	0	0	0	0	0	0	27.0%	10.4%
Process Refrigeration	48	109	0	0	1	121	0	0	0	0	0	0.6%	12.0%
Commercial Refrig.	0	3,605	0	0	627	911	0	0	0	0	0	10.5%	9.5%
Res. Refrig. & Freezers	0	691	0	0	0	0	0	0	0	0	0	1.4%	9.0%
Res. & Light Com'l AC	0	0	0	0	0	1,569	0	0	0	0	0	3.2%	8.8%
Commercial Chillers	622	310	0	15	0	565	0	0	0	0	0	3.1%	8.5%
Solvents	0	0	9,605	0	0	0	1,101	0	0	0	0	21.8%	18.1%
Foams	6,140	3,163	133	597	0	619	53	0	0	0	0	21.8%	15.0%
Sterilization	0	2,014	0	0	0	0	0	0	0	0	0	4.1%	8.3%
Miscellaneous	380	1,666	0	0	0	145	416	0	0	0	0	5.3%	11.8%
Fire Extinguishing	0	0	0	0	0	0	0	0	325	0	0	0.7%	12.2%
ODC Manufacturing	11	81	49	3	2	14	8	0	1	146	0	0.6%	11.1%
Total	7,202	24,910	9,787	615	630	3,945	1,578	0	326	146	1	100.0%	
Percent of Total	14.7%	50.7%	19.9%	1.3%	1.3%	8.0%	3.2%	0.0%	0.7%	0.3%	0.0%	100.0%	

Source: ICF Consulting Associates, Incorporated estimates.

The estimates in Exhibit 40 are based on published 100 year GWPs (IPCC, 1990). A GWP for Halon 1211 has not been estimated, so the GWP-weighted emissions of this ODC are not reported. If a shorter time period for the GWPs were used the relative importance of HCFC-22 and MC emissions would increase.

As described above for each of the end uses, there are a variety of factors that make the end-use-specific national and state emissions estimates uncertain. However, the total emissions are driven substantially by total annual production, which is known reasonably well for each of the ODCs. Consequently, the total emissions estimates associated with annual use, e.g., from CFC-113, MC, and portions of CFC-11, CFC-12, and HCFC-22, are quite precise. The emissions associated with leakage from refrigeration and air conditioning equipment is known less precisely, but is based on detailed assessments of industry service practices. The delayed emissions from insulating foams in buildings and appliances are the most uncertain estimates.

HCFC-22 emissions have been less well studied than the other emissions. Although total HCFC-22 production is reported by industry, the annual use and emissions from each of its applications are less certain. To date, the total reported HCFC-22 production has not been successfully reconciled with the sum of the estimated end-use-specific use requirements. The estimates in this report assume that the "excess" HCFC-22 production is used in servicing a variety of refrigeration and air conditioning equipment. Until better data are obtained, the HCFC-22 emissions estimates will remain uncertain.

The rapid changes in the use and emissions of the ODCs are expected to continue. Federal regulations are phasing out production of the CFCs, halons, and MC over the next five to 10 years. Consequently, use and emissions will change substantially in response to these restrictions. The following section presents estimates of emissions by end use in 2005.

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4. EMISSIONS INVENTORY FOR 2005

4.1 INTRODUCTION

This section presents the ozone depleting compound (ODC) emissions inventory for the State of California for 2005. The emissions inventory is based on: (1) emissions estimates for ODCs and their substitutes in 2005 in the United States; and (2) estimates of the portion of total national emissions that takes place in the state. The estimates of the share of national emissions accounted for by the state are based on the estimates of U.S. and California emissions in 1990 and expected national and state growth rates from 1990 to 2005. Because ODC use and emissions are being controlled, the estimates of 2005 emissions reflect the penetration of product substitutes, chemical substitutes, and recycling practices expected in response to current and future restrictions on the use and emissions of ODCs.

4.2 METHODOLOGY

The emissions inventory for 2005 is developed by modeling the market for ODCs and ODC-related products in the U.S., and estimating the emissions associated with the products and activities in the market. First, the national use and emissions are estimated. These national values are then used to estimate California emissions by estimating the portion of the U.S. total that occurs in the state.

Using modeling tools developed for the U.S. EPA (EPA, 1988), the following was performed to estimate national emissions in 2005.

1. The market for ODCs and ODC-related products in the absence of controls on ODCs was estimated for the period 1990 to 2010. This "unregulated baseline" represents the expected demand for the "services" supplied by ODCs. The future demand for ODCs and ODC-related products was developed based on detailed assessments of the turnover in the equipment stock and future growth in each of the applications discussed in Section 3. These assessments are described in EPA (1987, 1988) and Hammitt et al. (1986).

2. The technologies for reducing ODC use and emissions were identified and evaluated in terms of: costs; use and emissions reductions achieved; and potential rate of market penetration over time. Over 400 technologies were analyzed, including non-ODC product substitutes, chemical substitutes, process modifications, and recycling options. The cost per kilogram of use avoided was estimated for each technology.

3. The federal restrictions on ODC production and use were identified. The limits on future ODC production were defined in the Montreal Protocol, as modified by the

London Agreements and the Clean Air Act Amendments (CAAA) of 1990 (see Section 6). More recently an accelerated phaseout of the ODCs has been announced, which was also analyzed.

4. Federal recycling requirements were identified and characterized in terms of use and emissions reductions achieved. Full compliance with recycling was assumed to be achieved by 2005.

5. Using the federal phaseout of ODC production as a starting point, ODC use and emissions for each year from 1990 to 2005 were simulated in each of the applications by:

   - estimating the demand for ODCs in the absence of regulations based on the expected market for ODCs and ODC-related products;
   - modeling the effect of federally-mandated recycling and product restriction requirements on the demand for ODCs and the supply of recycled ODCs;
   - estimating the shortfall in available ODCs due to the federal production restrictions;[11]
   - modeling the penetration of emissions reduction technologies needed to balance supply with demand; and
   - estimating ODC emissions based on the simulated adoption of emissions reduction technologies.

The strength of the above approach is that it explicitly takes into account the effects of current and future restrictions on ODC production and use as well as the expected supply of recycled ODCs and the service needs of long-lived capital equipment. Additionally, it models the implementation of control technologies based on cost so that the least costly options for reducing ODC use and emissions are implemented first. Consequently, ODCs are simulated to be used in their most highly valued uses as long as possible. In most cases, the most highly valued use for ODCs is their use in long-lived high-cost capital equipment for which there is no "drop-in" substitute.

The weakness of the above approach, which is inherent in any estimate of future ODC use and emissions, is that it requires estimates of the costs and effectiveness of various product

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[11] The shortfall in supply is the difference between the "unregulated baseline" demand as reduced by the impacts of the federal recycling and product restriction rules, and the ODC production allowed under the federal phaseout. To be consistent with the federal restrictions, all the CFCs, MC, and CT are modeled as a group, with trading among compounds allowed. The halons are treated separately from the CFCs.

and chemical substitutes that are currently under development. In particular, several HCFC and HFC substitutes are being developed. The future applicability and costs of these substitutes remain uncertain at this time. To reflect this uncertainty, two chemical substitute scenarios were analyzed, as described below in Section 4.3.

The 2005 emissions inventory for California is estimated from the national estimate as follows.

1. The 1990 emissions inventory is used to provide "initial" estimates of the portion of national emissions that occur in California in each end use.

2. Proxy data were collected to estimate the growth rate for each end use in California and nationally.

3. The "initial" estimates of the share of national emissions that occurs in California based on the 1990 inventory were adjusted using the national and California growth rates for each end use.

4. The adjusted estimates were used to estimate California emissions in 2005.

Exhibit 41 summarizes the data used to estimate the California emissions from the national emissions estimates. As shown in the exhibit, California accounted for between 8 and 18 percent of the national emissions of each of the end uses in 1990. However, in all the end uses, California activity levels are projected to grow more rapidly than national activity levels. As shown in Exhibit 41, California population is projected to grow 8 percent more than the national population during the period 1990 to 2005. Consequently, for those end uses for which population is a proxy, the 2005 emissions are expected to be 8 percent higher than extrapolation would suggest based on the 1990 emissions estimates.

Population growth is the proxy used for most of the end uses because end-use specific growth rates for the period 1990 to 2005 were not available. However, data on oil and gas and chemical industry employment projections were used to estimate the proxy activity level growth rates for Process Refrigeration. Projected employment in the solvent-related industries (by SIC code) was used to estimate the proxy activity level growth rates for Solvent emissions. Finally, the average of the growth rates for population and employment in the construction industry was used to estimate the proxy activity level growth rates for Foam production.

These adjustments to the California share of national emissions lead to a slightly higher estimate of 2005 emissions as compared with the estimate that would result from assuming that the share of emissions in 2005 is the same as the share of emissions in 1990. Because California population and employment are expected to grow more rapidly than the nation's population and employment during the period of 1990 to 2005, these adjustments are warranted.

Exhibit 41: California Emissions as a Share of U.S. Emissions

End Use	1990 Share[a]	Additional CA Growth[b]	Proxy[c]
Mobile AC	10.4%	8.0%	Population
Process Refrigeration	12.2%	4.0%	Employment in the oil, gas, and chemical industries
Commercial Refrigeration	9.5%	8.0%	Population
Residential Refrig & Freezers	9.0%	8.0%	Population
Res. & Light Com'l Cooling	8.8%	8.0%	Population
Commercial Chillers	8.5%	8.0%	Population
Solvents	18.1%	2.8%	Employment in SICs 35 to 38
Foams	16.4%	9.3%	Average of growth rates for population and construction industry employment
Sterilization	8.3%	8.0%	Population
Miscellaneous	12.0%	8.0%	Population
Fire Extinguishing	12.2%	8.0%	Population

a California 1990 emissions as a share of national 1990 emissions.
b The extent to which the California growth exceeds the national growth from 1990 to 2005
c Proxy used to estimate the national and California growth rates from 1990 to 2005.
Source: Growth rates of proxies from U.S. Bureau of Economic Analysis (1990).

4.3 CHEMICAL SUBSTITUTION SCENARIOS

A variety of HCFCs and HFCs are currently under development as replacements for the CFCs. The extent to which these substitutes are used and emitted will be influenced by the costs and suitability of the substitutes as well as potential future restrictions on their use and emissions. Based on current expectations of future prices of the substitutes, economic factors will favor their use. Prior to 2005, recycling will be required during the servicing and disposal of air conditioning and refrigeration equipment containing the HCFC and HFC substitutes. However, other limitations on their use and emissions are not likely to be in place by that time. Therefore, by 2005 it is anticipated that in most cases these replacements can capture a large portion of the market currently served by CFCs. Over the longer term, by 2015 for example, the use of HCFCs will be limited. Controls on HFCs are not being contemplated at this time.

While HCFC and HFC substitutes are expected to become widely used, their future use could be less than currently envisioned as the result of various unanticipated factors, such as: toxicity concerns; production difficulties; or more stringent control of the HCFCs and HFCs than

currently expected. Under these circumstances, alternative chemical and product substitutes would be implemented that cost more than the expected costs of the HCFC and HFC substitutes.

To reflect the uncertainties in the future use of the HCFCs and HFCs, two chemical substitution scenarios were examined:

- High Chemical Substitute Scenario assumes that the HCFCs and HFCs currently under development will achieve a large market share in the demand for services currently supplied by the ODCs.

- Low Chemical Substitute Scenario assumes that in cases where non-HCFC and non-HFC product and chemical substitutes exist that they achieve a large market share in the demand for services currently supplied by ODCs.

Current assessments indicate that the High Chemical Substitute Scenario is more likely. The HCFC and HFC substitutes appear to have good performance and safety properties that make them suitable as replacements (see Section 5). Additionally, the price of the substitutes, although higher than the ODCs they are replacing, is expected to be competitive with other product and process alternatives.

Exhibit 42 summarizes the chemical substitute scenarios for each end use. As shown in the exhibit, the High Chemical Substitutes Scenario includes nearly complete conversion to HFCs and HCFCs in the refrigeration and air conditioning applications. Only commercial refrigeration is estimated to switch to increased use of ammonia refrigeration systems in the High Scenario. In the Low Chemical Substitutes Scenario, the refrigeration and air conditioning end uses switch to hydrocarbons, ammonia, and other non-HFC/HCFC substitutes.

For example, a substitute that includes 65 percent propane is under development for use in residential refrigerators and freezers and commercial refrigeration applications. Controls on HCFCs could result in the use of this formulation in some portion of the market. Due to flammability concerns, only a 15 percent penetration is assumed in the home refrigerator/freezer market (resulting in a 10 percent displacement of HCFCs), and a much larger penetration is assumed for the commercial end use.

In the solvents end use the High Chemical Substitutes Scenario includes HCFC-123 use along with substantial penetration of "no clean" technologies for producing electronic components. The "no clean" techniques, which are currently being implemented, do not require the use of solvents during the manufacturing process. Some market penetration of aqueous cleaners, in some cases with terpenes (a volatile organic compound) is also expected. In the Low Chemical Substitutes case the use of HCFC-123 is assumed to be reduced by 75 percent principally in favor of aqueous cleaners.

About 85 percent of Foam production is expected to switch to HCFC substitutes. The remaining 15 percent is expected to switch to non-foam substitutes or water-blown foam. Large reductions in HCFC use as a foam blowing agent will be possible if alternative building and

appliance insulation techniques become available and if alternative foam manufacturing systems are developed. In the Low Chemical Substitutes Scenario a 90 percent penetration of the non-HCFC technologies is used.

Exhibit 42: Chemical Substitutes Scenarios

End Use	High Chemical Substitutes Scenario	Low Chemical Substitutes Scenario
Mobile AC	Complete conversion to HFC-134a	10% served by non-HFC/HCFC substitute (HC)[a]
Process Refrigeration	Complete conversion to HCFC-22, with some HCFC-123 and HFC-134a	75% served by non-HFC/CFC substitute (ammonia or HC)
Commercial Refrigeration	Complete conversion to HCFC-22, with some HCFC-124 and HFC-134a and ammonia	50% served by non-HFC/CFC substitute (ammonia or HC)
Residential Refrig & Freezers	Complete conversion to HCFC-22, HCFC-124 and HFC-152a	10% served by non-HFC/HCFC substitute (HC)
Res. & Light Com'l Cooling	Complete conversion to HCFC-22	50% served by non-HFC/CFC substitute (ammonia or HC)
Commercial Chillers	Complete conversion to HCFC-22, with some HCFC-123, 124 and HFC-134a and HFC-152a	50% served by non-HFC/CFC substitute (ammonia or HC)
Solvents	Complete conversion to HCFC-123, with some aqueous, terpene, and no clean[b]	75% switch to non-HFC/HCFC substitutes (aqueous, terpenes, no clean)
Foams	Partial conversion (85%) to HCFC-22, 123, 124, 141b, 142b	90% switch to non-HFC/HCFC substitutes (alternative resin systems or products)
Sterilization	Complete conversion to HCFC Substitute,[c] with some switching to pure EO and CO_2	75% switch to non-HFC/HCFC substitutes (pure EO or CO_2)
Miscellaneous	Partial conversion to HCFC-22 and HCFC Substitute	75% switch to non-HFC/HCFC substitutes
Fire Extinguishing	Complete conversion to non-HFC/HCFC substitutes	Same as High Scenario

a HC = hydrocarbon.
b "no clean" = electronic component manufacturing technology that does not require solvent cleaning.
c HCFC Substitute = proprietary formulation of HCFCs.
Source: ICF Consulting Associates, Incorporated estimates.

Sterilization applications are expected to switch principally to a proprietary HCFC substitute in place of CFC-12. Some switching to pure EO and CO_2 as the EO carrier gas is also expected among contract sterilizing facilities. In the Low Chemical Substitutes Scenario 75 percent of the use of the HCFC substitute is estimated to be replaced.

Among Miscellaneous applications non-HCFC substitutes are anticipated to be used in most cases in the High Chemical Substitutes Scenario. In the Low Scenario, an additional 75 percent reduction is assumed.

In Fire Extinguishing applications HCFCs and HFCs are not currently being considered as substitutes because they do not have the necessary fire and explosion suppression characteristics. CO_2 and water-based systems are expected to be used at this time. Consequently, the High and Low Chemical Substitutes Scenarios are the same for the fire extinguishing application.

4.4 SCENARIO ANALYSES

Exhibit 43 presents the estimate of national emissions in 2005 for the High Chemical Substitutes Scenario and the 2000 ODC phaseout as required under the Clean Air Act Amendments of 1990 (CAAA). The top half of the exhibit shows the emissions of the ODCs, and the bottom half shows the emissions of the substitutes. The total listed on the bottom half is the total across all the compounds including both the ODCs and their substitutes.

By 2005 the emissions from the fully-halogenated CFCs and the halons are reduced substantially from 1990 levels. The emissions of the CFCs in 2005 are due to leakage from refrigeration and air conditioning equipment and emissions from insulating foams in buildings and appliances. By 2005 all air conditioning and refrigeration system service and disposal activities will be conducted with recycling equipment. Consequently, the emissions estimated for these applications in 2005 are only associated with the leakage during operations or from system rupture.

The halon emissions in 2005 are associated with the use of remaining halon-charged equipment to extinguish fires. By 2005 control measures are estimated to be in place that will prevent most unwanted discharge, all training-related emissions, and most emissions from disposal. Only older hand-held halon 1211 extinguishers that do not have the connections needed to recycle the halons are assumed to cause emissions in 2005.

The High Chemical Substitutes Scenario shown in Exhibit 43 includes substantial use of HCFCs and HFCs in the various applications. For example, HFC-134a will be used on MACs. HCFC-22, HCFC-123, HCFC-124 and HFC-134a are used as replacements in other refrigeration and air conditioning applications. The choice of which substitutes will be used is made based on current assessments of the thermodynamic properties of the substitutes and the temperature range of the equipment.

Exhibit 43: U.S. 2005 Emissions for High Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	7,881	0	0	0	0	0	0	0
Process Refrigeration	29	170	0	0	1	1,442	0	0	0
Commercial Refrig	0	1,023	0	0	302	6,902	0	0	0
Res. Refrig. & Freezers	0	144	0	0	0	82	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	3,331	0	0	0
Commercial Chillers	721	343	0	19	0	3,066	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	2,460	0	0	0	17,177	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	29	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	364	521
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	12,022	0	19	303	32,029	0	364	521

ODC Substitutes:

	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL
Mobile AC	0	0	0	0	0	31,289	0	0	0	0	39,170
Process Refrigeration	67	2	0	0	0	150	7	0	0	0	1,869
Commercial Refrig	0	34	5	0	0	1,180	68	0	0	136	9,651
Res. Refrig. & Freezers	0	41	0	0	0	0	82	0	0	0	349
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	3,331
Commercial Chillers	1,589	40	0	0	0	326	40	0	0	0	6,144
Solvents	23,971	0	0	0	0	0	0	0	5,542	178	29,691
Foams	28,097	2,489	0	28,097	7,385	0	0	0	0	0	114,445
Sterilization	0	0	0	0	0	0	0	8,399	0	430	8,829
Miscellaneous	0	0	0	0	0	0	0	15	0	0	44
Fire Extinguishing	0	0	0	0	0	0	0	0	0	1,715	2,600
Subs Manufacturing	262	13	0	140	37	8	0	42	0	0	502
Total	53,986	2,619	5	28,237	7,422	32,953	198	8,455	5,542	49,125	263,291

Source: ICF Consulting Associates, Incorporated estimates.

Several HCFC substitutes are expected to be used to produce foams. The 2005 HCFC emissions estimates for foams include the leakage emissions from the foam put in place between 1990 and 2005.

Solvent applications are expected to switch primarily to HCFC-123. A terpene solvent is also anticipated to be used. The emissions from this substitute are listed in the column for VOC Substitutes in Exhibit 43. Emissions from Other Substitutes are also listed for solvents. These are small emissions from aqueous cleaning systems. Because "no clean" technologies do not produce emissions they are not listed in the 2005 inventory.

The emissions in the Sterilization application are listed under a column for HCFC Substitute. A proprietary blend of HCFCs is being developed for use in sterilization equipment, and consequently the individual components of the mixture cannot be identified. A small level of emissions of Other Substitutes are also listed for Sterilization, which include CO_2-based systems and pure EO systems. The substitutes for the Fire Extinguisher application are also listed under the Other Substitutes column. These emissions are principally CO_2 from CO_2-based fire extinguisher systems.

Estimates of emissions from manufacturing activities are estimated at 0.5 percent of use as was done for the 1990 emissions inventory. Note that CT emissions are not estimated because CFC-11 and CFC-12 are not produced in 2005. At this time it is not known whether CT will be used to produce the HCFC and HFC substitutes. If CT is produced for this purpose, CT emissions may result in 2005.

Exhibits 44 and 45 show the 2005 emissions weighted by ozone depleting potential (ODP) and global warming potential (GWP). As shown in the exhibits, the ODP- and GWP-weighted emissions in 2005 are dominated by the CFC-11 and CFC-12 emissions from foams. CFC-12 emissions from MACs are the second largest ODP-weighted source and CFC-12 and HFC-134a emissions from MACs are the second and third largest GWP-weighted sources. The ODP- and GWP-weighted emissions from the substitutes are relatively small because of their low ODP and GWP values. As contrasted with 1990, the total 2005 ODP- and GWP-weighted emissions are only about 20 percent of the 1990 totals.

Exhibits 46 through 48 show similar information for the Low Chemical Substitutes Scenario. Compared to the High Scenario, the principal difference is that emissions from the HCFC and HFC substitutes are substantially reduced. For example, in the High Scenario HCFC-123 emissions are estimated to be nearly 54 million kilograms in 2005. In the Low Scenario emissions are estimated to be only about 10 million kilograms. The displaced HCFCs and HFCs are listed in a column of Extra Substitutes to show the quantity that was eliminated in the Low Scenario. This quantity of Extra Substitutes is included in the Total column.

Exhibit 47 and 48 show the ODP- and GWP-weighted emissions estimates for the Low Chemical Substitutes Scenario. Relative to the High Scenario, the ODP-weighted emissions are reduced by only about 10 percent despite large shifts in the estimated use of the HCFCs. Only

Exhibit 44: U.S. 2005 ODP-Weighted Emissions for High Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

ODP Weight	1.00	1.00	0.80	0.60	0.50	0.05	0.11	3.00	10.00
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	7,881	0	0	0	0	0	0	0
Process Refrigeration	29	170	0	0	0	72	0	0	0
Commercial Refrig	0	1,023	0	0	151	345	0	0	0
Res. Refrig. & Freezers	0	144	0	0	0	4	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	167	0	0	0
Commercial Chillers	721	343	0	12	0	153	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	2,460	0	0	0	859	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	1	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	1,092	5,211
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	12,022	0	12	151	1,601	0	1,092	5,211

ODP Weight	0.02	0.02	0.00	0.08	0.06	0.00	0.00	0.05	0.00	0.00	
	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL
Mobile AC	0	0	0	0	0	0	0	0	0	0	7,881
Process Refrigeration	1	0	0	0	0	0	0	0	0	0	273
Commercial Refrig	0	1	0	0	0	0	0	0	0	0	1,520
Res. Refrig. & Freezers	0	1	0	0	0	0	0	0	0	0	149
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	167
Commercial Chillers	32	1	0	0	0	0	0	0	0	0	1,262
Solvents	479	0	0	0	0	0	0	0	0	0	479
Foams	562	50	0	2,248	443	0	0	0	0	0	35,361
Sterilization	0	0	0	0	0	0	0	420	0	0	420
Miscellaneous	0	0	0	0	0	0	0	1	0	0	2
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	6,303
ODC Manufacturing	5	0	0	11	2	0	0	2	0	0	21
Total	1,080	52	0	2,259	445	0	0	423	0	0	53,839

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 45: U.S. 2005 GWP-Weighted Emissions for High Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

100 yr GWP Weight	1.00	2.10	1.20	2.00	2.00	0.43	0.03	0.00	1.70
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	16,551	0	0	0	0	0	0	0
Process Refrigeration	29	357	0	0	1	620	0	0	0
Commercial Refrig	0	2,148	0	0	605	2,968	0	0	0
Res. Refrig. & Freezers	0	303	0	0	0	35	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	1,433	0	0	0
Commercial Chillers	721	720	0	39	0	1,318	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	5,166	0	0	0	7,386	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	12	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	0	886
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	25,246	0	39	606	13,773	0	0	886

100 yr GWP Weight	0.02	0.12	0.71	0.13	0.05	0.34	0.03	0.20	0.00	0.00	
	HCFC-123	HCFC-124	HFC-125	HCFC-1418	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL
Mobile AC	0	0	0	0	0	10,732	0	0	0	0	27,283
Process Refrigeration	2	0	0	0	0	52	0	0	0	0	1,061
Commercial Refrig	0	4	4	0	0	405	2	0	0	0	6,136
Res. Refrig. & Freezers	0	5	0	0	0	0	2	0	0	0	346
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	1,433
Commercial Chillers	38	5	0	0	0	112	1	0	0	0	2,954
Solvents	575	0	0	0	0	0	0	0	0	0	575
Foams	674	306	0	3,540	337	0	0	0	0	0	46,150
Sterilization	0	0	0	0	0	0	0	1,680	0	0	1,680
Miscellaneous	0	0	0	0	0	0	0	3	0	0	15
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	886
ODC Manufacturing	6	2	0	18	2	3	0	8	0	0	38
Total	1,296	322	4	3,558	339	11,303	6	1,691	0	0	88,558

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 46: U.S. 2005 Emissions for Low Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	7,881	0	0	0	0	0	0	0
Process Refrigeration	29	170	0	0	1	361	0	0	0
Commercial Refrig	0	1,023	0	0	302	3,451	0	0	0
Res. Refrig. & Freezers	0	144	0	0	0	73	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	1,666	0	0	0
Commercial Chillers	721	343	0	19	0	1,533	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	2,460	0	0	0	1,718	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	7	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	364	521
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	12,022	0	19	303	8,809	0	364	521

ODC Substitutes

	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subs	Extra Sub	TOTAL
Mobile AC	0	0	0	0	0	28,160	0	0	0	0	3,129	39,170
Process Refrigeration	17	1	0	0	0	38	2	0	0	0	1,252	1,869
Commercial Refrig	0	17	3	0	0	590	34	0	0	136	4,095	9,651
Res. Refrig. & Freezers	0	37	0	0	0	0	73	0	0	0	20	349
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	1,666	3,331
Commercial Chillers	794	20	0	0	0	163	20	0	0	0	2,530	6,144
Solvents	5,993	0	0	0	0	0	0	0	5,542	178	17,978	29,691
Foams	2,810	249	0	2,810	738	0	0	0	0	0	74,921	114,445
Sterilization	0	0	0	0	0	0	0	2,100	0	430	6,299	8,829
Miscellaneous	0	0	0	0	0	0	0	4	0	0	33	44
Fire Extinguishing	0	0	0	0	0	0	0	0	0	1,715	0	2,600
ODC Manufacturing	45	1	0	14	4	7	0	11	0	0	0	82
Total	9,659	325	3	2,824	742	28,957	130	2,114	5,542	49,125	111,923	262,870

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 47: U.S. ODP-Weighted 2005 Emissions for Low Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

ODP Weight	1.00	1.00	0.80	0.60	0.50	0.05	0.11	3.00	10.00
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	7,881	0	0	0	0	0	0	0
Process Refrigeration	29	170	0	0	0	18	0	0	0
Commercial Refrig	0	1,023	0	0	151	173	0	0	0
Res. Refrig. & Freezers	0	144	0	0	0	4	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	83	0	0	0
Commercial Chillers	721	343	0	12	0	77	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	2,460	0	0	0	86	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	0	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	1,092	5,211
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	12,022	0	12	151	440	0	1,092	5,211

ODP Weight	0.02	0.02	0.00	0.08	0.06	0.00	0.00	0.05	0.00	0.00	
	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth/Extra Subst	TOTAL
Mobile AC	0	0	0	0	0	0	0	0	0	0	7,881
Process Refrigeration	0	0	0	0	0	0	0	0	0	0	218
Commercial Refrig	0	0	0	0	0	0	0	0	0	0	1,347
Res. Refrig. & Freezers	0	1	0	0	0	0	0	0	0	0	149
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	83
Commercial Chillers	16	0	0	0	0	0	0	0	0	0	1,169
Solvents	120	0	0	0	0	0	0	0	0	0	120
Foams	56	5	0	225	44	0	0	0	0	0	31,616
Sterilization	0	0	0	0	0	0	0	105	0	0	105
Miscellaneous	0	0	0	0	0	0	0	0	0	0	1
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	6,303
ODC Manufacturing	1	0	0	1	0	0	0	1	0	0	3
Total	193	6	0	226	45	0	0	106	0	0	48,995

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 48: U.S. GWP-Weighted 2005 Emissions for Low Chemical Substitutes Scenario and 2000 Phaseout (Thousands of Kilograms)

100 yr GWP Weight	1.00	2.10	1.20	2.00	2.00	0.43	0.03	0.00	1.70
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	16,551	0	0	0	0	0	0	0
Process Refrigeration	29	357	0	0	1	155	0	0	0
Commercial Refrig	0	2,148	0	0	605	1,484	0	0	0
Res. Refrig. & Freezers	0	303	0	0	0	32	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	716	0	0	0
Commercial Chillers	721	720	0	39	0	659	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	28,740	5,166	0	0	0	739	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	3	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	0	886
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	29,490	25,246	0	39	606	3,788	0	0	886

100 yr GWP Weight	0.02	0.12	0.71	0.13	0.05	0.34	0.03	0.20	0.00	0.00	
	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth/Extra Subst	TOTAL
Mobile AC	0	0	0	0	0	9,659	0	0	0	0	26,210
Process Refrigeration	0	0	0	0	0	13	0	0	0	0	556
Commercial Refrig	0	2	2	0	0	202	1	0	0	0	4,444
Res. Refrig. & Freezers	0	5	0	0	0	0	2	0	0	0	342
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	716
Commercial Chillers	19	2	0	0	0	56	1	0	0	0	2,217
Solvents	144	0	0	0	0	0	0	0	0	0	144
Foams	67	31	0	354	34	0	0	0	0	0	35,130
Sterilization	0	0	0	0	0	0	0	420	0	0	420
Miscellaneous	0	0	0	0	0	0	0	1	0	0	4
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	886
ODC Manufacturing	1	0	0	2	0	2	0	2	0	0	8
Total	232	40	2	356	34	9,932	4	423	0	0	71,077

Source: ICF Consulting Associates, Incorporated estimates.

a small reduction results because the HCFCs have relatively low ODPs, and the 2005 ODP-weighted emissions are dominated by CFC-11 and CFC-12 emissions from MACs and foams and halon emissions from fire extinguishing equipment.

The Low Chemical Substitutes Scenario has about a 20 percent reduction in the GWP-weighted emissions in 2005 relative to the High Scenario. The reduction relative to the High Scenario is larger for the GWP-weighted emissions because HCFC-22, HCFC-141b and HFC-134a have relatively higher GWP values as compared to their ODP values.

While these U.S. emissions estimates for 2005 are based on the Clean Air Act Amendments (CAAA) 2000 phaseout schedule, the Federal government has recently announced its intention to accelerate the phaseout to 1996. Accelerating the phaseout will reduce 2005 CFC-11 and CFC-12 emissions from MACs, process refrigeration, and chiller applications. These applications are estimated to be major users of CFCs in the period between 1996 and 2000 under the CAAA phaseout schedule. Other applications would use CFCs as well during this period, however these other uses do not contribute significantly to emissions in 2005. For example, CFC use in solvents and sterilization during the 1996 to 2000 period does not contribute to emissions in 2005.

Because foam uses of CFCs are estimated to be among the first to switch to substitutes as the result of Federal controls on CFC production, the acceleration of the phaseout schedule does not affect 2005 emissions from this application. Additionally, the halon industry has committed to phasing out production of halons by 1995, even under the CAAA schedule, so the emissions estimates under the 1996 and 2000 phaseout schedules are equal.

Exhibit 49 summarizes the ODP- and GWP- weighted emissions under both the 1996 and 2000 phaseouts. As shown in the exhibit, the 1996 phaseout reduces ODP-weighted emissions in 2005 by about 2.5 percent in both the High and Low Chemical Substitutes Scenarios. The emissions during the period 1996 through 2000 are reduced by a much larger percentage as the result of the accelerated phaseout schedule. By the year 2005, however, the effects of accelerating the phaseout on emissions in that year are relatively minor. A similar reduction in GWP-weighted emissions in 2005 results from the accelerated phaseout.

Because the California emissions estimates are based on the U.S. estimates, the 2005 emissions for California follow the same pattern as the U.S. Exhibits 50 through 52 show detailed emissions estimates for the High Chemical Substitutes 1996 phaseout scenario. Exhibit 53 compares the various phaseout and chemical substitution scenario estimates of ODP- and GWP-weighted emissions. As was observed in the U.S. estimates, the emissions from Foams dominate the ODP- and GWP-weighted emissions estimates for 2005. The ODP-weighted emissions are smaller by about 10 percent in 2005 for the Low Chemical Substitutes Scenario as compared with the High Scenario. The 2005 accelerated phaseout ODP-weighted emissions in California are about 2 percent lower than the 2000 phaseout emissions.

On a GWP-weighted basis a similar pattern is observed. The role of MACs is larger on a GWP-weighted basis because the GWP for HFC-134a is relatively high.

Exhibit 49: U.S. Weighted 2005 Emissions for the 1996 and 2000 Phaseouts (Thousands of Kilograms)

Application	ODP-Weighted Emissions			GWP-Weighted Emissions		
High Chemical Substitutes Scenario						
	2000 Phaseout	1996 Phaseout	Difference	2000 Phaseout	1996 Phaseout	Difference
Mobile AC	7,881	7,093	788	27,283	25,898	1,385
Process Refrigeration	273	205	68	1,061	942	119
Commercial Refrig	1,520	1,520	0	6,136	6,136	0
Res. Refrig. & Freezers	149	149	0	346	346	0
Res. & Light Com'l AC	167	167	0	1,433	1,433	0
Commercial Chillers	1,262	842	420	2,954	2,432	522
Solvents	479	479	0	575	575	0
Foams	35,361	35,361	0	46,150	46,150	0
Sterilization	420	420	0	1,680	1,680	0
Miscellaneous	2	2	0	15	15	0
Fire Extinguishing	6,303	6,303	0	886	886	0
ODC Manufacturing	21	21	0	38	39	1
Total	53,839	52,563	1,276	88,558	86,531	2,027
Low Chemical Substitutes Scenario						
	2000 Phaseout	1996 Phaseout	Difference	2000 Phaseout	1996 Phaseout	Difference
Mobile AC	7,881	7,093	788	26,210	24,798	1,412
Process Refrigeration	218	149	69	556	419	137
Commercial Refrig	1,347	1,347	0	4,444	4,444	0
Res. Refrig. & Freezers	149	149	0	342	342	0
Res. & Light Com'l AC	83	83	0	716	716	0
Commercial Chillers	1,169	746	423	2,217	1,668	549
Solvents	120	120	0	144	144	0
Foams	31,616	31,616	0	35,130	35,130	0
Sterilization	105	105	0	420	420	0
Miscellaneous	1	1	0	4	4	0
Fire Extinguishing	6,303	6,303	0	886	886	0
ODC Manufacturing	3	3	0	8	8	0
Total	48,995	47,716	1,280	71,077	68,978	2,098

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 50: CA 2005 Emissions for High Chemical Substitutes Scenario and 1996 Phaseout (Thousands of Kilograms)

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	794	0	0	0	0	0	0	0
Process Refrigeration	4	13	0	0	0	183	0	0	0
Commercial Refrig	0	104	0	0	31	705	0	0	0
Res. Refrig. & Freezers	0	14	0	0	0	8	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	318	0	0	0
Commercial Chillers	40	19	0	2	0	282	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	5,143	440	0	0	0	3,074	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	4	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	48	69
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	5,186	1,384	0	2	31	4,572	0	48	69

ODC Substitutes:

	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL
Mobile AC	0	0	0	0	0	3,590	0	0	0	0	4,384
Process Refrigeration	9	0	0	0	0	28	1	0	0	0	237
Commercial Refrig	0	3	1	0	0	120	7	0	0	14	985
Res. Refrig. & Freezers	0	4	0	0	0	0	8	0	0	0	34
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	318
Commercial Chillers	172	4	0	0	0	43	4	0	0	0	564
Solvents	4,451	0	0	0	0	0	0	0	1,029	33	5,513
Foams	5,028	445	0	5,028	1,322	0	0	0	0	0	20,480
Sterilization	0	0	0	0	0	0	0	756	0	39	794
Miscellaneous	0	0	0	0	0	0	0	2	0	0	6
Fire Extinguishing	0	0	0	0	0	0	0	0	0	226	342
ODC Manufacturing	48	2	0	25	7	1	0	4	0	0	86
Total	9,707	459	1	5,053	1,328	3,782	20	761	1,029	311	33,743

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 51: CA ODP-Weighted 2005 Emissions for High Chemical Substitutes Scenario and 1996 Phaseout (Thousands of Kilograms)

ODP Weight	1.00	1.00	0.80	0.60	0.50	0.05	0.11	3.00	10.00
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301
Mobile AC	0	794	0	0	0	0	0	0	0
Process Refrigeration	4	13	0	0	0	9	0	0	0
Commercial Refrig	0	104	0	0	15	35	0	0	0
Res. Refrig. & Freezers	0	14	0	0	0	0	0	0	0
Res. & Light Com'l AC	0	0	0	0	0	16	0	0	0
Commercial Chillers	40	19	0	1	0	14	0	0	0
Solvents	0	0	0	0	0	0	0	0	0
Foams	5,143	440	0	0	0	154	0	0	0
Sterilization	0	0	0	0	0	0	0	0	0
Miscellaneous	0	0	0	0	0	0	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	144	685
ODC Manufacturing	0	0	0	0	0	0	0	0	0
Total	5,186	1,384	0	1	15	229	0	144	685

ODP Weight	0.02	0.02	0.00	0.08	0.06	0.00	0.00	0.05	0.00	0.00	
	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL
Mobile AC	0	0	0	0	0	0	0	0	0	0	794
Process Refrigeration	0	0	0	0	0	0	0	0	0	0	26
Commercial Refrig	0	0	0	0	0	0	0	0	0	0	155
Res. Refrig. & Freezers	0	0	0	0	0	0	0	0	0	0	14
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	16
Commercial Chillers	3	0	0	0	0	0	0	0	0	0	77
Solvents	89	0	0	0	0	0	0	0	0	0	89
Foams	101	9	0	402	79	0	0	0	0	0	6,328
Sterilization	0	0	0	0	0	0	0	38	0	0	38
Miscellaneous	0	0	0	0	0	0	0	0	0	0	0
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	829
ODC Manufacturing	1	0	0	2	0	0	0	0	0	0	4
Total	194	9	0	404	80	0	0	38	0	0	8,370

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 52: CA GWP-Weighted 2005 Emissions for High Chemical Substitutes Scenario and 1996 Phaseout (Thousands of Kilograms)

100 yr GWP Weighted	1.00	2.10	1.20	2.00	2.00	0.43	0.03	0.00	1.70			
	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	MC	H-1211	H-1301			
Mobile AC	0	1,667	0	0	0	0	0	0	0			
Process Refrigeration	4	27	0	0	0	79	0	0	0			
Commercial Refrig	0	219	0	0	62	303	0	0	0			
Res. Refrig. & Freezers	0	29	0	0	0	3	0	0	0			
Res. & Light Com'l AC	0	0	0	0	0	137	0	0	0			
Commercial Chillers	40	40	0	4	0	121	0	0	0			
Solvents	0	0	0	0	0	0	0	0	0			
Foams	5,143	924	0	0	0	1,322	0	0	0			
Sterilization	0	0	0	0	0	0	0	0	0			
Miscellaneous	0	0	0	0	0	2	0	0	0			
Fire Extinguishing	0	0	0	0	0	0	0	0	117			
ODC Manufacturing	0	0	0	0	0	0	0	0	0			
Total	5,186	2,907	0	4	62	1,966	0	0	117			
100 yr GWP Weighted	0.02	0.12	0.71	0.13	0.05	0.34	0.03	0.20	0.00	0.00		
	HCFC-123	HCFC-124	HFC-125	HCFC-141B	HCFC-142B	HFC-134A	HFC-152A	HCFC Subst	VOC Subst	Oth Subst	TOTAL	
Mobile AC	0	0	0	0	0	1,232	0	0	0	0	2,899	
Process Refrigeration	0	0	0	0	0	9	0	0	0	0	119	
Commercial Refrig	0	0	0	0	0	41	0	0	0	0	626	
Res. Refrig. & Freezers	0	0	0	0	0	0	0	0	0	0	34	
Res. & Light Com'l AC	0	0	0	0	0	0	0	0	0	0	137	
Commercial Chillers	4	0	0	0	0	15	0	0	0	0	223	
Solvents	107	0	0	0	0	0	0	0	0	0	107	
Foams	121	55	0	634	60	0	0	0	0	0	8,258	
Sterilization	0	0	0	0	0	0	0	151	0	0	151	
Miscellaneous	0	0	0	0	0	0	0	0	0	0	2	
Fire Extinguishing	0	0	0	0	0	0	0	0	0	0	117	
ODC Manufacturing	1	0	0	3	0	0	0	1	0	0	6	
Total	233	56	0	637	61	1,297	1	152	0	0	12,679	

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 53: CA Weighted 2005 Emissions for the 1996 and 2000 Phaseouts
(Thousands of Kilograms)

Application	ODP-Weighted Emissions			GWP-Weighted Emissions		
High Chemical Substitutes Scenario						
	2000 Phaseout	1996 Phaseout	Difference	2000 Phaseout	1996 Phaseout	Difference
Mobile AC	882	794	88	3,054	2,899	155
Process Refrigeration	35	26	9	135	119	16
Commercial Refrig	155	155	0	626	626	0
Res. Refrig. & Freezers	14	14	0	34	34	0
Res. & Light Com'l AC	16	16	0	137	137	0
Commercial Chillers	116	77	39	271	223	48
Solvents	89	89	0	107	107	0
Foams	6,328	6,328	0	8,258	8,258	0
Sterilization	38	38	0	151	151	0
Miscellaneous	0	0	0	2	2	0
Fire Extinguishing	829	829	0	117	117	0
ODC Manufacturing	4	4	0	6	6	0
Total	8,506	8,370	136	12,897	12,679	219
Low Chemical Substitutes Scenario						
	2000 Phaseout	1996 Phaseout	Difference	2000 Phaseout	1996 Phaseout	Difference
Mobile AC	882	794	88	2,934	2,776	158
Process Refrigeration	28	19	9	70	53	17
Commercial Refrig	138	138	0	454	454	0
Res. Refrig. & Freezers	14	14	0	33	33	0
Res. & Light Com'l AC	8	8	0	68	68	0
Commercial Chillers	107	69	38	204	153	51
Solvents	22	22	0	27	27	0
Foams	5,658	5,658	0	6,286	6,286	0
Sterilization	9	9	0	38	38	0
Miscellaneous	0	0	0	0	0	0
Fire Extinguishing	829	829	0	117	117	0
ODC Manufacturing	0	0	0	1	1	0
Total	7,696	7,560	135	10,232	10,006	226

Source: ICF Consulting Associates, Incorporated estimates.

As discussed above, there are a variety of factors that contribute to uncertainty in the 2005 emissions estimates. Because CFC and halon production will certainly be phased out by 1996 or at the latest 2000, the CFC and halon emissions in 2005 will be driven solely by emissions from products produced prior to the phaseout. Because recycling during servicing and disposal will be required in 2005, emissions from refrigeration and air conditioning equipment will only result from leakage during system usage. These emissions are a function of the size and leakage characteristics of the remaining stock of equipment in 2005. If equipment is retired faster than currently expected, then CFC emissions in 2005 could be lower than estimated here.

Foam products containing CFCs are not currently expected to be subject to CFC-recapture requirements during disposal because technologies for capturing CFCs from foam during disposal remain to be demonstrated. Additionally, emissions occur during the useful life of the foam. Consequently, these emissions estimates are driven by expected leakage rates and disposal rates of insulating foams in buildings, refrigerators, and other appliances. These leakage and disposal rates are among the most uncertain estimates in the analysis. The rate of leakage from foams during use is influenced by the manner in which the foam was initially installed. Punctures in the foam can greatly increase the leakage rate. Additionally, rates of disposal of building insulation are not well characterized.

Although the 2005 foam emissions estimates are very uncertain, it is clear that all the CFCs used to make foams since the 1960s will be released eventually so that the total emissions over time from foams is relatively well known. Therefore, it is relatively certain that emissions of CFC-11 and CFC-12 from foams will be the most important source of fully halogenated CFC emissions in the U.S. during the 10 to 20 year period following the implementation of the CFC and halon production phaseout.

While the Low and High Chemical Substitutes Scenarios show a range of potential future emissions of HCFC and HFC substitutes, the ODP- and GWP-weighted emissions are very similar for the two cases. Considerable debate is continuing on how to restrict the use and emissions of HCFCs and HFCs in the future. While these substitutes are viewed as essential for the near-term phaseout of the CFCs, their use in the long term will likely be limited or eliminated by Federal regulation.

4.5 REFERENCES

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5. CONTROL MEASURE DESCRIPTIONS

5.1 INTRODUCTION

This chapter describes the technical options available to control ozone-depleting compound (ODC) emissions. The information presented was obtained by reviewing the national and international studies and technical manuals that have been prepared under the auspices of regulatory programs and the United Nations Environment Program (UNEP). Additionally, members of national and international advisory committees were consulted.

The available information was summarized and organized to facilitate ease of use. Consequently, control measures common to many end uses are summarized first. Then, the control measures are organized by end use application. Following these summaries, the control measures are evaluated to estimate their cost per kilogram of emissions avoided and the amount of emissions reduction that can be achieved. This evaluation allows the most cost effective control measures to be identified.

During the preparation of this material, several control measures have become mandatory under federal statute and regulation. These requirements are mentioned as applicable in this section. A full review of federal, state, and local requirements is presented in Section 6.

The remainder of this chapter is organized as follows:

- Section 5.2 summarizes the methodology used.
- Section 5.3 summarizes the major chemical substitutes that may be used across a variety of end use applications.
- Section 5.4 describes the recycling options that are applicable to a variety of refrigeration and cooling applications.
- Section 5.5 summarizes the control measures by application.
- Section 5.6 evaluates the control measures in terms of cost per kilogram and other factors.

5.2 METHODOLOGY

The summary of control measures was developed by first defining the information desired on each control option and then reviewing available published information. To develop as comprehensive a summary as possible, U.S. EPA regulatory assessments and UNEP technical manuals were reviewed in detail. In particular, the data in previous EPA studies were used

because ICF has characterized the available information and developed a database that is used by the Agency to evaluate the availability and cost of controlling ODCs (e.g., EPA, 1988 and its updates). These data have been updated and were extracted and used to prepare this summary.

Additionally, data from the UNEP technical manuals were reviewed, in particular to identify the risk and toxicity characteristics of control options. Risk and toxicity information do not exist for many of the control options. The available information is summarized to the extent possible. Similarly, studies of the various control measures on energy requirements have produced a range of estimates of the impacts on energy use, and consequently energy-related emissions. The range of estimates is discussed where information is available.

In many cases, the EPA restrictions on ODC production and use, coupled with the excise taxes levied on ODCs have led to the adoption of many controls. Additionally, some controls are now mandated by federal regulation. Information on the controls that are starting to be implemented in the market place is emphasized.

All cost information was first developed for model plants or model pieces of equipment or processes. These data are presented along with the descriptions of the control measures. To evaluate the cost effectiveness of the control measures, these costs were analyzed to estimate a cost per kilogram of emissions avoided over the life-cycle of the equipment or plant. In the case of "drop-in" chemical substitutes with no energy-use impacts, this estimate is simply the increased cost of using the substitute. In cases where there are increases or reductions in energy use, or changes in the cost of capital equipment or maintenance activities these changes in costs are estimated for the life of the equipment so that an increased (or decreased) cost of operation is computed. These costs are then annualized and divided by the annual emissions reduction from the technology to estimate costs per kilogram of emissions avoided. This procedure was used to evaluate control options in EPA (1988).

5.3 MAJOR CHEMICAL SUBSTITUTES

This section summarizes the major chemical substitutes that may be used in a variety of applications. This information is summarized here so that it need not be repeated under each end use discussion. First, existing chemical substitutes are discussed, i.e., those that are currently in use. New chemical substitutes, i.e., those that have only recently been developed or that are currently under development and testing, are discussed separately. The following information is presented for each chemical substitute: ozone depleting potential (ODP); global warming potential (GWP); human health and safety impacts; implications for the control of criteria pollutants and toxic air contaminants; and cross-media impacts (if applicable). Impacts on energy use vary depending on the end use application, and consequently this impact is discussed with each end use.

5.3.1 Existing Chemical Substitutes

HCFC-141b

HCFC-141b (CH_3CCl_2F) is currently being evaluated as a potential chemical substitute for CFC-113 and methyl chloroform (MC) in electronics and precision cleaning applications, and as a substitute for CFC-11 and CFC-12 in foam blowing applications. Its low boiling point makes it a viable substitute for CFC-113 in most solvent cleaning applications, but it also is more volatile than CFC-113. HCFC-141b can be used as a solvent in existing equipment with a minimal amount of equipment modification. The primary modification which would be required for typical vapor degreasing equipment in order to make it available for use with HCFCs is increasing the freeboard height (the distance from the vapor/air interface to the top of the equipment). It has been recommended that a 100 percent freeboard ratio be used with HCFCs as opposed to the EPA standard 75 percent ratio (Dorsey, 1991).

While its chemical properties make HCFC-141b a good candidate for foam blowing applications, its high flammability may affect its market penetration because significant plant modifications may be necessary in order to maintain adequate safety precautions.

HCFC-141b, with an ODP of 0.08, is unacceptable as a substitute for MC because the two substances have the same ODP. Because of its relatively high ODP, HCFC-141b is rarely recommended as a substitute for CFCs. However, it is possible that HCFC-141b might be used as part of a blend in combination with HCFC-123. Thus, it appears as if HCFC-141b will be used sparingly in future applications as a chemical substitute for CFCs and MC.

HCFC-141b is not a criteria pollutant and is not anticipated to directly increase emissions of criteria pollutants. If used as a solvent, HCFC-141b can be recycled such that cross media impacts in terms of increases in water discharges or land application are not anticipated. Additionally, CFC-113 and MC are listed as air toxics under AB 2588 and are subject to state maximum contaminants levels (MCLs). Consequently, the use of HCFC-141b may not increase in cross-media impacts as compared with the current chemicals.

HCFC-22

HCFC-22 ($CHClF_2$) is a hydrochlorofluorocarbon and is considered an ODC in this report. It can be used as an alternative blowing agent in foams and has been commonly used as a refrigerant in many air conditioning and refrigeration end uses.

HCFC-22 can be used as both a substitute for CFCs in new equipment and as a retrofit for existing equipment because it is an efficient refrigerant that meets all toxicity and flammability requirements. It is thermodynamically suited to variable pressures and temperatures and is generally compatible with all common construction materials and nearly all commonly used lubricants. HCFC-22 has a higher discharge pressure than CFCs, and usually requires a stronger compressor.

As with HCFC-141b, HCFC-22 is not a criteria pollutant and is not anticipated to directly increase emissions of criteria pollutants. Additionally, if used as a refrigerant HCFC-22 can be recycled such that cross media impacts are not anticipated.

Ammonia

Ammonia is a refrigerant with excellent thermodynamic properties. Ammonia is, however, highly flammable and toxic, which significantly limits its use as a refrigerant where safety is a primary concern. Currently it is being used in large refrigeration systems somewhat removed from the general public. Current building codes limit ammonia system use to HVAC "equipment rooms" where alarm and venting devices can ensure safety. There is concern over the safety of ammonia when exposed to hazardous conditions such as fire and natural disaster. It is being considered as a substitute for process refrigeration and some commercial refrigeration equipment.

Ammonia is not a particularly good substitute for use in existing CFC-based equipment because its use requires major system modifications at significant cost when the system includes copper tubing or parts. For example, copper is commonly found in hermetically sealed systems such as home refrigerators. Compatibility is not a problem when steel is used. Ammonia-based systems can be engineered to include the cooling capacity and temperature ranges of current CFC-based equipment.

A considerable advantage of ammonia over the other chemical substitutes (existing and new) is that ammonia has been in use for a long time, and there exists considerable experience regarding manufacturing, operation and maintenance procedures. Ammonia is not a criteria pollutant, and its use is not anticipated to directly increase emissions of criteria pollutants. However, ammonia is highly toxic, and it is currently listed as an air toxic in California under AB 2588. It is also subject to the Federal requirements of SARA Section 313 (Toxic Chemicals) and SARA Section 302 (Extremely Hazardous Substances). Exhibit 54 summarizes the information on these three existing chemical substitutes.

5.3.2 New Chemical Substitutes

HCFC-123

HCFC-123 ($CHCl_2CF_3$) is currently being evaluated as a potential chemical substitute for CFC-113 and MC in electronics and precision cleaning applications, as a substitute for CFC-11 and CFC-12 in foam blowing applications, and as a substitute for CFC-11 in low pressure centrifugal chillers. Its low boiling point makes it a viable substitute for CFC-113 in most solvent cleaning applications, but is also more volatile than CFC-113.

HCFC-123 can be used as a solvent in existing equipment with a minimal amount of equipment modification. The primary modification which would be required for typical vapor degreasing equipment in order to make it available for use with HCFCs is increasing the

freeboard height (the distance from the vapor/air interface to the top of the equipment). It has been recommended that a 100 percent freeboard ratio be used with HCFCs as opposed to the EPA standard 75 percent ratio (Dorsey, 1991).

Exhibit 54: Summary of Major Chemical Substitutes

Chemical Substitute	ODP[a]	GWP[a]	Flammability	Toxicity[b]	Criteria Pollutant/ Cross Media Impact
Existing Chemical Substitutes					
HCFC-141b	0.08	0.13	Highly Flammable	Slightly toxic TLV = 500 ppm	None
HCFC-22	0.05	0.43	Not Flammable	Nontoxic TLV=1000 ppm	None
Ammonia	0.0	0.0	Highly Flammable	Highly Toxic	Air Toxic
New Chemical Substitutes					
HCFC-123	0.02	0.02	Not Flammable	Toxicity testing underway	None
HFC-134a	0.0	0.34	Not Flammable	Toxicity testing underway	None
Ternary Blends	≈.025	≈0.20	Slightly Flammable	Slightly Toxic	None
HCFC-22	0.05	0.43	Not Flammable	Nontoxic TLV=1000 ppm	None
HFC-152a	0.0	0.03	Flammable	Nontoxic TLV=1000 ppm	None
HCFC-124	0.02	0.12	Not Flammable	Slightly Toxic TLV=500 ppm	None

a ODP and GWP relative to CFC-11. The 100 year GWP for CFC-11 relative to CO_2 is about 3,500 (IPCC, 1990).

b TLV = threshold limit value for exposure.

Its non-flammability, coupled with good blowing efficiency make HCFC-123 an attractive chemical substitute in polyurethane foam applications. However, the high solvency of HCFC-123 has caused some problems in foam applications, particularly when it is used in refrigerators and other appliances with plastic components.

HCFC-123 has an ozone depletion potential (ODP) of 0.02, as compared with ODPs of 0.80 and 0.11 for CFC-113 and MC, respectively. In addition, it has a relatively short lifetime of 1.6 years. HCFC-123 has been viewed as a very promising chemical substitute, but recent toxicity test results have made industry experts more pessimistic about its future usefulness. The preliminary results from a two-year study of HCFC-123 toxicity show that the chemical has caused benign tumors in male rats (PAFT, 1991). Further testing of the chemical is currently in progress, and the results of these tests will most likely determine whether HCFC-123 will be available for future use as a CFC substitute.

HCFC-123 is not a criteria pollutant and is not anticipated to directly increase emissions of criteria pollutants. When used as a solvent HCFC-123 can be recycled such that cross media impacts are not anticipated. Additionally, CFC-11, which it may replace in some foam blowing applications, is already listed in the state by the Department of Health Services (DHS) as a Well Monitoring Chemical, a contaminant with a Maximum Contaminant Level (MCL), and chemical with a Drinking Water Action Level (Cal EPA, 1992). Consequently the use of HCFC-123 may not increase cross media impacts.

HFC-134a

HFC-134a (CH_2FCF_3) is a non-flammable, non-ozone depleting hydrofluorocarbon with properties that make it a good candidate for a refrigerant, as well as a substitute for CFCs in foam blowing applications. As a refrigerant, HFC-134a is considered a primary substitute for CFC-12 and in some cases as a substitute for HCFC-22. HFC-134a is expected to replace CFC-12 in medium temperature applications, but not for very low temperature applications.

In the air conditioning and refrigeration sector, the reduced energy efficiency of HFC-134a is a drawback, but is not considered to be significant. Efficiency may be improved by enlarging the heat exchangers and increasing the compressor and motor efficiencies of the systems. Some desiccants and virtually all lubricants used with CFC-12 are not compatible with HFC-134a. For example, mineral oil lubricants, such as polyalkylene oils, in CFC-12 systems are insoluble in HFC-134a. However, ester-based oils have been developed recently that appear to overcome this incompatibility problem. Although HFC-134a has an ODP of 0.0, its GWP is 0.34.

Toxicity testing of HFC-134a is still underway. HFC-134a is not a criteria pollutant and is not anticipated to directly increase emissions of criteria pollutants, other than possibly through energy use impacts. Additionally, when used as a refrigerant HFC-134a can be recycled such that cross media impacts are not anticipated.

Ternary Blend

Dupont has developed two ternary blend refrigerants comprised of HCFC-22, HFC-152a (CH_3CHF_2), and HCFC-124 ($CHClFCF_3$).[12] The blends, designed to be used for air conditioning and refrigeration equipment, differ only in the mixture of each chemical by weight as follows:

- Ternary Blend A: 36 percent HCFC-22; 24 percent HFC-152a: and 40 percent HCFC-124.
- Ternary Blend B: 31 percent HCFC-22; 24 percent HFC-152a: and 45 percent HCFC-124.

The blend is a non-azeotropic mixture exhibiting thermodynamic and transport properties similar to CFC-12. The blend is a strong candidate for retrofit applications in existing equipment, including in mobile air conditioners, domestic refrigeration equipment, and chillers. One advantage of the blend over HFC-134a is that by changing the concentration of the blend constituents, lower or higher evaporating temperatures can be attained, allowing the blend to be tailored to a particular end-use.

Testing to date has determined that the Dupont blends are compatible with the lubricants currently used in CFC-12 systems, but are not compatible with most desiccants used today. These need to be changed in order to protect the system from breakdown. In some cases the permeation rate of HCFC-22 through system hoses is greater than the other chemicals in the blend. Uneven leakage with current hose materials, therefore, will result in a change in blend composition over time.

Research on the Dupont blends is still ongoing. There is some evidence, however, that the heat transfer properties of the mixture degrade over time, leading to a reduction in efficiency. Toxicity testing has not been completed for HFC-124, one component of the blend. None of the blend constituents is a criteria pollutant, and use of the blend is not anticipated to directly increase emissions of criteria pollutants. The ability to recycle the blend is undergoing evaluation. Assuming the blend can be recycled, cross media impacts are not anticipated.

5.4 RECYCLING FOR REFRIGERATION AND AIR CONDITIONING APPLICATIONS

Recovery and recycling of ODCs is an important control option for solvent applications, halon fire extinguishing equipment, and all air conditioning and refrigeration end uses. Recovery and recycling technology is in the developmental stage for halon systems, but is becoming widespread in the air conditioning and refrigeration sector. In solvent applications, recycling is now commonly used for all types of solvents. This section provides a general description of

[12] A "ternary blend" is defined as a mixture of three different refrigerants.

recycling and recovery as it applies to refrigeration and air conditioning applications. Specific details of technical feasibility and cost are presented in the next section under the applicable discussions of each end use.

It is well known that a large share of ODC emissions has been associated with the venting of refrigerants during the manufacture, installation, servicing and disposal of refrigeration and air conditioning equipment. Except for equipment with very large refrigerant charges, it has generally been more economical to vent systems than to recover the charge during leak testing, service, and disposal. Refrigerant recovery has been practiced for over 15 years for equipment with large charges such as process refrigeration systems, supermarket refrigeration systems, and large chillers. In these cases the value of the recovered refrigerant offsets the labor and capital costs associated with recovery. Additionally, refrigerant recovery has been (and remains) economical for MACs in fleets of buses and automobiles in some cases.

Although often discussed together, recovery and recycling are two separate technologies. Simply stated, recovery involves the collection of refrigerant from a system. Typically, this collection is performed prior to servicing or disposal. The recovery equipment is attached to the unit being worked on. Nearly all the refrigerant is then pumped into a collection device in the recovery equipment. Once the refrigerant is collected, the unit being worked on is disconnected from the recovery equipment. Because only a small amount of refrigerant remains in the unit, emissions during subsequent servicing or disposal are very small. If repairs are made to the unit, it will then be recharged with <u>new</u> refrigerant (not the recovered refrigerant). The recovered refrigerant would then typically be sent off-site for recycling so that it can be re-used.

Recycling equipment differs from recovery equipment in that it includes the recycling step as well as the recovery step. Once the refrigerant is collected, the recycling equipment cleans and analyzes it to assess whether it meets appropriate quality standards. If it does, it can be re-used in the piece of equipment being serviced once it is repaired. This combined recovery-recycling equipment has broad application in the servicing of MACs, which generally require recharging once repaired.

The advantage of the equipment that combines recovery and recycling is that it allows the refrigerant to be re-used immediately in the equipment from which it was drawn. Cross contamination of refrigerant from different sources is minimized, and shipment off-site is avoided. The combined recovery-recycling equipment is more costly than the simpler recovery equipment, however. Additionally, the lack of a standard for re-using recycled refrigerant had been an obstacle to widespread adoption of the combined recovery-recycling technology in MAC repair. In the absence of such as standard, there was no guidance as to the purity that must be achieved by the recycling process. Recently, such a standard has been developed for MACs, and recycling equipment is available that meets the standard. Federal regulations now require the use of recovery or combined recovery-recycle equipment during MAC servicing, so that these technologies are becoming widely used.

It is technically feasible to recover refrigerant from all types of air conditioning and refrigeration equipment. The degree to which the entire charge can be retrieved varies

depending on the system pressure and the sophistication of the recovery equipment. Blend refrigerants, that are a mixture of two or more CFCs or HCFCs, may prove difficult to recover and recycle on-site because of the varying characteristics of the individual chemicals and the need to keep the balance in the mixture consistent. Because both recovery and recycling equipment are fully sealed, technicians are not expected to be exposed to refrigerant during recovery and recycling operations.[13]

Over the next 10 to 15 years recycling will be an increasingly important component of efforts to control ODC emissions and minimize the costs of eliminating ODC production. As CFC production is phased out, there will be a residual demand for CFCs for servicing equipment that was designed to operate with CFC refrigerants. In many cases it will be more economical to use recycled CFCs than to retrofit the equipment to use the new chemical substitutes. Therefore, a market for recycled CFCs is developing and is expected to grow over time. CFC manufacturers have indicated that they will collect recovered CFCs for reprocessing. Increased use of ODC recovery equipment, for example at product disposal, will help to supply this market for recycled ODCs.

5.5 CONTROL MEASURES BY END USE APPLICATION

5.5.1 Mobile Air Conditioning

Mobile air conditioners (MACs) for vehicles (light trucks and automobiles) use CFC-12 as the refrigerant. CFCs are emitted from MACs during manufacture, servicing, use and disposal. Emissions can be minimized by three types of control measures: recycling of existing CFC-12 refrigerant; use of refrigerant substitutes in both new and existing MAC systems; and implementation of several system modifications.

Recovery and Recycling

Description. CFC-12 from MACs can be recovered as part of servicing and disposal. Combined recovery-recycling equipment (described above) is expected to be an increasingly cost effective approach to servicing as the availability of new CFC-12 declines. CFC-12 recovery is now required at large MAC repair shops under federal statute and regulation, and will be required at all repair shops by January 1, 1993 (see Section 6).

Technical Feasibility and R&D. Recovery and recycling equipment has been developed for the CFC-12 MAC service market. Procedures exist to train and certify technicians who use the equipment. Many models are currently on the market. However, research and development

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[13] Small amounts of refrigerant are emitted during the process of connecting and disconnecting hoses. These emissions are much smaller than the emissions from venting, which until recently was standard practice. Worker exposure to emissions during connecting and disconnecting hoses is not currently a concern.

of more efficient models continue. Additionally, recycling equipment for the new MAC refrigerant (HFC-134a, see below) is also under development because the new refrigerant will be recycled in the future.

Recovery and recycling is expected to eliminate the emissions associated with venting during servicing. If used prior to disposal, this equipment can also eliminate the emissions of refrigerant that remains in the equipment at disposal. Recovery and recycling will not eliminate emissions due to normal and abnormal leakage, accidents, and accidental venting during servicing or other activities.

To maximize the efficacy of recovery and recycling it is important that MAC servicing be performed by trained technicians with proper equipment. Federal rules require that when service is done for a fee (e.g., by a repair shop) that trained technicians use appropriate equipment. However, the rules do not prevent people from servicing their own MACs. To reduce the frequency of these "backyard" repairs, rules limiting the sale of MAC recharge kits and small quantities of refrigerant are being put in place. By eliminating the availability of these materials, MACs will increasingly be serviced at shops that have the technicians and equipment needed to prevent emissions.

Cost. Original purchase cost of recovery equipment is on the order of $1,500 per unit and combined recovery-recycling equipment costs about $7,000 per unit, depending on the level of automation of the equipment. Containers to store recovered refrigerant may also have to be purchased. To date, CFC recyclers have indicated that they will pick up large quantities of recovered CFC-12 at no charge. Technician training costs are expected to be minimal. Operating the equipment will increase the time required to perform a repair by 5 to 15 minutes in most cases. Little data exist on equipment maintenance costs, which are expected to be minimal.

Other. Recovery and recycling of MAC refrigerant is not expected to pose any health or safety risks. Equipment safety standards have been developed, and Underwriters Laboratories in now certifying equipment that meets these safety standards. Exposure to refrigerants and lubricants during MAC repair is reduced when recycling equipment is used.

Market Feasibility and Technology Transfer. Recycling practices are expected to become standard and commonplace within a few years. Equipment to recover and recycle CFC-12 from MACs is readily available and competitively priced. The Society of Automotive Engineers (SAE) has set internationally recognized standards for purity of recycled refrigerant, performance of recovery and recycling equipment, and certification of service technicians.

Federal rules require that the equipment be used during MAC servicing. Initially, many small shops may decide not to service MACs because of the cost of the equipment. Enforcement programs will likely be initiated, although there is not adequate experience at this time to indicate whether non-compliance will be a problem. As the recovery and recycling industry matures, costs will likely decline and non-compliance may be minimal.

HFC-134a as a Substitute Refrigerant

Description. Extensive research has been conducted to find a replacement refrigerant for CFC-12 in MACs. HFC-134a has been selected by the automobile industry as the refrigerant of choice for new MACs. The industry has committed itself to switching all new MAC production to HFC-134a by the 1995 model year. HFC-134a is not a drop-in substitute refrigerant for CFC-12, so it cannot be used in MACs designed for CFC-12 without conducting a retrofit.

Technical Feasibility and R&D. HFC-134a has thermodynamic and transport properties very similar to CFC-12, and is suitable for use in MACs. HFC-134a is nonflammable, is believed to be low in toxicity and has an ODP of 0.0. However, current MAC systems must be redesigned to accommodate HFC-134a. Studies indicate that component changes are required so that the metal parts and hoses are compatible with the new refrigerant. Efforts are also underway to develop compatible lubricants and desiccants. Existing compressor and condenser designs can likely be retained, although improved efficiency may be achieved with designs developed specifically for HFC-134a. Engineering design and testing are currently being conducted to prepare for the switch by 1995. Mercedes and Saab produced 1992 model year automobiles with HFC-134a systems for sale in North America. Additional companies are expected to have HFC-134a MACs in the 1993 model year.

To use HFC-134a in existing MACs designed for CFC-12, the entire system must be thoroughly flushed to remove all lubricants, refrigerant, and desiccants. Some components can then be replaced, and the system charged with the new refrigerant, lubricants, and desiccants. The existing compressor and condenser can be used. The system will require about 3 percent more energy to operate after the retrofit is conducted.

Cost. HFC-134a is expected to be more expensive than CFC-12 was during the 1980s. Estimates are that HFC-134a may cost about $7.90 per kilogram (1990 dollars) when it becomes available in large quantities in the early to mid-1990s, but that about 10 percent less refrigerant will be required in the newly designed systems. CFC-12 cost about $1.00 per kilogram during the early 1980s, and costs about $6 to $10 per kilogram in 1992. About 3 percent additional energy is expected to be required to operate the HFC-134a-based system.

The costs for retrofitting existing vehicles is estimated to range from about $650 to $1,500 for a complete system replacement down to $275 to $750 for system flushing and component replacement. However, the effectiveness of the system flushing remains to be established.

Other. HFC-134a is not expect to pose any significant human health or environmental risks. Flushing existing systems will generate waste lubricants that will require proper handling and recycling to prevent uncontrolled emissions.

Market Feasibility and Technology Transfer. All testing to date appears to indicate that HFC-134a based systems will provide quality and performance similar to CFC-12 based systems. Auto manufacturers have already begun to design and install new air conditioners which require HFC-134a. The auto industry is expected to have full implementation by the 1995 model year.

The rate of vehicle conversion depends upon each vehicle manufacturer's ability to make the needed design changes to accommodate the new refrigerant in its makes and models of cars and trucks. No significant technology transfer issues are apparent.

The extent to which CFC-12 systems will be retrofitted to convert to HFC-134a is not known at this time. Analyses for EPA indicate that recycling at service will prevent substantial numbers of retrofits from being needed. If the market for recycled CFCs becomes well developed, retrofits may be avoided completely. The cost of the retrofits will also likely deter their use.

Ternary Blend as a Substitute Refrigerant

Description. Dupont has developed two ternary blend refrigerants comprised of HCFC-22, HFC-152a, and HCFC-124. The blends differ only in the mixture of each chemical which varies in per cent content by weight (HCFC-22: 36 or 31%, HFC-152a: 24%, and HCFC-124: 40 or 45%). The blend is a non-azeotropic mixture exhibiting thermodynamic and transport properties similar to CFC-12. The blend is a strong candidate for use in MACs originally designed for CFC-12, and is not under serious consideration for new systems.

Technical Feasibility and R&D. Testing to date has determined that Dupont blends are compatible with the lubricants currently used in CFC-12 systems, but are not compatible with most desiccants used today. These need to be changed in order to protect the system. The permeation rate of HCFC-22 through the system's hoses is greater than CFC-12, and leaks faster than the other chemicals in the blend. Uneven leakage, therefore, will result in a change in blend composition over time with current hoses. Research is continuing on desiccants and hose materials.

Cost. The ternary blend is expected to cost about $6.80 per kilogram, and about 7 percent more refrigerant is required as compared with CFC-12. The costs of a retrofit will vary depending on the hose material and desiccant selected. The CFC-12 system will require complete flushing, however. The cost is currently estimated at $275 to $750, although these are quite uncertain estimates.

Other. Because HFC-152a is slightly flammable, its use in MACs may present some hazard during an accident. However, when mixed appropriately with HCFC-22 and HCFC-124, the flammability is not expected to be a concern. The slight toxicity of the blend (due to HCFC-124) may also increase health and environmental exposure risks slightly. As with the HFC-134a retrofit, system flushing will generate waste lubricants that will require proper handling and recycling to prevent uncontrolled emissions. Finally, tests to date indicate that the ternary blend will be about 2 percent more energy efficient that the original CFC-12 system.

Market Feasibility and Technology Transfer. The ternary blend option will not likely be implemented unless CFC-12 based MAC repairs are significantly disrupted by a lack of CFC-12 in the future. The blend is not being considered for use in new equipment, and consequently will be limited to the service market. One drawback of introducing this blend is that separate

recycling equipment will be required to handle the blend during servicing. The added cost of this equipment may make this option too expensive to be considered.

System Modifications

Several mechanical or engineering changes can be made to MACs to reduce the inadvertent release or leakage of refrigerant. These design changes apply to newly built MACs and are expected to be incorporated into the HFC-134a based systems that are currently under development. Several examples of these changes include the following:

- Hose design modifications will help to better contain the refrigerant. Because some of the refrigerant leaks through the hoses, reducing the length of the hose and reducing its permeability (e.g., changing from more permeable nitrile to less permeable nylon hoses) would provide some measure of control.
- O-ring seals could be improved to prevent some leaking at connecting points.
- Improved fittings could be used to minimize refrigerant release during servicing.
- Filters could be added to the MAC to catch debris and prevent it from circulating with the refrigerant. This would maintain a cleaner system and reduce the number of times a MAC had to be serviced, thereby reducing the opportunities for service venting. Currently debris is typically removed by flushing the system with refrigerant.

In addition to these design changes, MAC refrigerant can be further conserved by using helium or HCFC-22 as a leak test gas during MAC assembly. HCFC-22 is currently used in some assembly plants.

Because MACs are being modified to use HFC-134a, an opportunity exists to incorporate these and potentially other design changes that will reduce ODC emissions. Cost and effectiveness data are not currently available for these options. However, it is anticipated that options that are cost effective for the automobile manufacturers will be adopted. Whether all options that could minimize emissions or reduce costs over the life-cycle of the MAC will be implemented cannot be assessed at this time.

5.5.2 Process Refrigeration

Process refrigeration refers to refrigeration equipment used during the manufacture of products and for other industrial applications. It is used primarily in the chemical, pharmaceutical, petrochemical, oil and gas, metallurgical and industrial ice making industries.

Emissions can be minimized by the application of three categories of control options: recovery and recycling of existing CFC-12 and CFC-11 refrigerant; introduction of refrigerant

substitutes in both new and existing equipment; and implementation of several system modifications.

CFC Recovery and Recycling

Description. Recovery and recycling of refrigerants during service and disposal in the process refrigeration sector can have a significant impact on emissions because of the large amount of refrigerant contained in the equipment. Although recovery has been performed for some time on this equipment, there is substantial opportunity for increased use of this technology.

Because of the substantial size of much of this equipment, the recovery and recycling equipment needed is substantially larger than the equipment applicable to other refrigeration equipment such as MACs. A wide range of high and low pressure recovery only or combined recovery-recycle equipment is now available. To use this equipment effectively, technicians require proper training.

Technical Feasibility and R&D. The equipment to recover and recycle refrigerant for large charges exists and is becoming increasingly available. In particular, recovery equipment is being used to collect the refrigerant prior to performing service. Off-site recycling and reclamation facilities will purify the used refrigerant for re-use.

Additional research is continuing on the best methods for combining recovery and recycling. Depending on how the off-site recycling market develops, the combined recovery-recycling equipment may not be used extensively in this end use.

Cost. The costs of recovery and recycling include the capital costs of the equipment and the labor costs of operating the equipment. These costs are off-set to some extent by the value of the recovered and recycled refrigerant. Exhibit 55 lists estimates of costs for the recovery and recycling equipment that can be used on process refrigeration equipment. As shown in the exhibit, the equipment costs cover a very wide range. Additional labor time per service event is generally under 2 hours. Costs of using the equipment (not including the off-set value for the recovered refrigerant) are generally less than $200 per service event, and much less in most cases. Costs will be lower if the equipment is used frequently, and will be higher if the equipment is seldom used.

Market Feasibility and Technology Transfer. Recovery and recycling has generally only been practiced when large amounts of refrigerant could be recovered. However, as the result of federal rules requiring that recovery and/or recycling be performed during all service and disposal events, recovery and recycling equipment will become more widespread, and technicians will be trained in its use.

Ammonia as a Substitute Refrigerant

Description. Ammonia is a candidate refrigerant that can be used in many new process refrigeration applications. Substantial retrofit costs would be incurred in order to use ammonia in a CFC-based system. Although ammonia is toxic and flammable, it is a highly efficient and cost effective refrigerant. It has excellent system efficiency and reliability. Its use to date has been limited by safety regulations which generally require that ammonia only be handled by qualified personnel in areas outside of general public access.

Exhibit 55: Recovery and Recycling Costs for Process Refrigeration - 1990

Equipment Type	Recoverable Charge[a] (kg)	Equipment Cost[b]	Additional Labor (hours)	Incremental Cost/Job[c]
Built up Centrifugal	90-150	$1,500-$12,000	<2.0	$50-$200
Built up Reciprocating	150-200	$1,000-$2,000	<2.0	$50-$200
Packaged Centrifugal	100-150	$1,500-$7,000	<2.0	$100-$200
Packaged Reciprocating	5-20	$1,500-$7,000	<2.0	$25-$75
Ice Makers	2-500	$1,000-$60,000	<5.0	$0-$2,000
Ice Rinks	25-30	$1,500-$7,000	<1.0	$25-$75

a Estimated charge that can be recovered or recycled at service. The estimates reflect the fact that some portion of the system charge often leaks out prior to servicing.

b Range of cost estimates for typical pieces of equipment. Costs vary for recovery and combined recovery-recycle equipment. Additionally, costs vary for high pressure and low pressure equipment.

c Cost of using the recovery or recovery-recycle equipment during a service event. Estimate includes additional labor cost (at $45 per hour) and recovery of capital costs and overhead. Estimates of the number of service jobs conducted with the equipment annually vary from 30 to 125. Equipment lifetime is assumed to be 5 years, except for the most costly equipment which is assumed to have a lifetime of 20 years. The value of the recovered/recycled refrigerant is not included in these estimates.

Source: ICF Consulting Associates, Inc. estimates for the U.S. EPA

Technical Feasibility and R&D. Ammonia is an established refrigerant that has been in use for many years. Its capacity range matches well with the temperature range of current CFC-based systems (above -45°C). It is also likely that its capacity and temperature range can be expanded. Additionally, leak detection for ammonia systems is far easier than for CFC-based systems.

Cost. Ammonia is much less costly than CFCs. However, retrofitting a CFC-based system to use ammonia is generally prohibitively expensive because of material compatibility problems. Ammonia-based systems are cost competitive with CFC-based systems, and are generally less costly to operate because they are more energy efficient.

Market Feasibility and Technology Transfer. Although ammonia is highly flammable and toxic, it is a suitable substitute in process refrigeration equipment because of the specialized nature of and generally restricted access to process refrigeration equipment. Several European countries, for example, have already moved into the ammonia, using smaller charges as one measure of safety control.

The use of ammonia-based systems is expected to increase as CFCs are phased out. Building codes and safety requirements will be the primary factors limiting the use of ammonia-based systems in the future. Improved leak detection systems may mitigate some of these safety concerns.

Hydrocarbons as a Substitute Refrigerant

Description. Hydrocarbon refrigerants such as propane, butane and isobutane are long term proven refrigerants with excellent refrigeration properties. Their benefits include low cost and a very wide range of refrigeration temperatures. Hydrocarbons are extremely flammable but are more energy efficient than CFCs. Their use is expected to increase in industries such as oil and gas and petrochemical production where the handling of flammable products is part of normal operations.

Technical Feasibility and R&D. Hydrocarbons offer excellent refrigeration properties. They have been used for many years, and systems designed for their use can be obtained. High costs of retrofitting will prevent hydrocarbons from being used in existing CFC-based systems.

Because of the flammability of hydrocarbons, special fire and explosion prevention equipment is needed when large amounts of hydrocarbon are used. These requirements can add considerably to the cost of using hydrocarbon refrigerants.

Cost. Hydrocarbon-based systems are cost competitive with CFC-based systems. However, the added cost of fire and explosion control equipment increases the cost of installing this equipment.

Other. Hydrocarbons have an ODP of 0.0 and a GWP of 0.0. They can be about 10 percent more energy efficient than CFC-based refrigerants. Hydrocarbons are not considered highly toxic, and have a TLV of 800 to 1,000 ppm. Hydrocarbons emissions are also controlled in most areas of California because they are photochemically reactive, and contribute to the formation of tropospheric ozone. Widespread use of hydrocarbon systems could increase hydrocarbon emissions.

Market Feasibility and Technology Transfer. Hydrocarbons are readily available, and hydrocarbon systems can be obtained. As with ammonia, building codes and safety requirements will be the primary factors limiting the use of hydrocarbon-based systems in the future.

HCFC-22 and Ternary Blend as Substitute Refrigerants

Description. HCFC-22 is used extensively in process refrigeration equipment and is expected to continue to be used over the next 10 years at least. HCFC-22 can be used in new process refrigeration equipment and can be used in conjunction with a retrofit in existing equipment that was designed for CFC-11 and CFC-12. Because HCFC-22 use will be phased out over the longer term, its use in place of CFC-11 and CFC-12 will only bridge the gap between current equipment and future equipment designed to handle new refrigerants. To limit the use of HCFC-22 in the medium term, a ternary blend is also being considered that includes HFC-152a and HCFC-124 along with HCFC-22.

Technical Feasibility and R&D. HCFC-22 is principally considered feasible for process refrigeration applications that currently use CFC-12, although some use in CFC-11 based systems is possible. Because HCFC-22 requires a higher system pressure and a higher discharge temperature than CFC-12, a two-stage design is currently being considered for retrofit situations. This approach requires additional research and development prior to its widespread use.

The applicability of the ternary blend remains to be demonstrated completely. Retrofit and new system designs are being considered that appear promising.

Cost. Newly designed HCFC-22 systems are expected to be slightly more costly than previously used systems because of the higher pressures involved. However, substantial energy savings are expected during operation, which may be on the order of 20 percent in some cases. Retrofit costs are not well known but are believed to be on the order of $200 to $600 per ton of cooling capacity (1990 dollars).[14] The costs of ternary blend systems are not available.

Market Feasibility and Technology Transfer. Whether HCFC-22 or ternary blend based process refrigeration systems are used to replace CFC-11 and CFC-12 based systems depends

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[14] A ton of cooling capacity is equal to 12,000 Btus per hour, where a Btu is a British Thermal Unit.

in part on the rate at which new refrigerants are developed and become available. If the development of the new refrigerants continues as expected, HCFC-22 (or the ternary blend) will have an important role as a transition refrigerant in this application, especially in new systems. Ammonia and hydrocarbons could limit the market penetration of HCFC-22 if safety concerns are addressed. Although HCFC-22 will be phased out in the long term, retrofits will likely be conducted if recycled CFC-11 or CFC-12 is not available.

Other Substitute Refrigerants

Several other refrigerants that can be used in process refrigeration equipment over the long term are expected to be developed. HFC-134a may become an important substitute for CFC-12 in process refrigeration equipment as HCFC-22 use is restricted. Because of costs, its use will likely be limited to situations where hydrocarbon and ammonia refrigerants cannot be used.

HFC-125 (CHF_2CF_3) could also be used in some applications, although significant work remains to be done on its suitability. HFC-125 is not flammable and has an ODP of 0.0. Its GWP is estimated at 0.71, and no toxicity data are yet available for it. Assessments of the energy efficiency properties and cost of HFC-125 are also not available.

5.5.3 Commercial Refrigeration

Commercial refrigeration equipment is primarily used for food storage and display. The major applications are in supermarkets, other retail food establishments, refrigerated warehouses, and refrigerated transportation equipment (primarily trucks, rail cars, and ships). The equipment ranges in type from self-contained stand alone equipment display cases to walk-in cold storage rooms.

The three common temperature ranges in this sector are high (0 to 13°C), medium (-15 to 2°C), and low (-32 to -18°C), and very low (down to -45°C). The ODC-based refrigerants most commonly used are CFC-12 for the medium and high temperature ranges (-15 to 15°C), HCFC-22 for low temperature (down to -37°C), and CFC-502 for the very low temperatures. Design of equipment and refrigerants used depends on desired operating temperatures.

Cold storage warehouse facilities most often use ammonia as the refrigerant, primarily due to its lower cost. Less than 20 percent of warehouses use either CFC-12, CFC-502 or HCFC-22. CFC refrigerants are often used when the facility is in a populated area and potential exposure to ammonia is a concern. Refrigerants CFC-12 and CFC-502 are used in refrigerated transport applications, and some HCFC-22 is now used in newer truck trailer units.

Commercial refrigeration also includes some minor applications, such as water coolers, vending machines, dehumidifiers, and ice machines.

CFC Recovery and Recycling Equipment

Description. Recovery and recycling of refrigerant from commercial refrigeration equipment is feasible during installation, servicing, and prior to disposal. In retail food situations, one problem likely to be encountered is that portable recovery/recycling equipment may be difficult to maneuver around food refrigeration displays in confined areas.

Supermarket refrigeration equipment is often designed using extensive piping with display cases located separately from the compression equipment. Under these conditions, the percentage of refrigerant retrieved into recovery equipment will likely be lower than the percentage recovered from smaller and more compact equipment, such as water coolers or MACs. Contamination of refrigerant is also a greater possibility, and although much of the refrigerant temporarily stored during servicing will be returned to its original equipment, the increased possibility of refrigerant contamination will likely result in more frequent use of off-site recycling services.

Recovery and recycling of refrigerants from transport applications are expected to be widespread. Because units are generally maintained in central locations, recovery and recycling equipment will be cost effective in many situations.

Technical Feasibility and R&D. Commercial refrigeration poses no special technical problems for recovery and recycling. As mentioned above, the space limitations in supermarkets put a premium on small and easily maneuvered equipment. Additionally, speed of servicing has always been an important factor in retail food situations.

Cost. The cost of recovery and recycling equipment will vary depending on the size needed and the features desired. Initial purchase costs will be on the order of $2,000 to $6,000 for high pressure systems. Given the incremental time needed to operate the equipment, the incremental cost per service job may be on the order of $25 to $50. Larger systems will require larger recovery and recycling units, and may cost more to operate.

Market Feasibility and Technology Transfer. Recovery and recycling equipment for commercial refrigeration applications is currently available. Because federal regulations require that this equipment be used during service and disposal, a variety of suppliers are expected to serve this market.

HFC-134a as a Substitute Refrigerant

Description. HFC-134a is an appropriate substitute for CFC-12 in new commercial refrigeration equipment. Existing equipment will require a retrofit to use HFC-134a.

Technical Feasibility and R&D. HFC-134a can be used to supply the temperature range currently supplied by CFC-12. Research to date has shown that HFC-134a is not compatible with current lubricants and some materials used in existing systems. Compatible materials, lubricants,

and desiccants have been developed. Using HFC-134a in existing equipment will require a complete system flush, and replacement of some parts.

Cost. HFC-134a is expected to be one of the least costly alternatives for providing cooling in retail food situations and other areas with public access. There are indications that HFC-134a may be about 3 percent less energy efficient than existing CFC-12 based systems. However, research is ongoing to improve system efficiency, e.g., by enlarging the heat exchangers and increasing compressor and motor efficiency.

Market Feasibility and Technology Transfer. HFC-134a is expected to replace CFC-12 in medium temperature applications. Future restrictions on HFC-134a could reduce the market penetration of this refrigerant. However, indications today are that it is non-toxic and an effective substitute.

HCFC-22 as a Substitute Refrigerant

Description. HCFC-22 can be used in both medium and low temperature systems in place of CFC-12 and CFC-502. It is currently used in newer retail food and transport applications.

Technical Feasibility. HCFC-22 is now used in approximately 15 percent of commercial refrigeration systems, but its use is expected to increase significantly as efforts are made to increase the range of its capacity. In new equipment, HCFC-22 can substitute for CFC-502 but the system will be more complex to accommodate HCFC-22's higher discharge pressure. HCFC-22 can also substitute for CFC-12 but will require a change of compressor because of its higher discharge pressure. Consequently retrofits with HCFC-22 may be costly.

Use of HCFC-22 will, however, induce some technological difficulties. HCFC-22 results in higher discharge temperatures from the compressor for a single stage operation, making the refrigerant more susceptible to chemical breakdown. Two-stage processes are being developed that will alleviate this problem. In two-stage processes, HCFC-22 will need to be used with alkylbenzene as a lubricant, which is more miscible with HCFC-22 than currently used lubricants.

In refrigerated transport applications HCFC-22 is a preferred substitute because it can operate in the wide range of conditions generally encountered. New refrigerated trailers are currently using HCFC-22 refrigerant.

Cost. Two-stage HCFC-22 systems are expected to be up to 10 percent more costly than existing systems to design and install. However, energy savings as high as 20 percent may offset this increased cost. Simpler one-stage systems will have initial costs similar to existing systems, but will likely have very little energy efficiency improvement.

HCFC-22 retrofits are expected to cost on the order of $300 to $750 per ton of cooling. However, there is very little experience with the steps necessary to retrofit the systems, so costs could be higher or lower.

Market Feasibility and Technology Transfer. Cost, technical feasibility, and availability make HCFC-22 an attractive choice as a substitute for commercial refrigeration. Two-stage systems have been demonstrated that provide the performance required at a competitive cost. Future restrictions on HCFC-22 use and emissions may limit the extent to which this substitute is used, however. Because HCFC-22 will be phased out over the long term, its role in this application will likely be a transitional one.

Ternary Blend

To limit the use of HCFC-22 in the medium term, a ternary blend is also being considered that includes HFC-152a and HCFC-124 along with HCFC-22. This blend could be used to replace CFC-12 in new equipment such as vending machines, water coolers, and other similar systems.

The applicability of the ternary blend remains to be demonstrated completely. Retrofit and new system designs are being considered that appear promising. The costs of ternary blend systems are not available. Whether the ternary blend is used to replace CFC-12 based commercial refrigeration systems depends in part on the rate at which new refrigerants are developed and become available. If the development of the new refrigerants continues as expected, the ternary blend could play a limited role as a transition refrigerant in portions of this application, especially in new systems.

New Blends as Substitute Refrigerants

Two new refrigerant blends, containing HFC and HCFC chemicals, are being considered for retrofits in the commercial refrigeration sector. The first is a medium pressure blend to replace CFC-12 and consists of HCFC-22 and HFC-134a. The second is a high pressure blend to replace CFC-502 and consists of HCFC-22 and hydrocarbons.

Servicing of equipment with blend refrigerants will be complicated as it will be more difficult to recover and recycle a combination of refrigerants. Due to the inherent leakage of remote systems, there is a problem of fractional evaporation and condensation, leading to separation effects. This will effect performance, compressor durability and safety (e.g. flammability). HCFC-22, for example, evaporates more quickly, resulting in improper balances of the other chemicals in the blend. This is likely to affect the equipment's efficiency. Blend refrigerants offer the advantage of matching capacities close to the current ones offered by CFC-12 and CFC-502.

Significant work remains to demonstrate and develop these blend-based systems. Because HCFC-22 will be restricted in the long term, these new blends may not play a significant role in future designs.

Ammonia or Hydrocarbons as Substitute Refrigerants

Although the efficiency of ammonia and hydrocarbons far exceeds that of other alternatives, their high flammability and ammonia's high toxicity produce a serious safety risk, not likely to be acceptable under current technology in areas with great public access. The use of ammonia in this sector is now limited to cold storage where trained personnel are available. Hydrocarbons are not used extensively. Ammonia may be considered more seriously in the future after considerable design improvements have been made to improve safety. These could include the development of isolation features, expanded used of indirect systems, enhanced leak detection, and smaller systems.

Other New Chemicals

HFC-32 (CH_2F_2), HFC-125 and HFC-143a (CH_3CF_3) are chlorine free chemicals which may eventually become substitutes. Primary initial concerns include: the flammability of HFC-143a (HFC-32 is marginally flammable); the high GWPs of HFC-125 (0.71) and HFC-143a (0.83) (HFC-32 has a GWP of about 0.11 to 0.12); and the high compressor discharge temperature and pressure of HFC-32. All three compounds have an ODP of 0.0. Toxicity testing on these new chemicals has yet to be completed. Although not viable for the immediate future, these chemicals could be long term substitutes as HCFC-22 is phased out.

5.5.4 Residential Refrigeration

Domestic refrigerators and freezers are used primarily for food preservation and storage. During the past 50 years, manufacturers have developed high efficiency systems using the basic vapor compression refrigeration cycle. Compressors and other system components have been optimized to be compatible with CFC-12, the existing refrigerant.

For the domestic refrigeration sector, the most important properties of CFC-12 are its non-toxic and non-flammable characteristics. The household refrigerator is also unique from other commercial refrigeration equipment in the U.S. in that energy efficiency standards have been developed and implemented for this sector. Any substitute technology or alternative refrigerant must be equally or nearly as energy efficient as CFC-12.

For this application, it is important that technologies be non-flammable and non-toxic. Additionally, domestic appliances are expected to have an average lifetime of at least 15 to 20 years, with little requirements for service. Recent trends have been toward more efficient designs that require less refrigerant per unit. This trend is expected to continue as designs shift away from CFC-12 and toward substitute refrigerants.

Recovery and Recycling

Description. Recovery and recycle equipment can be used to reduce CFC-12 emissions during service and disposal of residential refrigerators and freezers. Because service-related emissions are relatively small (about 25 percent of the total for this category), recovery at disposal is currently the major focus for this application. Consequently, unlike the situation with MACs, emphasis is currently on recovery equipment as opposed to combined recovery-recycle equipment.

To facilitate recovery, a refrigerant recovery bag has been developed that recovers refrigerant without the use of a pump. The bag is connected to the system and can be used to recover about 75 percent of the refrigerant in typical household appliances. Because federal regulations will soon mandate recovery at service and disposal, this recovery bag will need to be approved for use under the regulations in order for it to achieve widespread acceptance. Recovery equipment described above could also be used with home appliances. Their collection efficiency will be better than the recovery bag, and will be more costly to purchase.

Technical Feasibility and R&D. Refrigerant recovery from home appliances is technically feasible with mechanical equipment and the recovery bag. Efforts to develop lower cost portable systems that can be used easily are continuing. Steps are also being taken to require that appliances have labels that indicate the refrigerant they use. These labels will help prevent the inadvertent mixing of incompatible refrigerants during servicing or recovery at disposal.

Cost. Mechanical recovery equipment is expected to cost less than $2,000, with low pressure systems being about $1,000. The time to use the equipment during a service call is expected to be about 15 minutes. Shorter times, as low as 5 minutes, are expected to operate the equipment to perform recovery at disposal because it is expected that such recovery will be conducted at a central location. The total cost of using the system, including labor time, is expected to be less than $25 per job.

The cost of the recovery bag is not known at this time, although initial purchase costs are expected to be much less than the mechanical recovery systems.

Market Feasibility and Technology Transfer. Recycling equipment is available. Because federal regulations will require the use of this equipment, the market for the equipment is expected to be competitive. The principal barrier preventing recovery at disposal today is the distributed nature of appliance disposal practices. Refrigerators and freezers are not routinely routed to a central location for disposal. Until the disposal system becomes more centralized or manageable, recovery at disposal may not occur in any significant way.

HFC-134a as a Substitute Refrigerant

Description. Given the pressure levels and thermodynamic properties of HFC-134a, it is an acceptable replacement for CFC-12. Currently HFC-134a is expected to be the principal substitute adopted by the industry for use in new systems. HFC-134a is not compatible with existing systems, and it will be too costly to retrofit existing systems to use it.

Technical Feasibility and R&D. HFC-134a has been demonstrated to be feasible in home refrigerator and freezer equipment. Efforts are underway to optimize system efficiency and reliability with the new refrigerant.

Because HFC-134a has a lower density than CFC-12, less of it will be needed in charging new appliances. However, some concerns have been raised with respect to the longevity of HFC-134a. Lubricants have not yet been thoroughly tested to determine that over the lifetime of an appliance the lubricant (presumably an ester oil) remains intact and does not induce refrigerant failure or breakdown. Accelerated life tests are being conducted to select the best lubricants.

Cost. Because HFC-134a operates at a higher pressure than CFC-12, the compressor of a HFC-134a system will likely be slightly larger, contributing to increased costs for initial purchase of the equipment. With existing designs the HFC-134a systems require about 3 percent more energy to operate. However, research is ongoing to improve system efficiency, e.g., by enlarging the heat exchangers and increasing compressor and motor efficiency.

Market Feasibility and Technology Transfer. It is likely that residential refrigerator and freezer manufacturers will choose a common new refrigerant to replace CFC-12. Choosing a single refrigerant will simplify servicing for the entire industry. HFC-134a is likely to be that refrigerant, once its long term reliability can be confirmed.

Ternary Blend as a Substitute Refrigerant

A ternary blend of HCFC-22, HFC-152a, and HCFC-124 is being considered as a transitional refrigerant for residential refrigerators and freezers. The blend has good properties for use in this application, and is currently the other major candidate substitute. Even if HFC-134a becomes the refrigerant of choice, the ternary blend may be used extensively in the near term as CFC-12 is phased out. If HFC-134a becomes widely available in the near term, the ternary blend may be used principally to retrofit existing appliances that require servicing because the retrofit cost is expected to be less than the retrofit cost for HFC-134a. Despite its lower cost, retrofitting to use the ternary blend will be less attractive than obtaining a new unit in nearly all cases.

Other Substitute Refrigerants

Other substitute refrigerants are being investigated, including ammonia, hydrocarbons, HCFC-22, and HFC-152a. Ammonia is considered too toxic for residential use, and will not likely be pursued. Hydrocarbons, or hydrocarbon blends are being considered despite their flammability because of their excellent energy efficiency properties. If the quantity of hydrocarbon required to operate the system is reduced, hydrocarbon systems may be considered viable.

HFC-152a may provide potential energy savings relative to CFC-12 systems. However, is not likely to be a candidate substitute because of its flammability. A few appliances with HFC-152a have been manufactured and marketed in China.

5.5.5 Residential and Light Commercial Air Conditioning

Residential and light commercial air conditioning systems include: window units; unitary systems; and packaged terminal systems. All three types use HCFC-22 almost exclusively because it: meets all toxicity and flammability requirements; is thermodynamically suited for the temperature ranges typically encountered; and is compatible with all common construction materials and nearly all commonly used lubricants. Almost all are electrically driven vapor-compression cycle systems, virtually all of which use HCFC-22 as the working fluid.

In the near term HCFC-22 production is not being controlled, so no changes from HCFC-22 are anticipated in the near term. Recovery and recycling (as discussed in Section 5.4) are technically feasible and can be performed when required by regulation at servicing and disposal. Only recovery in combination with off-site recycling is likely to be pursued. Recycling equipment similar to the equipment used for commercial refrigeration will likely be used.

Over the long term alternative refrigerants will be required. Candidate substitutes include HFC-134a, HFC-125 and HFC-143a, but none have yet undergone extensive testing for this application. Propane-based systems and improved evaporative coolers are also likely to be considered because they provide improved energy efficiency.[15] It is unlikely that a drop in substitute will be found given the experience in the other refrigeration and air conditioning applications.

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[15] Evaporative coolers work by drying the air and then cooling it by evaporating water into the dry air stream. The process of evaporation requires energy, and consequently cools the air. Recent advances in desiccant technologies (used to dry the air to be cooled) may improve the performance of these systems and make them more widely applicable (NYT, 1992).

5.5.6 Commercial Chilling

Chillers are large air conditioning units used primarily for commercial and industrial buildings. Chillers cool water (or a water/glycol mixture) which is then passed through a heat exchanger to cool and dehumidify the air being conditioned.

There are two basic types of water chillers, categorized by compressor types: positive displacement compressors and centrifugal compressor systems. Positive displacement compressors (reciprocating and screw) cover the smaller end of the capacity range of commercial chillers. Some positive displacement chillers use CFC-12 but nearly all use HCFC-22.

Centrifugal compressor systems are usually larger in capacity and primarily use CFC-11 as the refrigerant. Some CFC-12 is used in systems that cover a broad range of capacities. Some centrifugal chillers designed for CFC-12 are charged with CFC-500 in order to broaden their capacity range. Very large chillers are often charged with HCFC-22. CFC-114 is used for chilling aboard submarines because it is capable of being used with reduced levels of vibration.

CFC Recovery and Recycling

Description. Recovery and recycling of refrigerants during service and disposal can have a significant impact on emissions because of the large amount of refrigerant contained in the equipment. Although recovery has been performed for some time on this equipment, there is substantial opportunity for increased use of this technology.

Because of the substantial size of much of this equipment, the recovery and recycling equipment needed is substantially larger than the equipment applicable to other refrigeration equipment such as MACs. A wide range of high and low pressure recovery only or combine recovery-recycle equipment is being developed.

Technical Feasibility and R&D. Techniques for recovering refrigerant from large chillers has been demonstrated. Recovery equipment will be used to collect the refrigerant prior to performing service or disposal. Off-site recycling and reclamation facilities will purify the used refrigerant for re-use.

One barrier to increased use of recovery equipment is that chilling equipment is often located in remote locations (e.g., on the roof of a building) or in areas without excess open space (e.g., in an equipment room). Recovery equipment is needed that is adequately portable and maneuverable to be useable in these situations.

Cost. The costs of recovery include the capital costs of the equipment and the labor costs of operating the equipment. These costs are off-set to some extent by the value of the recovered refrigerant. The costs of recovering are expected to be similar to the costs of recovering refrigerant from process refrigeration equipment (see Section 5.5.2).

Market Feasibility and Technology Transfer. To date, recovery has only been practiced to a small degree. However, federal rules will soon require that recovery and/or recycling be performed during all service and disposal events. As a result, recovery equipment will become more widespread, and technicians will be trained in its use.

HCFC-123 As a Substitute for CFC-11

Description. Research has shown that HCFC-123 is an effective substitute for CFC-11 both for retrofitting existing chillers designed to use CFC-11, and for new chillers. In fact, HCFC-123 is currently being used in both cases. HCFC-123 is a low pressure refrigerant and is thermodynamically suitable for centrifugal systems only.

Technical Feasibility and R&D. CFC-11 is used in water-cooled centrifugal water chillers from approximately 100 to 1,600 tons cooling capacity. The compressors used are gear drives and may have either hermetically sealed or open motor drives. CFC-11 has very high energy efficiency and has the highest cycle efficiency of the commonly used refrigerants.

HCFC-123 can be used in new systems to meet the cooling requirements in this range. New systems will likely be about 10 percent more expensive to purchase, and will require about one percent more energy to operate.

Existing systems can be retrofitted to use HCFC-123. Because HCFC-123 is a more aggressive solvent than CFC-11, it is unlikely to be compatible with existing elastomers and seals and other non-metal materials in the CFC-11 system. Hermetic motors designed for CFC-11 systems are not compatible with HCFC-123, so that motor insulations must be developed. HCFC-123 is expected to result in increased energy requirements of about 1 to 4 percent when used in a system designed for CFC-11.

Cost. HCFC-123 systems will likely be about 10 percent more costly because they will require larger compressors. Operating costs are also expected to increase because of the extra energy required. The costs of retrofitting a CFC-11 system to use HCFC-123 has not been estimated, but may be on the order of 10 percent of the original equipment cost.

Other. HCFC-123 has a higher toxicity than CFC-11, and more restrictive safety codes will likely be required to assure reduced exposure time to the chemical. This may mean, for instance, equipping HCFC-123 chillers with sensitive detectors to alert operators in the event of a significant leak.

Market Feasibility and Technology Transfer. HCFC-123 is becoming increasingly available and HCFC-123 chillers are currently being produced. Toxicity concerns may limit its use in the near term until procedures for limiting exposure, particularly among service personnel, can be developed and demonstrated. Improved recovery techniques may be one factor that enables exposure risks to be reduced. Because HCFC-123 has a non-zero ODP, its use will be limited in the long term. Consequently, HCFC-123 is viewed as a transitional refrigerant.

HFC-134a as a Substitute for CFC-12

Description. HFC-134a is thermodynamically suitable as a substitute for CFC-12 and is now in use in some new high pressure chillers. Its use will be to replace CFC-12 primarily in both air and water cooled centrifugal chillers in the range of 100 to 1200 tons cooling capacity. HFC-134a is not expected to replace CFC-12 in reciprocating and screw compressors because alternatives will be less costly.

Technical Feasibility and R&D. HFC-134a can be used in new systems to provide the cooling currently supplied by CFC-12 systems. System materials and lubricants have been developed and are now in use. Efforts are continuing to optimize the operating efficiency of the new systems.

To use HFC-134a, existing CFC-12 systems must be retrofitted. Because HFC-134a requires faster centrifugal compressors, impeller and/or gear box replacements will be required. Volumetric flow rates are, however, similar to CFC-12. Some desiccants and virtually all lubricants used with CFC-12 must also be replaced, meaning that a complete system flush will be required.

Cost. New HFC-134a systems are expected to cost no more than the CFC-12 systems that would have been used. Increased energy consumption of about 3 percent may result, however.

The costs of retrofitting existing systems to use HFC-134a may be prohibitive. Performing an adequate system flush under expected field conditions may be extremely difficult and time consuming. Nevertheless, retrofits may be conducted in some cases.

Market Feasibility and Technology Transfer. HFC-134a is becoming increasingly available, and is starting to be used in some new chillers. The rate at which HFC-134a penetrates the market will depend on how well HCFC-22 chillers can serve this market in the near term.

Expand the Range of HCFC-22 Chillers

Description. HCFC-22 is currently used as the refrigerant in most positive displacement chillers (reciprocating and screw compressors) and large centrifugal chillers. While HCFC-22 is not a direct replacement for CFC-11 or CFC-12 in systems designed for those refrigerants, the range of cooling capacity served by HCFC-22 equipment could be expanded to displace new CFC-11 and CFC-12 based equipment.

Technical Feasibility and R&D. HCFC-22 is currently used in the larger air cooled and water cooled positive displacement chillers and centrifugal chillers. Recently, HCFC-22 centrifugal chillers went into production with capacities as low as 300 cooling tons, where CFC-11 and CFC-12 chillers have traditionally dominated.

It may also be possible to increase the high end of the range of HCFC-22 based positive displacement chillers to take the place of the smaller CFC-11 and CFC-12 centrifugal systems. Research is needed to develop new designs and to demonstrate reliability, however.

Cost. The cost of HCFC-22 chillers is very competitive, which is why they dominate the overall chiller market. The principal barrier to their increased use is demonstrating techniques to cover the capacity ranges served by CFC-11 and CFC-12.

Market Feasibility and Technology Transfer. Substantial shifts to HCFC-22 for new systems are likely in the near term because there is considerable experience with HCFC-22 based systems. Over the long term, HCFC-22 use and emissions will be controlled so that alternatives will be required.

HCFC-124 as a Substitute for CFC-114

HCFC-124 is expected to be a future substitute for CFC-114 in chillers, although it is not readily available for either new or retrofit uses. HCFC-124 requires operation at higher pressures, higher compressor speeds and smaller impeller diameters than CFC-114. Complete compressor replacement would be necessary in order to use HCFC-124 in existing CFC-114 systems.

The cost of HCFC-124 equipment is expected to be about 10 percent higher than the cost of CFC-114 equipment because of the higher operating pressures required. Energy efficiency may decline slightly, although additional research is needed to assess this impact. Considerable research is required to develop HCFC-124 systems.

Ternary Blend Refrigerant

A ternary blend of HCFC-22, HFC-152a, and HCFC-124 is being considered as a retrofit replacement for CFC-12 in reciprocating compressor systems and CFC-500 in centrifugal systems. Additional research is necessary to develop system materials that will not permit selective permeation of HCFC-22. Because HCFC-22 systems are expected to take a large share of the new product market, the use of the ternary blend will likely be limited.

Other Substitutes

Ammonia, HFC-152a, and HFC-143a have all been considered as substitute refrigerants because of their thermodynamic properties. However, these alternatives are flammable and, therefore, are considered inappropriate for use in commercial areas and unacceptable for widespread use. HFC-125 is not flammable but has poorer energy efficiency because of its low critical pressure.

Fluorethers, which have zero ODP, are in the very early stages of evaluation as replacement refrigerants for chillers. Their refrigerant properties are expected to be close to those of CFCs. Fluorethers could potentially be a good candidate for future refrigerant because

energy efficiency is expected to improve by approximately 5 percent over the CFC-based systems.

5.5.7 Solvent Applications

CFC-113 and methyl chloroform (MC) are widely used as solvents to clean electronics assemblies, delicate instruments and surfaces, and metal parts. These substances are also used in a number of countries for the dry cleaning of clothing, but this use is not significant in the U.S. The three main types of solvent cleaning in the U.S. are: electronics cleaning; metal cleaning; and precision cleaning. The three main types of equipment used are: conveyorized vapor degreasing; open top vapor degreasing; and cold cleaning.

ODC emissions from solvent applications can be reduced substantially at low cost. Significant reductions have been achieved to date, in some cases at a cost savings. Solvent recycling is now commonly practiced, which reduces solvent use and emissions. Improved equipment design and operating practices have also been implemented that reduce worker exposure as well as emissions.

A variety of alternative chemicals and processes are available in this market as CFC-113 and MC are phased out. In some cases, the substitutes are more toxic and present human health risks themselves. At least one new manufacturing process, "no clean soldering," has been developed for producing circuit boards without any solvent. Because circuit board manufacturing is a large user of solvents, the no clean process will help reduce emissions significantly.

Because electronic component production is an important user of solvents, and because both the commercial and military electronic component markets have traditionally abided by military production specifications (Mil Specs), the Mil Specs have had an important influence on the choice and use of solvents in this industry. The U.S. EPA and the Department of Defense are working to modify the Mil Specs to enable alternatives to be used. This process is leading to the specification of alternative production processes as well as substitute solvents.

Solvent Recovery Systems

Description. Solvent recovery systems are equipment which are built into, or attached to, a cleaning machine or conveyor line. They recover solvent after it has been used in the cleaning process. Depending on the process, the solvent may be used again as is, treated on site and used again, sent to an off-site recycler, or sent off site to be disposed of in a safe manner. One example of such equipment is a carbon-adsorption system which collects solvent exhaust fumes. The effectiveness of solvent recovery systems varies with the type of solvent used.

Technical Feasibility and R&D. Solvent recovery systems have been demonstrated to reduce emissions by large amounts, up to 90 percent. Recovery equipment has been developed for all commonly used solvents and solvent using equipment. On-site recycling systems have

also been developed and are commonly used when justified economically. Whether on-site or off-site recycling is performed, care must be taken to avoid mixing different solvents.

Costs. Solvent recovery and recycling have become cost effective for a variety of reasons. The cost of ODC solvents has increased, thereby resulting in significant savings from reduced solvent purchases. The cost of transporting and disposing of waste solvents has also increased significantly. In particular, restrictions on landfilling waste solvents, and the cost of incineration have led to widespread adoption of recovery and recycling techniques.

Both on-site and off-site recycling are cost effective. It has been estimated that on-site recycling is currently economical if at least 8 gallons of solvent waste are generated daily (EPA, 1991a). The cost associated with solvent recovery vary widely and are dependent upon the amount of solvent processed, the efficiency of the operation, and the type of solvent used.

Other. Energy is used in the recovery/recycling process, leading to emissions of energy-related pollutants. The amount of energy required depends on the type of system used. However, recycling generally requires less energy than manufacturing and transporting new solvent. There are no inherent hazards to the health or safety of those working with solvent recovery equipment.

Market Feasibility and Technology Transfer. Solvent recovery and recycling are commonly used throughout the solvent cleaning industry. Both large and small solvent users are recovering used solvent, and no significant difference in market penetration has been noted by size.

HCFCs

Description. A variety of HCFCs are being considered as substitutes for CFC-113 and MC, including HCFC-123, HCFC-141b, HCFC-225ca and HCFC-225cb.[16] HCFCs would be used in cleaning applications in a similar fashion as conventional solvents.

Technical Feasibility and R&D. HCFCs are only now beginning to be developed as substitutes in solvent applications. Although the performance characteristics of HCFC-141b are relatively better known, its high ODP makes it less desirable. Research and development is needed to identify and engineer effective HCFC solvents that may replace the existing ODC solvents.

Developing HCFCs for some solvent uses has proven to be challenging. For example, HCFCs tested to date are not compatible with acrylic resins. Alternatively, applying HCFCs to metal cleaning using vapor degreasers will likely be straightforward.

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[16] HCFC-225ca and HCFC-225cb are isomers with the following formulae: HCFC-225ca = $CF_3CF_2CHCl_2$; HCFC-225cb = CF_2ClCF_2CHFCl.

Costs. The cost of using the HCFCs will include the cost of purchasing new equipment designed for the HCFCs or retrofitting existing equipment. These costs have not been estimated, but retrofit costs are expected to be modest. Operating costs may increase slightly because the HCFCs are more volatile, leading to additional cooling requirements to capture solvent vapors. Because the HCFCs will be available in limited quantities, at least initially, they will likely cost more than the current ODC solvents.

Other. The primary concerns associated with the use of HCFCs as solvents are environmental health and safety. Since HCFC-123 has been shown to be toxic in laboratory tests, it is no longer being considered as a viable substitute in solvent applications. Also, because HCFC-141b has a relatively high ODP, it is not an acceptable substitute for MC. Therefore, the two U.S. manufacturers of HCFC-123 and HCFC-141b have announced plans to limit their production of these compounds for solvent uses. Additionally, both Allied-Signal and DuPont have withdrawn from the market all solvent cleaning formulations containing HCFC-123.

HCFC-225ca is currently undergoing toxicity testing, and recent results indicate that it may be toxic. In response to these results, the general industry consensus has been to disregard HCFC-225ca from further consideration as a substitute. HCFC-225cb is still undergoing testing, and currently appears to be an acceptable substitute.

Market Feasibility and Technology Transfer. Due to environmental health and safety consideration, it appears that HCFCs are not likely to replace CFC-113 and MC in solvent applications to any large degree. HCFC-225cb is a promising substitute, but is expected to be available in 1994 at the earliest. To the extent that HCFCs are used, they will be transitional substitutes as they will be phased out in the future.

Alcohols and Alcohol Blends

Description. Alcohols and alcohol/perfluorocarbon[17] blends are substitutes for CFC-113 and MC in precision cleaning processes. Alcohols are often used in an agitation process in order to achieve maximum cleanliness in the parts being washed. The perfluorocarbon is used as a "blanket" to reduce the flammability of the alcohol solvent.

Technical Feasibility and R&D. Alcohols have excellent cleaning properties and alcohol-based precision cleaning techniques are well developed. Because alcohol is highly flammable, blends are being developed to improve safety and perfluorocarbons are currently being examined. However, although perfluorocarbons have an ODP of 0.0, they are expected to have high GWPs because their stability indicates they have long atmospheric lifetimes. Consequently, alternative methods of reducing the flammability of alcohol cleaners are also being investigated.

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[17] Perfluorocarbons are compounds that contain carbon and fluorine, for example, tetrafluoromethane, CF_4.

Materials compatibility is a barrier to alcohol use in some cleaning procedures. Careful selection of cleaning agents is generally necessary on a case-by-case basis.

Cost. Although alcohol is less costly than CFC-113 and MC, perfluorocarbons are much more costly. Current expectations are that the cost of alcohol/perfluorocarbon blends will be comparable to or less than the costs of CFC-113 and MC used today. New equipment designed for alcohol-based cleaners will likely cost more than current equipment designs because of agitation requirements. Retrofitting existing equipment may be costly, and is not anticipated.

Other. The flammability of alcohol makes it a potential safety risk if not handled properly. The alcohols which may be used as cleaners have a range of flash points and special care is needed when using the lower flash point alcohols such as methanol and ethanol. Additionally, alcohols have a strong odor and they dry the skin on contact. While these attributes contribute to worker discomfort, alcohols are not considered toxic and there are no exposure limits. Alcohol is a photochemically reactive organic compound (PROC) that contributes to tropospheric ozone formation, so that a switch to alcohol-based cleaning would likely increase PROC emissions.

"Market" Feasibility and Technology Transfer. To date, a variety of alcohols including methyl, ethyl, and isopropyl alcohol have been used successfully to clean precision components as well as printed circuit boards. Isopropanol has been proven to be an effective alternative to CFC-113 in precision cleaning when used in conjunction with ultrasonic agitators.

The future penetration of alcohols into the market is uncertain. A variety of cleaning techniques are competing for market share, and alcohol-based cleaners may find a market niche in precision cleaning applications. If less costly methods of controlling flammability become available, alcohols may be used more widely in the future.

Other Chlorinated Solvents

Description. There are currently three chlorinated solvents that are used as substitutes for CFC-113 and MC in cleaning applications: trichloroethylene, perchloroethylene, and methylene chloride. These solvents have undergone extensive testing and due to health and safety hazards, will most likely be used very sparingly as substitutes.

Technical Feasibility and R&D. These three chlorinated solvents have well known solvent cleaning abilities. Each has been used successfully in a variety of applications. If the use of these compounds were to expand, developing low-emission equipment would be a high priority to prevent worker exposure.

Cost. To use these substitutes, strict emissions controls will be required that will increase costs, possibly substantially. Newly designed "tight" equipment is available that reduces emissions, but is prohibitively expensive for most potential users. Disposal costs for spent solvents will also be costly because of the tight controls on the disposal of these compounds.

Other. Health and safety are significant concerns. These three compounds have undergone extensive testing and have relatively low exposure limits: 50 ppm for trichloroethylene and methylene chloride; and 25 ppm for perchloroethylene. All three solvents are listed as air toxics under AB 2588 and are listed or under review under AB 1807 as toxic air contaminants. They are also listed under SARA Section 313 as toxic chemicals. Trichloroethylene and perchloroethylene are also PROCs that contribute to tropospheric ozone formation.

Extensive toxicological testing has been performed on these three solvents. The International Agency for Cancer Research identified trichloroethylene as "a substance not classifiable as to its carcinogenicity in humans." Both perchloroethylene and methylene chloride were found to be "possibly carcinogenic to humans."

Market Feasibility and Technology Transfer. While it is feasible to increase the use of these solvents as CFC-113 and MC are phased out, widespread market penetration is not anticipated due to toxicity concerns and costs of controlling emissions. There is some concern that small solvent users may switch to these compounds without adequate worker protection because they can be used easily in existing equipment. Steps to educate solvent users, and small users in particular, on the risks of these compounds may be warranted.

Aqueous Cleaning

Description. In aqueous cleaning processes, printed circuit boards or metal parts are cleaned using water in the place of conventional solvents. The cleaning process is similar to that used with ODC-based solvents. There are three basic types of aqueous cleaning equipment: immersion with ultrasonic agitation, immersion with mechanical agitation, and spray washing (UNEP, 1991a).

Technical Feasibility and R&D. The use of aqueous cleaning processes can greatly reduce the emission of ODCs. In these processes, water is used as the primary solvent. Aqueous cleaning equipment and techniques have recently been demonstrated to be very effective. Operating practices have been developed and the equipment is currently widely available.

Cost. The cost of water-based cleaning systems is expected to be competitive with or less costly than existing CFC-113 and MC based systems. The aqueous cleaning equipment itself is no more costly than the existing equipment, and the solvent is much less costly. However, water treatment equipment must be installed and operated. This equipment requires additional space and requires energy and trained technicians to operate. The impact of the water treatment equipment on the total costs varies depending on the quantity of water used and other site-specific factors.

Other. Aqueous cleaning systems have an ODP and GWP of 0.0. However, the increased energy requirements of the system, as much as 2.5 times that of other solvent cleaning processes, will increase energy-related emissions. Aqueous cleaning systems are much safer than solvent cleaning systems because they do involve toxic or flammable compounds.

Because the aqueous systems ultimately discharge their water to surface or ground water, effective water treatment is needed to prevent cross-media contamination. Those using aqueous systems must comply with discharge requirements or Publicly Owned Treatment Works (POTW) requirements for discharge into sewers.

Market Feasibility and Technology Transfer. Aqueous cleaning processes are gaining market share. The demonstrated success of such systems in achieving the required levels of cleanliness has led to increased interest in aqueous cleaning techniques. As aqueous cleaning techniques compete for market share, care is required to ensure that adequate water treatment technology is available and implemented, particularly among small solvent users which may have the option of discharging their wastewater into the sewer.

Semi-Aqueous Cleaning

Description. Semi-aqueous cleaning is performed in a manner similar to cleaning with CFC-113 or MC. In this process a hydrocarbon solvent cleans the product by dissolving contaminants. A surfactant is usually added to enhance wetting, emulsification, and rinsing properties. The final step is usually a water rinse to remove the hydrocarbon solvent residue (EPA, 1991d).

Technical Feasibility and R&D. A switch to semi-aqueous cleaning using hydrocarbon-surfactant (HC/S) blends will eliminate ODC emissions because these blends have an ODP of 0.0. Semi-aqueous systems are becoming widely used in both electronics and metal cleaning. However, process specific parameters must be tested by individual users to prevent problems such as corrosion of metal parts.

Cost. The most significant costs associated with the switch from conventional solvent cleaning to semi-aqueous cleaning are for adapting existing cleaning facilities or purchasing new equipment. Additional costs will also result from the need for wastewater treatment facilities on-site or the transport of wastewater to a treatment plant. Special treatment or disposal processes may be required for the surfactants, which may be costly.

Other. Flammability is a major concern with most HC/S cleaners, especially those that are concentrated and used in spray cleaners. These issues, however, can be mitigated with improved equipment (EPA, 1991c). In addition, there are no worker exposure limits associated with HC/S cleaners which would prevent their usage.

As with aqueous cleaning, wastewater treatment is an important concern. Additionally, hydrocarbon emissions will contribute to tropospheric ozone formation, so controls on these emissions will be important.

Market Feasibility and Technology Transfer. To date, HC/S cleaners have been tested, and have been introduced in a wide variety of applications. One application in which they have proven to be quite effective is in metal cleaning where high viscosity, high molecular weight soils, and corrosion-sensitive substrates are present (UNEP, 1991a). In electronics applications, HC/S

cleaners may be especially useful in cleaning boards with surface mount components because these cleaners work well in close spacing. It is expected that the HC/S systems will replace a large portion of the CFC-113 and MC solvent currently used.

"No-Clean" Processes

Description. Solvents are currently used to remove flux residue after soldering operations in the manufacture of printed circuit boards (PCBs). "No-clean" fluxes have been developed that eliminate the need for solvent cleaning following soldering. These fluxes have a low solids content; they contain between one and ten percent rosin as opposed to the 15 to 35 percent found in conventional fluxes. The relatively low solids content of these fluxes results in very little post-solder residue, which, depending on the product, may not need to be removed. These fluxes are often used in an inert atmosphere, such as nitrogen, which improves solder joint quality.

Technical Feasibility and R&D. "No-clean" processes have recently been introduced in a variety of electronics applications. Testing has been performed that demonstrates that system performance is not degraded when no-clean flux residues remain on various PCBs. Testing is continuing to demonstrate the effectiveness of no-clean fluxes on additional assemblies. Product specifications that allow no-clean processes to be used are in the process of being adopted.

Cost. The majority of the costs of switching from conventional fluxes to "no-clean" processes will be incurred in converting existing soldering lines. This conversion often involves the adaptation of existing equipment, but the purchase of new equipment is sometimes required. These additional costs, however, are countered by the savings realized by eliminating the post-solder cleaning process. In most cases, switching to no-clean processes will result in significant cost savings.

In the case of inert atmosphere soldering, existing soldering equipment can usually be modified relatively inexpensively. Additionally, costs will be incurred due to the purchase of industrial-grade nitrogen.

Other. No-clean fluxes do not pose human health or environmental risks. Eliminating the solvent cleaning process reduces potential worker exposure to toxic solvents or discharge of water. Eliminating the solvent cleaning process also reduces energy consumption.

Market Feasibility and Technology Transfer. No-clean processes are being adopted in an increasing number of applications. Initial applications have been for components where a very high level of cleanliness is not required to assure product performance. Additional research on reliability is required on each manufacturing line before no-clean processes can be implemented. It is expected that no-clean processes will be a widely used replacement for CFC-113 and MC solvents.

It has been suggested that the use of no-clean processes requires more monitoring and adjustment of soldering parameters and that significant system testing is required to assure

reliability. Additionally, materials compatibility and reliability may be more important. Small manufacturers may be less able to undertake these tasks without technical assistance. Therefore, technical assistance may be warranted to promote the successful use of no-clean processes by small manufacturers.

5.5.8 Foam Production

Foams are used in a variety of products, including building and appliance insulation, cushioning materials, packaging, and flotation devices. CFC-11, CFC-12, CFC-113 and CFC-114 have been used in the manufacture of the four main types of foam:

- Flexible Polyurethane Foam is made from a polyurethane resin and is primarily used in cushioning products such as furniture, carpet padding, and packaging. CFC-11 is used to produce this foam.

- Rigid Polyurethane Foam is made from a polyurethane resin in a manner that produces a very stiff material. This foam can be factory-produced as boards with laminated sealants on the outside for use as building insulation. This foam can also be sprayed onto surfaces or injected into molds. Rigid polyurethane foam is currently used in the walls of refrigerators and freezers to supply both structural strength and insulation. CFC-11 and CFC-12 are used to produce this foam.

- Extruded polystyrene (EPS) foam is produced in two forms: sheet and boardstock. EPS sheet has been used for food service and packaging applications. EPS boardstock has been used almost exclusively for insulation in buildings. EPS has been produced primarily with CFC-12.

- Other Foam Products include polyolefin foams made from polypropylene or polyethylene resins and phenolic foams made from phenol-based resins. These foams are used in a wide variety of products, including building insulation, flotation devices, aircraft seating, automotive bumper systems, packaging, and other applications. CFC-11, CFC-12, CFC-113, and CFC-114 are used in the production of these foams.

Since the signing of the Montreal Protocol and the implementation of federal regulations restricting CFC production, the use of CFCs in making foam has declined significantly. State and local restrictions on the use of CFCs in foam production have also played a role (see Section 6). HCFC-22 is being used in increasing amounts as a substitute blowing agent in many foam formulations. Additionally, MC is being used in some areas, as are alternative foam production systems and non-foam substitute products. However, as of January 1, 1994 HCFC use in non-insulating foams will be banned under the Clean Air Act Amendments (See Section 6). Consequently, non-HCFC substitutes are being emphasized in these products.

The controls applicable to each type of foam are discussed separately.

Flexible Polyurethane Foams

Flexible polyurethane foams are made with two processes:

- Slabstock foam is produced in large pieces, typically six feet wide, four feet high and 200 feet long. The slabstock is cut and trimmed to meet client specifications. Slabstock production is found throughout the U.S., and is not considered capital intensive.

- Molded foam is produced in specially designed molds to produce intricately-shaped products precisely. Molded foam is used almost exclusively to make automobile seats. Unlike slabstock foam production, molded foam production is highly automated and capital intensive.

In response to restrictions on the production of CFC-11, manufacturers have nearly eliminated the use of CFC-11 as an auxiliary blowing agent in the production of flexible foams. Foaming resin and blowing agent combinations have been adopted that do not require CFC-11 to enhance the development of the foam "cells" that provide the cushioning characteristics of the foam. These new foam systems are very similar to the previously used foam formulations, and can be used in existing foam production equipment with only minor modification.

Methylene chloride has been used in the past to produce slabstock foam, and nearly all manufacturers have switched to this substitute for CFC-11. Methylene chloride is listed under AB 2588 as an air toxic and under AB 1807 as a toxic air contaminant. Consequently, this switch increases toxic air emissions. In some areas methylene chloride use is not permitted, and manufacturers have switched to HCFCs and MC. The use of these chemicals as substitutes is only transitional, however.

Molded foam production has adopted a new system often referred to as "water blown foam" because water is used exclusively as the blowing agent in the process. The water blown foams do not pose any increased environmental or health risk. These formulations use toluene diisocyanate (TDI) in the foaming process, as did the previous formulations that also relied on CFC-11. TDI is listed as a Proposition 65 chemical in the State of California. TDI does not remain in the product after manufacture, however, as it is reacted with water to produce carbon dioxide during the foaming process. Water blown foam systems are an acceptable long term substitute in the molded foam production market.

HCFCs in Slabstock Production

HCFCs have properties that make them promising substitutes for CFC-11 in flexible slabstock foam production applications. The most probable substitute is a blend of HCFC-123 and HCFC-141b. Costs are a major consideration in the determination of a suitable alternative for CFC-11 in foam blowing production. In the case of HCFCs, costs of facility modifications to accommodate flammable blowing agents may be high.

Because the HCFCs will be banned in flexible foam production in 1994, their use in foam blowing will not likely be significant. Additionally, use of the highly flammable HCFC-141b may be limited by building codes because foam production plants are often located in populated areas to be close to the market for foam products.

HFCs in Slabstock Production

HFCs may be used in the long term to produce flexible foam slabstock. HFC-134a and HFC-152a are the prime candidates currently under consideration. Research is being conducted on the safety, cost, and toxicity of these substitutes.

Costs may limit the future use of HFC-134a and HFC-152a in this application. In particular, because HFC-134a is expected to be a major substitute for CFC-12 in MACs, it is expected to be in high demand. The price may be too high to be justified for foam products, except for very specialized products. If the price of HFC-134a declines as it becomes more available, it could play a larger role in foam blowing in the long term. Costs to modify existing equipment will also be incurred due to the flammability of HFC-152a.

Rigid Polyurethane Foams

Rigid polyurethane foams have been made with CFC-11 and CFC-12 in several ways. A large portion of this foam is made as boards which are used as building insulation. This foam is also injected into the walls of appliances to provide insulation and structural integrity. The foam hardens in place within the walls of the appliance. Refrigerators and freezers are made with rigid polyurethane foam in this manner. Rigid foam is also sprayed into place in building applications where uneven surfaces or odd shapes require insulation.

CFC-11 and CFC-12 perform several functions in the process of rigid foam production. They act as a solvent in the preparation of the foam resin. During foaming they help to form the cells of the foam and become trapped within the cells. Once trapped, CFC-11 and CFC-12 enhance the insulating properties of the foam. Because the CFCs are trapped within the foam, this foam is often referred to as "closed cell" foam. The CFCs are emitted slowly over time, depending on how the foam is manufactured and handled.

Currently there are no methods for reducing the slow emissions from the rigid foams currently in place in appliances and buildings. There is the possibility of limiting emissions that occur when products are crushed at disposal, but no process is yet commercially available. Consequently, efforts to date have concentrated on developing alternatives for making new foams that do not require CFC-11 and CFC-12.

Chemical Substitutes

As with the flexible foams, a blend of HCFC-123 and HCFC-141b is currently the most promising mid-term substitute. Rigid polyurethane foams are exempt from the 1994 HCFC foam production ban because they are used for insulation. Efforts are ongoing to identify compatible

materials to use with this blend. In particular, the plastic used in refrigerator and freezer construction must be modified to accommodate the greater solvency of the HCFC blend. Refrigerators made with rigid foam insulation that does not contain CFC-11 or CFC-12 are now reaching the market for the first time.

The HFC-134a and HFC-152a are being considered for long term substitution. Because rigid foams are more valuable than flexible foams due to their insulating and structural properties, it is expected that the costs of the HFCs will be less of a deterrent to their use in this application. Foam production systems remain to be engineered to use these substitutes.

Water-blown systems or other foaming systems do not have wide applicability in rigid insulating foam manufacturing. Some systems can use water or HCFC-22 to reduce CFC-11 and CFC-12 requirements by about 20 percent. These options are short term, however, because the CFCs are being phased out. Options that combine product substitutes are currently being considered that enable the foam to forego its insulating properties while retaining its structural characteristics.

Product Substitutes

A variety of product substitutes are being considered to reduce the requirement for rigid foams. One important investigation being conducted is into the use of vacuum panels in the walls of refrigerators and freezers. These light-weight panels are constructed to have a vacuum within a honey-comb shaped core. These panels would provide the insulation needed for these appliances.

One approach being considered is to imbed these panels in rigid foam that would be foamed in place in a manner similar to current production methods. The foam would provide the necessary rigidity and protect the vacuum panels from inadvertent damage, while the panels would provide the insulation. By relieving the foam of its primary responsibility as insulation, the pool of candidate blowing agents is expanded to include hydrocarbons or water/TDI systems. Considerable work remains to develop a workable vacuum panel - foam combination, and data are not currently available for assessing costs and impacts.

Product substitutes are also available for other rigid foam applications. Fiberglass insulation competes well with rigid foam insulation in many building applications. It is expected that fiberglass can be used in combination with slightly thicker walls and insulation to provide the same insulating performance as rigid foams at almost no increase in cost.

Extruded Polystyrene Foams

Extruded polystyrene (EPS) foam comes in two forms: boardstock (used as building insulation), and sheet (used for packaging). These foams have used CFC-12 as a blowing agent, but its use has already been discontinued in EPS sheet production for packaging. There are several substitutes being evaluated for replacing CFC-12 in boardstock production.

To date nearly all EPS sheet manufacturers have switched to hydrocarbons, HCFC-22, or HCFC-22/hydrocarbon blends. Because of the flammability of hydrocarbons, modifications to foam blowing plants have been required. Consequently, HCFC-22 has been preferred by some, although its use will likely be banned in EPS sheet production in 1994. HCFC-22 has been approved as a blowing agent for the production of EPS food packaging products (such as meat trays used in retail sale).

New formulations using carbon dioxide as a blowing agent are also being researched. These formulations may provide a long term substitute for EPS sheet manufacturing. HFC-134a and HFC-152a are also long term options for EPS sheet production. However, the market for packaging material is highly competitive and the cost of the HFCs may preclude their widespread use in this application. In particular, recyclable packaging materials such as paper, card board, or other cellulose-based products may increase market share at the expense of EPS sheet. Additionally, molded expanded polystyrene foams that do not require CFCs or HCFCs are vying for market share. Consequently, it is unlikely that these foam products will be a significant source of emissions in the future.

In the extruded polystyrene boardstock industry, the blowing agent not only helps to form the foam, it also provides insulating properties. While fiberboard, cellular glass board, and expanded polystyrene foams will be competing for this market, EPS boardstock is expected to maintain market share as production shifts to alternative blowing agents. A HCFC-22/HCFC-142b blend has been tested and has exhibited good foam blowing characteristics and compatibility with resins and materials used in the EPS process. This blend is reportedly being used by at least one major foam manufacturer. Because boardstock is used for insulation, HCFCs are not expected to be banned from this application.

HCFC-142b (CH_3CClF_2) is flammable, so that plant modifications will be required. It has a relatively low ODP (0.08) and GWP (0.05), making it attractive as a mid-term substitute. Its exposure limit is set at 1000 ppm, indicating that it is not considered toxic. As with EPS sheet, HFC-134a and HFC-152a are considered potential long term substitutes. The applicability of hydrocarbons is also being investigated.

Other Foams

Other foam products include polyolefin foams made from polypropylene or polyethylene resins and phenolic foams made from phenol-based resins. These foams are used in a wide variety of products, including building insulation, flotation devices, aircraft seating, automotive bumper systems, packaging, and other applications. CFC-11, CFC-12, CFC-113, and CFC-114 have been used in the production of these foams.

Phenolic foams comprise less than five percent of all foam insulation currently produced, and their production has reportedly declined substantially because other insulation products are available. A HCFC-123/HCFC-141b blend is being considered as a promising short-term substitute for CFCs in phenolic foam blowing. Because of concerns over HCFC-123's toxicity,

efforts are now focusing on HCFC-141b by itself. Hydrocarbons are also being considered, but they do not provide the insulating characteristics desired in some applications.

Polyolefin foams are used most often as protective packaging for various consumer goods. These foams are also used in personal floatation devices and some specialty construction materials. In the past, these foams have been blown with CFC-11, CFC-12, and CFC-114 (UNEP, 1989b). Most of these foams will not likely qualify for an exemption to the ban on HCFC use in production in 1994. A determination has yet to be made by EPA under the Clean Air Act Amendments.

The most promising short-term substitutes for CFCs in polyolefin foam blowing are HCFC-22, HCFC-142b, and hydrocarbons. Hydrocarbons appear to be the most likely short-term substitute in light of the potential HCFC ban. As is the case with the foam types previously mentioned, HFC-134a and HFC-152a are the most likely long-term alternatives to CFCs in blowing polyolefin foams.

5.5.9 Sterilization

CFC-12 with ethylene oxide (EO) is widely used for sterilization of medical equipment and devices by medical device manufacturers and contract sterilization services, as well as by hospitals. EO, the main cleaning ingredient of sterilization solutions, is used for its ability to penetrate a wide variety of packaging materials to destroy microorganisms on medical products and devices. Due to the high flammability and explosion risk associated with EO, it is often diluted with CFC-12 to a mixture of 12 percent EO and 88 percent CFC-12 (by weight), a combination commonly referred to as "12/88".

Strict performance requirements for sterilization equipment must be met by any chemical substitute or process modification. Additionally, EO emissions are controlled because of EO's high toxicity. Therefore, any modifications must be compatible with preventing EO emissions.

There are two main types of sterilizer users:

- Contract Sterilizers are principally in the business of providing sterilization services. These firms typically have large capacity sterilization equipment. Systems are typically highly automated and capital intensive.

- Hospitals and Other Small Sterilizer Users are typically not in the sterilization business, but require sterilization on an ongoing basis. Hospitals generally use small sterilization equipment that is operated manually. Worker exposure to EO is a major concern, and facilities are not typically designed for handling explosive gases like pure EO.

It has been suggested that contract sterilizers will be able to reduce CFC-12 emissions more cost effectively than small users such as hospitals, and that hospitals should therefore consider

shifting from in-house sterilization to using contract sterilizers. Such shifts have not been common to date, possibly due to increased instrument inventory requirements and reduced flexibility of using contract sterilizers.

If diluted EO continues to be used as the sterilant, alternative diluent gases can be used by both contract sterilizers and small users. Pure EO can also be used, but its explosiveness makes it unattractive for small users. Alternative sterilization gases or processes are also under development. Each of these approaches for reducing CFC-12 emissions is discussed separately.

It should also be noted that it has been suggested that hospitals increase their use of disposable instruments and products in order to reduce their sterilization requirements. Because these products generally require sterilization themselves, the sterilization burden is merely shifted from hospitals to contract sterilizers or product manufacturers. Increased use of disposable products will also increase the need to dispose of infectious wastes. Consequently, this alternative is not discussed.

Alternative Diluent Gases

Description. In the 12/88 mixture, CFC-12 acts to dilute the EO and suppress its flammability and explosiveness. The 12/88 mixture is shipped pre-mixed, so sterilizer users do not handle any explosive gas. To replace CFC-12, alternative diluent gases are being considered, including carbon dioxide and HCFCs.

Technical Feasibility and R&D. Carbon dioxide (CO_2) had been used as the diluent gas when EO sterilization was first introduced. It was used in a mixture of 10 percent EO and 90 percent CO_2, and was referred to as 10/90. During the 1950s 12/88 was adopted in favor of 10/90 because it allowed the sterilizers to be operated at lower pressures and because the pre-mixed 10/90 mixture tended to separate, thereby increasing the chance that a flammable EO mixture would result as the mix was used. Additionally, because the concentration of EO declines in the 10/90 mix as it is used, the effectiveness of the sterilization process also declines.

Despite these problems, it is technically feasible to use CO_2 as the diluent gas. In addition to safety and efficacy concerns, the existing sterilization equipment is not designed to operate at the higher pressures required by 10/90. Therefore, existing equipment would require modification or replacement.

HCFCs are being examined as possible drop-in substitutes for CFC-12. Indications are that an HCFC blend may be applicable, and the technical feasibility of the blend is undergoing evaluation. Research into the blend remains to be performed, and regulatory approval for efficacy and safety will be required.

Cost. The principal cost of switching to 10/90 is the cost of replacing or modifying existing equipment designed to use 12/88. The 10/90 mixture costs less than the 12/88 mixture and is expected to be compatible with EO emissions controls.

The costs of the HCFC blend are not yet available. Assuming that the blend is a drop in substitute, the cost will be driven by the cost of the HCFCs themselves. This cost will likely be higher than the cost of CFC-12 in the 1980s. HCFC recovery equipment will likely be cost effective for larger sterilizers and will help to reduce HCFC emissions.

Market Feasibility and Technology Transfer. The 10/90 mixture will not likely gain acceptance if a drop-in substitute is developed. If 10/90 does penetrate the market, it will be important that all sterilizer operators, including operators of small sterilizers, be adequately trained to avoid explosion risks and a loss of sterilization effectiveness.

Pure EO

Description. Pure EO can be used in large and small sterilizers. Two approaches for using pure EO are: (1) to use it alone; and (2) to use it in conjunction with nitrogen. When used alone, the sterilization chamber is put under a vacuum and then filled to about 70 percent of atmospheric pressure with pure EO. When used in combination with nitrogen, the chamber is put under a vacuum and then filled with nitrogen prior to introducing pure EO.

Technical Feasibility and R&D. Pure EO is an effective sterilant. The principal drawback of using pure EO is its explosiveness. Cylinders of pure EO are extremely dangerous to handle, and require special equipment and in some cases special building designs. Hospitals will not likely be inclined to adopt systems that require handling pure EO in large quantities.

When used alone, the pure EO process requires that a very deep vacuum be developed within the chamber so that an adequate density of EO can be attained while maintaining sub-atmospheric pressures. Some product packages that are currently sterilized using 12/88 equipment cannot sustain the vacuum necessary to operate a pure EO system. Additionally, the pure EO mixture is potentially explosive within the chamber, so that explosion proof chambers must be used. Existing equipment generally does not meet this requirement.

The introduction of nitrogen in the sterilization chamber does not eliminate the need to handle pure EO, but has other advantages. The EO mixture within the chamber is not explosive during normal operation. Although this reduces risk, explosion-proof equipment is still recommended. Additionally, a shallow vacuum can be used when nitrogen is introduced into the chamber. By avoiding a deep vacuum, the process is applicable to a wider range of products.

Cost. The cost of using pure EO is principally the cost associated with obtaining explosion proof sterilization equipment, gas handling equipment, and storage spaces. In areas with space limitations, such as hospitals, the cost of these modifications may be prohibitive.

Market Feasibility and Technology Transfer. Pure EO systems may gain market share among contract sterilizers that have automated equipment and the specialized gas handling conditions required. By eliminating the diluent gas, these users will reduce their operating costs, and may avoid costs associated with HCFC recovery.

Alternative Sterilization Gases and Processes

Several alternative sterilization gases and processes are currently being examined. By their nature, the alternative gases are very toxic. The ability to control emissions will be important for preventing additional toxic air emissions. As discussed above, EO emissions are now controlled in most instances. The main alternatives under consideration include the following:

- Ozone (O_3) sterilization relies on ozone to oxidize and sterilize products placed within a chamber. An ozone generator creates the ozone, which is introduced into the chamber at a controlled rate for a specified period of time. One of the advantages of this system is existing 12/88 chambers used by hospitals can be retrofitted easily. Ozone has also been shown to be compatible with most commonly used hospital products and instruments, and is currently undergoing FDA review for approval. Following FDA approval, expected within several years, expectations are that ozone sterilization systems could achieve significant market penetration.

- Chlorine dioxide (ClO_2) is undergoing development as a sterilant gas that is cost competitive with EO. Current efforts are aimed at high-volume contract sterilizers. Advantages of this process are that existing equipment can be retrofitted and no diluent gas is required.

- Ionizing Radiation has been proven to be an effective method of sterilization. Gamma radiation from cobalt 60 has been used commercially, although is generally considered costly. This approach is only applicable to very large sterilizer users. Compatibility with materials is sometimes a problem.

- Steam Sterilization. Steam is used by hospitals and contract sterilizers when materials permit. The 12/88 systems have principally been developed and used to meet the sterilization requirements for products that cannot withstand steam sterilization. Although the use of this option may expand slightly, it is not expected to displace a significant amount of current 12/88 sterilization.

The extent to which these alternatives will penetrate the market is not currently known. If a drop-in substitute for CFC-12 is developed that is not too costly it will likely be used by most small users such as hospitals because it will not require modifications to existing equipment and operating procedures. Contract sterilizers may, however, move to alternative approaches if there is a cost or performance advantage. In some applications, for example, ozone sterilizers may be preferred because they do not leave toxic residues.

5.5.10 Miscellaneous Uses

ODCs are used in a variety of miscellaneous applications, including: adhesives (MC); coatings and inks (MC); and aerosols (MC, CFC-11 and CFC-12). Controls for these applications

are summarized below. ODCs, principally HCFC-22, are also used in a variety of other minor products. Control options for these products have not been described in detail in previous analyses, and are not considered here. The emissions from these minor products are less than 2 percent of total ODP-weighted emissions in the state.

Adhesives

Methyl chloroform is used as a solvent to transfer an adhesive to a surface and to aid in increasing binding strength. Its low flammability and compatibility with a wide range of materials make it desirable in this application. It may be technically feasible to substitute some HCFCs and HFCs for MC in this application. However, a very low ODP is needed (MC's ODP is 0.11) and low flammability and low toxicity are required. To date, adhesive formulations using HCFCs and HFCs have not been developed.

Alternative chlorinated solvents, especially methylene chloride, can be used in adhesives. Recently manufacturers switched away from methylene chloride due to concerns about toxicity and worker exposure. The use of other chlorinated solvents in place of MC in this application would increase emissions of air toxics. Several alternative adhesive systems that do not rely on chlorinated solvents are available that may substitute for MC-based adhesives. These are as follows.

Water-based Adhesives

Water-based adhesives use water as the primary solvent in place of MC. They are applied in the same manner as MC-based adhesives, using, among other methods, a brush, spray, roll coat, or flow. The use of water-based adhesives will likely increase substantially as MC is phased out.

The performance of water-based adhesives, while adequate in most cases, appears to be inferior in some situations. In low temperature applications the adhesive may freeze. When applied to some materials, the water causes corrosion or the adhesive becomes contaminated, which leads to poor binding. In addition, water-based adhesives do not bind well to a variety of surfaces, thus making them less flexible than MC-based adhesives. It is estimated that by switching to water-based adhesives, users could reduce their costs by 26 percent (ICF, 1989a).

Hot-melt Adhesives

Hot melt adhesives are applied as a molten liquid. As the liquid cools it forms a bond and returns to a solid state. These adhesives are used in limited applications, most often bookbinding, packaging, textiles, and product assembly. Application of hot melt adhesives is usually accomplished using a pressure-feed system or a melt-reservoir.

Hot melt adhesives will displace some MC-based solvent use in applications where high temperatures can be tolerated and performance problems do not exist. Limitations of hot melt systems generally include limited strength, limited heat resistance, and poor bond strength to a

number of materials. In addition, high cost in some applications may limit its use. Regardless of the adhesive composition, all hot melt systems will require significant expenditures for the purchase and installation of new equipment. Safety precautions must also be taken since the use of hot equipment can be a danger to workers (ICF, 1989a).

Radiation Cured Adhesives

Radiation cured adhesives use radiant energy such as ultraviolet, infrared, and gamma radiation for drying and curing. The radiant energy is converted to chemical energy in the form of an adhesive bond. Radiation cured adhesives may find application in the electronics and communications industries. While energy costs and emissions are reduced with the use of this process, large capital expenditures are required for the purchase of cure units (ICF, 1989a and UNEP, 1991a).

Moisture Cured Adhesives

Moisture cured adhesives contain only binding substances and fillers and have no solvent or other carrier. These adhesives cure when they are exposed to the humidity in air, thus making them most useful in wetter climates. Currently, moisture-cure adhesives are available in a variety of forms, including solids, liquids, and hot melts (ICF, 1989a and UNEP, 1991a).

Coatings and Inks

MC-based coatings and inks account for only a small portion of the coatings and inks market, about 1.2 percent. Most of the market is served by alternative substances and processes, including: chlorinated solvents, petroleum distillates, high solids products, water-based products, and powders (UNEP, 1991a). Although MC is used primarily for its good solvency power and its low flammability, other chlorinated solvents and petroleum distillates are commonly used. Most of the alternatives available to replace MC-based coatings and inks can be used with little or no increase in cost or loss of performance. Several options under consideration include the following.

High-Solid Coatings

Although high-solid coatings resemble conventional solvent coatings in appearance and use, high-solid coatings contain less solvent and a greater percentage of resin. Many methods are used to apply high-solid coatings, including: dipping, flow coating, conventional air and airless atomizing, air and airless electrostatic spraying, rotating disks and bells, rolling, continuous coating, centrifugal coating, and tumbling. High-solid coatings are currently used for appliances, metal furniture, and farm and road construction equipment. Because of the refinement of application technology and the addition of flow-control agents and thinners, the finish of high-solid coatings is superior to that of solvent-based coatings. This occurs despite the fact that high-solid coatings require much less solvent than do standard solvent-based coatings (UNEP, 1991b).

Water-based Coatings and Inks

Water-based coatings contain water rather than conventional solvents such as MC. They are applied using methods similar to those used for high-solid coatings. Recent advances in technology have improved the dry-time, durability, stability, adhesion, and application of water-based coatings. Primary uses of these coatings include furniture, electronics in automobiles, aluminum siding, hardboard, metal containers, appliances, structured steel, and heavy equipment. In some water-based coatings, standard solvents are added for ease of application, but even these contain much less solvent than conventional coatings because the primary solvent is water (UNEP, 1991a).

While solvent-based inks have good wetting properties because of the low surface tension of solvents, the high surface tension of water requires the use of co-solvents to lower the surface tension to enable the wetting of treated surfaces. A mixture that is 80 parts by volume of water and 20 parts of alcohol and ethyl acetate can be used to achieve an effective surface tension. Continued growth of aqueous inks has been projected by various industry sources.

Powder Coatings

Powder coatings contain resins in powder form, and have no solvent. They are applied using fluidized beds, electrostatic spray, and electrostatic fluidized beds. Typically, the object coated is heated above the powder's melting point so that the resin fuses into a continuous film. The resin then hardens, either at the heated temperature or as the object cools, to form a finish that has excellent durability and corrosion resistance. While powder coatings were first used only for electrical transformer covers, they are now also used in the following areas (UNEP, 1991a):

- underground pipes;
- electrical components;
- concrete reinforcing bars;
- appliances;
- automobiles;
- farm and lawn equipment;
- lighting fixtures;
- aluminum extrusions;
- steel shelving; and,
- some furniture.

Aerosols

Over the past 15 years there have been tremendous changes in aerosol products. In 1978 the use of CFCs in non-essential aerosol propellant applications was banned in the U.S. (see Section 6). A small number of essential products were exempted from the ban. In response to the ban, aerosol manufacturers principally switched to hydrocarbon propellants and various chlorinated solvents, including MC, to provide the solvency needed in aerosol formulations. In some cases methylene chloride was used (e.g., in hair sprays). Virtually all methylene chloride

has since been eliminated from personal products due to toxicity concerns, although some industrial products (such as spray paints) continue to use methylene chloride. Alcohols are now used in many personal products to provide solvency (e.g., in hair sprays).

Most recently, the California ARB initiated a policy to restrict the use of photochemically reactive organic compounds (PROCs) in some aerosol consumer products. Consequently, the use of hydrocarbon propellants and various solvents, including alcohols, will be restricted.

Within the context of these large changes to the aerosol market, a small amount of CFCs and MC are used. Generally, alternative formulations or product delivery systems can be used to eliminate CFCs and MC from these products at relatively low cost, and without a significant loss of performance. However, with restrictions on PROC usage in aerosol products in California, reformulation may be more difficult.

A variety of alternatives are being considered, not solely to eliminate ODCs in aerosol products, but to eliminate PROCs and methylene chloride as well. These include alternative solvents, alternative propellants, and alternative packaging. In a very small number of aerosol products, CFCs are used as the active ingredient (e.g., in spray cleaners). Because the active ingredients of these products are being phased out, they will switch to alternative formulations as well.

Alternative Solvents

Both CFCs and MC are used as solvents in aerosol products. A wide variety of alternative solvents have been and are currently used, so that these ODCs represent only a tiny portion of all solvents used in aerosol products. The solvent in an aerosol product is generally used to dissolve the resin or other active ingredient to be delivered by the device so that it can be propelled from the can in an even spray. For example, in hair sprays solvents are used to dissolve the fixative (i.e., glue) so that it can be sprayed from the can.

To be usable in an aerosol product, a solvent must have several key properties, including:

- it must provide an adequate amount of solvency for the target material(s);
- it must be compatible with other constituents in the product formulation and the product package;
- it must have good spray characteristics;
- it must dry in a period of time consistent with the intended use of the product (most products require that the solvents dry very quickly);
- it cannot present an offensive odor in many cases; and
- it cannot be toxic.

Additionally, aerosol products must meet flammability requirements, so it is preferred that solvents be non-flammable. When flammable solvents are used, compatible flame retardants must be identified and added to the product.

Because the active ingredients of aerosol products are very diverse, a very wide range of solvents are currently used. Several that are under consideration as substitutes include the following.

- Petroleum Distillates. Petroleum distillates have excellent solvency that is applicable to a variety of aerosol products. Products formulated with petroleum distillates are currently available for various automotive products such as tire cleaners, lubricants, spray undercoatings, and in household products such as water repellents/shoe waterproofers, glass frostings, and insecticides. It is estimated that research and development costs to facilitate the switch to petroleum distillates from MC will be about $6 million (ICF, 1989b).

- Water-based Systems. Water is an excellent solvent, although it dries relatively slowly. Nevertheless, reformulation from MC to water-based systems can be performed in certain shoe polishes and insecticide foggers. Research into water-based foggers is still required because initial tests indicate that they do not disperse as well as MC-based systems and result in larger particle size. Additionally, the water tends to be less effective at penetrating the exoskeleton of insects.

- HCFCs. HCFCs have excellent solvent properties for aerosol products. In particular HCFC-22 has been evaluated. Although HCFC-123 and HCFC-141b were also considered, their toxicity properties and the ODP of HCFC-141b make them undesirable. With the exception of products that may be exempted by the U.S. EPA, HCFC use in aerosol products will be banned in the U.S. under the 1990 Clean Air Act Amendments as of January 1, 1994. Consequently, HCFCs will not gain significant market share in aerosol products.

Chlorinated solvents and alcohols may also be considered as substitutes. These products are widely used in various aerosol formulations. In California, non-PROC alternatives, such as water-based systems will be preferred.

Alternative Propellants

Similar to choosing a solvent, choosing a propellant requires good compatibility with the product formulation and packaging. In addition to the solvent selection criteria, the propellant must be able to expel the product from the container with an appropriate and even force. It is also important that the force of the spray remain fairly constant as the can is emptied, and that nearly all the active ingredient be expelled reliably.

Since CFCs were banned as propellants, hydrocarbons (propane and butane) have been the preferred propellant for most products. Several essential medical devices continue to use CFCs. As CFC production is phased out, hydrocarbons will likely be used in many cases. Several alternative delivery systems under consideration include the following:

- Compressed Gases. Compressed gases such as CO_2, nitrous oxide (N_2O) and nitrogen (N_2) are effective propellants for aerosol products that must deliver a high quantity spray. One drawback is that because of limitations on maximum can pressure, only relatively small amounts of active ingredient can be expelled from the can. Additionally, as the pressure in the can declines, the spray quantity and quality deteriorate quickly. Compressed gases are not likely to be used as propellants in applications that require small and carefully measured doses, such as the medical devices that are currently exempt from the CFC propellant ban.

- Dimethyl Ether (DME). DME is a medium pressure flammable liquified propellant. DME is water soluble and also has excellent solvent properties. When used in conjunction with water, the drying time of the DME/water mixture has been found to be acceptable in several products tested (ICF, 1990). As a PROC its use may be limited in California products.

- HCFCs. HCFCs, and HCFC-22 in particular have good propellant properties as well as solvent properties. An HCFC/DME blend has been developed that appears to be a good propellant/solvent system with reduced PROC emissions (ICF, 1990). As discussed above, HCFC use will be banned with the exception of essential products. Consequently, HCFCs may only find application in a small number of essential medical devices.

- HFCs. HFC-134a is being considered to replace CFC propellants in pharmaceutical inhalant drug products, sometimes referred to as metered dose inhalant drugs (MDIDs). HFC-134a would act as the propellant only since it has shown poor performance as a solvent. These devices require excellent fine-spray characteristics and control over spray quantity. If approved as safe and efficacious, HFC-134a could fill a small but important product niche.

Alternative Packaging

In most instances, aerosol packaging is merely an extremely convenient method of delivering a product that can be delivered in a variety of other ways. In fact, aerosol products are so convenient that consumers are willing to pay extra for this form of packaging. However, alternative packaging often exists. For example, MC is used in an aerosol brake cleaner product. Manual brushing with a liquid cleaner is also commonly used. Similarly, MC is used in an aerosol spot remover. Alternatives include products that come in tubes and bottles. Additionally, rather than use an aerosol spot remover, clothing can be dry cleaned and carpet can be cleaned using non-aerosol products.

When spray systems are particularly desirable, alternative spray packaging is available. "Pump" sprays are available in various forms. Finger-activated pumps provide reasonable spray quality and control for some products. At least one new hair spray package is available that provides a mechanism for the user to "pump it up" or pressurize it prior to each use. This system provides good spray characteristics without using any propellant. These types of pump sprays do not deliver large quantities of product, however.

Barrier packages are also under development that provide aerosol-like performance. The Exxel® system uses a rubber sleeve crimped to a valve. When the can is filled, the sleeve expands. When the valve is depressed, the rubber sleeve contracts and expels the product. Growpak® has developed an inflatable barrier pouch that is inserted into the can. The pouch is expanded when CO_2 is formed at a controlled rate through the reaction of sodium bicarbonate with citric acid. The inflation of the pouch expels the product. Compatibility with product formulations is very important for these systems.

5.5.11 Fire Extinguishers

Halon 1301 is used principally in total flooding systems to protect electronic equipment rooms. Upon detection of a fire, the total flooding system discharges halon 1301 very rapidly, extinguishing the fire. The total flooding systems are designed to produce a sufficient concentration of halon in the room in order to fight the fire. Total flooding systems are also used in areas where flammable liquids are stored or handled, in military applications, and other miscellaneous situations.

Halon 1211 is used principally in portable fire extinguishers. These systems are used to protect the same types of areas that use total flooding systems, with electronic equipment and military applications being the largest uses. Halon 1211 hand-held fire extinguishers have also been marketed to consumers for home use. A small amount of halon 1301 is used in portable systems, and small amounts of both halon 1211 and 1301 are used in locally applied systems which are similar to total flooding systems, but only are effective in a portion of the room.

Because halon production is being phased out, alternative methods of fire protection will be required. Additionally, emissions from existing halon systems and systems that will be installed prior to the phaseout of production should be controlled. Several very effective control measures have been identified that can eliminate most of the halon emissions from installed systems. Fire protection professionals are implementing these measures in order to extend the useful life of the existing halon equipment and available halon compounds.

Control Measures to Limit Emissions from Halon Systems

Only a small portion of halon emissions have been associated with actual fire suppression activities. When a fire or explosion threat is detected, a halon system releases halon (automatically or manually) to extinguish the fire or eliminate the explosion threat. During this activity, halon is released. Controls on these emissions are not anticipated.

Most halon emissions are controllable because they are associated with testing, servicing, training, inadvertent release, and disposal. Effective control measures can eliminate nearly all of these emissions.

Testing Emissions

All halon systems require one or more types of testing. Most systems are tested by the manufacturer when constructed. Fire codes require testing when flooding systems are installed. The installation test usually requires that the system be activated and the halon released. A given halon concentration must be achieved in the room for a given period of time in order for the system to be judged effective. If the system does not pass the test, it must be modified and retested.

Several alternatives are being developed to eliminate these emissions. Most importantly, alternative test gases are being developed. Rather than test the systems with halon, as has been the traditional practice, research is being conducted to identify gases with similar dispersion characteristics that can be used to establish the efficacy of the halon systems. CO_2 is a leading candidate for installation testing. The use of CO_2 will be less costly than the use of halon. HCFCs are also being considered, although it would be preferable to avoid the use of a compound with a non-zero ODP. Additionally, toxic gases are not under consideration.

To reduce emissions, manufacturer testing may be performed using special recovery equipment. Rather than discharge the system into the environment, the equipment can be discharged into a recovery tank which will collect all the halon. The halon can then be collected and re-used. This approach enables the manufacturer to test new equipment designs without emitting any halon.

Portable halon 1211 extinguishers are required to be discharged at regular intervals to ensure that they are in working order (5, 10, or 20 years). This testing should also be done using recovery equipment to eliminate emissions. Such recovery equipment is now available.

Testing emissions accounted for over one-third of halon 1301 emissions and over 10 percent of halon 1211 emissions in 1990. Consequently, these low-cost control measures will reduce emissions substantially.

Servicing Emissions

In the past, systems were vented during servicing. Halon recovery can be performed so that these emissions are eliminated. Halon recovery equipment is similar to CFC recovery equipment, and is expected to be very effective. Based on discussions with halon system installers, the high cost of halon has already led to reductions in venting activities.

Training Emissions

Large amounts of halon have been emitted during civilian and military training activities, accounting for about 50 percent of emissions in 1990. Alternative training procedures are being developed to avoid these emissions. Alternative test gases may be used during training with total flooding systems. Alternative portable systems are available for training in the use of portable equipment. Fire protection training manuals are being revised, and new procedures are expected to be implemented.

Inadvertent Release Emissions

Inadvertent releases from total flooding systems accounted for about 20 percent of emissions in 1990. These emissions are primarily associated with faulty automatic fire detection systems that activate the halon discharge when one is not required. Additionally, manually-operated total flooding systems are improperly activated by personnel in some cases.

Several avenues are being pursued to reduce these emissions. Improved standards for controls are being examined that would largely eliminate false activation. The costs of these controls may be high, however. As an alternative, automatic systems are being adjusted to decrease their sensitivity so that false activation is avoided. These adjustments may be combined with the addition of manual activation devices to maintain the overall level of fire protection and safety. Additional research is ongoing to identify the most cost effective and efficacious system designs.

Disposal Emissions

Small emissions result from the decommissioning of portable and total flooding systems. When total flooding systems are decommissioned, the halon container is usually removed intact, and can be reused. Alternatively, the halon can be recovered and reused. When portable fire extinguishers are no longer needed, they should be returned to their manufacturer for proper reconditioning. Some smaller hand held units do not have the valves necessary for recovering the halon easily. To date, these systems have been vented when disposed. However, because of the increasing value of halon, future practice will likely be to discharge these units into recovery apparatus to eliminate the emissions and conserve the halon.

Alternative Fire Protection Methods

As the halons are phased out, alternative fire protection methods will be implemented. The remaining available halons will be conserved (as described in the previous section) and will be deployed in their most highly valued uses. In cases where halons are not available, alternative extinguishing agents and system designs will be required. Broadly applicable drop-in substitutes are not expected to be identified (UNEP, 1991b). Consequently, a variety of replacements, substitutes, and changes in practices will likely be required.

Halon Replacements

Research is ongoing to identify halon replacements, i.e., gaseous compounds that are clean fire extinguishants, explosion suppression agents, and/or inertion agents (capable of introducing an inert atmosphere). To be considered, replacements should have low toxicity and be highly effective. Additionally, they should have a very low or 0.0 ODP.

Separate replacements will likely be required for halon 1211 and 1301. Halon 1301 is more gaseous, which is why it is used in total flooding systems. Exhibit 56 lists several candidates that are currently undergoing study. None is available commercially for fire protection, and considerable research remains to be performed before they can be adopted. At this time it is not possible to predict which, if any, of the candidate replacements may be used in the future.

Exhibit 56: Candidate Halon Replacement Chemicals

Compound	Formula	Application	Extinguish Concentration	ODP	LC_{50} (%)
HCFC-123	CF_3CHCl_2	Portable	7.5	0.02	3.2
HFC-125	CF_3CHF_2	Flooding	9.1	0.0	>70
HFC-23	CHF_3	Flooding	13.0	0.0	>65
HBFC-22B1	CHF_2Br	Portable/Flooding	3.9	1.1	10.8
HBFC-124B1	CF_3CHBrF	Portable	3 (approx)	0.4	--
FC-218	$CF_3CF_2CF_3$	Flooding	6.	0	>80
FC-3-1-10	$CF_3CF_2CF_2CF_3$	Portable/Flooding	5.	0	>80

Extinguish Concentration is the concentration in air required to extinguish a heptane flame as defined with a cup burner.

LC_{50} is the concentration in air lethal to 50 percent of a population (usually determined in a 4-hour rat study). The values for FC-218 and FC-3-1-10 were estimated.

Source: UNEP (1991b).

Halon Alternatives

A variety of alternative systems/chemical agents have been identified that may be used in place of halon systems. However, the alternatives generally have some measure of reduced

performance as compared with existing halon systems. The selection of a preferred alternative depends on the specific characteristics of the fire risks. UNEP (1991b) lists factors that should be considered in making these determinations. The available alternatives include the following:

- Monitored Early Warning Detection Systems are automatic or manually-operated warning devices that are connected to a fire department dispatch station or other manned facility. These systems enable faster response to a fire.

- Automatic Sprinklers put water on a fire quickly. Various designs are possible, including fast-response detectors, and "pre-action" systems in which the piping is empty until a fire is detected. Water-based systems can damage electronic equipment and sensitive objects unnecessarily. Water is not effective for chemical and fuel fires.

- CO_2 Systems can be used in various ways. Total flooding systems could be used in electronic equipment rooms. However, the high CO_2 concentrations required for effective fire suppression may present a danger to occupants. CO_2 can also be designed for under-floor spaces or individual equipment enclosures.

- Dry Chemical systems are effective on fuel fires and are widely used in such applications. They leave a residue which makes them less desirable around sensitive equipment or objects (e.g., in museums).

Hand held alternatives also exist, including CO_2, dry chemical, and water based extinguishers.

Alternative Practices

In some cases changes in practices can reduce the risks of fire. For example, the use of non-combustible equipment and supplies can be increased. Additionally, smaller inventories of highly flammable materials could be maintained so that there is no immediate threat to life or critical equipment prior to the time when manual intervention can take place. If possible, flammable materials could be segregated into non-occupied areas. Finally, critical pieces of equipment could be duplicated so that the loss of a single item does not adversely affect system reliability.

The extent to which these alternative practices will be employed has not been estimated. Modifications and improvements in fire protection practices will likely continue to be integrated into newly designed systems and standards.

5.5.12 ODC Manufacturing

Emissions from ODC manufacturing result from fugitive leaks. Control measures to reduce these leaks have not been identified or evaluated. However, the application of inspection

and maintenance requirements could be investigated as a means of reducing these emissions. To implement such a program, a rapid and convenient method of detecting leaks would be required. Halogen compound detectors (such as electron capture) could be adapted for this purpose, but are not currently available.

5.6 CONTROL MEASURE EVALUATION

As presented above, there are a large number of control options that may be implemented across the various ODC applications. This section evaluates these options in terms of their costs, emissions reduction, and economic impact. Additionally, the information on applicability of the control options to new and existing equipment, and the toxicity, flammability, and other environmental impacts of the options are summarized. The results of these evaluations indicate which control options are the most promising alternatives for reducing ODC emissions.

Exhibit 57 summarizes the information on applicability, toxicity, flammability, and other environmental impacts of the control options. The exhibit is organized by end use and lists the controls within each. In some cases, several similar control alternatives have been grouped together (e.g., as "Other Substitute Refrigerants"). The following information is presented for each control option:

- New Equip.: This column indicates whether the control is applicable for use in new equipment, such as newly manufactured refrigeration systems. A "Yes" indicates that the control is applicable to new equipment. In some cases, the control is not likely to be used in new equipment even though it is applicable. In these cases a "--" is listed. Finally, "NA" is listed for product substitutes that would not likely be manufactured with existing ODC-based manufacturing equipment.

- Exist. Equip.: This column indicates whether the control is applicable for use in existing equipment, such as existing refrigeration systems. Controls requiring that existing equipment be retrofitted are listed as "RR" for "requiring retrofit."

- Toxic: This column summarizes the control option toxicity information. Substitute chemicals that are undergoing toxicity testing are listed as "Testing." The toxicity information in the table is only a qualitative summary. For more detailed information the control option description should be consulted.

- Flammable: This column identifies whether the control option is flammable. "Some" is listed in cases where several chemical or product substitutes are included in the control option, and one or more is believed to be flammable.

- Other Environmental Impacts: This column gives a brief description of the other potential environmental impacts of the control option.

As shown in the exhibit, many of the control options are not applicable to existing equipment, or require retrofits to be implemented on existing equipment. Therefore, existing refrigeration and air conditioning systems will require ODCs for servicing during their remaining useful lives. Because ODC production is being phased out, recovered and recycled ODCs will be an important source of ODCs for these systems.

Exhibit 58 summarizes the costs of the control options as follows:

- Emit Reduction: This column qualitatively describes the emissions reduction achieved by the control option within the application. The control option(s) that have the largest reduction within the application are labeled as "large." Those options with reductions that are only about one-third to one-half of the "large" options are listed as "moderate." Those options with less emissions reductions are labeled as "small."

- Cost: This column lists the estimate of the cost of the control option per kilogram of emissions avoided. In the case of a drop-in chemical substitute, the cost is the difference in cost in the chemicals, plus any impacts on equipment design or manufacturing costs or energy use requirements. The costs of the recycling options include the costs of the recycling equipment, the labor costs, and the offsetting value of the recovered ODC. In many cases a range of costs is shown, reflecting ranges of estimates that have been prepared. In cases where the control option may be profitable, costs are listed as "savings." In some cases cost information is not available (NA).

- Economic Impact: The impact of the control option on the end use is listed as a qualitative assessment. A high (low) impact is expected if: (1) the cost of the control is large (small) relative to the final product price; and (2) the demand for the product is sensitive (insensitive) to product price. In most refrigeration and air conditioning uses, the incremental costs of the control options are small relative to the manufacturing and operating costs of the systems.

- Likely Market Penetration: This column provides a brief summary of the likely manner in which the control option will penetrate the market. For example, Recovery and Recycling is required for MACs, and HFC-134a is the preferred alternative for new MACs. Alternatively, within the Solvent end use Other Chlorinated Solvents are not expected to be implemented significantly due to toxicity concerns.

As shown in Exhibit 58, there are a number of low-cost control options which are expected to have low economic impacts. However, in some cases the market penetration of even low-cost options may be limited by various factors, such as building code requirements or safety concerns. These constraints are particularly important for ammonia and hydrocarbon refrigeration and air conditioning systems, which would otherwise be low-cost alternatives for reducing ODC use and emissions.

To provide a summary of the maximum emissions reduction potential of each of the controls, Exhibit 59 and 60 present the estimated emissions reduction for each control option in terms of ODP and GWP-weighted emissions. Using the 1990 California emissions inventory as the starting point, the maximum emissions reduction that could be achieved by each control individually was estimated by computing the ODP and GWP-weighted emissions that would have occurred with and without the control (assuming the control had been able to penetrate the market fully). The estimates are based on 100 percent use of the control where technically feasible, without regard to cost or other safety or environmental limitations.

As shown in Exhibit 59, using non-ODC alternative solvents is the single largest emissions reduction option in terms of ODC-weighted emissions. These alternatives include alcohols and alcohol blends, semi-aqueous cleaning solutions, aqueous cleaning solutions, and other chlorinated solvents. Solvent recovery systems would also reduce emissions substantially, but not by 100 percent. Using HFC-134a in all MACs would eliminate the ODP-weighted emissions from this source. Using the ternary blend would reduce emissions by nearly as much because the ODPs for the components of the blend are very low.

Similar results are presented for the GWP-weighted emissions in Exhibit 60. Both of these exhibits show the importance of the control options for the uses with large emissions. Barriers that prevent the use of these controls increase difficulty of eliminating ODC use and emissions. The key controls, and gaps in the available controls are summarized in Exhibit 61.

Within the refrigeration and air conditioning end uses, HFC-134a and HCFC-123 are expected to be important chemical substitutes used in newly-manufactured systems. The principal potential gap in these end uses is the need for CFC-11 and CFC-12 for servicing existing systems. This is not a potential gap in emissions reductions, but instead is a potential gap in the ability to service the equipment and maintain it for its expected useful life as CFC production is phased out. While, the recycling and recovery requirements being implemented under the Clean Air Act Amendments are expected to provide adequate recycled CFC-11 and CFC-12 to service existing equipment, if this market does not materialize as expected servicing costs could be higher than expected as retrofits are undertaken.

The principal emissions reduction gap is that there is no control option for reducing emissions from insulating foams that are currently in place. Although the emissions rate from these foams is particularly uncertain, estimates are that the slow leakage from these foams found in buildings and appliances is a significant source of emissions. Low-cost opportunities for reducing these emissions, e.g., during product disposal, remain to be identified.

Exhibit 57: Summary Control Option Characteristics

End Use/Control	New Equip.	Exist. Equip.	Toxic	Flammable	Other Environmental Impacts
Mobile Air Conditioning					
Recovery and Recycling	Yes	Yes	No	No	Possible waste oils
HFC-134a	Yes	RR	Testing	No	Possible waste oils (w/RR)
Ternary Blend	--	RR	Slightly	Slightly	Possible waste oils
System Modifications	Yes	No	No	No	None
Process Refrigeration					
Recovery and Recycling	Yes	Yes	No	No	Possible waste oils
Ammonia	Yes	No	Very	Very	Air Toxics
Hydrocarbons	Yes	No	No	Very	VOC Emissions
HCFC-22 and Ternary Blend	Yes	RR	Slightly	Slightly	None
Other Substitute Refrigerants					
HFC-134a	Yes	RR	Testing	No	Possible waste oils (w/RR)
HFC-125	Yes	RR	Testing	No	Possible waste oils (w/RR)
Commercial Refrigeration					
Recovery and Recycling	Yes	Yes	No	No	Possible waste oils
HFC-134a	Yes	RR	Testing	No	Possible waste oils (w/RR)
HCFC-22	Yes	RR	No	No	None
Ternary Blend	--	RR	Slightly	Slightly	None
New Blends	Yes	No	No	Yes	VOC Emissions
Ammonia or Hydrocarbons	Yes	No	Very	Very	Air Toxics
Other New Chemicals	Yes	No	Testing	Yes	None
Residential Refrigeration					
Recovery and Recycling	Yes	Yes	No	No	Possible waste oils
HFC-134a	Yes	No	Testing	No	None
Ternary Blend	--	RR	Slightly	Slightly	Possible waste oils
Other Substitute Refrigerants	Yes	No	Some	Some	Toxic/VOC Emissions
Commercial Chilling					
CFC Recovery and Recycling	Yes	Yes	No	No	Possible waste oils
HCFC-123	Yes	RR	Testing	No	Possibly Air Toxics
HFC-134a	Yes	No	Testing	No	None
Expand Range of HCFC-22	Yes	No	No	No	None
HCFC-124	Yes	No	Slightly	No	None
Ternary Blend Refrigerant	--	RR	Slightly	Slightly	Possible waste oils
Other Substitutes	Yes	No	Testing	Some	None
Solvents					
Solvent Recovery Systems	Yes	Yes	No	No	Reduces solvent disposal
HCFCs	Yes	RR	Testing	Some	None
Alcohols and Alcohol Blends	Yes	No	No	Highly	None
Other Chlorinated Solvents	Yes	Yes	Highly	No	Increased air toxics
Aqueous Cleaning	Yes	No	No	No	Wastewater effluent
Semi-Aqueous Cleaning	Yes	RR	No	Yes	VOCs and Wastewater eff.
"No-Clean" Processes	Yes	RR	No	No	None
Foam Production					
Flexible Polyurethane Foams					
Methylene Chloride	Yes	Yes	Yes	No	Increased air toxics
Water Blown Foam	Yes	Yes	No	No	None
HCFCs	Yes	Yes	Testing	Some	None
HFCs	Yes	Yes	Testing	Some	None
Rigid Polyurethane Foams					
Chemical Substitutes	Yes	Yes	Testing	Some	Lower insulating ability
Product Substitutes	Yes	No	No	No	Lower insulating ability
Extruded Polystyrene Foams					
HCFCs in EPS Sheet	Yes	Yes	No	Some	VOC Emissions
Product Substitutes for EPS Sheet	Yes	No	No	No	None
HCFCs in EPS Bdstock	Yes	Yes	No	Some	None
Product Subs for EPS Bdstock	Yes	No	No	No	None
Other Foams					
Chemical Substitutes	Yes	Yes	Testing	Some	None

RR = retrofit required to implement control option for existing equipment.

Exhibit 57: Summary Control Option Characteristics (Continued)

End Use/Control	New Equip.	Exist. Equip.	Toxic	Flammable	Other Environmental Impacts
Sterilization					
Alternative Diluent Gases	Yes	RR	No	Some	None
Pure EO	Yes	No	Yes	Highly	None
Alternative Gases and Processes	Yes	No	Yes	No	None
Miscellaneous Uses					
Adhesives					
Product Substitutes	Yes	Some	Some	No	None
Coatings and Inks					
Product Substitutes	Yes	Some	Some	Some	VOC Emissions
Aerosols					
Alt. Solvents/Propellants	Yes	RR	Some	Some	VOC Emissions
Alternative Packaging	Yes	No	No	No	None
Fire Extinguishing					
Limit Emissions from Halon Systems					
Testing Emissions	Yes	Yes	No	No	None
Servicing Emissions	Yes	Some	No	No	None
Training Emissions	Yes	Yes	No	No	None
Inadvertent Emissions	Yes	RR	No	No	Possible Lower Protection
Disposal Emissions	Yes	Yes	No	No	None
Alternative Fire Protection Methods					
Halon Replacements	Yes	RR	Some	No	Possible Lower Protection
Halon Alternatives	Yes	No	No	No	Possible Lower Protection
Alternative Practices	Yes	No	No	No	None

RR = retrofit required to implement control option for existing equipment.

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 58: Summary Control Option Costs

End Use/Control	Emit Reduction	Cost $/kg	Economic Impact	Likely Market Penetration
Mobile Air Conditioning				
Recovery and Recycling	Moderate	$7.25	Low	Required
HFC-134a	Large	$4.40-$6.10	Very Low	Preferred choice of automakers
Ternary Blend	Large	$3.00- >$100	High	Possibly used in repair of existing MACs -- Not in new MACs
System Modifications	Small	(NA)	(savings)	Being incorporated into new equipment designs
Process Refrigeration				
Recovery and Recycling	Moderate	$2.10	Low	Will be required
Ammonia	Large	(savings)	(savings) - High	Limited by building codes and safety requirements
Hydrocarbons	Large	(savings)	(savings) - High	Limited by building codes and safety requirements
HCFC-22 and Ternary Blend	Large	$4.00	Low	Likely near-term penetration -- not a long term substitute
Other Substitute Refrigerants				
HFC-134a	Large	$5.00	Low	Long term subst. when cannot use Ammonia or Hydrocarbons
HFC-125	Large	(NA)	Low	May be used in limited situations
Commercial Refrigeration				
Recovery and Recycling	Moderate	$0.00-$10.00	Low	Will be required
HFC-134a	Large	$4.00-$40.00	Low	Long term substitute -- Low cost for most applications
HCFC-22	Large	$0.00-$1.00	Low	Likely near-term penetration -- not a long term substitute
Ternary Blend	Large	$3.30-$4.00	High	Possibly used in repair of equipment -- Not in new equipment
New Blends	Large	(NA)	Unknown	Research required -- unlikely to be used
Ammonia or Hydrocarbons	Large	(savings)	(savings) - High	Unlikely to be used -- Limited by building codes
Other New Chemicals	Large	(NA)	Unknown	Research required -- may be used in the long term
Residential Refrigeration				
Recovery and Recycling	Moderate	$5.00	Moderate	Will be required
HFC-134a	Large	$75.00-$120.00	Low	Likely long term substitute
Ternary Blend	Large	$0.00- >$100	Very High	Possibly used in repair of equipment -- Not in new equipment
Other Substitute Refrigerants	Large	(NA)	Unknown	Unlikely to be used -- Limited by flammability and toxicity
Commercial Chilling				
CFC Recovery and Recycling	Moderate	(savings)	(savings)	Will be required
HCFC-123	Large	$6.00-$7.25	Low	Likely transitional substitute
HFC-134a	Moderate	$5.00-$13.00	Low	Likely long term substitute
Expand Range of HCFC-22	Moderate	(NA)	Very Low	Likely transitional strategy
HCFC-124	Moderate	(NA)	Unknown	May be used in specialty application
Ternary Blend Refrigerant	Moderate	$0.00-$4.00	High	Limited to retrofit during repair of existing systems
Other Substitutes	Large	(NA)	Unknown	In initial stages of development

NA = not available. All costs in 1990 dollars.

Exhibit 58: Summary Control Option Costs (Continued)

End Use/Control	Emit Reduction	Cost $/kg	Economic Impact	Likely Market Penetration
Solvents				
Solvent Recovery Systems	Large	(savings)	(savings)	In use widely throughout the industry
HCFCs	Large	$2.75	Low	Not likely to be used extensively
Alcohols and Alcohol Blends	Large	(NA)	(savings) - Low	Uncertain -- May have high penetration
Other Chlorinated Solvents	Large	$0.00	(NA)	Unlikely to be used due to toxicity
Aqueous Cleaning	Large	$0.00-$3.60	(savings) - Low	Currently increasing market share
Semi-Aqueous Cleaning	Large	(NA)	(savings) - Low	Currently increasing market share
"No-Clean" Processes	Moderate	(savings)	(savings)	Currently increasing market share
Foam Production				
Flexible Polyurethane Foams				
Methylene Chloride	Large	(savings)	(savings)	Currently widely used in slabstock production
Water Blown Foam	Moderate	(savings)	(savings)	Currently widely used in molded foams
HCFCs	Large	$2.75	High	Unlikely to be used due to costs, toxicity, and flammabil.
HFCs	Large	(NA)	High	Not likely to be used due to costs and flammability
Rigid Polyurethane Foams				
Chemical Substitutes	Large	$2.75	Moderate	HCFCs are transitional -- HFCs needed in the long term
Product Substitutes	Large	(NA)	Low	May be able to compete and gain market share
Extruded Polystyrene Foams				
HCFCs in EPS Sheet	Large	(savings)	Low	HCFCs banned in 1994 -- HFCs are possible in long term
Product Substitutes for EPS Sheet	Large	(NA)	Low	Substitutes will likely gain market share
HCFCs in EPS Bdstock	Large	$3.75	Moderate	HCFC are transitional -- HFCs are possible in the long term
Product Subs for EPS Bdstock	Large	(NA)	Low	Substitutes will likely gain market share
Other Foams				
Chemical Substitutes	Large	$0.00-$4.00	Moderate	HCFCs are transitional -- HFCs needed in the long term
Sterilization				
Alternative Diluent Gases	Large	$0.00-$4.00	Low	HCFC drop-in subst. under development -- CO_2 unlikely
Pure EO	Large	(NA)	High	Too costly for small users -- option for contract firms
Alternative Gases and Processes	Large	(NA)	Low-High	Main gain market share among contract sterilizers
Miscellaneous Uses				
Adhesives				
Product Substitutes	Moderate	(savings-costly)	Low	Market share will correspond to customer needs
Coatings and Inks				
Product Substitutes	Moderate	(savings-costly)	Low	Market share will correspond to customer needs
Aerosols				
Alt. Solvents/Propellants	Moderate	(savings-costly)	Low	Must meet low VOC emissions requirements in California
Alternative Packaging	Moderate	(savings-costly)	Low	Must meet low VOC emissions requirements in California

NA = not available. All costs in 1990 dollars.

Exhibit 58: Summary Control Option Costs (Continued)

End Use/Control	Emit Reduction	Cost $/kg	Economic Impact	Likely Market Penetration
Fire Extinguishing				
Limit Emissions from Halon System				
Testing Emissions	Large	(savings)	Low	Will be implemented as fire codes are updated
Servicing Emissions	Moderate	(savings)	Low	Steps are underway already to reduce these emissions
Training Emissions	Moderate	(NA)	Low	Alternate training programs are under development
Inadvertent Emissions	Large	(NA)	Low	Will be implemented as fire codes are updated
Disposal Emissions	Small	(NA)	Low	Recovery at disposal is beginning
Alternative Fire Protection Methods				
Halon Replacements	Large	(NA)	Moderate - High	Under development
Halon Alternatives	Large	(NA)	Low - High	Approaches for choosing alternatives are being developed
Alternative Practices	Small	(NA)	Moderate - High	Possible implementation uncertain

NA = not available. All costs in 1990 dollars.

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 59: Summary ODP-Weighted Emissions Reductions

End Use	Control Option	ODP-Weighted Reduction (000 kg)
Solvents	Alternative Solvents	10,441
Solvents	Solvent Recovery Systems	8,875
Solvents	HCFCs	8,353
Mobile Air Conditioning	HFC-134a	6,320
Mobile Air Conditioning	Ternary Blend	6,130
Foam Production	Product Substitutes	6,114
Foam Production	Chemical Substitutes	6,114
Mobile Air Conditioning	Recovery and Recycling	2,212
Solvents	"No-Clean" Processes	2,088
Commercial Refrigeration	Ammonia or Hydrocarbons	1,980
Commercial Refrigeration	Other New Chemicals	1,980
Commercial Refrigeration	HFC-134a	1,980
Commercial Refrigeration	Ternary Blend	1,881
Miscellaneous Uses	Alternative Packaging	1,423
Miscellaneous Uses	Alt. Solvents/Propellants	1,423
Commercial Refrigeration	HCFC-22	990
Sterilization	Pure EO	959
Sterilization	Alternative Gases and Processes	959
Foam Production	Product Subs for EPS Bdstock	921
Sterilization	Alternative Diluent Gases	911
Foam Production	HCFCs in EPS Bdstock	829
Commercial Chilling	HCFC-123	605
Commercial Refrigeration	Recovery and Recycling	495
Fire Extinguishing	Testing Emissions	460
Miscellaneous Uses	Product Substitutes	439
Foam Production	HCFCs	388
Foam Production	Methylene Chloride	388
Fire Extinguishing	Inadvertent Emissions	345
Residential Refrigeration	HFC-134a	329
Residential Refrigeration	Ternary Blend	319
Mobile Air Conditioning	System Modifications	316
Commercial Chilling	CFC Recovery and Recycling	294
Miscellaneous Uses	Product Substitutes	286
Fire Extinguishing	Servicing Emissions	230
Commercial Chilling	Expand Range of HCFC-22	168
Residential Refrigeration	Recovery and Recycling	165
Commercial Chilling	HFC-134a	143
Fire Extinguishing	Training Emissions	115
Fire Extinguishing	Disposal Emissions	115
Process Refrigeration	Hydrocarbons	114
Process Refrigeration	Ammonia	114
Process Refrigeration	HFC-125	114
Process Refrigeration	HFC-134a	114
Process Refrigeration	HCFC-22 and Ternary Blend	103
Foam Production	Water Blown Foam	97
Process Refrigeration	Recovery and Recycling	40

Estimated emissions reductions for 1990 based on the 1990 California emissions inventory, assuming 100 percent adoption of the control option where technically feasible. Each control option is evaluated individually. Consequently, these estimates are the maximum emissions reductions possible from these options.

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 60: Summary GWP-Weighted Emissions Reductions

End Use	Control Option	GWP-Weighted Reduction (000 kg)
Mobile Air Conditioning	Ternary Blend	11,945
Mobile Air Conditioning	HFC-134a	11,148
Solvents	Alternative Solvents	10,706
Solvents	Solvent Recovery Systems	9,100
Foam Production	Product Substitutes	6,587
Commercial Refrigeration	Ammonia or Hydrocarbons	5,143
Mobile Air Conditioning	Recovery and Recycling	4,645
Foam Production	Chemical Substitutes	4,611
Commercial Refrigeration	Ternary Blend	4,269
Commercial Refrigeration	HFC-134a	3,703
Commercial Refrigeration	HCFC-22	3,343
Foam Production	Product Subs for EPS Bdstock	2,154
Solvents	"No-Clean" Processes	2,141
Sterilization	Alternative Gases and Processes	2,014
Sterilization	Pure EO	2,014
Commercial Refrigeration	Other New Chemicals	1,800
Sterilization	Alternative Diluent Gases	1,611
Miscellaneous Uses	Alt. Solvents/Propellants	1,595
Miscellaneous Uses	Alternative Packaging	1,595
Foam Production	HCFCs in EPS Bdstock	1,508
Commercial Refrigeration	Recovery and Recycling	1,286
Solvents	HCFCs	1,071
Mobile Air Conditioning	System Modifications	664
Residential Refrigeration	Ternary Blend	622
Commercial Chilling	HCFC-123	605
Residential Refrigeration	HFC-134a	580
Commercial Chilling	CFC Recovery and Recycling	529
Residential Refrigeration	Recovery and Recycling	346
Commercial Chilling	HFC-134a	302
Process Refrigeration	Hydrocarbons	279
Process Refrigeration	Ammonia	279
Foam Production	Methylene Chloride	276
Process Refrigeration	HFC-134a	232
Commercial Chilling	Expand Range of HCFC-22	227
Process Refrigeration	HCFC-22 and Ternary Blend	195
Process Refrigeration	HFC-125	184
Foam Production	HCFCs	173
Miscellaneous Uses	Product Substitutes	120
Process Refrigeration	Recovery and Recycling	98
Miscellaneous Uses	Product Substitutes	78
Foam Production	Water Blown Foam	69
Fire Extinguishing	Testing Emissions	65
Fire Extinguishing	Inadvertent Emissions	49
Fire Extinguishing	Servicing Emissions	33
Fire Extinguishing	Disposal Emissions	16
Fire Extinguishing	Training Emissions	16

Estimated emissions reductions for 1990 based on the 1990 California emissions inventory, assuming 100 percent adoption of the control option where technically feasible. Each control option is evaluated individually. Consequently, these estimates are the maximum emissions reductions possible from these options. GWPs are relative to a value of 1.0 for CFC-11.

Source: ICF Consulting Associates, Incorporated estimates.

Exhibit 61: Key Control Options and Potential Gaps			
End Use	**Key Control Options**	**Potential Gaps**	**Comments**
Mobile Air Conditioning	HFC-134a in newly manufactured systems; recovery and recycling during service and disposal of all systems	Servicing of existing MACs designed for CFC-12. Retrofit options currently appear to be very costly for consumers.	A low-cost drop-in substitute for use during servicing of CFC-12-based MACs is needed. A strong market for recovered/recycled CFC-12 is needed.
Process and Commercial Refrigeration	HFC-134a in newly manufactured systems; recovery and recycling during service and disposal of all systems; possibly HCFC-22 in near term	Servicing of existing systems designed for CFC-12. Retrofit options exist, but may be costly.	Low-cost ammonia and hydro-carbon refrigerant-based systems could play a larger role if safety concerns are addressed adequately.
Residential Refrigeration	HFC-134a in newly manufactured systems; recovery and recycling during service and disposal of all systems	Servicing of existing systems designed for CFC-12. Retrofit options exist, but may be costly.	Residential refrigeration and freezer units are not serviced frequently. Consequently, the potential gap is not considered serious.
Commercial Chilling	HFC-134a and HCFC-123 in newly manufactured systems; recovery and recycling during service and disposal of all systems	Servicing of existing systems designed for CFC-11 or CFC-12. Retrofit options exist, but may be costly.	HCFC-22-based systems could also be used increasingly.
Solvents	Recovery systems; substitute solvents and solvent-cleaning processes: aqueous cleaning; semi-aqueous cleaning; "No-Clean" processes; alcohols and blends	None	Other chlorinated solvents are not expected to gain market share due to toxicity concerns.
Foam Production	Product substitutes; non-ODC blowing agents	Options for reducing emissions from insulating foams currently in place are not available	HFCs and HCFCs may not gain wide-scale acceptance in foam production due to costs and the ban on HCFCs in some packaging foams.
Sterilization	Alternative diluent gases	None	Drop-in substitutes under development. Alternative processes could gain market share
Miscellaneous Uses	Product substitutes; chemical substitutes	None	
Fire Extinguishing	Changes in practices dealing with halon-based systems	None	Over the long term, a substitute for the halons will be needed

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