CONTRACT NO. A032-131
EXECUTIVE SUMMARY
OCTOBER 1992

Study of Emissions and Control of Stratospheric Ozone-Depleting Compounds in California

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

STUDY OF EMISSIONS AND CONTROL OF STRATOSPHERIC OZONE-DEPLETING COMPOUNDS IN CALIFORNIA

EXECUTIVE SUMMARY
CONTRACT NO. AO32-131

Prepared for:

Research Division
California Air Resources Board
2020 L Street
P.O. Box 2815
Sacramento, CA 95812

Submitted by:

ICF Consulting Associates, Incorporated
10 Universal City Plaza, Suite 2400
Universal City, CA 91608

Prepared by:

Michael J. Gibbs
John Wasson
Thomas Magee
Peter Linquiti
Sudhakar Kesavan

OCTOBER 1992

DISCLAIMER

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.

ACKNOWLEDGEMENTS

This report was prepared by the staff of ICF Consulting Associates, Incorporated,* including Michael Gibbs, Tom Magee, John Wasson, Peter Linquiti, and Sudhakar Kesavan. ICF thanks the numerous industry representatives who provided insights and comments that improved the report.

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.

TABLE OF CONTENTS

LIST OF EXHIBITS

EXECUTIVE SUMMARY

OBJECTIVE

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.

To achieve the project objective, the following analyses were performed:

(1) an ODC emissions inventory for California for 1990 was prepared reflecting the latest changes in ODC use and emissions;

(2) ODC emissions for California for 2005 were projected taking in account current and expected restrictions on ODCs and their substitutes;

(3) the technical control options that can be used to reduce ODC use and emissions were summarized and evaluated; and

(4) an updated review of federal, state, and local regulations and ordinances controlling ODC use and emissions was prepared.

The methods used and the results of each of these analyses are summarized below. First, however, background on the ozone depletion issue and the major conclusions drawn from the report are presented.

BACKGROUND

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.

Concern about ozone depletion has arisen because stratospheric ozone shields the Earth's surface from ultraviolet (UV) radiation. UV radiation, including wavelengths 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."

ODCs and their Uses: For purposes of this study, 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: (1) they must be sufficiently stable so that they do not break down in the lower atmosphere; and (2) when they reach the stratosphere, the compounds must break down and release their chlorine and bromine atoms. ODCs can be divided into three main groups:

- 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. The sole source of these compounds is human activities.

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.

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 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.

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. In addition, they are electrically nonconductive, dissipate quickly, leave no residue; and pose little harm from human exposure (UNEP, 1991). As a consequence, halons are used to protect computers and other sensitive equipment from fire.

ODPs and GWPs: 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. Relative to CFC-11, estimates of ODPs for the major ODCs are given in Exhibit ES-1.

Similar to ODPs, Global Warming Potentials (GWPs) have been defined to 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, the GWPs are now routinely calculated over various time horizons, such as 20 or 100 years. GWPs vary with the time horizon selected because the trace gases have different lifetimes in the atmosphere. Relative to carbon dioxide, CFC-11 has a 100-year GWP on the order of about 3,500. Relative to CFC-11, the 100 year GWPs for the major ODCs are given in Exhibit ES-1.

One of the key factors driving the ODP and the GWP estimates for each of the ODCs is the ODC's atmospheric lifetime. The fully-halogenated CFCs have very long lifetimes, on the order of 100 years or more, which contributes to their relatively high ODP values. The HCFCs and methyl chloroform have much shorter atmospheric lifetimes, on the order of 2 to 20 years, which helps to reduce their impacts. Because the CFCs have very long atmospheric lifetimes, their impacts on stratospheric ozone will be felt for decades or longer after emissions are eliminated.

CONCLUSIONS

International Action: Through the Montreal Protocol and its subsequent amendments, production of key ODCs is being phased out. Current plans are that partially-halogenated HCFCs, which are less damaging than CFCs, will be controlled and eventually phased out over the next 30 to 40 years.

Exhibit ES-1: ODC ODPs and GWPs		
Compound	ODP (CFC-11 = 1.0)	100-Year GWP (CFC-11 = 1.0)
CFC-11	1.0	1.0
CFC-12	1.0	2.1
CFC-113	0.8	1.2
CFC-114	0.6	2.0
CFC-115	0.5	2.0
HCFC-22	0.05	0.43
Halon 1211	3.0	(Not estimated)
Halon 1301	10.0	1.7
Methyl Chloroform	0.11	0.03
Carbon Tetrachloride	1.1	0.37

U.S. Action: The U.S. has ratified the Montreal Protocol and its subsequent amendments, and through the Clean Air Act Amendments (CAAAs) of 1990 is phasing out ODC production. Additional CAAAs requirements include, *inter alia*: recovery and recycling of refrigerants from air conditioners and refrigeration systems; prohibition on the venting of refrigerant; and a ban on the use of CFCs and HCFCs in selected applications. The CAAAs authorize the Administrator of EPA to control ODC uses and substitutes for ODCs as well.

State and Local Action: States and localities have enacted ordinances and regulations to reduce ODC emissions within their jurisdictions. In most cases, these ordinances do not exceed the requirements of the CAAAs. In California, AB 859 exceeds the CAAAs requirements by phasing out the sale of ODC-based mobile air conditioners (MACs) by model year 1995.

1990 Emissions: As the result of existing and anticipated federal restrictions on ODC production and use, ODC use and emissions declined in the late 1980s in the U.S. In particular, use in foam production and in solvent cleaning declined. The 1990 emissions estimate reflects these trends, with total ozone depleting potential (ODP) weighted emissions for the U.S. estimated at about 264 million kilograms. Based on the U.S. estimates and California-specific activity levels, California ODP-weighted 1990 emissions are estimated at nearly 35 million kilograms, or about 13 percent of the U.S. total.

Key Sources: The largest sources of emissions both nationally and in California are MACs, solvent cleaning, and foams. In California, these three sources accounted for about 70 percent of ODP-weighted emissions in 1990.

Uncertainties in the Emissions Estimates: Historical total annual production and consumption of the ODCs is reasonably well known from industry data. The manner in which the ODCs have been used over time is more uncertain, and is based on estimates of the products manufactured and serviced with ODCs over the years. The largest uncertainties are in the amounts of ODCs used and emitted during the servicing of various types of refrigeration and air conditioning systems. Although there is uncertainty regarding the distribution of ODC use among system types, estimates of total annual emissions are relatively insensitive to this uncertainty because most refrigeration and air conditioning systems have similar leakage characteristics during operation and servicing.

A second major source of uncertainty is the emissions rate from insulating foams. These foams, found in buildings and appliances, slowly release their ODCs. The emissions estimates for any individual year such as 1990 are sensitive to the assumed rate of release from these foams, including the portion released during product disposal. However, because virtually all the ODCs in the foams will be released eventually, there is much less uncertainty regarding the eventual cumulative emissions from this source.

Future Emissions: Over time, ODC emissions will be limited by the ODC production phaseout. Estimating the time profile of emissions during and shortly following the phaseout is complex because the estimates must consider the inter-relationships among the various ODC uses and the costs of eliminating ODC use in each. The estimates must also consider the rate at which new chemical substitutes will become available and penetrate the market. Based on a range of assumptions about the rate of the phaseout and the availability and use of new chemical substitutes, U.S. ODP-weighted emissions in 2005 are estimated to range from about 48 to 54 million kilograms. This represents about an 80 percent reduction from 1990 levels.

Based on the national emissions estimates, California ODP-weighted emissions in 2005 are estimated to range from about 7.5 to 8.5 million kilograms. This is about 16 percent of national emissions, and represents nearly an 80 percent reduction from 1990 levels.

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.

Many of the control measures are expected to be relatively low cost, and some measures appear to be profitable given recent increases in the prices of ODCs. HCFCs are expected to play an important transitional role, enabling the use of fully-halogenated CFCs to be eliminated quickly. Simultaneously, researchers are developing product, process, and chemical substitutes to replace the HCFCs as well in the long term.

Enforcement: In addition to phasing out the production of ODCs, the federal rules being promulgated under the CAAAs cover a wide range of services and products found throughout the country. Based on discussions with EPA representatives, enforcement of the requirements is expected to be "complaint driven." Given the very large number of businesses and individuals affected by the rules (e.g., all MAC repair shops and all air conditioning and refrigeration service professionals), additional enforcement efforts may be appropriate. The enforcement area may be one in which state and local entities could make an important contribution by publicizing the requirements and checking for compliance as part of existing inspection and information collection programs. The cost and effectiveness of adding these responsibilities to existing programs should be examined.

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 be 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.

CALIFORNIA 1990 EMISSIONS INVENTORY

The 1990 emissions inventory was developed by applying emissions factors for the ODC uses to activity levels for those uses. A large volume of information exists on national ODC use and the mechanisms that lead to emissions from these uses. In addition to drawing on this information, the emissions estimates 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.

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.

3. Activity Levels. Activity levels describe the "sizes" of the applications in various ways, and 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, the production of equipment that is being added to the stock, and the retirement or disposal of equipment from the stock. 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 or proxies were developed to estimate California activity levels.

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 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 factors 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.

Exhibit ES-2 presents the 1990 emissions by major ODC application. As shown in the exhibit, solvents, foams, and MACs account for the majority of the ODP- and GWP-weighted emissions.

Exhibit ES-2: California Weighted Emissions Summary: 1990 and 2005
(Thousands of Kilograms)

Application	ODP-Weighted Emissions			GWP-Weighted Emissions		
High Chemical Substitutes Scenario						
		2005 Emissions			2005 Emissions	
	1990 Emissions	2000 Phaseout	1996 Phaseout	1990 Emissions	2000 Phaseout	1996 Phaseout
Mobile AC	6,320	882	794	13,272	3,054	2,899
Process Refrigeration	114	35	26	279	135	119
Commercial Refrig	1,980	155	155	5,143	626	626
Res. Refrig. & Freezers	329	14	14	691	34	34
Res. & Light Com'l AC	182	16	16	1,569	137	137
Commercial Chillers	840	116	77	1,512	271	223
Solvents	10,441	89	89	10,706	107	107
Foams	8,179	6,328	6,328	10,705	8,258	8,258
Sterilization	959	38	38	2,014	151	151
Miscellaneous	2,715	0	0	2,607	2	2
Fire Extinguishing	2,299	829	829	325	117	117
ODC Manufacturing	557	4	4	315	6	6
Total	34,915	8,506	8,370	49,138	12,897	12,679
Low Chemical Substitutes Scenario						
		2005 Emissions			2005 Emissions	
	1990 Emissions	2000 Phaseout	1996 Phaseout	1990 Emissions	2000 Phaseout	1996 Phaseout
Mobile AC	6,320	882	794	13,272	2,934	2,776
Process Refrigeration	114	28	19	279	70	53
Commercial Refrig	1,980	138	138	5,143	454	454
Res. Refrig. & Freezers	329	14	14	691	33	33
Res. & Light Com'l AC	182	8	8	1,569	68	68
Commercial Chillers	840	107	69	1,512	204	153
Solvents	10,441	22	22	10,706	27	27
Foams	8,179	5,658	5,658	10,705	6,286	6,286
Sterilization	959	9	9	2,014	38	38
Miscellaneous	2,715	0	0	2,607	0	0
Fire Extinguishing	2,299	829	829	325	117	117
ODC Manufacturing	557	0	0	315	1	1
Total	34,915	7,696	7,560	49,138	10,232	10,006

Estimates based on steady-state ODPs and 100-year GWPs.

Source: ICF Consulting Associates, Incorporated estimates.

CALIFORNIA 2005 EMISSIONS INVENTORY

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, 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.

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.

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 CAAAs of 1990. 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.

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;

   - 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 this approach is that it takes into account explicitly 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 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, High and Low.

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.

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 ES-2 presents the estimates of ODP- and GWP-weighted California emissions in 2005 for several scenarios. The High Chemical Substitutes Scenario assumes that HCFC and HFC substitutes are developed and used in most applications. The Low Chemical Substitutes Scenario assumes that non-HCFC and non-HFC product substitutes penetrate the market. The entire analysis was performed for two control scenarios: the phaseout by 2000 and the accelerated phaseout by 1996. By 2005, the difference in emissions from the two phaseout schedules is slight. However, during the period 1996 through 2000, the 1996 phaseout schedule reduces emissions significantly relative to the 2000 phaseout schedule.

TECHNICAL CONTROL OPTIONS

The summary of control measures was developed by reviewing available published information including U.S. EPA regulatory assessments and United Nations Environment Program (UNEP) technical manuals. Information on technical feasibility, costs, market penetration, health risks, and environmental impacts was obtained. It was found that risk and toxicity information do not exist for many of the control options. Additionally, it was found that impacts on energy consumption are expected to be small, and in general do not contribute significantly to the cost estimates.

Controls for reducing ODC use and emissions were identified for all applications. Using the available controls, the planned ODC production phaseout is technically feasible. Chemical substitutes, recycling, product substitutes, and engineering/process emissions controls were identified and evaluated. The major chemical substitutes under consideration include the following:

- 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. HCFC-141b, with an ODP of 0.08, is unacceptable as a substitute for MC because the two substances have similar ODP values. 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-22 ($CHClF_2$) is a hydrochlorofluorocarbon and is considered an ODC, although it has a low ODP of 0.05. 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.

- Ammonia is a refrigerant with excellent thermodynamic properties. However, ammonia is highly flammable and toxic, which significantly limits its use as a refrigerant where safety is a primary concern. It is being considered as a substitute for process refrigeration and some commercial refrigeration equipment.

- 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. HCFC-123 has an ozone depletion potential (ODP) of 0.02. 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.

- 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. Toxicity testing of HFC-134a is still underway.

- Dupont has developed two ternary blend refrigerants comprised of HCFC-22, HFC-152a (CH_3CHF_2), and HCFC-124 ($CHClFCF_3$) for use in air conditioning and refrigeration equipment.[1] The blends are strong candidates for retrofit applications in existing equipment, including in mobile air conditioners, domestic refrigeration equipment, and chillers.

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 due to federal requirements. In solvent applications, recycling is now commonly used for all types of solvents.

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. It is important that a market for recycled ODCs develops because "drop in" chemical substitutes for existing refrigeration and air conditioning systems are not anticipated. In the absence of such substitutes, recycled ODCs are required to maintain these existing systems for the remainder of their useful lives. If a supply of recycled ODCs does not develop, existing equipment may need to be retired earlier than expected, potentially at significant cost.

It should be noted that no control options are currently available for reducing emissions from existing insulating foams in appliances and buildings (new foams and other insulation systems can be produced without ODCs). The existing foams contain ODCs, which contribute to their insulating properties. The ODCs will leak out slowly over many years; the rate of leakage varies and is not well quantified. Eventually, nearly all the ODCs are emitted prior to or at disposal when the product is normally crushed. Options for reducing emissions during product use, or at the time of product disposal have not been identified. Emissions from these products will continue after the production of ODCs has been phased out.

FEDERAL, STATE, AND LOCAL REGULATIONS

Federal Controls: U.S. government restrictions on CFCs were first discussed in Congressional hearings in December 1974. In 1978, the U.S. 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

---

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

regulations requiring that exempted aerosol products bear a warning label identifying the product as containing CFCs, which may deplete ozone. Following the U.S. ratification of the Montreal Protocol in 1988, the U.S. implemented its obligations under the Protocol by restricting the production and import of CFCs and halons using a two-part quota system of production allowances and consumption allowances.

Current federal efforts to control the ODCs are taking place under the framework and authority established by the 1990 CAAAs. The eight key provisions of the amendments are summarized briefly as follows:

- Phaseout of Class I Substances: The CAAAs define Class I substances as all fully-halogenated CFCs, halons, carbon tetrachloride, and methyl chloroform. Under the amendments, production of these substances, except methyl chloroform, is to be phased out by the year 2000. Methyl chloroform is not fully phased out until 2002, which is three years earlier than required by the Montreal Protocol. The EPA is accelerating the phaseout of Class I substances to January 1, 1996.

- Phaseout of Class II Substances: The initial list of Class II substances consists of 33 HCFCs identified in the CAAAs. EPA has the authority to add to the list other substances that may cause harmful effects to the ozone layer. Production of Class II substances is subject to only limited control prior to 2015 under separate sections of the CAAAs. Even though the Montreal Protocol does not yet control HCFCs, the CAAAs call for a freeze in the production of Class II substances in 2015 and a phaseout will begin that will eliminate all production by 2030.

- National Recycling and Emission Reduction Program: Under section 608 of the CAAAs, EPA must develop regulations that: (1) limit emissions of Class I (CFCs and halons) and Class II (HCFCs) chemicals during their use and disposal to the "lowest achievable emissions level" (LAEL); and (2) maximize recycling. Regulations covering Class I refrigerants used or disposed of during servicing, repair, or disposal of air conditioners and refrigeration equipment are expected to be promulgated in early 1993. Statutorily, the provisions covering these refrigerants took effect on July 1, 1992, including a ban on venting refrigerants. Regulations for Class I and Class II substances in other uses are due by November 15, 1994, and take effect by November 15, 1995.

- Motor Vehicle Air Conditioners: Section 609 of the CAAAs establishes a basic requirement that the servicing of mobile air conditioners (MACs) be performed by a trained technician using approved refrigerant recycling equipment. To implement this basic requirement, the CAAAs also specify procedures for approving refrigerant recycling equipment and defines the training and certification required of service technicians. Finally, the CAAAs restrict the sale of small containers of refrigerant. EPA is implementing the statutory requirements.

- Nonessential Products: Section 610 of the CAAAs directs EPA to ban the distribution or sale of certain "nonessential" products that release Class I or Class

II substances during manufacture, use, or disposal of the product. Congress defined several products as nonessential and established guidelines for EPA to identify additional products that are nonessential. EPA plans to promulgate regulations banning emissions of Class I substances from nonessential products to become effective November 15, 1992. Similar regulations for emissions of Class II products are planned to become effective January 1, 1994.

- Labeling: Section 611 of the CAAAs directs EPA to develop and implement a labeling program for products containing or manufactured with Class I or II substances. EPA promulgated regulations on May 4, 1992 to become effective by May 15, 1993.

- Safe Alternatives Policy: EPA has initiated a program under Section 612 of the CAAAs to evaluate substitute products and manufacturing processes that do not use ODCs. The purpose of the program is to develop an overall strategy for moving from the use of ODCs to other, safer, products. EPA can prohibit or restrict the use of substitutes that it finds cause adverse effects on human health or the environment.

- Coordination with State Laws: Section 614(e) of the 1990 CAAAs imposes a two-year moratorium on state or local government activities to enforce any requirement related to the design of any new or recalled appliance for purposes of protecting the stratospheric ozone layer. "Appliance" in this case refers to any refrigeration or air conditioning equipment that contains Class I or Class II substances. The moratorium is intended to prevent states and localities from adopting inconsistent design requirements relating, for example, to the specification of purge devices or service apertures.

State and Local Action: States and localities have enacted ordinances and regulations to reduce ODC emissions within their jurisdictions. A total of 34 states and localities outside California have considered or enacted policies to control ODC use and emissions. Of these, 10 restrict the use of ODC-based building insulating foams beyond current federal requirements. Additionally, three states will restrict ODC-based automobile air conditioners in specific model years. Finally, several localities ban the sales of small cans of MAC refrigerant, which exceeds the CAAAs restrictions on such sales.

In California in 1990, five bills were introduced affecting the use and emissions of ODCs. A.B. 3994 (Scher), the only one of the five bills enacted, restricts the use of "ozone friendly" labels to products whose production or use does not accelerate stratospheric ozone depletion. The bill defined the conditions needed to be considered "ozone friendly" as meaning "any chemical or material released into the environment as a result of the use or production of a product, will not migrate to the stratosphere and cause unnatural and accelerated deterioration of ozone."

In 1991, two bills pertaining to ODCs were introduced:

- AB 691 (Hayden). This bill requires businesses with more than two service bays or three employees that service or install mobile air conditioners (MACs) to acquire Underwriter Laboratory (UL) or Society of American Engineers (SAE) certified refrigerant recycling equipment by January 1, 1993. All businesses must comply by January 1, 1994. The Bureau of Automotive Repair would have responsibility for drafting and enforcing regulations. Operators must receive Automotive Service Excellence (ASE), Mobile Air Conditioning Society (MACS) or equivalent training. Violations are punishable by fines of $50, not to exceed $1,000 a day.

- AB 859 (Vasconcellos). This bill bans the sale of 1995 or later model-year motor vehicles using CFC-based MACs after January 1, 1995. A phase out period begins January 1, 1993 through January 1, 1994 during which not more than 90 percent of the model-year vehicles sold or certified for sale that are equipped with MACs may have CFC-based MACs. During 1994, not more than 75 percent of the new 1994 model year or later may utilize CFC-based MACs. On or after September 1, 1994, not more than 10 percent of all model year 1995 may utilize CFC-based MACs. Substances with an ozone depletion potential (ODP) of 0.1 or greater and covered under the Montreal Protocol are considered to be CFC-based products. Automotive manufacturers must also file annual and quarterly reports on their compliance. Each phase-down deadline may be extended for up to two years upon a determination by the Air Resources Board that the original deadline cannot be met.

AB 859 was enacted into law October 12, 1991.

In California, 17 districts and communities have adopted policies affecting ODC use or emissions. Based on discussions with local representatives, one factor leading to the adoption of these policies is the hope of prompting state or federal action. Many of the local restrictions have very similar provisions, including the following:

- Foam Restriction: Thirteen localities restrict the manufacture and use of one or more types of ODC-containing foam products. Packaging foams are generally restricted.

- Recycling Required: Twelve localities require some type of ODC recycling when air conditioner and refrigeration systems are serviced or disposed. Most commonly recycling is required for MAC servicing and disposal.

- Refrigerant Sales Restriction: Eleven localities have restrictions on the sale of ODC refrigerant in small containers. In most cases sales are permitted in containers of a specified size (e.g., 20 pounds or more) to certified technicians or those with recycling equipment.

- Halon Restriction: Seven localities have enacted restrictions on halon emissions. Most commonly these restrictions involve recycling and reclamation of halon during servicing. In some cases the sale of portable halon fire extinguishers is prohibited, and testing of total flooding systems is regulated.

Although many California localities have enacted restrictions on ODC use and emissions, most of these restrictions are very similar to the requirements of the CAAAs. Exhibit ES-3 shows how the restrictions enacted by the State of California and localities within the state exceed the CAAAs requirements in two ways:

- In most cases, the restrictions are essentially identical to the CAAAs requirements, except that the local restrictions have an earlier effective date. These situations are shown in Exhibit ES-3 with an "A."

- In some cases, the local provisions include restrictions that are not currently required under the CAAAs. These situations are shown in Exhibit ES-3 with a "B."

As shown in the exhibit, many of the local requirements differ from the CAAAs requirements only in terms of the expected effective dates. For example, the CAAAs require recycling during MAC servicing by January 1, 1992 for large shops and January 1, 1993 for all shops (large and small). Many of the local ordinances require recycling at all shops by January 1, 1992, thereby having an earlier effective date than the CAAAs.

The primary area in which the local restrictions exceed the CAAAs restrictions is in the case of ODC-based building insulation. Six localities have restricted the use of banned ODC-based building insulation, whereas the CAAAs do not currently require that such insulation be banned as a nonessential product. EPA has the authority to ban these products, but has not yet indicated that it will. Even if EPA does not ban these products directly, federal restrictions will eventually result in their elimination because over the long term EPA is mandating a phase-out of ODCs, so ODC-based building insulation will necessarily be replaced by non-ODC-based products.

While various state and local restrictions are now in place, the production phaseout being implemented at the federal level will ensure that ODC use and emissions are reduced. The state and local efforts, however, may help by enforcing recycling requirements and other measures that may reduce the cost of phasing out production.

REFERENCES

Molina, M.J. and F.S. Rowland (1974), "Stratospheric sink for chlorofluoro-methanes: chlorine atom catalyzed destruction of ozone," Nature, 249, 810-814.

EPA (U.S. Environmental Protection Agency) (1987), Assessing the Risks of Trace Gases that Can Modify the Stratosphere, EPA 400/1-87/001, Washington, D.C.

UNEP (United Nations Environment Program) (1991), Montreal Protocol Assessment II, Report of the Halons Technical Options Committee.

WMO (World Meteorological Organization) (1989), Scientific Assessment of Stratospheric Ozone: 1989, Global Ozone Research and Monitoring Project - Report No. 20, Geneva, Switzerland.

Exhibit ES-3: Incremental Impact of CA State and Local ODC Policies Relative to CAAAs Requirements

State or Locality	National Recycling & Emission Reduction Program		Motor Vehicle Air Conditioners			Nonessential Products				Labeling
	Refrigerant Recycling	Halon Recycling	MACs Recycling	Model Years	Small Cans	Foam	Building Insulation	Cleaning Fluids	Halon Extinguishers	
California				B						B
BAAQMD			A		B					
Berkeley	A	A	A		A	A	B		A	
Highland						A[1]				
Irvine	A	A	A		A	A	B			
Los Angeles						A				
Newport Beach										
Rancho Cucamonga						A				
Redlands						A[1]				
San Diego			A[2]			A				
San Francisco			A		A					
San Jose			A		A[3]		B			
San Ramon	A	A	A		A[4]	A	B	A		
Santa Cruz County										
Santa Monica		A	A		A	A	B	A		
Sonoma										
South Pasadena	A	A	A		A	A	B	A		
SCAQMD	A	A	A		B	A			A	

A -- Refers to earlier effective date than required in CAAAs or anticipated EPA rules.
B -- Refers to provision beyond that of CAAAs.
1 -- Compliance is voluntary.
2 -- City-owned vehicles only.
3 -- Applies to containers of 10 pounds and smaller.
4 -- Applies to containers of 15 pounds and smaller.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*
PB93-159242

2. REPORT DATE
October 1992

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Study of Emissions and Control of Stratospheric Ozone-Depleting Compounds in California, Executive Summary

5. FUNDING NUMBERS
A032-131

6. AUTHOR(S)
Michael J. Gibbs, John Wasson, Thomas Magee, Peter Linuiti, Sudhakar Resavan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ICF Consulting Associates, Incorporated
10 Universal City Plaza, Suite 2400
Universal City, CA 91608

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
California Air Resources Board
Research Division
2020 L Street
Sacramento, CA 95814

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARB/R-93/ 451

11. SUPPLEMENTARY NOTES
Technical report available through NTIS-Report No. ARB/R-93/ 452

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Release unlimited. Available from National Technical Information Service
5285 Port Royal Road, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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 & 2005 that reflect current and expected future restrictions on ODC production, use & 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.

14. SUBJECT TERMS
Stratospheric ozone-depleting compounds, chlorofluorocarbon, CFC, hydrochlorofluorocarbon, HCFC, methyl chloroform, carbon tetrachloride, halon, hydrofluorocarbon

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102