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Energy Effects of Ending the Department of Defense's Use of Chemicals That Deplete Stratospheric Ozone

Frank Camm, Beth E. Lachman

National Defense Research Institute

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Prepared for the
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(Production and Logistics)

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Preface

Like any other large organization, the Department of Defense (DoD) must weigh many goals as it makes decisions on specific investments and operations. In a large organization, one office often has responsibility for addressing a specific goal. When this occurs, trade-offs can become complicated because the office tasked to make a specific decision can view the goals differently than the organization as a whole views these goals.

This report examines the potential for such a problem for the DoD in trading off goals associated with environmental and energy concerns. It asks whether, as DoD complies with national policy on stratospheric ozone depletion, the decisionmakers responsible for compliance might neglect important energy effects of their decisions that could reduce the department's overall energy efficiency. In particular, how does DoD currently consider energy use in policy decisions that deal with ozone depletion, and how much would energy use rise in DoD if current policy persists? Do the answers to these questions call for any policy changes to improve trade-offs made between environmental and energy goals?

The report should interest policymakers and analysts concerned with stratospheric ozone policy, especially those responsible for its implementation in large organizations like DoD. The text addresses the questions above. Several appendices support the text, effectively providing a basic primer on policy to protect stratospheric ozone.

The material reported here is current as of October 1993. The Director of the Energy Policy Office in the Office of the Assistant Secretary of Defense (Production and Logistics) sponsored the work underlying this report. This work was conducted in the Acquisition and Support Policy Program of RAND's National Defense Research Institute, a federally funded research and development center supported by the Office of the Secretary of Defense and the Joint Staff.

Contents

Appendix

Figure

Tables

Summary

The Clean Air Act Amendments of 1990 require that U.S. manufacturers phase out the production of an important class of chemicals by the end of the century. In an executive order in February 1992, President Bush accelerated the phaseout to the beginning of 1996. This phaseout is expected to affect operations in the Department of Defense (DoD).

Based on recent modeling and data collection, a scientific and political consensus has formed around the idea that emissions of these man-made chemicals deplete stratospheric ozone. These "ozone depleting chemicals" or ODCs include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform. The United States is the largest user of these chemicals in the world, and DoD is the largest user of these chemicals in the United States.

DoD is subject to the regulations enacted under the Clean Air Act Amendments, just as any other organization in the country is. In some ways, its visibility is unusually high. Defense Secretary Cheney committed DoD to lead the way toward greater environmental responsibility in the federal government. With regard to these particular chemicals, DoD's actions have implications that reach far beyond its own activities. DoD standards for the use of these chemicals affect their use by defense contractors; many other private firms have adopted these standards in their own activities, even if they have no direct dealings with DoD. Furthermore, manufacturers of substitutes for ODCs see the federal government in general and DoD in particular as vehicles whereby they can use their political influence to promote the sale of substitutes. Taken together, these factors have brought considerable pressure to bear on DoD to take the initiative in seeking alternatives to ODCs and phasing out their use.

To date, the actual regulations that dictate replacement of ODCs have little direct application to DoD. They require that U.S. production and net imports of ODCs drop by a certain amount each year. Understanding this, DoD (and other users) are anticipating the elimination of future supplies and seeking alternatives. In addition, DoD must anticipate that the Environmental Protection Agency (EPA) will regulate specific uses of ODCs, further motivating DoD to seek alternatives. That said, the nature of regulation in any future year is hard to predict. It has changed repeatedly in the past as international agreements have changed and new scientific data have become available to politicians. Further changes can be

expected. Hence, although DoD knows that the constraints on using ODCs will probably tighten, it cannot know for sure how fast this will happen or how it will affect specific ODCs or uses of ODCs.

Several years ago, a number of sources suggested that phasing out the use of ODCs might significantly increase DoD's consumption of energy. But the Federal Energy Management Act of 1988 directs DoD to reduce its use of energy per gross square foot 10 percent from FY 1985 to FY 1995. Faced with the possibility that compliance with the Clean Air Act Amendments could complicate DoD's compliance with the Federal Energy Management Act, the Defense Energy Policy Office in the Office of the Secretary of Defense (OSD) asked RAND to examine how phasing out ODCs in DoD might affect DoD's energy use. In particular, OSD asked the following three questions:

1. As decisionmakers in the services seek replacements for ozone depleting chemicals, are they considering the energy effects of such replacements?
2. How will the replacement of ozone depleting chemicals in DoD affect its use of energy?
3. Given answers to the first two questions, should OSD change its policies to encourage greater consideration of the energy effects of moving away from dependence on ozone depleting chemicals?

This report addresses these questions.

Two considerations are important to answering the first question. First, what role do energy considerations play in any assessment of replacements for ODCs, in DoD or elsewhere? Second, given the specific activities DoD has under way to identify and implement replacements, what role are energy considerations playing in those activities?

In general, four kinds of factors are important to assessing replacements for ODCs: technical performance, regulatory, cost, and energy factors. Technical performance concerns the ability of a replacement to provide the same level of quality in services that the ODC did. Regulatory factors concern the health and safety of people exposed to a replacement chemical and the effects of the chemical on the environment in which DoD uses it. Cost factors concern the lifecycle cost of the total system in which an ODC replacement is used to provide a commercial/industrial service. Energy factors concern the use of energy in this total system and, for the most part, the contribution of energy use to the lifecycle cost of the total system.

It should be apparent that DoD can make useful trade-offs among these factors only in very specific circumstances. That is, DoD uses ODCs in many different ways, and specific decisions about replacements must be considered for each way that DoD uses ODCs, one at a time. Three types of activities dominate DoD's use of ODCs:

- Refrigerants in large-scale chillers (mainly CFC-11 and CFC-12)
- Solvents in cleaning services (mainly CFC-113 and methyl chloroform)
- Fire extinguishants (halons).

DoD uses ODCs in many different ways within each of these classes. But we can make some general statements about them.

Large-scale chillers tend to be energy-intensive activities. As a result, fairly small differences in energy efficiency can affect total system costs and hence choices among alternatives. This is the use of ODCs within DOD that first drew OSD's attention to a potential energy problem. However, in the wide range of studies of alternatives to current ODC-based chiller systems, energy efficiency has received only secondary or tertiary consideration. That is true in part because energy efficiency depends on the performance of actual systems that are just now being fielded; only now are reliable data flowing on the actual energy use of alternatives to ODCs. But it also reflects a general judgment that, despite the energy intensity of chiller services, technical performance and regulatory factors should dominate cost factors, and hence energy factors, in choices among potential replacements for ODCs in chillers.

Broadly speaking, solvent services are not nearly so energy-intensive as chiller services. They are also far more diverse than chiller services. Individual replacements must be developed for each application of ODCs in solvent cleaning services. In any specific application, performance and regulatory factors tend to dominate cost and hence energy factors in choices among replacements. The cost of cleaning tends to be low relative to its effect on the performance of systems that depend on cleaning. Therefore, even substantial differences in energy cost—and they can be large—have not been able to draw attention away from differences in technical performance and the acceptability of new chemicals to regulators. Hence, it is not surprising that energy use receives far less attention in the extensive literature on alternatives to ODCs in solvent services than other factors.

Energy use rarely comes up in discussions of alternatives to halons. DoD uses halons (as others do) to protect high-value equipment, used in close proximity to people, from fire damage. Halons can be applied to a fire while humans are present without harming them or leaving residue that damages the equipment. In such applications, the cost of the fire extinguishant system and any energy use associated with it are secondary to performance and regulatory considerations, especially since the energy use associated with such applications is small. Engineers are having such difficulty finding replacements that match the performance of halons in a safe way that regulators continue to exempt the phaseout of halons in key applications; engineers give low priority to the energy use of potential replacements for halons.

In sum, engineers consider the energy use of replacements for ODCs used in chiller and solvent cleaning services but give it lower priority than the technical performance and safety of these replacements. Engineers have given the energy use of replacements for halons even lower priority. As a result, we focused our attention on chiller and solvent cleaning activities in DoD.

Specific efforts to replace ODCs in DoD give little attention to energy use as they address choices about chillers or solvent services. OSD and each of the services have developed directives or regulations to implement the intent of the Clean Air Act Amendments. These documents make almost no mention of the energy use of ODC replacements. The DoD Chlorofluorocarbon Advisory Committee, established in 1989 to help DoD formulate policy on replacements for ODCs, has given energy use low priority; its recommendations have not mentioned energy use. DoD has developed a system of priorities to determine which activities should replace ODCs first. This system makes no direct reference to energy effects.

DoD is working actively with private industry and other government agencies to revise the military specifications that dictate the use of ODCs by DoD and its contractors. DoD has not specified that energy effects should play a role in this process, and discussions of the process make little direct reference to energy effects.

Finally, DoD is participating in research and development (R&D) efforts to develop new alternatives to ODCs. But DoD is relying on innovation in the private sector to develop alternatives where DoD uses services like those in the private sector. The discussion above suggests that this approach tends to give less attention to energy factors than it does to other factors. Chiller and solvent cleaning services should be affected primarily by this approach. DoD is focusing its own R&D efforts on mission-critical applications of ODCs where cost and hence energy use is far less important than technical performance.

The answer to our first question, then, is this: *Private industry typically gives energy use less attention than other factors in comparisons of replacements for ODCs. At least in part as a result, DoD has given less attention to energy use than to other factors in its efforts to replace ODCs.*

To answer the second question, we sought information on the energy use of the various systems that might replace ODCs in chiller and solvent cleaning services. Great uncertainty persists about such energy use. The available estimates rarely provide enough information to allow careful comparisons between estimates for different systems. Even where comparisons can be made, they rely on theoretical calculations and bench tests that need not be borne out by the experience of new systems in the field. Although new systems are now entering the field, it is too early to say much about their long-term performance. And even if we could make accurate statements about existing systems, we know that future systems, as beneficiaries of continuing design and development work, will be more energy efficient.

To understand something about the likely general magnitude of energy effects in DoD, we relied on data from a study recently sponsored by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and the Department of Energy (DOE). This study combined engineering judgments from all of the major players in private industry in a systematic way that allows simple comparisons of energy use by (among other things) alternative chiller and solvent cleaning systems. We must use the results of the AFEAS/DOE study with caution, but most analysts involved in efforts to replace ODCs either view these results as the most complete public information currently available or present alternative results as specific departures from the AFEAS/DOE results. That is, relying on AFEAS/DOE results allows us to participate in ongoing debates on the effects of replacing ODCs by benchmarking our study to what is, in effect, the current standard in the debates.

By manipulating the AFEAS/DOE results in a simple way and combining them with DoD data, we can extract two simple results.

First, moving from the use of CFC-11 and CFC-12 in large-scale chillers to the most likely replacements, HCFC-123 and CFC-134a, respectively, could increase or decrease energy use in these activities by a small amount—no more than 3 percent in either direction. Focusing on the undesirable side, such replacement could increase total DoD energy use by as much as 620 million kilowatt-hours (kWh) per year or about 0.6 percent.

Second, moving from CFC-113 and methyl chloroform to replacement solvents will have trivially small energy effects unless DoD chooses aqueous or semi-aqueous alternatives. Regulatory concerns could cause decisionmakers to choose aqueous or semi-aqueous systems, despite their energy effects, in many applications. If this happened in enough applications, DoD's total energy use could rise by as much as 800 million kWh a year or about 0.8 percent as a result. In all likelihood, the change would be smaller since DoD is likely to use a wide range of alternatives, not just aqueous and semi-aqueous alternatives. Even if it were not going to use a wide range, however, giving energy more attention in the choice of replacements would probably not change these choices.

The answer to our second question, then, is the following: *Replacement of ODCs in chiller and solvent cleaning services could increase DoD's energy use by a small amount. Greater emphasis on energy considerations would probably not affect this outcome much. Energy effects should not be nearly as large for other DoD uses of ODCs.*

The answers to our first two questions strongly suggest an answer to the third: *OSD need not change its policies on ODC replacement to give greater emphasis to the energy use of replacements.* If OSD still seeks policy changes, we emphasize three points:

- *Encourage patience.* Although DoD is under pressure to lead the way in replacing ODCs, information on the performance of alternatives and EPA's regulation of these alternatives will improve over time. Their energy efficiency should also improve somewhat. OSD should resist demands to commit to alternatives too quickly, especially for chillers, where the 30-year lifetime for a new chiller can lock in the effects of a decision for a long time.
- *Emphasize oversight of chillers, not solvent cleaning services.* All replacement decisions ultimately require careful assessment of the special circumstances of a particular application. General guidance from OSD is more likely to affect such decisions productively for chillers than for solvent services because the circumstances of solvent cleaning are far more diverse.
- *Emphasize revision of military specifications, not individual decisions at installations.* OSD can apply its limited oversight resources more effectively to key military specifications that can affect many individual decisions in the years to come than to the individual decisions themselves. Because the effort to revise military specifications regarding ODC use still has a long way to go, OSD has time to affect it.

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Acronyms

AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
ARI	American Refrigeration Institute
ASHRAE	Association of Space Heating, Refrigeration, and Air-Conditioning Engineers
Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
CFC	chlorofluorocarbon
DoD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
GAO	General Accounting Office
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
kW	kilowatt
kWh	kilowatt-hour
METH	methylene chloride
MILSPEC	military specification
ODC	ozone depleting chemical
ODP	ozone depletion potential
OSD	Office of the Secretary of Defense
PERC	perchloroethylene
SNAP	Significant New Alternatives Policy
TCA	1,1,1-trichloroethane, another name for methyl chloroform

TCE	trichloroethylene
UNEP	United Nations Environment Programme
VOC	volatile organic compound

1. Introduction

Two scientific papers, published in 1974, suggested that rising levels of man-made chemicals, chlorofluorocarbons, in the atmosphere could lead to a reduced level of ozone in the stratosphere (Molina and Rowland, 1974; Cicerone, Stolarski, and Walters, 1974). The ozone layer limits the penetration of ultraviolet light into the atmosphere. Many scientists believe that damage to the ozone layer could allow more ultraviolet light to reach the surface of the earth, thereby increasing the incidence of melanomas and cataracts in humans and causing other serious problems elsewhere in the biosphere.

Public concern about the integrity of the stratospheric ozone layer grew gradually through the 1970s and suddenly escalated in the late 1980s as evidence accumulated of a growing hole in the ozone layer in the far southern hemisphere, especially around Antarctica. Dramatic and increasing thinning of the ozone layer during successive Antarctic springs transformed these concerns into immediate fears, demanding a global response to stop the deterioration of the ozone layer as quickly as possible. What had once been the concern of a small, if highly vocal, cluster of scientists and policymakers in North America and Europe suddenly created a new global vision of environmental awareness. Momentum built as evidence developed for similar thinning in the northern hemisphere during the Arctic spring.

Scientists linked actual thinning of the ozone layer to a family of chemicals emitted primarily from man-made, industrial sources. The most important of these, in terms of the volume of their emissions and the damage that a pound of any of them could cause to the ozone layer, are fully halogenated hydrocarbons, including chlorofluorocarbons (CFCs) and halons, and methyl chloroform. The dominant scientific view currently says that, once they are produced, these chemicals eventually find their way to the upper atmosphere, where they react with ozone, reducing its level in the stratosphere.[1]

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[1] Although some scientists continue to doubt this hypothesis, a strong consensus has developed around it among atmospheric chemists and other specialists who continue to study ozone depletion. For the purposes of this study, the validity of the hypothesis is irrelevant; we are concerned primarily with the effects of regulations that have grown from a (widely held) belief that the hypothesis is in fact correct. Throughout the report, we refer to chemicals that, according to this hypothesis, deplete stratospheric ozone as "ozone depleting chemicals" or ODCs, because that is their status under current U.S. law relevant to our analysis.

The United States is a major producer of these chemicals. Without near elimination of U.S. production of these chemicals, no global response can be expected to eliminate this perceived threat to stratospheric ozone. Recognizing this, the United States has passed legislation designed to eliminate new production of these chemicals by the end of the century. The president has pledged to phase out production even faster, by the end of 1995.

Within the United States, the largest single user of these chemicals is the Department of Defense (DoD). That is true in part because of the sheer size of DoD and in part because many of these chemicals are especially important to defense activities. For example, halons are the fire extinguishant of choice where humans work in close proximity to high-value equipment that can be damaged by water. Such circumstances exist throughout DoD. The importance of halons to DoD is compounded by inherently dangerous activities that increase the likelihood of fires. DoD is also a major user of industrial solvents, especially the chlorofluorocarbon CFC-113 preferred for use with delicate electronic equipment.

By coincidence, as ozone depletion was becoming a highly visible global concern in 1989, Secretary of Defense Cheney committed DoD to becoming the leader within the federal government at implementing environmental laws. For a variety of reasons, federal activities have typically lagged behind the private sector in responding to environmental initiatives. Given the secretary's commitment, DoD could not realistically expect exceptional treatment as the rest of the country sought ways to reduce its dependence on these chemicals.

But DoD has many priorities in addition to its commitment to comply with environmental law. One of particular relevance to ozone depleting chemicals is DoD's commitment to improve the energy efficiency of its activities. The Federal Energy Management Act of 1988 requires federal agencies, including DoD, to reduce their facilities energy use per gross square foot by 10 percent between FY 1985 and FY 1995. Pending legislation would require the secretary of defense to establish an additional goal for DoD through FY 2000. DoD viewed these as considerable but realistic goals before it faced the prospect of drastically reducing its reliance on ODCs. Many observers feared, however, that alternatives to these chemicals would require more energy to accomplish the same tasks. Chillers and air conditioners use CFC-11 and CFC-12, for example, in part because they allow low operating costs relative to the alternatives. Moving to inherently less attractive alternatives could easily require more energy to produce the same cooling services.

That is, DoD's goals for reducing dependence on ozone depleting chemicals and reducing energy use could easily be in conflict. Given the high profile of global ozone loss, policymakers responsible for DoD's energy efficiency feared that concern over ozone depletion might overshadow that for energy efficiency. Then DoD might make decisions to cut its use of ozone depleting chemicals without giving due attention to the energy use and lifecycle cost of the options available for doing this. Decisions made now to cut dependence on ozone depleters by any means available may look much less attractive from the perspective of several years hence when the urgency associated with ozone protection eases and decisions among the options available can be judged in a less heated environment.

With that concern in mind, these policymakers asked the following questions:

- As decisionmakers in the services seek replacements for ozone depleting chemicals, are they considering the energy effects of such replacements?
- How will the replacement of ozone depleting chemicals in DoD affect its use of energy?
- Given answers to the first two questions, should OSD change its policies to encourage greater consideration of the energy effects of moving away from dependence on ozone depleting chemicals?

This report addresses these questions.[2] To do so, we gathered materials on the anticipated regulatory environment, DoD's responses to that environment, and the likely energy effects of those responses from the principal organizations working on these questions today, including the Environmental Protection Agency (EPA), the United Nations Environment Programme (UNEP), the Department of Energy (DOE), the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Oak Ridge National Laboratory, the Electric Power Research Institute, and a number of offices in the Office of the Secretary of Defense (OSD) and the military services. We also surveyed the relevant trade literature to determine current industrial perspectives on these issues. We updated this material through direct discussions with officials at these organizations.

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[2] Many of the chemicals we examine have also been implicated as potential contributors to global warming. Because serious scientific controversy about this issue continues, a consensus strong enough to support regulation based on global warming has not developed. Such regulation could easily occur in the future. Since our study examines the energy implications of existing U.S. regulations, we do not give global warming nearly as much attention as ozone depletion. We attempt to raise specific concerns about potential global warming only when they help us answer one of the questions above.

Given the results of our initial survey of information, we determined that primary data collection was unlikely to yield additional information worth the cost of its collection. We expected that energy effects in DoD would be so small that we could use existing data to bound those effects to demonstrate that the need for new policy development in OSD was limited. To do that, we developed a simple set of accounts that could accommodate new data expected from the AFEAS. As soon as those data became publicly available, we used them to make the calculations presented here. The energy effects that we estimated using these data were somewhat larger than we expected, but still small enough to justify a recommendation not to develop new policies.

Very briefly, we find that the considerable efforts underway in the services to reduce dependence on ozone depleting substances give little attention to the energy effects of such reductions. We cannot say why that is with any certainty, but it is consistent with a general belief that (a) energy effects are not a major driver in most decisions to replace ozone depleting chemicals relevant to DoD and (b) the energy effects of such replacement in DoD are likely to be small. In particular, large-scale chillers and solvent services appear to be the places where energy effects are most likely to be important in DoD. Great uncertainty persists about how energy efficiency might change in these services as DoD moves to alternatives, but the best data currently publicly available suggest that DoD's energy efficiency is unlikely to change much. Hence, the conflict expected between DoD's goals of protecting the ozone layer and reducing energy use does not appear nearly as serious as many initially thought.

To the extent that a conflict exists, it is probably best addressed in the revision of military standards that specify how chiller and solvent cleaning services should be provided. These standards are relevant not only to practice within DoD, where the conflict addressed here is of greatest concern, but to practice in private firms that provide contract services to DoD as well.

The next three sections provide the background that we will need to address the questions above. Section 2 reviews the major chemicals believed to deplete stratospheric ozone and their uses. It identifies the uses of greatest relevance to DoD as large-scale chiller and solvent services. Section 3 briefly reviews the regulations relevant to DoD's use of these chemicals. Section 4 reviews the concerns that users must address as they seek alternatives to these chemicals.

The remaining three sections address each question in turn. Section 5 examines what DoD is doing to reduce its use of these chemicals and how it considers energy effects in the process. Section 6 reviews the available evidence on the energy effects of replacing the major ozone depleting chemicals used in DoD.

Section 7 concludes the report with recommendations for OSD policy on energy effects associated with eliminating DoD's use of these chemicals. A number of appendices provide details on topics addressed in the text.

2. Chemicals That Deplete Stratospheric Ozone

Many chemicals have the potential to deplete stratospheric ozone. Based on their emission levels and their potency per pound, scientists have identified a short list of chemicals that pose the gravest threat to the ozone layer. This section reviews these chemicals briefly, indicating their total levels of production in the world and of use in DoD. It also looks briefly at their principal uses in DoD.

This quick review indicates that the United States is the largest user of these chemicals in the world and DoD is the largest user of these chemicals in the United States. DoD and other users employ ODCs in many diverse applications, and substitutes must be developed one application at a time. That means that (a) efforts to develop substitutes must proceed on many diverse paths at once, (b) the resulting diversity frustrates efforts to analyze substitution alternatives and the factors that affect them, and (c) this diversity makes regulation of the substitution, by DoD or any other government agency, even more difficult.

Levels of Production and Use

Table 2.1 lists the key chemicals in question, showing their global and U.S. production levels and their use levels in DoD in several recent years.[1] Where a chemical is emitted is irrelevant. Hence, global emissions currently drive efforts to reduce ozone depletion. Note the high levels of U.S. production relative to global production. DoD use looks small relative to U.S. production, but it still constitutes the highest level of use by any single organization in the United States.

Note that the DoD use levels shown apply only to DoD per se; if use of defense contractors were included, the DoD use level would rise. For our purposes, however, only direct use by DoD itself is relevant.[2]

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[1] Comparable data are not readily available for a single year. Because levels of production and use have changed dramatically in the last few years, we should be cautious in comparing numbers from different years. Numbers in the table provide rough indications of the relative magnitudes for these chemicals. For greater detail, including chemical definitions, see Appendix A.

[2] That is because only energy use by activities within DoD is relevant to the constraint that motivated this study.

Table 2.1

Production and Use Levels for Major Ozone Depleters (in thousands of metric tonnes)

ODCs	World Production					U.S. Production	DoD Use
	1974	1980	1986	1989	1990	1985	1989
CFC-11	369.7	289.6	350.1	302.5	232.9	75.0	1.6[a]
CFC-12	442.8	350.2	398.4	379.8	231.0	135.0	(a)
CFC-113		103.7	196.6	251.3	174.8	73.2	2.6
CFC-114		15.0	19.0	15.0	8.0		(a)
CFC-115		9.3	11.8	14.2	10.0		(a)
HCFC-22	83.4	126.3	165.0	219.5	213.7		
Carbon tetrachloride			1029.0[b]			280.0	
Methyl chloroform			554.6[b]			270.0	
Halon 1211			10.8[b]			5.4	0.6
Halon 1301			10.8[b]			2.7	0.6

SOURCES: Chemical Manufacturers Association, 1991a (global CFC-11 and CFC-12), 1991b (other global CFCs), 1991c (HCFC-22); DoD CFC Advisory Committee, 1991 (DoD CFCs and halons); Hammitt et al., 1986 (U.S. levels and global non-CFC levels).

[a] All chemicals noted are combined on the row for CFC-11.

[b] Estimates for 1985 from Hammitt et al.

Production and use levels alone are not sufficient to define the threats posed by these various chemicals. Their potency per pound is also important. Roughly speaking, the CFCs and carbon tetrachloride are all about equally dangerous. HCFC-22 and methyl chloroform are about an order of magnitude less dangerous, per pound, than the CFCs. The halons are about an order of magnitude more dangerous, per pound, than the CFCs.[3]

When we weight DoD's use of chemicals by their relative ability to deplete ozone, we find that, among the chemicals for which DoD use is shown, halons account for about two-thirds of the total threat that DoD poses to stratospheric ozone. CFC-113 accounts for about 22 percent of the threat, while other CFCs, primarily CFC-11 and CFC-12, account for the remainder. Methyl chloroform could also have a significant effect if data were available to include it in this calculation.[4] These chemicals deserve special emphasis below.

How These Chemicals Are Used

A Brief Overview

The first chlorofluorocarbons were developed as refrigerants in the 1930s (Nagengast, 1988). Their relative simplicity and stability made them safe, cost-effective chemicals that found an increasingly broad range of applications as time passed. Their desirability grew as environmental and industrial health and safety laws tightened over time. They were not flammable, not acutely toxic, caused no apparent problems as carcinogens or mutagens, and did not exacerbate urban air quality problems.

By the mid-1970s, when concern about their effects on stratospheric ozone began, CFCs were used worldwide as foam-blowing agents, aerosol propellants, solvents, and in many other roles in addition to refrigeration. Halons had similar desirable properties and also began to be used extensively in fire suppression and safety systems. Methyl chloroform was broadly used as a solvent and in many other applications.

These ozone depleting chemicals are still used in many of these applications, often because opportunities for substitutes have been limited. As time has passed, each of these chemicals has been more and more carefully matched to

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[3] For more detail, see Appendix A.

[4] For example, if DoD used the solvents methyl chloroform and CFC-113 in proportions similar to those used worldwide, all of these fractions would fall by seven percent and methyl chloroform would account for 7 percent of the total; in all likelihood, this is an upper bound for the relevance of methyl chloroform, but it is high enough so that we should take it seriously.

specific applications. As a result, finding alternatives for these chemicals in each of these applications has proven to be challenging. No single chemical can replace any of these chemicals in all of its uses; substitutes must be sought one application at a time. That is why it is so important to appreciate the range of applications in which these chemicals are used. The implications for energy use associated with substitutes are likely to differ in each application. But this document is not the right place to describe applications in fine detail; we offer instead broad descriptions to define the general territory relevant to trade-offs between ozone-depletion and energy consumption in DoD.[5]

Summary of DoD Uses

As noted above, DoD is the single largest user of stratospheric ozone depleting chemicals within the United States. Table 2.2 proves a quick summary of DoD's use of CFCs in 1989, the most recent year for which data are available. Solvents, used during the maintenance of systems and components, are the most important CFC use. CFC-113 and methyl chloroform are the primary ODCs used as solvents. Refrigerants in large air conditioning units, primarily centrifugal chillers used to cool large buildings, are the next largest use, followed by refrigerant applications in mobile air conditioning for vehicles and weapon systems and in household refrigerators. CFC-11 and CFC-12 are the primary ODCs used as refrigerants. CFC-114 plays a specialized but small role in marine refrigeration. Many additional applications account for the remaining small share of use; sterilization of medical supplies and equipment using CFC-12 is the

Table 2.2

Chlorofluorocarbon Applications in DoD, 1989

	End Use	
Application	Metric tonnes	Percentage
Solvents	2621	61.6
Large refrigeration	1379	32.4
Mobile air conditioners	166	3.9
Household refrigerators	26	0.6
Sterilization	13	0.3
Other	51	1.2
Total	4255	100.0

SOURCE: DoD CFC Advisory Committee, 1991, p. 17.

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[5] Appendix A provides a brief overview of uses. For more detail, see Camm et al., 1986; Hammitt et al., 1986; Mooz et al., 1982; Palmer et al., 1980; Pekelney, 1991; and United Nations Environmental Programme, 1991a, 1991b, and 1991c.

most important of these. DoD also used 1212 metric tonnes of halon as fire extinguishants (DoD CFC Advisory Committee, 1991, p. 18).

Implications for Energy Use in DoD

Table 2.2 and the accompanying text suggest that DoD should be concerned about energy effects associated with changes in three areas: solvents, large-scale refrigeration, and halon fire extinguishants. CFC-113 is the only solvent implicated in Table 2.2, but the importance of solvents in the table reminds us that DoD is also a major user of methyl chloroform; we must also consider energy effects of replacing DoD's use of methyl chloroform as a solvent. CFC-11 mainly, but also CFC-12, is the principal ODC associated with large-scale refrigeration. Although we cannot know their relative importance to DoD, we should establish how changes in either would affect DoD's demand for energy. Halons 1211 and 1301 are the principal fire extinguishants of interest.

A review of available information on these three application areas suggests that the first two are more significant with respect to energy than the last, at least at this time. Few suitable substitutes have been found for halon fire extinguishing systems, especially in the kinds of applications relevant to DoD. Hence, it is hard even to discuss energy effects of alternatives. Where substitutes have been found, energy effects are a minor factor in the decisions being considered. Energy effects could more plausibly affect decisions on the first two areas and that is where we will focus our attention in the remaining sections.

3. Regulation of Chemicals That Deplete Ozone

U.S. regulation of chemicals that deplete ozone has changed repeatedly since the 1970s as the scientific consensus on ozone depletion has grown. Because scientists continue to refine their models of ozone depletion and to collect data on ozone depletion itself, we can expect regulation to continue changing. Negative evidence could potentially lead to less demanding regulation. This section briefly describes current regulations in the United States and illustrates large uncertainties associated with regulation by briefly tracing the course of regulation over time and noting upcoming events likely to affect regulation.

DoD must comply with U.S. regulations and must make decisions that recognize continuing uncertainty about the rules to which it will be subject. This section explains why DoD may feel this regulation even more strongly than other U.S. organizations.

Current U.S. Regulation

Current U.S. law is based on the Clean Air Act Amendments of 1990 (CAAA), Title VI—Stratospheric Ozone Protection, which became law in November 1990. Title VI phases out the production of the key ODCs and provides authority for the EPA to issue regulations promoting this phase out.

Table 3.1 displays the schedules of phaseout dates mandated in CAAA. "Transitional substances" are chemicals that deplete ozone but that are substantially less dangerous, per pound, than current ODCs and thereby are allowed to be produced for a longer time period than more dangerous ODCs. These transitional substances are typically HCFCs.[1] Title VI allows exceptions to these phaseout dates for essential uses of ODCs for which no promising substitutes exist. Exceptions include uses of ODCs in medical devices; halons in fire suppression, aviation safety, and explosion prevention devices; and methyl chloroform in essential applications such as airplane fatigue testing.

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[1] For a definition of these chemicals, see Appendix A.

Table 3.1

Summary of the CAA ODC Restrictions

Controlled Substance		Provision
CFC-11		Reductions in production:
CFC-12		15% reduction from 1986 levels in 1991
CFC-113		20% reduction in 1992
CFC-114		25% reduction in 1993
CFC-115		35% reduction in 1994
		50% reduction in 1995
		60% reduction in 1996
		85% reduction in 1997
		Phaseout by January 1, 2000
Halons: 1211, 1301, 2402		Same as for CFC-11, 12, 113, 114 and 115.
CFC-13	CFC-213	Reductions in production:
CFC-111	CFC-214	15% reduction from 1989 levels in 1991
CFC-112	CFC-215	20% reduction in 1992
CFC-211	CFC-216	25% reduction in 1993
CFC-212	CFC-217	35% reduction in 1994
		50% reduction in 1995
		60% reduction in 1996
		85% reduction in 1997
		Phaseout by January 1, 2000
Carbon tetrachloride		Freeze production at 1989 levels in 1991
		10% reduction in 1992
		20% reduction in 1993
		30% reduction in 1994
		85% reduction in 1995
		Phaseout by January 1, 2000
Methyl chloroform (1,1,1-trichloroethane)		Freeze production at 1989 levels in 1991
		10% reduction in 1993
		15% reduction in 1994
		30% reduction in 1995
		50% reduction in 1996
		80% reduction in 2000
		Phaseout by January 1, 2002
Transitional substances, i.e., the HCFCs		Freeze production at baseline year in 2015[a]
		Phaseout by January 1, 2030

SOURCE: Title VI.

[a] A representative calendar year has not yet been specified as the baseline year for the HCFCs (see Section 601 of Title VI of the CAA).

Title VI also specifies conditions, such as new scientific evidence of the increasing harmful effect to the ozone layer, under which the scheduled phaseouts can be accelerated. In response to evidence of accelerated ozone depletion in the northern hemisphere, President Bush used this authority in February 1992 to require that U.S. production of almost all ODCs would cease by the end of 1995.[2]

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[2] During 1991 and 1992 the scientific evidence of ozone depletion has increased. In early February 1992 a NASA-led team of scientists reported that they had measured record levels of chemicals that destroy the ozone layer over new areas outside the polar regions, specifically over

His order also lowered the 1992 allowable production for CFCs from the 80 percent amount dictated by CAAA to 50 percent. Limited exceptions will be allowed "for servicing existing equipment" (*ASHRAE Journal*, April 1992, p. 10, and Schneider, 1992).

The schedules in Table 3.1 address production and consumption where consumption means domestic production plus imports minus exports.[3] But, Title VI also calls for new regulations to affect U.S. use of ODCs. It specifies requirements for monitoring, reporting, and labeling. Title VI specifies the issuance of production and consumption allowance systems rules (CAAA, Section 607, "Exchange Authority"). It also prohibits nonessential consumer products containing chloroflurocarbons.

Title VI authorizes regulation of the servicing of equipment to maximize recycling and minimize emissions of ODCs. Section 608 states that rules establishing requirements for the use and disposal of ODCs during service, repair, or disposal of refrigeration equipment and other appliances using ODCs would be finalized by July 1992. In May 1992 EPA issued a draft rule that would establish certification programs for refrigeration and air conditioning technicians and equipment. These programs would require that technicians be properly trained to minimize ODC emissions during servicing and repair, that all recovery and recycling equipment sold minimize emissions, and that only certified technicians would be allowed to purchase ozone depleting refrigerants. This rule also requires that ozone depleting refrigerants be removed before equipment disposal (Current Reports, July 1, 1992).

Section 609 places restriction on the servicing of motor vehicle air conditioners. Since July 1, 1992 any person repairing or servicing 100 or more motor vehicles per year must use approved refrigerant recycling equipment and must be properly trained and certified to use such equipment.

CAAA specifies a Safe Alternatives Policy in which EPA must issue an initial list of prohibited substitutes and a corresponding initial list of acceptable substitutes by use sector. In January 1992 EPA issued its preliminary strategy for implementing the Safe Alternatives Policy by creating the Significant New Alternatives Policy (SNAP) program. This is EPA's program for evaluating safe alternatives. For this program EPA is analyzing risk characterization of proposed substitutes to develop the preliminary lists of prohibited and

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eastern Canada and northern New England. See *Science*, February 14, 1992, pp. 797–798. Subsequent measures did not detect serious ozone losses over heavily populated areas, but support continued for the President's decision.

[3] The definitions of production and consumption are consistent with the Montreal Protocol.

acceptable substitutes. The factors that EPA is using to evaluate these alternatives are: releases to the environment, toxicity exposure, chlorine loading, ozone depletion potential, global warming potential (GWP), flammability, and economic feasibility (Illig and Wesiman, 1992, p. 4).

Energy effects are being evaluated only to determine an alternative's GWP; alternatives that use more energy increase emissions of carbon dioxide when fossil fuels are burned to create such energy and thereby potentially contribute to global warming.

These initial lists of prohibited and acceptable substitutes were scheduled for release during the summer of 1992. The final rules implementing the SNAP program will be issued by November 15, 1992. Once SNAP is implemented, it will be unlawful to replace any of the controlled substances with any of the prohibited substitutes where an alternative has been identified. After that time, any new chemicals proposed as substitutes will be evaluated by EPA under the SNAP program.

Title VI also addresses federal procurements of ODCs. EPA, in consultation with the Secretary of Defense and the General Services Administration, will issue rules about federal procurement regulations conforming to the policies and requirements of this title to maximize the substitution of safe alternatives as specified by EPA's Safe Alternatives Policy. These rules should be finalized by the fall of 1992. DoD, and other federal agencies of the United States, must conform to these regulations by the spring of 1993.

The Dynamic Environment of Regulation

U.S. regulation of ODCs has changed markedly over time. Regulation began in 1978. In response to early scientific concern about a link between CFCs and potential ozone depletion, the United States unilaterally banned most uses of CFCs as aerosol propellants. Because substitutes were readily available for most banned uses, the regulation caused little controversy. Similar regulations were passed in a number of other industrial democracies.

Since then, the global nature of stratospheric ozone and the widespread sources of emissions linked to it have increasingly demanded a multilateral approach. By the late 1980s, the United States was working as part of an international effort to reduce dependence on ODCs embodied in the Montreal Protocol of 1987.[4] The

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[4] Appendix B provides additional detail on the Montreal Protocol.

Protocol took force in 1989. As a signatory, the United States agreed to cut its "consumption and production" of CFCs to 50 percent of their 1986 levels by 1998 and to freeze "consumption and production" of halons at their 1986 levels by 1992.[5]

Increasing evidence of stratospheric ozone depletion and of links between CFCs and ozone depletion led to a revision of the Montreal Protocol in 1990, called the London Amendments of 1990. These amendments expanded the number of substances controlled and called for complete elimination of production, with selected exemptions, of these substances by 2000. As a signatory to this revision, the United States became subject to these new restrictions. CAAA built on these restrictions and carried them even farther. And President Bush's executive order from February 1992 goes farther still.

Because of increasing evidence of the environmental degradation to the stratosphere and increasing availability of ODC substitutes, as well as national and international politics, the process of tightening regulations on the use of ODCs in the United States is likely to continue. In November 1992, delegates will meet again to revise the Montreal Protocol and the subsequent London Amendments. New international restrictions will likely be negotiated at this meeting, especially since many countries have already issued regulations to accelerate the phasing out of ODCs within their own countries.[6] Tighter restriction will probably be imposed on selected HCFCs, since some HCFCs are more harmful to the ozone layer than others; a variety of alternatives have been found feasible, and members of industry are proposing an accelerated phaseout. For example, the International Council of Air-Conditioning and Refrigeration Manufacturers' Association recommended in April 1992 that HCFC-22, HCFC-141b, and HCFC-142b be banned for use in new equipment in 2010 and banned in all equipment by 2020 (*ASHRAE Journal*, April 1992, p. 6).

How U.S. Regulation Affects DoD

DoD is subject to the CAAA and the president's executive order in the same way that other organizations are. It benefits from the exceptions, noted above, for

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[5] Within this agreement as within the CAAA, "consumption" refers to domestic production plus net imports. "Production" refers to the amount of new production less destruction of existing stocks in approved ways. Actual use was not directly controlled.

[6] Austria, Finland, Germany, The Netherlands, Norway, Sweden, and Switzerland already have some regulations that are more stringent than the U.S. restrictions imposed by CAAA and President Bush's executive order. For example, The Netherlands and Norway will phase out halons by January 1995. For the details on other countries' regulations that are more stringent than U.S. regulations see UNEP, 1991a.

halons in fire suppression and methyl chloroform in fatigue testing. More generally, Title VI allows the president to issue exemptions of up to one year's length from time of issuance to allow the production and use of CFC-114 or halons 1211, 1301, and 2402, if the president finds that adequate substitutes are not available and that the production and use of these chemicals are necessary to protect the national security (CAAA, Section 604, paragraph (f) of Title VI). But DoD does not benefit from broad protection from the regulation.

In fact, for a variety of reasons, DoD experiences special pressure to comply. In 1989, Secretary of Defense Cheney committed DoD to become a leader within the federal government in implementing environmental laws. The chemical industry is using its influence to promote compliance to help create a new market for the substitutes that it has developed for ODCs.[7] GAO has criticized the rate at which DoD is seeking and finding alternatives to ODCs (U.S. Congress, 1991). Critics note that DoD's influence extends well beyond the department itself. DoD policy affects ODC use by defense contractors. And military specifications maintained by DoD are widely used to govern the use of ODCs, especially CFC-113, in private firms that do not deal directly with DoD. As a result, DoD can expect to remain under close scrutiny as it determines how to reduce its use of ODCs. The regulation of ODCs should be at least as important to DoD as it is to other organizations in the United States.

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[7] For example, DuPont is criticizing the government for "not taking the lead in converting air conditioners in its vehicles and its chillers to non-CFC refrigerants." As a major user of mobile air conditioning and chillers, DoD is a major target of that criticism. (*Chemical Marketing Reporter*, 1992, p. 3.)

4. Developing and Using Alternatives to Chemicals That Deplete Ozone

As government efforts have begun to reduce U.S. dependence on ODCs, efforts to find alternatives have increased. Since there are so many uses of such chemicals in the United States, there are many different applications where alternatives must be found. Technical, regulatory, cost, and energy factors affect this process of developing and choosing alternatives. This section discusses the issues that arise in developing and using alternatives to ODCs. It discusses the key factors relevant to choosing alternatives, summarizes the generic kinds of alternatives available, and examines the role that energy use can play in making choices among such alternatives.[1]

In the areas most important to DoD, large-scale chillers and solvent cleaning services, factors other than energy are likely to dominate decisions among alternatives. Even where differences in energy use between alternatives are substantial, other factors can easily be important enough to override concerns about such differences.

Factors in Developing and Using Alternatives to ODCs

There is often no easy solution when choosing alternatives to ODCs. Four major kinds of trade-off factors need to be addressed in this decisionmaking process: technical, regulatory, energy, and cost concerns. Obviously, there is overlap among these different areas, and they could be organized differently. We will briefly discuss the main types of issues for each of these areas and then discuss how they can affect the options that DoD decisionmakers face when choosing alternatives for sample cooling and solvent applications.

Technical

From a *technical* standpoint, when seeking an alternative that dramatically reduces ozone depletion, the first priority is to choose an alternative that can

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[1] This document is not a catalog of the alternatives. For more details about the trade-off issues and potential alternatives see UNEP, 1991a, 1991b, and 1991c, and other references cited throughout this section.

effectively do the same job that the ODC does. For example, a solvent should remove the same contaminants that the ODC does without damaging any materials in the item being cleaned that the ODC does not damage. Ideally, one would like to use an alternative chemical that has physical and chemical properties identical to those of the ODC it is replacing, allowing its use in the same equipment with the same procedures. Such a chemical would be a drop-in substitute. Unfortunately, such chemicals rarely exist, because chemicals with the stability that has made ODCs so attractive in many applications would also threaten the ozone layer. Even if nonthreatening drop-ins of this kind existed, they would probably already have been in use.

The more realistic hope is to seek an alternative that performs almost as well as the original after adjustments are made in procedures, equipment used, or even the product served by the ODC. For example, one way to replace an ODC solvent is to redesign the product being cleaned so that the same standard of cleaning is no longer necessary. We speak more about specific alternatives below. The nature of such changes is likely to differ in each specific application where an ODC is used. Engineers are finding that technical requirements often differ in very specific ways in different applications. This phenomenon has induced a tedious development effort to find the best substitutes possible in each application. That effort is well underway and will continue for the foreseeable future. As long as it continues, the technical performance available from alternatives to ODCs will remain uncertain.

Regulatory

Regulatory issues can be classified into three main types: safety, health, and environmental concerns. Safety concerns include the acute toxicity and fire hazard associated with the substitute. For example, ammonia has a long history as a cost-effective refrigerant; however, because it is very flammable and toxic, using it as a refrigerant requires significant safety precautions, and it may not even be a feasible option in many densely populated areas because of fire regulations. Health concerns include the carcinogenic, mutagenic, and teratogenic risks of using substitutes. For example, trichloroethylene (TCE) and perchloroethylene (PERC) are two chlorinated solvents that often can be used in the place of ODC solvents; however, they are toxic and suspected carcinogens. Using them requires meeting strict regulations imposed by Occupational Safety and Health Administration (OSHA) and EPA. Environmental concerns include contributions to photochemical smog, wastewater treatment requirements, and the GWP of using a substitute chemical. For example, another chlorinated solvent that is an effective solvent alternative is methylene chloride (METH), but because METH contributes to photochemical smog, it is regulated by federal, state, and local air pollution regulations.

Energy

The potential *energy* efficiency penalties or savings associated with each ODC alternative should also be evaluated before choosing an alternative. There has been an immense body of studies focusing on technical concerns, environmental concerns, and how to evaluate alternatives, but energy has not been a primary focus in such studies. Often energy concerns have been ignored, briefly addressed, or addressed indirectly as an environmental issue when evaluating alternatives to ODCs. Actual energy effects are hard to estimate because we have little technical experience with alternatives to ODCs. Most estimates of their operating characteristics are based on theoretical calculations, bench tests, and technical opinion. Further, as design and engineering work on new systems continue, we can expect the energy efficiency of systems available for use at a given cost to rise. These characteristics of energy estimates have led to technical uncertainty about energy estimates. They have also led to estimates of eventual improvement in energy efficiency instead of energy penalties for some ODC alternatives.

Cost

The fourth area of concern is *cost*, by which we mean total lifecycle cost. Such costs include initial equipment and installation costs and operating and maintenance costs over a system's lifetime, suitably discounted. Because such costs clearly depend on the profile of a system's use over its lifetime, users must make assumptions about that profile as they compare alternatives.

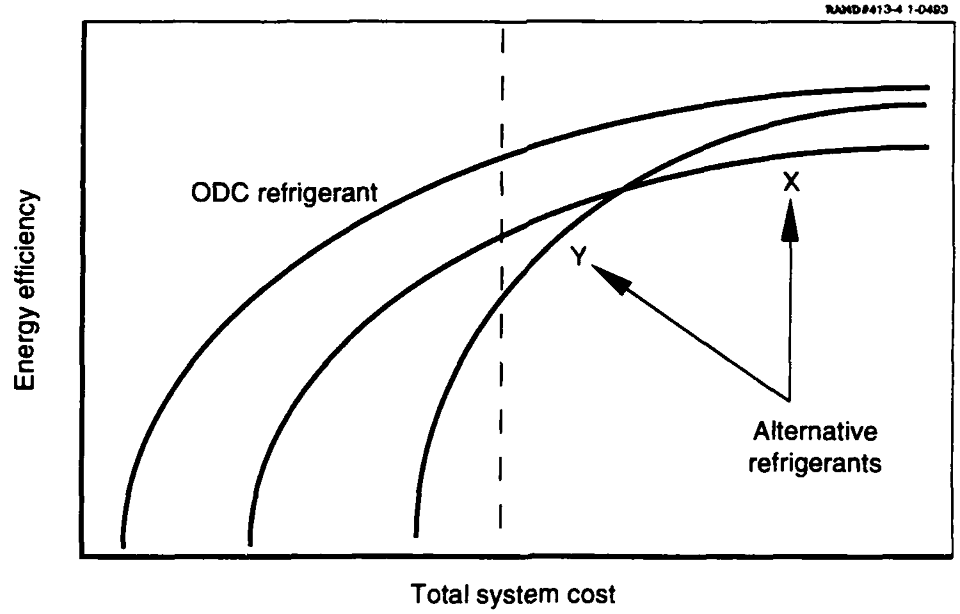
By spending more money on the equipment used in a system or on the maintenance and operation of this equipment, engineers can typically enhance the technical performance of the system, reduce its negative safety, health, and environmental effects, or reduce its energy consumption. Figure 4.1 illustrates this point with regard to energy efficiency. It shows that more expensive systems using an ODC refrigerant can be more energy efficient. And it shows that the same holds for two alternative refrigerants, labeled X and Y.

This relationship between cost and energy efficiency raises two points. First, for any refrigerant, a user must determine how much energy efficiency is enough—that is, what level of energy efficiency is cost effective. That level can change over time as the price or availability of energy changes over time. Second, comparing the energy efficiency of systems that use different refrigerants can be complicated. For example, at low system costs, the refrigerant X is more energy efficient than refrigerant Y in Figure 4.1. The relationship reverses at higher cost levels. The simplest way to make comparisons is to hold cost constant, as indicated by the dotted line, and compare the energy efficiency of alternatives at that fixed system cost. Given our focus, this relationship between cost and energy efficiency is especially important. But similar arguments could be made about how cost affects all other aspects of system performance as well.

Five Kinds of Options When Choosing ODC Alternatives

Given current technology, regulations, energy, and cost, five main types of options exist when trying to choose an ODC alternative:

1. Continue to use an ODC, recycling the chemical and minimizing emissions as much as possible, until more suitable alternatives are developed. Then replace the ODC with one of the four options below at some time in the future.



SOURCE: Based on Calm, 1991, p. F-2.

Figure 4.1—Relationship Between Cost and Energy Efficiency for Three Hypothetical Refrigeration Systems

2. Use a transitional substitute in the same or new equipment as a near-term solution or some other short-term alternative. Replace this transitional alternative with one of the three options below at some time in the future.
3. Use a permanent chemical substitute with the same equipment and process.
4. Use a permanent chemical substitute that requires different equipment but uses the same basic process.
5. Use an alternative that eliminates the need for such a chemical by changing the process or system.

Not all of these options will exist for each application area, and more than one alternative, and sometimes many, may exist within one of these five categories of options. We will discuss some of the technical issues and other trade-off factors involved in choosing between these different options. Obviously, the health, safety, environmental, energy, and cost factors are also part of this decisionmaking process until an alternative with suitable technical characteristics can be found. Pointing out all of the details on these trade-off factors is outside the scope of this document. We will provide only examples of such concerns and focus on areas with energy implications.

Recycle and Recover ODC as Interim Solution

This option is desirable when there is great uncertainty about suitable substitutes. Given EPA's SNAP program, which is in the process of designating acceptable and prohibited substitutes in a final rule to be issued by November 1992, some institutions may decide to wait for the final EPA rule before choosing an alternative to be sure they don't switch to a prohibited option. Also, decisionmakers may decide to wait because of the current uncertainty about alternatives and the fact that new information about options is becoming available over time. However, while they wait they must implement recycling and recovery techniques as outlined by EPA regulations (see discussion in Section III of CAAA).

DoD's current policy is indirectly causing some service agencies to choose this option since it emphasizes emission reduction without providing clear implementation directions on substitutes. Also, since it will take time to revise the military specifications (MILSPECs), technical manuals, and training procedures for military applications of ODCs, decisions on which alternatives to use may not occur in DoD until such procedural changes have been made.

Use Transitional Substance as Interim Solution

Timing is an important part of choosing to use a transitional substance in the near term in existing equipment or even new equipment, or some other short-term alternative, and then replacing it with a longer-term alternative at some time in the future. This option is attractive for cases where only transitional substitutes are currently available at near the same cost and efficiency, and especially attractive where there is a high cost of capital investment and long life of the equipment and transitional substances are available as near drop-in substitutes in current equipment. For example, in suitable cooling equipment, a DoD installation official could decide today to replace CFC-12 witn an HCFC blend such as Suva MP 39 or 66 as a refrigerant, using an alkylbenzene compressor oil, as a near-term solution.[2] Or he or she could wait for a year or two and invest in newly designed equipment using a promising alternative that is currently being developed, such as HFC-134a. Such an option can be desirable because of the current uncertainty about the best long-term alternatives. Timing of technology advancements, equipment life and servicing needs, cost, and energy performance factors are all key trade-off factors when deciding to use a transitional substance as a near-term solution.

Use Permanent Drop-in Substitute in Existing Equipment

Problems with this option are that a drop-in substitute may not be available, and if it is available then it may require retrofitting of the equipment, and/or may degrade the system performance by increasing energy, chemical, or other system costs. An example where such substitutes have been used successfully within the United States is in aerosol propellants within consumer products where alternative propellants have been used instead of CFCs.

Use New Chemical in New Equipment

Timing, technological advances, efficiency, and system cost issues are key concerns for this option. Such an option may increase user costs because of premature replacement of the equipment. It may also degrade system performance if alternatives have not yet had a chance to be fully researched, tested, and developed. Such issues are more crucial to refrigeration and cooling applications where the equipment often involves a large capital investment and has a long life—for a large chiller, 25 years or more. Much of this equipment has

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[2] We thank Lance Lankford for this illustration.

been technically designed, developed, and evolved for efficient operations with CFCs over the last 40 to 50 years. An important part of this operational efficiency has been energy efficiency, which is why energy implications of phasing out ODCs in this application are a key concern for DoD. Can alternatives be developed that are as energy efficient in cooling and refrigeration applications in a period of only a few years? Section 6 of this document will discuss the progress that has been made to answer this question.

Use Totally New System

Main issues for this option include the cost, redesign, and retraining efforts to use a totally different process. However, if it is unlikely that efficient and cost effective substitutes can be developed, process or system redesign can be the best option for many applications. For example, scientists coordinating their information through the United Nations Environment Programme believe that developing halon replacements that have the same fire extinguishing capability and low toxicity is highly unlikely because of technical difficulties (UNEP, 1991a). Therefore, using engineering design practices to design facilities without the fire hazards that require halon fire protection systems in the first place, so that other non-halon fire protection systems can be used, is a potential halon alternative. Similarly, for some solvent applications, totally new methods have been developed to replace CFC-113, such as no-clean flux methods for electronic defluxing.

Implications for Changes in Energy Use Associated with Decisions in DoD

When choosing among these options, technical, regulatory, energy, and cost factors all play a potential role. We can illustrate what role energy might play in such choices with examples from choices among large chiller and among solvent options.[3]

In large chillers, recovery and recycling will be mandated in any case. Recovery and recycling serve as a baseline against which to consider other options. Given the 30-year life of typical large chillers, the first question about going beyond recovery and recycling is whether to invest in new equipment. This decision distinguishes options 1, 2, and 3 from 4 and 5. Uncertainty about options and growing efficiency of new designs over time favor waiting to invest in general.

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[3] Appendix C provides additional details on these options.

In these terms, a recognition that future designs using alternative refrigerants will be more energy efficient than current designs for these refrigerants could play a role in this decision. Uncertainty about and likely improvements in all other factors push in the same direction. All of these factors, however, are likely to be dominated by the age of existing equipment. It is easier to justify waiting if existing equipment is new than if it is near the end of its life. One refrigeration equipment expert suggests that owners of chillers less than 10 years old should probably not shift from CFC-11 to new chillers using HCFC-123, owners of chillers over 20 years old should probably shift, and owners of chillers 10 to 20 years old could make a decision either way, depending on other factors.[4]

Given a decision not to buy new equipment yet—that is, to choose 1, 2, or 3—most discussions suggest that the choices among these options depend far more on the availability of safe, effective transitional or permanent substitutes than on any other factors. Without such substitutes, options are basically foreclosed. Similarly, given a decision to buy new equipment, the choice between options 4 and 5 is normally phrased in terms of the safety and efficacy of the options available. Only after safe, effective options are identified do other factors, including energy use, come into play. In the few cases where energy use is mentioned, it does not play a dominant role in choices.

Given the inherently dangerous types of materials often used in solvent cleaning services, questions about safety probably dominate all others. Unless a solvent is compatible with existing regulations, it is simply unavailable. As a wide variety of regulations are tightening, the range of chemicals available for use in solvent cleaning is steadily shrinking.

Within this range, efficacy becomes the dominant factor. Options relevant to solvents are especially complex because cleaning services are so carefully customized for particular applications. Hence, only a certain set of solvents can be used in any particular situation. Only in choices among these solvents do cost—and hence energy use—become important factors. That is because the cost of solvent services is typically a small fraction of the total cost of the product cleaned, even though the performance of that product depends heavily on the quality of cleaning provided. As a result, large differences in energy use can exist between options like those cited above without swaying the choice between them.

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[4] Verbal statement made in presentation by Eugene L. Smithart of the Trane Company at the Air and Waste Management Association's Annual Meeting, June 26, 1992.

That is, saying that energy plays a small role in choices does not necessarily imply small differences in energy use between options relevant to DoD. Other factors are important enough so that even significant differences in energy use need not override other factors. Section 6 will look in more detail at what the differences in energy use might be in these application areas.

5. How Does DoD Consider the Energy Effects of Replacing Chemicals That Deplete Ozone?

DoD has active programs in place to find ways to reduce its dependence on ODCs.[1] This section reviews these efforts briefly, giving special attention to what role the energy effects of alternatives to ODCs play in these efforts.[2] In general, DoD gives little attention to energy effects. Such apparent lack of interest is consistent with the general lack of interest elsewhere. It reflects a general belief that energy effects are unlikely to be large, and, even if they are large in selected locations, other factors will often be more important.

General Policy

In February 1989, OSD issued DoD Directive 6050.9 to establish policy on CFCs and halons. It has been updated since then to reflect the CAAA and hence to cover HCFCs, carbon tetrachloride, and methyl chloroform. Each of the services has issued its own directive or regulation to implement this policy. The policy calls for

- Using currently available recovery and recycling techniques
- Modifying operational training and testing procedures
- Incorporating minimization techniques in new system designs
- Developing and using acceptable substitutes
- Documenting DoD's level of dependence on ODCs and compiling an annual report on the amounts of ODCs procured by the services during the previous year.

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[1] The General Accounting Office (GAO) believes that these programs are moving too slowly. For example, GAO found that DoD is continuing to install equipment that uses ODCs into new aircraft and ships, that DoD is revising military specifications relevant to ODCs too slowly, and that its R&D to develop alternatives is underfunded (U.S. Congress, 1991). We have not attempted to examine these concerns in detail. To the extent that they are true, it may be easier than it might be otherwise to change policies, if need be, to give greater priority to energy concerns.

[2] For a more detailed summary of these activities, see Appendix D.

As noted in Section 4, energy considerations could easily play a role in many of these activities. But relevant OSD and service documents make almost no mention of energy considerations, suggesting that these activities could easily proceed without much attention to energy effects.

To help implement this DoD directive, the National Defense Authorization Act in 1989 established the DoD Chloroflurocarbon Advisory Committee. This committee's purpose was to study ODC use by DoD and defense contractors and to help speed the phaseout of such use by investigating the cost and feasibility of potential substitutes and establishing specific elimination goals for DoD. Committee reports have mentioned energy effects but give them a very low priority. Its recommendations do not mention energy effects (see, for example, DoD CFC Advisory Committee Report, 1991).

To help organize its reduction in dependence on ODCs, DoD has grouped its uses of ODCs into three categories:

- Mission-critical use: Uses that have a direct effect on combat mission capability.
- Essential use: Uses that have an indirect effect on combat missions.
- Nonessential use: Uses that are considered nonessential to the military mission.

The priority given to mission performance falls as we move from the top to the bottom of the list. Hence, technical performance is likely to outweigh any concern about energy effects in mission-essential uses of ODCs. The plausibility that energy effects could affect policy rises as we move down the list. The services currently apply these categories in very different ways, and the services are likely to be forced toward more consistency over time. That will tend to downgrade many activities, especially in the Navy. But even now, mission-critical uses with potentially significant energy implications are limited. They include the Navy's and Air Force's use of CFC-11, CFC-12, and CFC-114 for shipboard and aircraft refrigeration and chilling, and the Navy's use of CFC-113 and methyl chloroform for different types of solvent cleaning. Large chiller applications are far more likely to fall into the nonessential category, where energy considerations could potentially play a larger role. But OSD and service documents make no mention of such thinking about energy effects in their discussion of these categories.

Revision of Military Specifications

To achieve reductions in ODC use, DoD must revise a large number of MILSPECs, regulations that specify (among many other things) what chemicals and procedures can be used to perform specific industrial/commercial tasks, within DoD and at its various contractors. The DoD CFC Advisory Committee estimates that 500 military and federal specifications directly specify the use of ODCs and that another 9000 MILSPECs do not directly require these substances, but cannot be met without using ODCs (DoD CFC Advisory Committee Report, 1991, p. 36).

DoD is working with industry and other federal agencies to revise these specifications, but the work is going slowly. Unfortunately, an individual MILSPEC revision can take anywhere from 3 months to 3 years to complete and can cost \$200–\$1500 per page, plus distribution costs.[3] DoD is seeking ways to speed this process, but it ultimately must accommodate a consensus-building process used to test the state of the art and make sure that new specifications reflect the state of the art appropriately. DoD has provided no guidance indicating that energy concerns should play a role in testing the state of the art in these proceedings. In all likelihood, best-business practice will dominate these proceedings, and industry views about the relevance of energy effects will dominate. Such an approach is complicated in revisions that affect the use of ODCs because DoD MILSPECs have come to define business practices for many ODC applications in the private sector; DoD and the private sector will likely have to find their way to new standards together. The discussion in Section 4 suggests that energy effects will typically play a small role in such an effort.

Research and Development to Find New Alternatives

The state of the art is also important in DoD's effort to develop new alternatives to activities that depend on ODCs. DoD has begun R&D efforts in-house and jointly with the commercial sector. DoD is depending on private industry to develop alternatives for commercial uses that are similar to DoD uses. DoD has focused its internal R&D efforts on mission-critical applications where no substitutes exist and commercial research is inadequate. Because large-scale chillers and most solvent cleaning activities have close commercial analogs, DoD is unlikely to place serious R&D effort in these areas. To the extent that it does, its effort will focus on mission-critical areas where technical performance

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[3] We thank Lance Lankford for these cost estimates.

dominates energy concerns. Elsewhere, private-sector views of energy concerns will affect the R&D that DoD ultimately applies. As already noted, concerns about energy use will typically play a small role in such commercial efforts.

Regarding Energy Effects

Taken together, these considerations suggest that concerns about energy use do not play a large role in DoD's efforts to reduce its dependence on ODCs. We should not expect a large role in mission-critical uses of ODCs. Other uses are likely to reflect the private sector's views of energy use; to date, energy effects have played a small role in decisions in these areas. Perhaps as a result, energy considerations rarely surface in DoD's directives and regulations or in discussion of its policies to reduce ODC dependence.

6. How Will the Replacement of Chemicals That Deplete Ozone Affect DoD's Use of Energy?

Great uncertainty persists about the rate at which regulators will require elimination of ODCs and about the technical performance of alternatives when they are introduced. Nonetheless, recent studies provide a basis for making informed judgments about how the elimination of ODCs will affect energy use.

This section draws on a recent study of the technical performance of alternatives to ODCs to make inferences about how compliance with current regulations will affect DoD's energy use. It focuses on the use of ODCs in the two application areas most likely to affect energy use in DoD: large centrifugal chillers and solvent cleaning services. It uses data from a recent study by the AFEAS and the DOE to make inferences about how eliminating ODCs could affect energy use in DoD.[1] AFEAS is a comprehensive group that includes all the major private organizations developing alternatives to ODCs. The AFEAS/DOE study is currently regarded as the best single source of information on the likely energy effects of replacing ODCs in particular applications.[2]

We find that energy effects are likely to be small. Elimination of ODCs in centrifugal chillers can change total DoD energy use by -0.7 to 0.6 percent. Elimination of ODCs in solvent cleaning services could, at most, increase total DoD energy use by between 0.2 and 0.8 percent; smaller changes are likely. Changes in energy use in other applications should not be important.

Methodology

Very little detail is known about how DoD, as a whole, uses substances that deplete stratospheric ozone or how much energy is consumed in conjunction with the use of these substances.[3] It would be time consuming, difficult, and

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[1] Oak Ridge National Laboratory and Arthur D. Little, Inc., conducted the study, which is documented in Fischer et al., 1991.

[2] For more detail on this study, see Appendix E.

[3] The same cannot be said about individual installations, which are undertaking detailed efforts to find replacements for ODCs. Those efforts often yield very good data on local uses. Unfortunately, such data cannot easily be consolidated to yield good numbers for DoD as a whole.

costly to collect such detail in a systematic and comprehensive way. But we can use information from the AFEAS/DOE study to make rough inferences about activities in DoD. Our approach is simple:

Step 1. For each application area—for example, chillers—the AFEAS/DOE study constructs representative systems—for example, chillers of different sizes—and estimates the chemical emissions and energy use associated with different chemicals—for example, various ODCs and alternatives—used in such a system. We can use these data to infer the relationship between emissions and energy use for each system in each application area.

Step 2. DoD purchases of an ODC each year must equal the sum of (a) emissions of that ODC in that year and (b) additions to DoD's stock of that ODC, held in inventories or in devices that use the ODC. By assuming that DoD's stock does not change much from year to year, we can use data on DoD purchases of each ODC to estimate emissions of that ODC from DoD activities in a particular year.

Step 3. Using data from steps 1 and 2, we can infer the total use of energy in DoD associated with any kind of use of an ODC by assuming that one of the system types in step one is the sole system type used in DoD. By using the range of system types from step 1 to bound the systems that might be used in DoD, we can bound the levels of energy use that might be associated with any kind of use of an ODC in DoD.

Step 4. We can also use inferences from step 1 to estimate how energy use might change if DoD switched from one chemical to another within a given system type. We must be cautious using the AFEAS/DOE data in this way, because the AFEAS/DOE study optimizes each system type for each chemical. For example, it assumes that a chiller of a particular size is optimized given current technology to whatever refrigerant it uses. This presents two potential problems. First, switching refrigerants within any given system should increase energy use more than the AFEAS/DOE numbers would suggest, even with some retrofits to the system, because the retrofits could not fully optimize the system for the new refrigerant. Second, the AFEAS/DOE data reflect current capabilities. Presumably, as technology improves over time, energy use by new systems will fall, suggesting that increases in energy use will in fact be smaller than those suggested by the AFEAS/DOE numbers. We cannot say how important these two countervailing problems are relative to the numbers that the AFEAS/DOE study provides. Because we are looking for orders of magnitude and robustness, we believe that we can use this approach without worrying about serious errors.

Step 5. Combining information from step 4 on percentage changes in energy use with information from step 3 on baseline energy use in DoD, we can generate ranges of changes in DoD energy use for various changes from any ODC to the most likely alternatives now being discussed. The remainder of this section calculates such numbers for typical ODC-using large centrifugal chillers and solvent cleaning systems.

Centrifugal Chillers

Centrifugal chillers are energy-intensive. For a typical water chiller, the cost of the energy consumed in the first two years following installation is higher than the equipment cost of the chiller itself (Smithart, 1992, p. 12). We can use the technical data that the AFEAS/DOE study used to develop its results to calculate the energy intensity of centrifugal chiller operation. In particular, we can determine the energy use associated with consumption of a kilogram of CFC-11 or CFC-12 in representative chillers. Combined with data on DoD's use of CFCs in large refrigeration, we can estimate how much energy DoD employs in large refrigeration and how much that might change as DoD eliminates its use of CFC-11 and CFC-12 in chillers.

Table 6.1 summarizes information based on AFEAS/DOE input data about the relative electricity intensity of the CFC-11 and CFC-12 chiller types discussed above.[4] Their energy intensity is very sensitive to assumptions about the annual loss of refrigerant to leaks. The typical nationwide rate of loss in 1990 was believed to be about 8 percent, but the level varies widely from one installation to another.[5] Dated systems with dated specifications and limited incentives for controlling leaks could easily have much higher rates of loss; state-of-the-art installations, diligently maintained, could have losses approaching zero. The table shows that the higher the loss rate, the lower the energy intensity of producing a given amount of cooling.

Little is known about specific DoD practice, but it seems reasonable to expect that annual losses in DoD were at or above the national average in 1990. Hence, an

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[4] The AFEAS/DOE report presents results in its Appendix G that separate "direct"—based on emissions of chemicals that potentially contribute directly to global warming—and "indirect"—based on emissions of carbon dioxide generated by increased energy demands—contributions to GWP. These contributions are stated in terms of equivalent kilograms of carbon dioxide per tonne of refrigeration service. We use data from AFEAS/DOE Appendix R to transform the direct effect into emissions of the relevant refrigerant per tonne of refrigeration and data from Table 3.8 (p. 3.13) to transform the indirect effect into kilowatt-hours per tonne of refrigeration. The results in our report's Table 6.1 are simply the ratio of kilowatt-hours per tonne to kilograms of refrigerant per tonne. Appendix E of our report explains the system types used in the table.

[5] The AFEAS/DOE study also assumes that the chiller charge is fully recovered upon retirement. Although regulation now requires recovery, recovery was not common in the past and may not have been typical even by 1990. Hence, any charge not recovered at retirement should be amortized over the life of a system and added to normal annual losses to achieve the effective annual loss shown in the table.

Table 6.1

Relative Energy Intensity of Centrifugal Chillers (in kWh/kg of refrigerant)

		Effective Annual Loss Rate			
Chiller Size	Refrigerant	4%	8%	12%	16%
300 RT	CFC-11	39,600	19,300	13,000	9,790
	CFC-12	28,500	14,200	9,490	7,110
1000 RT	CFC-11	34,800	17,400	11,600	8,710
	CFC-12	25,800	12,900	8,580	6,440
3000 RT	CFC-11	n.a.	n.a.	n.a.	n.a.
	CFC-12	32,000	16,000	10,600	8,000

SOURCE: Calculation based on data from Fischer et al., 1991.
NOTE: n.a. is not applicable.

energy intensity in the range of 6,000 to 19,000 kWh/kg of refrigerant consumption seems reasonable. In 1989, DoD purchased 1379 metric tonnes of CFCs for use in large refrigeration services (DoD, 1991, p. 17). Assuming that DoD's stocks of these CFCs did not change much in 1989, we can use this purchase amount as an estimate of the annual loss that had to be replaced in 1989. That would suggest that DoD consumed about 8 to 26 billion kWh (27 to 89 trillion Btu) in 1989 in large refrigeration services. To calculate a lower and upper bound estimate on DoD energy changes for chillers we use the smallest and largest energy change estimates from Table E.5, namely, –2.6 percent for using HCFC-123 within 1000 RT chillers and +2.4 percent for using HCFC-123 within 3000 RT chillers. Multiplying these estimates by our estimates of DoD energy use in large refrigeration suggests that DoD energy used in large refrigeration could fall as much as 676 million kWh (2.3 trillion Btu) or rise as much as 624 million kWh (2.1 trillion Btu) a year as DoD replaces CFC-11 and CFC-12 in centrifugal chillers with HCFC-123 and HFC-134a. Comparing this lower and upper bound estimate of energy changes for chillers to DoD's total annual energy use of 0.35 quads gives a –0.7 percent to 0.6 percent change, a very small change of total energy use.

Solvents

We can use a similar approach to examine DoD's use of CFC-113; because data are not available on DoD's aggregate use of methyl chloroform, we can only speculate about its importance to DoD energy use.

Table 6.2 presents information based on inputs to the AFEAS/DOE study about the relative energy intensity of solvent services in the four generic cleaning

Table 6.2

Relative Energy Intensity of Solvent Cleaning Services

Type of Cleaning Service		CFC-113 (kWh/kg)	Methyl chloroform (kWh/kg)	Imputed DoD electricity use for CFC-113 (million kWh)
Metal cleaning	Batch	66.8	71.0	175
	In-line	104.0	104.0	272
Electronic cleaning	Batch	6.29	6.60	16
	In-line	76.4	73.4	200

SOURCE: Calculation based on data from Fischer et al., 1991.

processes discussed above.[6] The variation in energy use per kilogram of solvent consumed is striking. Energy use in DoD's use of CFC-113 could vary by two orders of magnitude depending on how DoD uses CFC-113, from 16 to 270 million kWh (55 to 922 billion Btu) per year. Energy use would be particularly low if DoD concentrated its use of CFC-113 on batch electronics cleaning. Although such cleaning is likely to account for a large share of DoD's use of CFC-113, energy use in a narrower range of, say, 125 to 175 million kWh (425 to 600 billion Btu) per year seems more plausible.

The most energy intensive alternative, aqueous cleaning, would increase energy use by 110 percent and 17 percent for batch and in-line metal cleaning processes, respectively, and 332 percent and 132 percent for batch and in-line electronics cleaning, respectively, according to the estimates from Table E.6. Applying these energy changes to the last column of Table 6.2, we estimate the energy use in cleaning activites switching to aqueous cleaning would be 193 or 46 million kWh if all DoD cleaning were metal batch or in-line cleaning, respectively, and would be 53 or 264 million kWh, respectively, if all DoD cleaning were electronics batch or in-line cleaning, respectively. From this calculation we have an upper bound on solvent energy changes, namely, that energy use in cleaning activities that used CFC-113 in 1989 might rise as much as 264 million kWh (900 billion Btu) a year if (a) DoD used CFC-113 only for in-line electronics cleaning and (b) it substituted aqueous cleaning for all of these CFC-113 applications. This scenario in a sense offers an upper bound on what might happen to energy use in activities associated with CFC-113. If, on the other hand, (a) CFC-113 activities were equally distributed among the four generic processes in Table 6.2 and

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[6] AFEAS/DOE Appendices Y and Z provide data on direct and indirect effects in terms of equivalent kilograms of carbon dioxide per tonne or square meter of output. We use data from AFEAS/DOE Appendix R to transform the direct effect into emissions of the relevant refrigerant per unit of output and data from Table 3.8 (p. 3.13) to transform the indirect effect into kilowatt-hours per unit of output. The results in our Table 6.2 are simply the ratio of kilowatt-hours per tonne to kilograms of refrigerant per unit of output. Appendix E of our report explains the system types included in the table.

(b) half of these activities switched to aqueous and half to semi-aqueous cleaning in each process area, energy use would rise only 104 million kWh (355 billion Btu). This increase would be smaller in size if chlorinated solvents played a role as substitutes.

Without information on DoD's aggregate use of methyl chloroform, we cannot perform similar calculations on energy changes associated with its elimination. However, Table 6.2 makes it clear that the energy intensity of methyl chloroform use is similar to that for CFC-113. Hence, energy changes should be proportional in size to the relative levels of DoD's use of CFC-113 and methyl chloroform. The United States used twice as much methyl chloroform as CFC-113 in the 1980s (Hammitt et al., 1986). DoD probably makes greater relative use of CFC-113 than the nation as a whole, but methyl chloroform is likely to be at least as important as CFC-113 to DoD. Hence, energy changes associated with its elimination should be at least as large as those estimated here for CFC-113, but less than twice as large.

Taken together, these estimates suggest that, at the low end, the elimination of ODCs in solvent cleaning could increase DoD's use of energy by about 200 million kWh (0.7 trillion Btu) a year: 100 million kWh from increases associated with current CFC-113 applications and an equivalent increase from current methyl chloroform applications. At the high end, elimination of ODCs could increase DoD's use of energy by about 800 million kWh (2.8 trillion Btu): 260 million kWh a year from increases associated with current CFC-113 applications and an amount about twice that for current methyl chloroform applications. These judgments yield a range of 200–800 million kWh a year, probably with the mass of subjective probability closer to the bottom than the top.

If we focus on the worst that could happen, potential increases in energy use in solvent cleaning are similar to those for centrifugal chillers. Both of these potential increases are small relative to DoD's total annual energy use of 0.35 quads: –0.7 to 0.6 percent for centrifugal chillers and 0.2 to 0.8 percent for solvent cleaning services.

The Effect of Replacing Chemicals That Deplete Ozone on DoD's Energy Use

When we apply data from the AFEAS/DOE study to DoD, we find that the elimination of ODCs could increase DoD's use of energy in large chillers as much as 620 million kWh (2.1 trillion Btu) a year and in cleaning processes, at worst, 200 to 800 million kWh (0.7 to 2.8 trillion Btu) a year. Both of these changes are small relative to DoD's total annual energy use of 0.35 quads: –0.7 to 0.6 percent for large chillers and 0.2 to 0.8 percent for solvent cleaning services. Changes in energy use in other applications should not be important.

7. How Should OSD Change Its Policies to Reflect the Energy Effects of Replacing Chemicals That Deplete Ozone?

We have seen, in Section 5, that DoD currently appears to give low priority to energy effects as it considers alternative ways of replacing ODCs. Section 6 tells us that the decisions that result from this attitude are unlikely to have a large effect on DoD's energy use. In fact, they could reduce energy use, at least in certain important applications. That is, the current OSD deemphasis of energy effects is unlikely to yield large negative outcomes. The very fact that energy effects are likely to be small is consistent with current evidence about effects elsewhere in the economy. This evidence, through its effects on priorities in the private sector, may help explain why energy effects have not received more attention to date in DoD.

Taken together, these conclusions lead us to believe that the conflict between DoD's energy and environmental goals in this instance is not serious. We recommend that OSD should not implement a major undertaking to change the outcomes that current DoD efforts are likely to yield. That is our principal policy recommendation. OSD should continue to monitor the situation to ensure that circumstances do not change unexpectedly. But at this time, energy effects associated with the replacement of ODCs do not deserve any more attention than energy effects associated with other environmental policies, like those designed to reduce sulfur or nitrogen oxides in urban air sheds or those that could be designed to deal with global warming.

If OSD still feels a need to act, we offer three other recommendations about how to direct that action:

Have Patience

Technology is improving. As DoD weighs the options available at any point in time, it should anticipate that better options will become available in the very near future. The trade press relevant to ODCs announces progress regularly and will continue to do so as engineering efforts continue.

Dates for terminating production of ODCs have tightened as concern has increased about how serious stratospheric ozone depletion is. Restrictions on the use of ODCs have not tightened in a similar way. In fact, they are still in the process of being developed. The prices of ODCs have increased more rapidly than expected as phaseout dates have moved forward; such changes encourage earlier dates for switching to alternatives. But improvements in technologies bought for long-term use should easily override the transitional costs of paying for more expensive chemicals that will be phased out in a few years in any case. And information on alternatives can only improve as time passes; it is worth paying some premium in the short-run to have better information on long-term investments.

Focus on Chillers, Not Solvent Cleaning Services

Energy effects for chillers are likely to be more important than for solvent cleaning services relative to environmental, safety, and health issues. And perhaps most important, energy effects associated with chillers should be simpler to monitor and analyze from a distance than those for solvent cleaning services.

It is easier to seal chillers to avoid emissions of coolant than it is to seal solvent cleaning systems to avoid emissions of solvent. And routine human contact is less important to cooling than to solvent services. As a result, users can reasonably expect to maintain effectively lower levels of human exposure to dangerous chemicals in centrifugal chillers than in solvent cleaning. Hence, chemicals that might be approved for use in chillers could easily be prohibited as solvents; HCFC-123 is a likely example. Such concerns illustrate why environmental, health, and safety issues play a larger role relative to energy concerns in solvent services than in chillers.

Solvent cleaning services must be tailored to each cleaning task contemplated. The materials used in an item to be cleaned, its shape, the importance of cleaning it to some standard, and other factors call for very specific cleaning activities that embody knowledge that can only be fully appreciated at the site where cleaning occurs. By comparison, centrifugal chillers provide a fairly generic service. The size of the cooling load and ambient conditions can affect choices among chiller alternatives, but variation in these considerations is likely to be far smaller than that between the precision cleaning of a particular surgical device and, say, dry cleaning a uniform.

Acting in effect as an external regulator, OSD is likely to have greater success affecting decisions with regard to chillers than those relevant to solvent cleaning.

OSD must rely on limited resources at the installation to characterize and compare alternatives and has limited resources of its own to monitor this activity. OSD will be better able to develop standard procedures that it can apply to installations and better able to second guess local decisions constructively if it focuses on the relatively simpler decisions associated with chillers.

Focus on Changing Military Specifications, Not Affecting Individual Investment Decisions on Installations

MILSPECs drive many investment and production decisions in DoD and, often, in the economy at large. Specifications take time to develop. They absorb considerable analytic talent and effort. Once they exist, it is typically cheaper to comply with these established standards than to question them and develop still others. Hence, once they are in place, the range of options available to a decisionmaker at a DoD installation narrows considerably. This is especially true where DoD specifications drive decisions outside DoD, as they often do in solvent cleaning, thereby limiting the range of options that a DoD decisionmaker, or a private-sector salesman trying to influence that decisionmaker, might see in practice.

An example that illustrates how MILSPECs affect an installation decisionmaker's approach to ODC alternatives is McClellan Air Force Base's use of CFC-113 as an electrical contact cleaner. MILSPECs directly restrict the installation's solvent choice. If the MILSPECs for electrical contact cleaner and lubricant were revised, McClellan could reduce its use of CFC-113 up to 2100 pounds a year by switching to viable alternatives (Beekley and Lankford, 1992, p. 10).

Decisionmakers at DoD installations cannot afford to undertake the careful analysis underlying MILSPECs when they make investment decisions affecting individual chillers or cleaning operations. And they do not have the analytic talent and information typically available to those developing MILSPECs.

All of the MILSPECs that have called for the use of ODCs in the past are now under review. DoD has developed an aggressive program to draw up new specifications as suitable information on alternatives develops. To the extent that OSD seeks to influence decisions about alternatives so that they reflect its concerns about energy efficiency, the current DoD effort to revise its MILSPECs relevant to these alternatives looks like the natural place to do it.

In the end, energy considerations are only one among many factors that users must consider as they weigh alternatives to the ODCs that they have relied upon for so long. Analyses of alternatives to date have focused on factors other than energy because they are likely to play a larger role in decisions than energy considerations per se. As time passes, better information on energy effects will become available. But unless it carries very large surprises, it is unlikely to affect any of these basic suggestions.

Appendix A

The Key Ozone Depleting Chemicals and Their Substitutes

This appendix provides a brief primer on the chemicals discussed in the text. It describes broad chemical classes and then discusses individual chemicals. It then describes patterns of production and use for each of these chemicals. It closes with a brief overview of other environmental issues relevant to ODCs.

Chemical Classes

CFCs are chemicals whose molecules contains only chlorine, fluorine, and carbon atoms.[1] The absence of hydrogen in these compounds makes them extremely stable and this stability is ideal for many commercial applications. This stability also prevents these chemicals from being broken down in the lower atmosphere so they slowly drift up to the stratosphere. In the stratosphere these molecules are broken down by the ultraviolet radiation. Highly reactive chlorine atoms are freed by this process and react with ozone, reducing the ozone level in the stratosphere.

Chemicals that contain hydrogen along with the chlorine tend to react with other chemicals before reaching the stratosphere. Therefore, they can be significantly less destructive to the ozone layer. One class of such chemicals, hydrochlorofluorocarbons (HCFCs), has properties similar to CFCs and, thereby, are well suited for CFC substitutes in many applications. However, since HCFCs also contain chlorine they still pose some danger to the ozone layer and are currently considered transitional substitutes.

Hydrofluorocarbons (HFCs) do not contain chlorine or bromine and, therefore, pose no threat to the ozone layer. These chemicals are also being researched and developed as substitutes for CFCs. Chemicals containing only bromine, fluorine, and carbon atoms, called halons,[2] are also extremely stable in the lower

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[1] Sometimes the term CFC is used to refer to any chemical that contains chlorine, fluorine, and carbon atoms as well as other atoms. Throughout this document we use the strict definition that it only contains chlorine, fluorine, and carbon atoms.

[2] Technically, halons refer to halogenated hydrocarbons. Halogenated hydrocarbons are acyclic saturated hydrocarbons in which one or more of the hydrogen atoms has been replaced by atoms from the halogen series: fluorine, chlorine, bromine, and iodine. Therefore, CFCs, HCFCs, and carbon tetrachloride can be called halons. To avoid confusion within this document, halon refers only

atmosphere so that they drift up to the stratosphere where these molecules are also broken down. The bromine atoms are released and react with ozone, reducing the stratospheric ozone layer. Table A.1 summarizes these chemical class definitions and their comparative threat to the ozone layer.

Table A.1

Key Chemicals and Chemical Classes Definitions

Class Name(s)	Molecule Contents	Ozone Threat
CFC	Contains only **chlorine**, fluorine, and carbon atoms.	High
	Contains only hydrogen, **chlorine**, fluorine, and carbon atoms.	Low
Halon	Contains **bromine**, fluorine, and carbon atoms.	Very High
Carbon Tetrachloride	Contains four **chlorine** atoms and one carbon atom.	High
Methyl Chloroform[a]	Contains three **chlorine** atoms, three hydrogen atoms, and two carbon atoms.	Low
HFC	Contains only hydrogen, fluorine, and carbon atoms.	None

[a] Also known as 1,1,1-trichloroethane and TCA.

This table describes two other chemicals that contain no fluorine, but they contain carbon and chlorine atoms: carbon tetrachloride and methyl chloroform. These chemicals are also dangerous to the ozone layer because their chlorine atoms are eventually released in the stratosphere. However, methyl chloroform is less dangerous because it contains hydrogen atoms that cause it to be partially broken done in the lower atmosphere.

In this table the presence of bromine and chlorine within these chemicals was highlighted since the presence of these chemicals indicates they are dangerous to the ozone layer.

Individual Chemicals

When we compare individual chemicals, we can be more precise about the relative threats that they pose, per pound emitted, to stratospheric ozone. Atmospheric chemists have developed complex models that allow them to

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to chemicals that contain bromine, fluorine, and carbon atoms. For more information on these chemical definitions see UNEP, 1991a, Annex B.

increment emissions of chemicals, one at a time, and observe their effects on stratospheric ozone. These models indicate that important CFCs, HCFCs, halons, and other chemicals have the effects shown in Table A.2 relative to the effect of CFC-11, one of the first and most important CFCs to be developed and commercialized.

The table indicates that bromine-containing halons differ in their danger per pound by a factor of three but are generally an order of magnitude more dangerous than the CFCs as a class. CFCs and carbon tetrachloride, on the other hand, are an order of magnitude more dangerous than methyl chloroform and the HCFCs. There is great variability among HCFCs as well. HFCs, of course, pose no threat to the ozone layer.

This table suggests why it might make sense to substitute methyl chloroform for CFC-113 in similar solvent applications, but not to substitute most of the HCFCs shown for methyl chloroform. It also indicates why it makes sense to allow continuing production of HCFCs as substitutes for CFCs, but to plan for their ultimate elimination as alternatives are developed for them. The next section will show that current regulations do exactly that.

Table A.2

Relative Abilities of Chemicals to Deplete Ozone

Chemical	Depletion Potential Relative to CFC-11
Halon 1211	3
Halon 1301	10
Halon 2402	6
CFC-11	1.0
CFC-12	1.0
CFC-113	0.8
CFC-114	1.0
CFC-115	0.6
Carbon tetrachloride	1.1
Methyl chloroform	0.11
HCFC-22	0.05
HCFC-123	0.02
HCFC-141b	0.10
HCFC-142b	0.06
HFC-134a	0
HFC-152a	0

SOURCE: DoD CFC Advisory Committee, 1991, p. 23; UNEP, 1989, pp. 6–8.

Levels of Production and Use

Stratospheric ozone depletion ultimately depends on global emissions of these chemicals; where the emissions occur is irrelevant. Table A.3 puts U.S. production and DoD use levels in perspective by comparing them with recent levels of production in the world as a whole.

World production of CFCs initially peaked in 1974, the year that the first scientific studies suggesting problems with CFCs were published. The data shown for CFC-11 and CFC-12 reflect this peak. In the next few years, the United States and several western European countries imposed restrictions on aerosol uses of these chemicals that cut demand for them. World production levels did not approach those for 1974 again until the late 1980s. These restrictions did not much affect the use of CFC-113, whose global production level continued to grow until limited by the Montreal Protocol.

The Montreal Protocol initiated a process that is causing a precipitous drop in the production of all three chemicals, CFC-11, CFC-12, and CFC-113. The change from 1989 to 1990 illustrates this drop; it has continued since, although comprehensive global figures are not yet available to show it explicitly. Production has been falling even more rapidly than the regulations in place at the time required. Meanwhile, the prices that users pay for CFCs have been rising as taxes on CFCs have increased. This price rise accelerated following President Bush's announcement in 1992 accelerating the phaseout. Smaller stocks of CFCs would be available to service the existing stock of equipment than was anticipated. As a result, the price has risen to ration the remaining inventory among potential users.

Together, these three major CFCs account for the lion's share of CFC production and have received much more attention than other chemicals in policy discussions. CFC-114 and CFC-115 have a much more constrained set of uses; their production levels are commensurately lower.

Production of HCFC-22 grew continuously through the period shown, until it leveled off in 1989. On the one hand, it will substitute for CFCs in selected applications; on the other, recycling and recovery will reduce the virgin HCFC-22 required to meet all demands for it. These trends appeared fairly balanced as of 1989. When the phaseout of HCFC-22 production per se begins remains highly uncertain; that phaseout schedule probably has only small effects on HCFC-22 demand today.

Table A.3

Production and Use Levels for Major Ozone Depleters (in thousands of metric tonnes)

	World Production					U.S. Production	DoD Use
ODCs	1974	1980	1986	1989	1990	1985	1989
CFC-11	369.7	289.6	350.1	302.5	232.9	75.0	1.6[a]
CFC-12	442.8	350.2	398.4	379.8	231.0	135.0	(a)
CFC-113		103.7	196.6	251.3	174.8	73.2	2.6
CFC-114		15.0	19.0	15.0	8.0		(a)
CFC-115		9.3	11.8	14.2	10.0		(a)
HCFC-22	83.4	126.3	165.0	219.5	213.7		
Carbon tetrachloride			1029.0[b]			280.0	
Methyl chloroform			554.6[b]			270.0	
Halon 1211			10.8[b]			5.4	0.6
Halon 1301			10.8[b]			2.7	0.6

SOURCE: Chemical Manufacturers Association, 1991a (global CFC-11 and CFC-12), 1991b (other global CFCs), 1991c (HCFC-22); DoD CFC Advisory Committee Report, 1991 (DoD CFCs and halons); Hammitt et al., 1986 (U.S. levels and global non-CFC levels).

[a] All chemicals noted are combined on the row for CFC-11.

[b] Estimates for 1985 from Hammitt et al., 1986.

Estimates of global production levels for carbon tetrachloride and methyl chloroform, readily available for only one year, 1986, show even higher levels of production than those for the major CFCs. Production levels for halons, on the other hand, are more nearly comparable to those for the minor CFCs. As Section 2 indicates, of course, these production levels are not good indicators of the relative threats that these chemicals pose to stratospheric ozone.

The United States has accounted for a large share of the production of these chemicals. Data in the table point to a range of about 30 to 50 percent for various chemicals. In 1989, although DoD use accounted for a very small percentage of U.S. production of CFCs, DoD was—and remains—the largest single user of CFCs in the country. Its use accounts for a substantially larger share of halon production. These shares reflect DoD's sheer size and, as we shall see in a moment, the particular importance to DoD of a number of applications of these chemicals.[3]

These numbers include only direct DoD purchases of these chemicals. If the purchases of contractors providing systems and services directly to DoD were included, the share would grow. Only direct purchases, however, are relevant to our major concern, the effects of the regulation of these chemicals on the use of energy within DoD.

How Ozone Depleting Chemicals Are Used

This subsection provides a brief overview of how each of the key ozone depleting chemicals is used. Specific data on DoD are not readily available. We can use information on the broader use of these chemicals to put DoD use in perspective and comment on uses relevant to DoDs application of these chemicals.[4]

CFC-11

One of the most commonly used CFCs throughout the world is CFC-11. Historically, CFC-11 has been used extensively as a foam-blowing agent and aerosol propellant. Table A.4 breaks down 1989 production of CFC-11 by the

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[3] Detailed data on DoD's total use of the other chemicals are not available. DoD uses very little carbon tetrachloride; it is a major consumer of methyl chloroform.

[4] For more detail, see Camm et al., 1986; Hammitt et al., 1986; Mooz et al., 1982; Palmer et al., 1980; Pekelney, 1991; and United Nations Environmental Programme, 1991a, 1991b, and 1991c. The discussion below draws heavily on these sources.

Table A.4

Major Global Applications of CFC-11 and CFC-12, 1989 (percentage)

	CFC-11	CFC-12
Foam blowing agent	71.3	13.0
Aerosol propellant	13.0	15.3
Refrigeration, air conditioning	8.9	64.5
Other	6.8	7.1

SOURCE: Chemical Manufacturers Association, 1990a, Schedules 5 and 6.

world's major producers into broad use categories.[5] CFC-11 is now used globally primarily as a foam-blowing agent. It plays two roles in this activity. It forms bubbles in resin that allow a foam to set up properly. And to the extent that it is retained in these bubbles, CFC-11 contributes to the foam's insulating capability. DoD buys foams made with CFC-11 but does not manufacture them or use CFC-11 to maintain them. Hence, this application is of little importance to DoD's concerns of balancing environmental and energy goals.

The second largest global use of CFC-11 is as an aerosol propellant. Because alternatives are available at almost no economic or performance penalty, the United States banned such uses of CFC-11 in 1978, excepting only specialized uses that account for a very small fraction of CFC-11 use. Although DoD takes advantage of some of these exceptions, this is not a significant use within DoD.

The next largest global use of CFC-11 occurs in refrigeration, mainly as the coolant in large centrifugal chillers used to air condition large buildings. While global sales of CFC-11 fell faster than 5 percent a year from its 1987 peak, its use in refrigeration—and primarily in large chillers—continued to rise at almost 6 percent a year.

When used in chillers, CFC-11 is contained for the duration of its use as a refrigerant. So long as the CFC-11 is contained, it can provide useful cooling services without threatening the ozone layer. Until a few years ago, users allowed CFC-11 to leak from such chillers and released remaining CFC-11 to the atmosphere when they recharged their chillers. New regulations and CFC-11's rapidly rising price—it has more than tripled since the mid-1980s and is expected to continue rising—encourage active efforts to seal existing systems against leaks and to recover and recycle CFC-11 when a charge is replaced. Properly fitted

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[5] These numbers reflect an annual survey of the dominant CFC producers in the world. Although it is not a complete estimate of global CFC production, it is the best estimate available. It is certainly adequate for our purposes as an indication of the general global scale of production for CFCs.

and maintained, then, existing chillers that continue to use CFC-11 should be able to provide cooling services at far lower risk to stratospheric ozone than they did in the past. Nevertheless, installation owners who do not give adequate attention to recent regulatory and price changes will continue to allow leaks and discharge during servicing.

DoD has a significant interest in this application of CFC-11. As Table 2.2 indicates, large refrigeration applications accounted for about a third of CFC purchases in DOD in 1989. CFC-11 is the dominant coolant used in such applications. Because the stock of CFC-11 is not changing much in DoD, these purchases approximate the annual rate of emissions from DoD refrigeration activities; CFC-11 is bought primarily to replace CFC-11 lost to the atmosphere.

CFC-12

The largest global application of CFC-12 remains refrigeration and air conditioning. Of these, mobile air conditioning is by far the largest application globally. Others include home and retail food refrigeration and centrifugal and reciprocating chillers. As noted above, such applications confine coolant until it leaks out or is discharged into the atmosphere. Recent regulatory and price changes should discourage leaks and discharge, substantially reducing the emissions of CFC-12 associated with the production of cooling services. Mobile air conditioning accounts for a small portion of DoD's use of chlorofluorocarbons; chillers could easily rival mobile air conditioning as the dominant use of CFC-12 in DoD refrigeration.

Aerosol propellant is the second largest global use of CFC-12. As noted above, most such applications are banned in the United States and are of little importance to DoD. Foam blowing is also an important global use of CFC-12. As noted above, DoD uses such foams but does not produce or maintain them internally in a way that involves direct application of CFC-12.

Of the many other applications in which CFC-12 is used globally, one is used more than the others: CFC-12 used with ethylene oxide to sterilize medical and surgical products. As noted in Table 2.2, this accounts for a very small portion of DoD use.

CFC-113

CFC-113 is used in a variety of applications, including cleaning of electronics, precision components, and metal and dry cleaning. The principal user is the civilian electronics industry. Such uses as a mild solvent to remove flux from electronic components; to help fabricate printed circuit boards; and to clean precision components and instruments like gyroscopes, disk drives, and medical instruments dominate global demand for CFC-113. DoD has similar demands for CFC-113. In fact, demands are so similar that, until very recently, military specifications for the application of CFC-113 governed about half of its U.S. use outside DoD.

Until recently, cleaning applications allowed CFC-113 to escape into the atmosphere when it was used. Equipment redesign to capture emissions and efforts to recycle and recover CFC-113 looked cost-effective even in the early 1980s. Rising prices and regulations encourage efforts to cut emissions dramatically from those experienced a decade ago. By the late 1980s, annual global use of CFC-113 grew at only 1.5 percent a year, well below the growth of 13 percent a year experienced in the early 1980s and well below the growth in demand for the speciality items that CFC-113 has been used to clean in the past.

CFC-114 and CFC-115

CFC-114 and CFC-115 are both used primarily in refrigeration applications. CFC-114 is of special interest to DoD because it provides unique marine refrigeration services used to cool electronics and weapon systems on shipboard and in the E-3C aircraft radome. But as Table A.3 indicates, these chemicals taken together account for less than 3 percent of global CFC use. They are relatively more important in DoD, but their levels of use do not approach those of the major CFCs. Furthermore, CFC-114 is used primarily in mission-critical applications where economic and energy considerations are less compelling than they are elsewhere.

Carbon Tetrachloride

Carbon tetrachloride is an important solvent globally, but its acute toxicity has strongly limited its use as a solvent in the United States. It is used primarily as a chemical intermediate in the United States. Ninety-eight percent of it is consumed in the production of CFC-11 and CFC-12. Much of the remainder is consumed in the production of chlorine, chlorinated rubber, pharmaceuticals, and pesticides. Almost none is actually emitted into the atmosphere. Production of carbon tetrachloride for such uses is not restricted by the Montreal Protocol. Even if it were, it would not affect DoD; none of these uses is relevant to DoD.

Methyl Chloroform

Half of methyl chloroform is used in metal, precision components, and electronics cleaning. Eleven percent is consumed as an intermediate in the production of CFCs. The remainder is used mostly in adhesives, aerosols, and coatings.

Methyl chloroform interests DoD primarily as a solvent, especially as a metal cleaner. In that role, its cleaning effectiveness and relative safety have made it the best cleaning solvent available historically in many applications. Users continue to have great difficulty developing alternatives. Details on DoD's use of methyl chloroform, including its total annual demand, are not available. But DoD presumably faces problems in its metal cleaning applications similar to those found elsewhere.

A minor use of some special interest to DoD is the use of methyl chloroform as a penetrating fluid in aviation metal-fatigue testing. No substitutes have been found; EPA currently formally exempts this use from controls.

Halons

Halons are used primarily as fire extinguishants. Halon 1211 is used primarily in hand-held and mobile fire extinguishers. Halon 1301 is used in total flooding systems to protect valuable equipment in enclosed spaces. Both are used despite their high cost because they can be applied rapidly enough to suppress a fire without endangering humans exposed to the application or leaving a residue that would damage the high-value equipment that they protect. By definition, they are contained until they are used. Until recently, most use occurred when fire control systems were tested. Emissions to the atmosphere could be reduced substantially by using alternative chemicals to test halon systems.

DoD is a major user of halons. Halon 1211 accounts for about half of its use; Halon 1301 accounts for most of the remainder. These chemicals offer an unparalleled capability to protect the military's high-tech equipment without endangering human life in an inherently dangerous environment. The Army uses them inside armored vehicles. The Air Force and Navy use them on aircraft and missiles. The Navy also uses them on ships.

Other Environmental Concerns Associated with These Chemicals

CFCs and halons have been highly successful products in part because they are safe to humans and to the environment more generally. CFC-113 and methyl chloroform are regulated as chlorinated solvents, but they are among the least dangerous major chlorinated solvents in use today.[6] The most serious additional environmental concern associated with these chemicals is their potential to contribute to global warming. How real a threat global warming poses remains an open and highly contentious scientific issue. But the contribution of these chemicals to stratospheric ozone depletion was just such an issue only a decade ago. We do not address global warming in this report because it should not be the driving regulatory force relevant to these chemicals over the next decade. But it creates a source of uncertainty that compounds already difficult problems associated with plans to eliminate CFCs and related chemicals and find substitutes for them. That is, new insight into the global warming issues could dramatically change the regulatory environment for many of these chemicals.

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[6] Carbon tetrachloride is a much more dangerous solvent but has essentially been excluded by regulation from this application in the United States.

Appendix B

The Montreal Protocol and Revisions

The Montreal Protocol

During the 1970s and early 1980s the scientific community began extensive studies to analyze the theory that the stratospheric ozone layer might be depleted through reactions with CFC emissions. In 1984 an international scientific effort was undertaken to analyze the threat to the ozone layer by human activities. Over 150 scientists participated in this effort including scientists from NASA, National Oceanic and Atmospheric Administration (NOAA), UNEP, the World Meteorological Organization (WMO), and the West German Ministry for Research and Technology. Their results were published by UNEP and WMO in 1986. One of the major findings of this UNEP/WMO report was the fact that accumulations of CFC-11 and CFC-12 in the atmosphere had nearly doubled from 1975 through 1985. This report also predicted that the continued emissions of CFC-11 and CFC-12 at the 1980 rate could cause about a 9 percent global average reduction in the ozone layer (Benedick, 1991, p. 272). However, as the report noted, there were data inconsistencies and other scientific uncertainties regarding their findings. There was no direct evidence that the level of ozone in the stratosphere was falling. Therefore, the ozone-depletion theory was still regarded by many scientists and policymakers as only theory.

About the time that this report was being finalized, a seasonal ozone hole over Antarctica was discovered. However, this hole could not yet be explained by the existing ozone-depletion theory. As the scientists continued to collect and analyze data to attempt to clear up the uncertainty in this important international environmental theory, diplomats began to discuss the need for imposing international controls on CFCs.

After several months of negotiations, in Montreal in September 1987, delegates from around the world, including the United States, adopted the Montreal Protocol on Substances That Deplete the Ozone Layer. This Montreal Protocol limited the production and consumption of certain chemicals, defined as controlled substances, that contribute to the destruction of the stratospheric ozone layer. Table B.1 summarizes the chemical limits imposed by the 1987

Table B.1

Summary of the Montreal Protocol Controls

Controlled Substance	Provision
Chloroflurocarbons:	Freeze consumption and production at 1986 levels beginning in July 1989
CFC-11	
CFC-12	20% reduction beginning in July 1993
CFC-113	50% reduction beginning in July 1998
CFC-114	
CFC-115	
Halons: 1211, 1301, 2402	Freeze consumption and production at 1986 levels in 1992

SOURCE: Montreal Protocol of 1987, Article 2 and Annex A.

Montreal Protocol on these controlled substances. The U.S. Senate ratified this treaty and the president signed it into law in 1988. The Montreal Protocol entered into force on January 1, 1989, with ratifications by 29 countries and the European Commission. These nations accounted for an estimated 83 percent of global consumption of CFCs and halons (Benedick, 1991, p. 117).

An important part of this treaty was its definitions of production and consumption:

> "Production" means the amount of the controlled substance produced minus the amount destroyed by technologies to be approved by the Parties.... "Consumption" means production plus imports minus exports of controlled substances. (Benedick, 1991, p. 231)

Because of these definitions and the fact that the treaty limits only production and consumption, the actual use of these chemicals is not limited. This law places no limits on the future use of recycled chemicals.

The Montreal Protocol allowed for potential exceptions for essential uses. It also included special provisions for developing countries, including promoting technology transfer, financial assistance, and allowances for basic needs.[1] The treaty also specified trade restrictions for controlled substances. Another key part of this Protocol was the fact that the parties of the treaty agreed to meet at regular intervals to assess the current control measures given the current scientific, environmental, technical, and economic information regarding such

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[1] A 10 percent increase of controlled substances based on 1986 levels was allowed for developing countries to satisfy basic needs and for the purpose of industrial rationalization between countries (see Articles 2 and 5 of the Montreal Protocol).

measures and the threat to the ozone layer.[2] The first such meeting was held in 1990 in London.

The 1990 London Revisions

In June 1990 delegates met in London to revise the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer. Between 1987 and 1990 scientific investigations had continued, and the evidence of the threat to the ozone layer continued to mount. In March 1988 hard scientific evidence to confirm the ozone depletion theory was presented by a worldwide scientific panel study.[3] Because of the mounting scientific evidence of the destruction of the ozone layer, strict revisions were negotiated in London. Accelerated reductions in the consumption and production of the 1987 Montreal Protocol-controlled substances were specified as well as a complete phaseout in the year 2000. Other ODCs, including 10 additional CFCs, carbon tetrachloride, and methyl chloroform, were added to the list of controlled substances. A summary of the limits placed on the controlled substances by the 1990 London revisions appears in Table B.2.

Again special provisions were included for developing countries, which included more specific financial aid and special production and consumption allowances.[4] The London Revisions included the same specifications for continued review of the control measures at subsequent meetings. It also included stricter trade restrictions on the controlled substances.

A new key part of the 1990 London Revisions was the classification of transitional substances, namely, the HCFCs listed in Table B.3. These substances are considered transitional because they are less harmful to the ozone layer and are the most viable near-term substitutes for CFCs in many applications. A nonbinding resolution calls for the phaseout of these substances by the year 2040, and if possible by 2020. Future reassessments of the transitional substances may place limits on their use as other substitutes are developed and if scientific evidence of ozone depletion continues to increase.

The London Revisions were scheduled to be revised in November of 1992 when delegates met to reassess this treaty.

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[2] The Montreal Protocol, Article 6.

[3] Over 100 scientists from around the world, including NASA and NOAA, participated in a 16-month study, which issued the Ozone Trends Panel Report in March 1988. This report concluded that emissions of man-made chemicals including CFCs and halons were increasing atmospheric concentrations of chlorine on a global scale (Benedick, 1991, p. 110).

[4] A 15 percent increase of controlled substances based on 1986 (1989 for newly controlled substances) levels was allowed for developing countries to satisfy basic needs (see Articles 2A, 2B, 2C, 2D, 2E, and 5 of the London Revisions).

Table B.2

Summary of the 1990 London Revisions Controls

Controlled Substance		Provision
CFC-11 CFC-12 CFC-113 CFC-114 CFC-115		Accelerated reductions in consumption and production: 50% reduction from 1986 levels in 1995 85% reduction in 1997 Phaseout in 2000
Halons: 1211, 1301, 2402		Accelerated reductions in consumption and production: 50% reduction from 1986 levels in 1995 Phaseout in 2000[a]
CFC-13 CFC-111 CFC-112 CFC-211 CFC-212	CFC-213 CFC-214 CFC-215 CFC-216 CFC-217	20% reduction from 1989 levels in 1993 85% reduction in 1997 Phaseout in 2000
Carbon Tetrachloride		85% reduction from 1989 levels in 1995 Phaseout in 2000
Methyl Chloroform (1,1,1-trichloroethane)		Freeze at 1989 levels in 1995 30% reduction in 1995 75% reduction in 2000 Phaseout in 2005

SOURCE: London Revisions to the Montreal Protocol, 1990.

[a] May exclude essential uses of halons for which no adequate alternatives are available. At subsequent meetings, the parties of the treaty will decide whether any essential uses will be exempt from the reductions.

Table B.3

Transitional Substances

HCFC-21	HCFC-133	HCFC-226	HCFC-244
HCFC-22	HCFC-141	HCFC-231	HCFC-251
HCFC-31	HCFC-142	HCFC-232	HCFC-252
HCFC-121	HCFC-151	HCFC-233	HCFC-253
HCFC-122	HCFC-221	HCFC-234	HCFC-261
HCFC-123	HCFC-222	HCFC-235	HCFC-262
HCFC-124	HCFC-223	HCFC-241	HCFC-271
HCFC-131	HCFC-224	HCFC-242	
HCFC-132	HCFC-225	HCFC-243	

SOURCE: London Revisions to the Montreal Protocol, 1990, Annex C.

Appendix C

Comparing Alternatives for Chiller and Solvent Service Applications

This appendix focuses on the two areas where the energy effects of reducing DoD's dependence on ODCs are likely to be most important: cooling/refrigeration applications and solvent applications. It discusses the main trade-off factors and options for choosing refrigerant alternatives for DoD and then the main factors and options for the solvent alternatives.

Cooling and Refrigeration Applications

Because of environmental, health, safety, energy, and cost factors and because of the chemical, thermodynamic, and transport properties needed for a good refrigerant, CFCs have been used extensively as the refrigerant of choice in everything from mobile air conditioners to large-scale chillers. Alternative refrigerants must be able to meet the same basic requirements. These basic criteria for refrigerants are summarized in Table C.1. In practice, it takes years to test a refrigerant for health, safety, and environmental factors and then to optimize its use with lubricants, desiccants, materials, and the physical characteristics of air conditioning or refrigeration equipment.

When a refrigerant must be replaced, this process usually involves redesigning the entire refrigeration system. This process includes not only finding an appropriate refrigerant but also finding compatible materials and components for reliable and durable performance of the equipment. Compatibility refers to the working relationship between the refrigerant and lubricant working fluids and the structural materials and functional components. Finding the right refrigeration construction materials to meet this compatibility requirement requires extensive testing and development. Table C.2 summarizes key construction materials and pertinent operating parameters that must be addressed within this process.

The lubricant and refrigerant fluid properties are a key part of this refrigeration compatibility and design process. For example, an ODC alternative may have

Table C.1

Refrigerant Criteria

Category	Key Criteria
Chemical	Stable and inert
Health, safety, and environmental	Nontoxic
	Nonflammable
	Does not harm the environment
Thermophysical properties	Critical point and boiling point temperatures are appropriate for the application
	Low molar vapor heat capacity
	Low viscosity
	High thermal conductivity
Miscellaneous	Soluble in lubricating oil
	High vapor dielectric strength
	Low freezing point
	Compatible with common materials
	Easy leak detection
	Low cost

SOURCE: UNEP, 1991b, p. 57.

Table C.2

Key Refrigeration Construction Materials and Operating Parameters

Key Materials	Application Parameters
Working Fluids	Temperature
Refrigerants	
Lubricants	Pressure
Metals and alloys	Force (loads)
Polymers:	Fluid dynamics
Structural	
Electrical	Electrical stresses
Elastomers	Dynamic cycling
Desiccants/filter driers	

SOURCE: Spauschus, 1989, p. 34.

desirable properties as a refrigerant but a compatible working fluid may be hard to develop for it. HFC-134a is an example of an alternative refrigerant for which it has been hard to find a suitable lubricant. Therefore, for particular applications such an alternative may require further research, may not work out as a suitable alternative, or may be acceptable but have a high performance degradation because of technical difficulties, resulting in decreased energy efficiency and/or increased system cost. Ester oils overcome important difficulties in finding compatible oil lubricants for HFC-134a in large chillers (UNEP, 1991b, p. 148); as experience accumulates, additional engineering work will be needed. We can expect such refinement efforts to continue, improving and perfecting refrigeration system alternatives' performance.

Materials compatibility is just one of many research areas that must be addressed when designing a new refrigerant alternative. The fluid development; testing of the thermophysical properties; testing health, safety, and environmental factors; and equipment testing and design are also key parts of this R&D process. All of these different areas are currently being investigated in parallel for promising CFC substitutes to minimize the time that it will take to prepare these alternatives for commercial use.

Clearly, there are many technical details and difficulties that must be researched, tested, and developed when developing and choosing alternatives to refrigerants. Also, the risk and the capital investment required to redesign, train, operate, and maintain new refrigeration systems for a large organization like DoD can be significant. Discussing the details of all of these difficulties is outside the scope of this document.[1] However, with these considerations in mind let us now examine current alternatives for refrigeration applications. Table C.3 summarizes the main CFC alternatives in the refrigeration sector, which includes applications likely to interest DoD.

In this table the refrigeration alternatives are divided up by three time frames: immediate/short-term, mid-term, and long-term options. Today immediate and short-term options are available, such as using the transitional substance HCFC-22 as a refrigerant. Mid-term options include alternatives currently in the R&D process that seem most promising and should be available in the near future. Many of the short-term and mid-term options have problems, such as the acute toxicity of ammonia and the ozone depleting potential (ODP) of HCFCs, which limit their widespread use as a long-term solution. Such options may also have degraded performance because the refinement and optimization process for these alternatives and their equipment design has not occurred yet.

This table also summarizes the promising long-term alternatives and the alternatives that are expected to work by retrofitting existing equipment. Most of the long-term solutions mentioned in this table are still in the R&D process since the refrigeration design process is so time consuming. There is still much technical uncertainty about which alternatives will be the best given the numerous trade-off factors in designing refrigeration equipment. Also, it should be stressed that there is not one alternative for all situations. For example, some industrial food processing applications may be able to use the acutely toxic

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[1] For more details on compatibility and other technical issues in designing alternative refrigerants and refrigeration systems see: *CFCs: Today's Options—Tomorrow's Solutions: Proceedings of ASHRAE's 1989 CFC Technology Conference*, September 27–28, 1989; *CFCs: Time of Transition*, 1989; and UNEP, 1991b.

Table C.3

CFC Alternatives in the Refrigeration Section

Refrigeration Sector	Immediate/ Short-Term Option	Mid-Term Option	Long-Term Option	Retrofit
Domestic refrigerators and freezers	Absorption mixtures	Blends HCFC-22 HFC-134a HFC-152a Mixtures	Alternative cycles Ethers HFC-134a HFC mixtures Hydrocarbons	Blends HCFCs
Commercial refrigeration including display cases and vending machines	HCFC-22	Blends HCFC-22 HFC-32 HFC-134a Mixtures	Alternative cycles Ethers Ammonia HFC mixtures HFC-125 HFC-134a	HCFC-22 HFC-134a Mixtures
Cold storage and food processing	Ammonia HCFC-22	Ammonia HCFC-22	Ammonia HFCs	Blends HCFC-22
Industrial refrigeration including chemical, pharmaceutical, and ice making	Ammonia HCFC-22 Hydrocarbons	Ammonia HCFC-22 HFC-134a Hydrocarbons	Ammonia HFCs	HCFC-22 HFC-134a
Chillers	Absorption HCFC-22	Ammonia HCFC-22 HCFC-123 HCFC-124 HFC-134a HFC-152a	Ethers HFCs	Blends HCFC-123 HCFC-124 HFC-134a
Transport refrigeration (truck, ship, rail)	HCFC-22	HCFC-22 HFC-134a Mixtures	HFCs	HCFC-22 HFC-134a Mixtures
Mobile air conditioning		HFC-134a Ternary blend	Alternative cycles HFCs	Blends HFC-134a
Heat pumps (cooling/ heating and heating only)	HCFC-22	Ammonia HC-160 HFC-134a HFC-152a HCFC-123	Ammonia HFCs HC-160	HCFC-22 HCFC-123 HFC-134a

SOURCE: UNEP, 1991c, p. 60.

alternative ammonia while other food processing applications may not because of the proximity of human workers and customers.

To illustrate the trade-off factors that a decisionmaker faces in choosing refrigeration alternatives, consider water chillers used for cooling large buildings. These large air conditioning units are DoD's primary use of refrigerants. Water chillers range in capacity from 7.0 kW to over 35,000 kW. The two main types of water chillers can be classified by the type of compressor that they use, either centrifugal or positive displacement compressors. Centrifugal compressors are used for applications ranging from capacities of 350 kW to over 35,000 kW, while the positive displacement compressors are used for lower capacity applications, the 7.5 kW to 6000 kW range. DoD's water chillers are primarily centrifugal compressor chillers; so we will focus the rest of this discussion on these chillers.

There are four main refrigerants used in centrifugal chillers, depending on their capacity: CFC-11, CFC-12, HCFC-22, and R-500, an azeotropic mixture of CFC-12 and HFC-152a. A special centrifugal chiller refrigerant for DoD is CFC-114, which is used on naval vessels because of ideal properties for operation at sea.[2]

Since the majority of centrifugal chillers in DoD, as well as over 80 percent of the centrifugal chillers in the United States (Smithart, 1992, p. 13), use CFC-11, we will discuss the options that a DoD decisionmaker faces when trying to choose an alternative for his or her CFC-11 chillers. Unfortunately, there are no obvious choices for a simple CFC-11 chiller alternative. No drop-in substitutes are available for existing CFC-11 chillers currently in service. However, a decisionmaker has four basic options available today for choosing a CFC-11 chiller alternative:

1. The first option is to wait. Since these chillers are large capital equipment investments that have an equipment life of 25 years or more and the capital investment required to retrofit, train, operate, and maintain these units can be significant, a decisionmaker may decide to wait a few years before making any changes. This decisionmaker will continue to use the CFC, recycling and reducing emissions as required by EPA regulations, and then switch at some future date to a suitable CFC alternative. This option is highly desirable for decisionmakers whose chillers are fairly new, less than 10 years old, and for which the costs of replacing or trying to retrofit the equipment are extremely high. In such a situation, taking advantage of the capital investment in existing equipment outweighs the benefits in changing this equipment.
2. Use HCFC-123 as a transitional option by retrofitting or buying new equipment. Using HCFC-123 in the place of CFC-11 requires redesign of

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[2] For details on capacity ranges of different refrigerants see UNEP (1991b, p. 141), and the Oak Ridge National Laboratory study in Fischer and Creswick, 1989, pp. 39–40.

some systems, which includes a new motor and gasket material. HCFC-123 is an efficient refrigerant; however, higher flow rates (0–20 percent) are required to generate the same cooling capacity as with CFC-11. Therefore, the cost and compressor size may increase to achieve the same energy efficiency (UNEP, 1991b, p. 141). Another problem with using this alternative is that there is uncertainty about its long-term effects on human health. Exposure limits have been set for its use but the toxicity test evaluations have not yet been fully evaluated.

Technically, many new centrifugal chillers have dual capabilities, which means they are designed to be compatible with both traditional and alternative refrigerants. This capability allows a chiller to be converted to an alternative refrigerant at some point in the future at a much lower cost than with older machines that are not dual capable (Smithart, 1992, p. 2). Buying a dual-capable machine that can use CFC-11 or HCFC-123 can be a desirable option for equipment over 20 years old that needs to be replaced today if no feasible or efficient long-term alternative currently exists for the chiller application.

Energy efficiency cost, costs for the equipment replacement or retrofitting, expected lifetime of the current equipment, and health and safety concerns must all be traded off when choosing to use this option over another option.

3. Another option is to replace the existing chillers with chillers that use an alternative technology that is already in use. This option can be desirable if the equipment is old and needs to be replaced with new equipment in the near future and the decisionmaker wants to invest in a current technology knowing the equipment can be used as it is for 25 years or more. For water chilling, such options that are currently used include ammonia chillers and absorption chillers. Ammonia chillers are used today in large systems that are isolated from the general public because ammonia is a toxic and flammable refrigerant. Such an option is going to be suitable only for specialized applications, such as large isolated refrigerated warehouses. A DoD decisionmaker may find that this option is suitable for some chilling applications and use a different option for others. The advantages of ammonia chillers are that they are energy and cost efficient and there is extensive experience in using them since they have been in existence even longer than CFC chillers.

4. Redesigning which type of chillers are used to cool a space is another option that could be chosen. Instead of using one large chiller to cool a large building, several smaller units might be used. These units might have originally used CFC-12 as the refrigerant of choice. However, since

> HFC-134a is currently available within existing CFC-12 chillers by retrofitting the equipment, HFC-134a could be used in place of CFC-12 in these smaller capacity chillers. There are currently some increases in efficiency and in compressor costs associated with using HFC-134a. However, HFC-134a is currently the most promising alternative for CFC-12 chillers, and the chiller R&D process is seeking to develop better alternatives. Also, the efficiency of HFC-134a-based chillers should continue to improve somewhat over time as systems are optimized for its use. Therefore, some decisionmakers may decide to switch to smaller chillers using CFC-12 immediately while such equipment is still available and then switch at some time in the future to a CFC-12 substitute, either retrofitting for HFC-134a or some other option when it becomes available. Such an option can be desirable if the equipment needs to be replaced now and the decisionmaker wants to choose a new chiller system where an alternative to ODCs currently exists for such equipment, whether or not he or she chooses to use it now, and it is clear that there exists a nontransitional and non-CFC refrigerant that can be used in that equipment for the next 25 years. Calculating all the energy and cost implications of redesigning the cooling system is a key part of assessing the benefits of this option.

For other chiller choices, such as CFC-114 chillers, DoD faces similar types of options and trade-offs. This document cannot address all these options for all the different DoD refrigerants. However, what is important here is the decisionmaking process and how energy impacts this decisionmaking process. The example just provided of CFC-11 chiller options shows how complex a decisionmaking process it can be to choose an alternative and how energy, cost, and timing issues and current uncertainty play such a key role in this process.

Solvent Applications

CFC-113 and methyl chloroform are used in a variety of solvent applications, as was discussed in Appendix A. The main criteria for choosing a solvent alternative is that it cleans the circuit board, machinery, clothes, or other item as effectively as the ODC. The specific cleaning requirements and choice of alternatives will vary depending on the application area. The contaminants and residues that these solvents remove are often grouped as polar, nonpolar, and particulate contaminants, and include items such as dust, salts, oils, and greases. Many solvent alternatives have been rated on their effectiveness for cleaning such contaminants and residues. Table C.4 provides an evaluation for one class of solvent alternatives, organic solvents.

Table C.4

Relative Cleaning Effectiveness of Organic Solvents

	Hydrocarbons and Derivatives			Blends
Contaminants/Residues	Alcohols	Ketones	Aromatics/ Aliphatics	Blend/ Azeotrope
Particulates				
Resin and fiberglass debris	M	M	M	M
Metal and plastic machining debris	M	M	M	M
Dust	M	M	M	M
Handling soils	M	M	M	M
Lint	M	M	M	M
Polar, ionic, inorganics				
Fingerprint salts	E	E	I	G
Rosin activators	E	I	I	G
Activator residues	E	I	I	G
Cutting oils	G	G	I	G
Temporary solder masks/ solder stops	G	I	I	G
Postsoldering salts	I	I	I	I
Residual plating salts	I	I	I	I
Residual etching salts	I	I	I	I
Nonpolar, nonionic, organics				
Resin fixative waxes	E	E	G	E
Waxes	I	G	G	G
Soldering oils	E	E	E	E
Cutting oils	E	E	E	E
Fingerprint oils	E	E	E	E
Flux rosin	E	E	G	E
Markings	I	E	E	G
Hand cream	G	E	G	E
Silicones	I	I	I	I
Tape residues	G	E	E	G
Temporary solder masks/solder stops	I	I	I	G
Organic solvent films	E	E	E	G

SOURCE: Institute of Printed Circuits (IPC), cited in UNEP, 1991c, p. 60.

LEGEND:
E—Effective in dissolving contaminant.
I—Ineffective in dissolving contaminant.
G—Gray area (moderately effective).
M—Mechanical action required.

Evaluating an alternative's cleaning effectiveness is not always a straightforward simple process. At least 11 different techniques can be used to quantify solvent cleaning effectiveness. These techniques range from visual examination to gravimetric, ferrocyanide paper, and radioactivity analysis techniques (McCullough and Gold, 1992, p. 4–5). When evaluating such test results, a user must determine what level of cleanliness is acceptable and how close to the performance of the ODC the alternative must be. For example, is alcohol's moderate effectiveness on cutting oils (see Table C.4) good enough for the application? For many DoD applications, such as cleaning of delicate electronics weapons equipment, such an effectiveness level is not good enough since many DoD uses require high standards of reliability and durability for operation under hostile conditions. Because of DoD's high cleaning standards, which are incorporated into the MILSPECs, the MILSPECs are often used as the standard within the commercial world as well. For example, the MILSPEC solvent standard for removing RMA flux (i.e., rosin, mildly activated flux) has become the industry standard.

Health, safety, and environmental factors are also major concerns in finding a solvent alternative. One of the main reasons CFC-113 has been used so extensively as a solvent, besides its being well matched to the cleaning tasks in which it is used, is that it has a low toxicity level, it is not a carcinogen, and it does not contribute to photochemical smog. Methyl chloroform is not quite as safe; it has medium to low toxicity and is being tested as a possible carcinogen but may be better than other chlorinated solvents in these regards. Other chlorinated solvents, like TCE, METH, and PERC, have historically been used in many of the same applications as CFC-113 and methyl chloroform. However, these three solvents all have health, safety, and environmental hazards. TCE has medium toxicity, is a suspected carcinogen, and contributes to the formation of smog. METH has medium toxicity and is a suspected carcinogen. PERC has medium toxicity, is a suspected carcinogen, and is regulated as a contributor to photochemical smog. Using any of these three solvents as an alternative can require special operating procedures because of federal, state, and/or local regulations regarding air emissions, worker safety, and waste treatment and disposal. The cost and risk of these factors are key trade-off issues when considering alternatives.

Energy concerns can be another factor for choosing a solvent alternative since energy implications of selected alternatives can be significant. However, energy effects have been only a tertiary concern behind the effectiveness, health, environmental, and cost issues for most researchers and decisionmakers in government and the private sector. For example, under the EPA SNAP program the matrix of key factors being used to evaluate CFC-113 and methyl chloroform alternatives in metal and electronic cleaning operations does not directly include energy. It includes health, environmental, safety, and cost concerns. One of the environmental factors is the global warming potential, which includes the "indirect energy effect" that we discuss in Section 7.[3]

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[3] The specific factors in the matrix are: releases to the environment, toxicity concerns, worker exposure, chlorine loadings, ODP, GWP, flammability, volatile organic compound (VOC) concerns, and cost concerns (Illig and Weisman, 1992, p. 13).

Given all of these different issues, it is not easy to choose an alternative for a given solvent use. However, many alternatives have been developed and continue to be developed for all of the different uses. Table C.5 summarizes the main alternatives for CFC-113 and methyl chloroform that currently exist in main solvent application areas for DoD.

To illustrate how the various trade-off factors affect DoD's choice of solvent alternatives, consider the electronics industry application area of defluxing. Defluxing is the removal of residue from assemblies after soldering. An example of this application for DoD occurs in the maintenance of electronic equipment when printed circuit boards are repaired. CFC-113 has historically been the main solvent of choice for defluxing.

Table C.5

Solvent Alternatives for Main Application Areas for DoD

Solvents Sector	Substitutes and alternatives for CFC-113	Substitutes and alternatives for 1,1,1-trichloroethane
Electronics cleaning	• No-clean (low-solid fluxes, controlled atmospheric soldering) • Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Organic solvents • Chlorinated solvents • HCFCs • Conservation and recycling	• No-clean (low-solid fluxes, controlled atmospheric soldering) • Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Organic solvents • Chlorinated solvents • HCFCs • Conservation and recycling
Metal cleaning	• Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Petroleum distillates • Chlorinated solvents • HCFCs • Conservation and recycling	• Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Petroleum distillates • Chlorinated solvents • HCFCs • Conservation and recycling
Precision instrument cleaning	• Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Perfluorocarbons • Organic solvents • Aliphatic hydrocarbons • Chlorinated solvents • HCFCs • Super-critical fluids • Conservation and recycling	• Aqueous cleaning • Hydrocarbon/surfactant-based solvents • Perfluorocarbons • Organic solvents • Aliphatic hydrocarbons • Chlorinated solvents • HCFCs • Super-critical fluids • Conservation and recycling

SOURCE: UNEP, 1991a, p. 2-9.

There are six main types of alternatives to current use of CFC-113 that a decisionmaker can choose from for defluxing:

1. The first option that a DoD decisionmaker might choose today is to continue to use CFC-113, recycling and reducing emissions as much as possible, and then switch at some later date. This option can be desirable if more aggressive options, discussed below, are not available or judged too costly for the specific application area and if promising new alternatives are about to be developed. Many private electronics companies, such as Intel, Toshiba, and Apple Computer, had planned to phase out their use of CFC-113 by the end of 1992, suggesting that viable alternatives exist for many applications of CFC-113.[4] DoD, of course, has requirements in certain critical applications of CFC-113 far more demanding than those found in the private sector.
2. A more aggressive option uses an alternative chemical such as an HCFC or HCFC blend. Promising HCFC alternatives include: HCFC-123, HCFC-141b, HCFC-225ca, and HCFC-225cb. With these HCFCs, as well as with the HCFC blends, there is uncertainty about their long-term toxicity, which is currently being investigated. Also, they can only be used as interim solutions because they are classified as transitional substances that have positive ODP. Because of these limitations, the HCFCs and their blends should only be used in applications where the equipment limits their emissions to acceptable levels and there is no acceptable alternative available (UNEP, 1991c, p. 68).
3. A third option uses an alternative to ODC solvents, such as a chlorinated or organic solvent. As we have already mentioned, the chlorinated solvents require special procedures because of their health, safety, and environmental hazards, which are well known and carefully regulated. Such solvents are only attractive in applications where the emissions throughout the entire cleaning process are carefully controlled.

   Organic alternative solvents include: ketones, aromatics, aliphatics (mineral spirits), and alcohols. These solvents can cause problems because they are flammable, volatile, and contribute to global warming. Using such alternatives could incur a cost increase because of equipment and/or system changes and special training and operational procedures for the new system. Because of local regulations, they may not even be feasible for many applications. However, if used in small amounts in well-ventilated areas for specific applications they can be effective and cost-efficient alternatives. For

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[4] See UNEP, 1991c, p. 18-20, for specific solvent reduction and phase-out policies of 36 industry solvent users.

example, pure isopropanol effectively cleans RA (rosin activated) fluxes to current military standards (UNEP, 1991c, p. 58).

The energy associated with using these solvents would be similar to the current uses of CFC-113.[5] In choosing to use one of these solvent alternatives, the predominating issues are cost, safety, health, and environmental risks and procedures.

4. Concern over environmental effects of chlorinated solvents has stimulated great interest in a third option: the use of aqueous cleaning methods. Such methods require using water-soluble fluxes and solder pastes that can be cleaned by water with or without an additive. There are two main cleaning alternatives with this option: (a) completely water-soluble fluxes and water cleaning and (b) rosin fluxes with a saponifier[6] and water cleaning. Water removes ionic contaminants and water soluble flux residues. Water, with a saponifier additive, removes nonpolar and weakly polar contaminants such as some oils, rosin, and carboxylic acid activators.

   Such aqueous cleaning methods usually consist of the reactive cleaning, rinse, and drying stages by using batch machines that are similar to household dishwashers, mechanized brush cleaning machines, or other types of batch and conveyorized machines. This process, like a household dishwasher, can have high energy costs because of the energy required throughout this process. The energy is needed for the mechanical agitation, water heating, and drying requirements. Another disadvantage of this method includes the need for wastewater treatment and disposal. Also, there may be higher capital costs for this alternative because it may require purchasing new equipment. However, for many applications aqueous cleaning is a cost-effective, though energy-intensive, alternative. When comparing and costing alternatives the DoD decisionmaker needs to be sure that he or she does not leave out the energy concerns for this option.

5. A related option is semi-aqueous cleaning. Semi-aqueous cleaning uses rosin and synthetic activated fluxes with a hydrocarbon/surfactant solvent blend and water cleaning. This process is a two-phase cleaning process. First, the hydrocarbon/surfactant solvent blend is used to clean the item. Then, the item is water washed and rinsed to remove the residues of the blend and any other water-soluble soils. Two rinses may be required as part of this process. Drying of the item is usually required as well. The surfactant, a chemical

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[5] Energy use could be slightly higher in vapor degreasing applications that use solvents with higher boiling points, like perchloroethylene and trichloroethylene. Appendix E addresses these in more detail.

[6] A saponifier is a chemical that is designed to react with organic fatty acids such as rosin, greases, and oils to create a water-soluble soap.

that reduces surface tension of water, ensures the water-solubility of the normally insoluble hydrocarbon.

This process uses flammable fluids such as terpenes and alcohols. Therefore, it requires special safety procedures and equipment that can increase the cost of using this alternative. It also requires strict environmental procedures to minimize air emissions since the blends are VOCs. The wastewater from this process also requires treatment before disposal. Another disadvantage of this method is its energy implications. Like aqueous cleaning, semi-aqueous cleaning can incur significant energy use because of the energy required in the wash, rinse, and drying processes. However, semi-aqueous cleaning has more safety and cost implications because of its flammability problem.

Despite the safety and environmental factors and energy increase associated with this method, it can be an effective option for some applications. DoD decisionmakers should be sure to consider the energy costs for semi-aqueous, as with aqueous, cleaning methods before choosing such an alternative. They are the worst alternatives from an energy standpoint.

6. The ideal current option is to change the system so that a solvent is no longer needed for defluxing. In some soldering applications, no-clean flux methods are effective alternatives. Such methods include low-solid fluxes in "no-clean" assembly, high-solids rosin-based fluxes without postsolder cleaning, and controlled atmosphere soldering. Some of the technical problems with this option can be higher levels of residue, equipment redesign requirements, and adhesion problems. Also such an option is only feasible for certain types of applications. However, for those applications where no-clean methods work, they are highly desirable because they are cost efficient, have no energy penalties, no solvent emissions to contain, nor any solvent wastes to process and dispose of.[7] Unfortunately, this option becomes available only as new items are designed for use in DoD. For the foreseeable future, most of DoD's solvent use will involve existing designs since the solvents are used to clean electronics boards that are already in circulation.

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[7] For more information on limitations and uses of no flux alternatives see UNEP, 1991c, Section 2.3.5.

Appendix D

DoD's Response to the Regulation of Chemicals That Deplete Ozone

In response to the approval of the Montreal Protocol, in February 1989 the Office of the Secretary of Defense issued Directive 6050.9 establishing DoD policy on CFCs and halons and the responsibility of managing these chemicals within DoD. After the passage of the Clean Air Act Amendments in 1990 and the London Amendments to the Montreal Protocol this DoD directive was revised to include HCFCs, methyl chloroform, and carbon tetrachloride. This DoD directive established DoD's long-term goal of eliminating dependence on ozone depleting chemicals and outlines plans for achieving this goal. This section summarizes this DoD plan and steps that have been taken to implement it. First, it provides a general overview of DoD's policies regarding CFCs and other ozone depleting chemicals. Second, it discusses the prioritization of DoD uses of these chemicals and the scheduled reductions for these chemicals. Third, it discusses R&D efforts and some of the individual services'[1] responses.

DoD Policy Statements and Recommendations

In Directive 6050.9 each of the military services was directed to take a series of actions to reduce its current emissions of ODCs. These actions included: using currently available recovery and recycling techniques, modifying operational training and testing procedures, incorporating minimization techniques in new system designs, and developing and using acceptable substitutes to meet mission requirements. This directive also stated that a system for documenting the level of dependence on ODCs was to be developed and required that each of the services submit an annual report on the amounts of ODCs procured during the previous year.

Usually a DoD directive is accompanied by specific implementation requirements on quantitative goals. Such implementation requirements do not accompany this directive. However, each of the services issued directives to

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[1] The term services refers to the U.S. Air Force, Army, and Navy, including the Marine Corps.

begin implementing the DoD directive. These directives outline responsibilities and policies to reduce use and emissions of ODCs. They do not mention anything about the cost or the energy implications of such policies. These directives are discussed in more detail near the end of this section when we discuss individual services' responses.

To help implement this DoD directive, at the end of 1989 the DoD Chlorofluorocarbon Advisory Committee was established by the National Defense Authorization Act. This committee's purpose was to study the use of ozone depleting chemicals by DoD and defense contractors and to help speed the phaseout of these uses by investigating the cost and feasibility of potential substitutes and establishing specific elimination goals for DoD. The committee presented its findings to the Senate and House Committee on Armed Services in July 1991. These recommendations dealt with contracts and military standards modifications, R&D, education and technology transfer, materials management, and compliance. We can only touch upon some of these recommendations within this report.[2] Within the DoD CFC Advisory Committee's final recommendations there was no mention of energy concerns and only minimal discussion of cost issues. This committee did not address the energy or energy cost implications of eliminating the use of ODCs within DoD.

Prioritization of DoD Uses

DoD has developed a target schedule for reducing emissions and phasing out the use of ODCs for different usage categories based on the potential availability of substitutes and the priority of the individual DoD use. Uses that are essential to national security, namely mission-critical uses, will be phased out last and only as suitable substitutes are developed. Uses that are considered nonessential to national security, such as residential air conditioning, will be phased out first.

Assessing which uses of ODCs are essential to national security and which uses are nonessential needed to be completed before specific elimination goals could be established. Therefore, we will describe the usage classifications before discussing DoD's schedule of goals. To establish a prioritization of usage, military uses of ODCs were categorized into three main types:

Category I: Mission-Critical Use—These uses have a direct impact on combat mission capability. This category includes uses that are integral to combat missions or affect operability of combat assets. Examples of mission-critical uses

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[2] This committee issued a report of its findings, see DoD CFC Advisory Committee Report, 1991.

include: cooling operational assets and fire and explosion suppression systems on board aircraft, vessels, and vehicles to protect the lives of mission-critical personnel.

Category II: Essential Use—These uses are those applications that have an indirect effect on combat missions. They play an auxiliary role in ensuring the operability of those assets. Examples of essential uses include: process cooling applications and portable fire extinguishers for area protection of electronics.

Category III: Nonessential Use—These uses are considered nonessential to the military mission. Examples of nonessential uses include: comfort cooling in family housing and installation support activities.

The Army, Navy, and Air Force each categorized its individual use of ODCs. Table D.1 presents a summary list of the services' mission-critical uses by chemical type. All three services classified halons as a mission-critical application in fire protection and suppression. Halons are the only ODCs prioritized as mission critical by all three services.

The only mission-critical uses with potentially significant energy implications are the Navy's and Air Force's use of CFC-11, CFC-12, and CFC-114 for shipboard and aircraft refrigeration and chilling and the Navy's use of CFC-113 and methyl chloroform for different types of solvent cleaning.

The three services clearly used different principles to assign activities to these three categories. The Army used a very narrow definition of mission critical while the Navy used a broader definition. A General Accounting Office (GAO) study questioned the inconsistency of the category classifications between the different services and stated that the mission-critical definition is "vague" (U.S. Congress, 1991, p. 20).

DoD Schedule for Ozone Depleting Chemical Reductions

DoD has developed a target schedule for reducing emissions and phasing out the use of ODCs for each of these different categories based on the potential availability of substitutes and the priority of the individual DoD use. Since mission-critical uses are essential to national security, these uses will be phased out last and only as suitable substitutes are developed. In fact, as was noted earlier in this document, there is a special exception for such mission-critical uses in the CAAA. Table D.2 presents a summary of DoD's goals for reducing emissions and use of ODCs.

Table D.1

Summary of Services' Mission-Critical Uses

Service	ODC	Mission-Critical Use
Air Force	CFC-11 and CFC-114	Aircraft cooling systems, examples: for RC-135 V/U, C-12, T-1a, EC-18B, E-8A Active cooling of airborne weapons pods, such as the PAVE TACK, LANTIRN, and ECM Pods
	Halon 1301	Aircraft airframe and engine halon fire protection and fuel tank inerting systems
Army	Halon 1301	Explosion suppression for crew and turret areas of the Abrams tank, Bradley fighting vehicle, and Sheridan light tanks, armored gun systems
Navy	CFC-12	Refrigerant on ships and aircraft Sterilization of heat-sensitive medical equipment Cleaning agent for electrical circuit boards by shipyards
	CFC-114	Shipboard chilled water plants to cool electronics, weapon systems, and other shipboard uses E-2C Early Warning aircraft radome cooling
	CFC-113 and methyl chloroform	Electronics and oxygen/nitrogen gas cleaning Hydraulic patch test and electrical contacts Missile guidance cleaning, ordnance production and maintenance, and aircraft maintenance Repair shops as cleaning agent for electronics and other components
	Halon 1211	Aircraft firefighting activities
	Halon 1301	Fire suppression protection on board ships, onshore vital electronic and control spaces, and aviation applications

SOURCE: DoD CFC Advisory Committee Report, 1991, p. 31-34.

How do these goals compare with CAAA requirements to reduce emissions and production of ODCs? DoD's goals for phasing out current applications to the 50-percent level are the same or even earlier for nonessential and mission-essential uses than the CAAA's restrictions on production. However, for DoD mission-critical uses of CFCs, DoD's 50 percent reduction goals exceed the CAAA's 50 percent production reduction requirement by two years and for halons it exceeds it by one year. This difference means that DoD will have to create a bank for such chemicals to be sure they are available or that DoD assumes that it will still be able to buy such chemicals. If such chemicals are still available, they will probably be available only at a much higher price because of limited supply. DoD's goal for reducing uses to zero in all application areas is earlier or the same target as the CAAA's total elimination of ODC production.

Reduction goals will be achieved by conservation, recycling, and substitutions where alternative substitutes already exist. Achievement of the targeted elimination deadlines depends on the availability and development of suitable substitutes. Given current technical knowledge of potential alternatives, are

Table D.2

DoD's Goals for ODC Reductions

Category	Milestones to				
	Institute Plans to Reduce Unnecessary Releases During Operation, Maintenance, and Training	Institute Plans to Eliminate Procurement and Use	Stop Use in New Procurements	Phase Out Current Applications to 50 Percent of 1986 Levels	Reduce Use in All Applications to Zero[a]
CFCs					
Nonessential	October 1990	January 1992	January 1993	January 1993	January 1994
Mission essential	October 1990	January 1993	January 1994	January 1995	January 1996
Mission critical	October 1990	January 1994	January 1996	January 1998	January 2000
Halons					
Nonessential	October 1990	October 1990	October 1990	Not available	January 1994
Mission essential	October 1990	October 1990	October 1990	January 1993	January 1996
Mission critical	October 1990	October 1990	January 1995	January 1997	January 2000
Methyl chloroform					
Nonessential	January 1992	January 1992	January 1993	Not available	January 1993
Mission essential	January 1992	January 1992	January 1993	January 1994	January 1995
Mission critical	January 1992	January 1994	January 1995	January 1996	January 2002
Carbon tetrachloride					
Nonessential	January 1992	January 1992	January 1993	Not available	January 1993
Mission essential	January 1992	January 1992	January 1993	January 1995	January 1996
Mission critical	January 1992	January 1994	January 1995	January 1995	January 2000
HCFCs					
Nonessential	January 1992	Not available	Not available	Not available	Not available
Mission essential	January 1992	Not available	Not available	Not available	Not available
Mission critical	January 1992	Not available	Not available	Not available	January 2015

SOURCE: U.S. Congress, 1991, p. 16.

[a] Except for recycled material use.

DoD's elimination goals realistic? According to the technically feasible phaseout dates discussed in the UNEP Technology and Assessment Panel Report, DoD's phaseout goals are realistic except perhaps for halons.[3] Since substitutes for halons are so hard to find and they are mission-critical uses for DoD, DoD may still have to use halons after the year 2000. For such mission-critical uses of halons DoD would have to create a halon bank.

DoD has taken some initial steps to meet these reduction goals. For example, Army policy prohibits the procurement of new halon fire extinguishing systems and portable extinguishers, except for mission-critical uses. However, specific data was unavailable as to how successful they have been at meeting these goals. GAO felt that not enough progress had been made to meet these goals. For example, GAO found that DoD is continuing to install equipment that uses ODCs into new aircraft and ships (U.S. Congress, 1991, p. 25). These two examples illustrate how some progress and decisions are being made about substitutes for ODCs in procuring new equipment and systems, but that many decisions have not yet been made, nor steps taken to change procurement procedures. Therefore, if energy considerations are not being considered within these decisions, there is still a chance to include energy policy within this process.

Another key factor in reaching these goals is the revision of the MILSPECs. The MILSPECs are the technical requirements specified in military contracts. The DoD CFC Advisory Committee estimates that 500 military and federal specifications directly specify the use of ozone depleting chemicals and that another 9000 MILSPECs do not directly require these substances, but cannot be met without using ODCs.[4] These MILSPECs need to be revised to specify the available substitutes for ODCs, which is a very time-consuming process and can be quite costly. Unfortunately, for an individual MILSPEC revision the process can take anywhere from 3 months to 3 years. The GAO report (U.S. Congress, 1991) criticized the fact that the DoD MILSPEC revision process for ODCs has been so slow. The DoD CFC Advisory Committee acknowledges this problem when it is necessary to make speedy changes to the MILSPECs and makes recommendations about speeding up this process. These recommendations include: MILSPEC prioritization; adopting industry nongovernment standards, since industry is already using substitutes in many of its formerly ODC-dependent processes such as electronics cleaning; and developing special MILSPEC teams focusing on revisions pertaining to ODCs.

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[3] UNEP, 1991a, pp. 2-5, 2-6, 2-10, 2-12, and 2-15.

[4] DoD CFC Advisory Committee Report, 1991, p. 36.

At this time, we do not know if any of these suggestions have been implemented or whether or not energy implications of substitutes will be considered when revising the MILSPECs. However, we do know that DoD is participating in a joint effort with industry and other federal agencies to revise the MILSPECs for electronics cleaning. The Military Electronics Technology Advisory Group (METAG) addresses national technical and policy concerns regarding military electronics technologies. METAG has a subgroup investigating alternatives for electronics cleaning. This subgroup has also begun reviewing MILSPECs and standards with respect to ODCs. Also, in February 1991 MILSPEC MIL-STD-2000 was approved. This MILSPEC recommends that CFC solvents be phased out and conditionally permits the use of non-rosin fluxes and alternatives to ODC solvents and cleaning processes for most electronics assembly and retroactively for existing contracts.[5]

Within the DoD CFC Advisory Committee's report there was only a brief mention of energy efficiency being an environmental concern when discussing alternatives to ODCs and the MILSPEC revisions.[6]

To meet mission-critical needs until alternatives become available DoD proposed a plan in October 1990 to develop a CFC and halons bank to store sufficient quantities of these chemicals for such uses. If needed such a bank can be created from recycling the chemicals from old equipment when it is retired and from bulk purchases prior to the production phaseout. Such strategic reserves will ensure the availability of these chemicals for DoD mission-critical uses beyond the scheduled phaseout dates for these chemicals. Such reserves will be used only until suitable substitutes are available and usable within all DoD processes and equipment.

Research and Development Efforts

Directive 6050.9 states that DoD conduct R&D programs as needed to support mission requirements. DoD has begun such R&D efforts, both in house and jointly with the commercial sector. DoD has been depending on private industry to develop alternatives for commercial uses that are similar to DoD uses. DoD has focused its internal R&D efforts on mission-critical applications where no substitutes exist and there is inadequate commercial research. The DoD CFC Advisory Committee recommended in its report issued in July 1991 that DoD increase priority of R&D efforts investigating ODC alternatives and coordinate

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[5] UNEP, 1991c, p. 24.

[6] DoD CFC Advisory Committee, 1991, p. 36.

R&D programs within the services and other government organizations such as EPA and DOE.

DoD has been participating in various joint efforts with private industry to find alternatives for ODCs. Such efforts include working with the Ad Hoc Solvents Working Group to find solvent alternatives and the Halon Research Corporation to find halon alternatives. Another joint effort is the Industry Cooperative for Ozone Layer Protection (ICOLP). The ICOLP is a consortium of industry and government that is collecting and disseminating information on alternatives for ODCs. One of their projects was creating the electronic database, OZONET. This on-line worldwide database provides ODC users with information on substitute technology, processes, and chemicals. The Air Force has signed a memorandum of understanding to be able to provide OZONET technical information directly to its technical centers as well as providing OZONET access to all DoD components. The DoD CFC Advisory Committee recommended that DoD investigate the feasibility of adding MILSPEC information to OZONET.

The individual services have begun R&D efforts to test and evaluate potential ODC alternatives for mission-critical uses unique to the military. For example, the Navy funded a National Institutes of Standards and Technology study to analyze the potential suitability of ether-134 (E-134) as a CFC-114 substitute on shipboard cooling plants. GAO has stated that such efforts have not gone far enough and have been limited by funding priorities. GAO states that more funding priority needs to be given to such R&D programs (U.S. Congress, 1991, p. 24).

Individual Services' Responses

The Air Force, Army, and Navy have all taken steps to begin implementing DoD Directive 6050.9 and the reduction of their use and emission of ODCs. Each service issued its own implementation policies similar to DoD Directive 6050.9. Within this section we will provide examples from some of these policies to illustrate how each of the services has begun efforts to phase out ODCs. These examples focus on specific activities that each service has taken to restrict the use of ODCs and change operational procedures to eliminate ODC uses.

The Air Force issued AF Regulation 19-15, "Reduction in Use of Chlorofluorocarbons (CFCs), Halons, and Other Substances that Deplete Stratospheric Ozone" to implement DoD Directive 6050.9. This regulation's policy includes statements that the Air Force will: modify procedures, military specifications, and technical orders to expedite the adoption of appropriate ODC replacements; in the short term use ODCs with lower ODPs where substitutes for ODCs are not yet available; implement recovery, recycling and reuse procedures; and comply with the CAAA and other EPA regulations relating to ODCs. This regulation also specifies responsibility for implementing this policy. For example, each major command (MAJCOM) must develop and implement a formal plan to meet the reductions schedule outlined in DoD Directive 6050.9 while the Deputy Chief of Staff, Logistics, must develop procedures for adopting ODC alternatives in weapons and weapons system maintenance activities.

The Air Force has also issued other implementation statements to reduce its dependency on ODCs, such as Engineering Technical Letters. The Air Force issued an Engineering Technical Letter requiring the use of HCFC-22 in place of CFCs where available as a substitute. The Air Force placed restrictions on the use of halons, such as the purchase of portable halon 1211 extinguishers except for use on board aircraft.

Individual Air Force bases have also begun efforts to implement these directives by developing plans to reduce emissions and use of ODCs and beginning to implement such plans. For example, McClellan Air Force Base has conducted and documented a study to identify and evaluate alternatives to reduce or eliminate its use of ODCs. For this study McClellan inventoried its 1990 uses of ODCs, reviewed all regulations and timelines for phaseout, evaluated potential alternatives, and made recommendations for implementation. The base has begun to implement the recommendations of this study. Such implementation efforts include: Refrigerant recycling systems are being installed; free spray processes that have used CFC-12 are being phased out; and an automated aqueous cleaning machine for circuit board defluxing has been installed at the base's printed wireboard facility, reducing emissions of CFC-113 by over 1000 lbs in 1991. The base has also identified key areas where stockpiling may be necessary, such as stockpiling CFC-113 and its azeotrope CFC-503 for important specialized equipment with low chemical usage rates. Energy implications were not really addressed within this evaluation process nor within this implementation process.[7]

The Army issued the policy statement DAEN-ZCZ-A, "Eliminating or Minimizing Atmospheric Emissions of Ozone-Depleting Substances" in the summer of 1990. This statement echoes many of the policy statements of DoD Directive 6050.9 and outlines specific responsibilities within the Army for implementing such policies. For example, it states that the Deputy Chief of Staff

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[7] For the evaluation criteria and implementation details of the McClellan Air Force Base study see Beekley and Lankford, 1992.

for Operations and Plans must develop policy for operational procedures and training for Army personnel on the proper conservation techniques when using ODCs, while U.S. Training and Doctrine Command must develop programs of instruction for minimizing emissions and use of ODCs during training and the major Army command (MACOM) commanders must modify existing operational procedures to minimize or eliminate the emissions of these chemicals. This policy statement also prohibits the disposal of ODCs by direct release into the atmosphere.

The Army also adopted a policy that prohibits the procurement of new cooling and refrigerations systems that use CFCs as the refrigerant and a policy that prohibits the procurement of new halon fire extinguishing systems and portable extinguishers except for mission-critical uses. The U.S. Army Corps of Engineers issued an Engineer Technical Letter that provides criteria and restrictions on the use of halon fire extinguishing agents in buildings and structures.

The Navy issued OPNAV Instruction 5090, "Management of Ozone Depleting Substances," for implementing DoD Directive 6050.9 and assigning responsibilities for its implementation. For example, this instruction specified that commanding officers ashore and afloat must adopt conservation practices, such as substitution and recycling of ODCs, where possible; and establish procedures and modify training and testing practices to eliminate emissions of ODCs. The Navy has also begun modifying some Navy specifications that require CFC-113 as a solvent to specify suitable alternatives instead.

The Navy has also started testing and evaluating refrigerant alternatives for use on some of their vessels. For example, they have retrofitted three 80-ton air-conditioning plants aboard the FFG-45 guided-missile frigate USS Dewert to replace CFC-12 with HFC-134a. Similar retrofits have been made on another vessel. After a 6- to 12-month test period during normal operations, they are going to evaluate the effectiveness of these replacements and then begin buying equipment to retrofit all of the fleet's CFC-12 chilled water-plants (*Defense News*, May 25–31, 1992, pp. 22–23).

Clearly, each of the services have taken some initial steps to restrict the use of ODCs and their emissions. Some of these activities are decisions about substitutes that have potential energy implications for DoD. Such decisions are continuing as new alternatives are developed.

Appendix E

How Replacing Chemicals That Deplete Ozone Affects Energy Use: Recent Studies

This appendix first examines how the principal clearing house for information on alternatives to ODCs, the UNEP, treats energy effects. It then reviews the two key studies that examine the energy effects of eliminating ODCs in detail, one by Oak Ridge National Laboratory and the other by AFEAS, a comprehensive group that includes all the major private organizations developing alternatives to ODCs, and DOE.

United Nations Environment Programme Reviews

Technology is moving so fast that information on alternatives to ODCs becomes dated rapidly. To keep up with this change, UNEP has set up international technology panels for each major application area to review available information periodically. These periodic reports have provided the most complete assessments of all factors relevant to alternatives to ODCs. Energy considerations have played what can only be characterized as a minor role in these reviews. For example, the 1989 report of the UNEP Technology Review Panel highlights energy in only two situations that might be relevant to DoD's goals to reduce energy use.[1]

The first is home refrigeration, where the review suggests that losses in energy efficiency could increase energy consumption enough to aggravate global warming concerns, even if the use of CFCs fell to zero.[2] But insufficient data were available to determine how serious this threat is. The second is the substitution of aqueous cleaning systems for systems that use CFC-113 and methyl chloroform. Such substitution increases energy consumption; the report offers no quantification (UNEP, 1989, p. 78).

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[1] The report also identifies potentially important energy effects associated with insulation but does not attempt to quantify these. Presumably, heavier applications of insulation could overcome increases in thermal conductivity in most applications. See UNEP, 1989, p. 68.

[2] UNEP, 1989, pp. 29 and 478. Increased energy consumption would increase the use of carbon-based fuel, increase carbon dioxide emissions, and hence could aggravate global warming if the increase were large enough relative to the elimination of CFCs.

These observations presumably reflect three factors. First, because ODCs have dominated the applications in which they have been used so thoroughly, few engineering data are available on how much energy alternatives might require. Second, based on theoretical considerations, engineers conjecture that changes in energy use are likely to be small in most circumstances. This belief probably lies behind the dearth of engineering studies; changes in energy use were not considered a serious enough matter to investigate in most circumstances. Third, other factors are far more important to driving the choice among alternatives. The technical characteristics relevant to engineering performance and regulation are probably far more important than energy considerations in most choices.

The most recent UNEP review of technology and economics confirms the relevance of such considerations (UNEP, 1991a). Again, changes in energy use associated with alternatives to ODCs receive far less attention than other factors.

The review reports that data collected since 1989, when HCFC-123 first became available for use in chillers, indicate that HCFC-123 is as energy-efficient as the ODC that it replaces, CFC-11 (UNEP, 1991b, p. 141). Recent data on HFC-134a used to replace CFC-12 and R-500[3] in chillers indicate that HFC-134a is less energy efficient than these ODCs; the review does not quantify this statement (UNEP, 1991b, p. 141). The source for this statement shows that the change varies widely by application, but is generally very small; we return to this question below.[4]

Similarly, the study reiterates that aqueous and semi-aqueous systems can use more energy than CFC-113 and methyl chloroform systems and provides a few quantitative illustrations to make the point. It also notes that carefully planning operations, selecting operating cycles, and using recycled (hot) water and heat recovery can limit and even reverse this effect (UNEP, 1991c, p. 915).

Even this more detailed information, however, is overwhelmed in the UNEP review by discussions of more influential factors. More generally, the review defers repeatedly to the ongoing AFEAS/DOE study as the best source of information on how energy use might change as alternatives are substituted for ODCs. Let us turn now to Oak Ridge National Laboratory's initial work on the energy effects of substitution and the AFEAS/DOE study that grew out of this work.

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[3] R-500 is an azeotropic blend of CFC-12 and HFC-152a.

[4] The source is an Oak Ridge National Laboratory working paper, prepared for the AFEAS/DOE study, discussed below.

Oak Ridge National Laboratory and AFEAS/DOE Studies

S. K. Fischer and F. A. Creswick of Oak Ridge National Laboratory completed a study for the DOE in 1989 that represents the first systematic attempt to quantify how a switch from CFCs to alternatives would affect energy use in the United States (Fischer and Creswick, 1989). The lack of refined engineering data at the time meant that Fischer and Creswick had to rely heavily on expert opinion. By feeding this expert opinion into a systematic accounting framework, however, they were able to develop useful conclusions and explain clearly the basis for these conclusions. Looking across the inputs from many experts, they found that substitution was likely to have a small effect on aggregate energy demand in the United States.

Table E.1 summarizes their key findings. It reports, in quads,[5] how much energy use would rise in a variety of end uses relevant to CFCs under four sets of assumptions about alternatives to CFCs. End uses are limited to refrigeration and insulation applications. The near drop-in technology case assumes that HCFC-123 and HCFC-141b replace CFC-11 in appropriate uses, with minor changes in the processes themselves to accommodate the new chemicals, and that HFC-134a replaces CFC-12 in a similar way. The fallback case assumes that regulatory concerns prevent the use of near drop-ins and requires the use of HCFC-22 as a refrigerant and Extruded Polystyrene insulation as a substitute for CFC-blown insulation foams. The worst case assumes that regulators prohibit use of HCFC-22 and Extruded Polystyrene insulation as well, forcing the United States to fall back on other currently available systems like gas-fired absorption chillers for chillers and fiberglass and fiberboard as insulation. The advanced technology case is applied selectively where sufficient data are available to specify likely options. They include things like Stirling and absorption refrigeration cycles and vacuum panels for insulation.

The numbers in Table E.1 are hard to interpret without some way to scale them relative to total energy use in each end-use area. Unfortunately, total use in each area is not known. But we can aggregate the categories in a slightly different way to compare the results with what we do know about national energy use. Table E.2 aggregates the categories into three major categories often used to

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[5] Quadrillion Btu, a standard unit of large-scale energy use.

Table E.1

Summary Results of the 1989 Oak Ridge Study [additional energy used (in quads)]

Application	Near Drop-ins	Fall-back	Worst Case	Advanced Technology
Equipment	0.12	0.61	1.43	–0.72
Centrifugal chillers	0.01	0.03	0.36	—
Retail refrigeration	–0.01	–0.01	0	–0.05
Refrigerators, freezers	0.10	0.52	0.92	–0.58
Water heaters	0.01	0.04	0.09	–0.06
Vending machines	0.01	0.03	0.06	–0.03
Building envelopes	0.06	0.34	0.65	–0.12
Residential walls	0.01	0.02	0.05	–0.04
Residential foundations	0	0.17	0.32	—
Commercial walls	0.02	0.04	0.08	–0.08
Low-slope roofs	0.03	0.11	0.20	—
Transportation	0.03	0.05	0.10	0.01
Mobile air conditioning	0.03	0.04	0.08	0.02
Refrigerated	0	0.01	0.02	–0.01
Total	0.21	1.00	2.18	–0.83

SOURCE: Fischer and Creswick, 1989, p. xxiv.

NOTE: For an explanation of the four cases shown in the columns, see the text.

Table E.2

Percentage Changes in Net Energy Use, by Use Category

Application	Total Net Use (Quads)	Near Drop-ins (%)	Fallback (%)	Worst Case (%)	Advanced Technology (%)
Commercial/Industrial	26.5	0.26	0.91	2.98	–0.83
Transportation	20.8	0.14	0.24	0.48	0.05
Residential	8.4	1.31	8.45	15.36	–0.74

SOURCE: Net use calculated from DOE data reported in the *Monthly Energy Review and Statistical Abstract*. Percentage changes calculated from net use and changes reported in Fischer and Creswick, 1989.

study national energy use.[6] The first column shows net U.S. energy use in 1986, the relevant base year for these data, for each category.[7] The remaining columns express increases in energy use as a percentage of this level of usage. Note that

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[6] It groups the two transportation end uses into the transportation category; the refrigerator/freezers, water heater, residential walls, and resident foundations into the residential category; and the remaining end uses into the commercial/industrial category.

[7] Gross use includes all energy used to satisfy needs in each category. Net use excludes losses associated with electricity generation and transmission, thereby including only energy actually delivered for final use. This is the quantity relevant to the changes calculated in the Oak Ridge National Laboratory report.

the resulting percentage changes refer to change relative to net total use, not the baseline use in any end-use like chillers or mobile air conditioning.

The table indicates extraordinarily small effects relative to net total energy usage viewed in this way. This is particularly true in the category likely to be of greatest concern to DoD, commercial/industrial use. Most of the changes in this category are likely to occur in commercial buildings; the changes would be small even if we focused on commercial energy use.

The study that yielded these results was generally viewed as the best available at the time. But as regulations spawned by the Montreal Protocol took hold, the need for more detailed information became apparent. Technology and policy were both moving rapidly. Policymakers needed a way to keep up with that movement and anticipate problems as quickly as possible. The energy effects of replacing ODCs took on a new significance as emissions of many ODCs were implicated in contributing to global warming. If efforts to replace ODCs increased energy use enough, they could increase the use of coal-based fuels, increase carbon dioxide emissions, and on net actually increase the threat of global warming.

Concern about this problem spawned a more complete and detailed analysis of how eliminating ODCs would affect energy use. This analysis has been the primary focus of the study cosponsored by AFEAS and DOE. This joint effort began in 1988 and issued its formal technical report on this issue in June 1992.[8] Participants in policy discussions of the effects of eliminating ODCs all agree that this study now offers the best consensus statement on energy effects; all other recent discussions defer to this study or use it as a baseline against which to voice differences of opinion on specific issues.

The AFEAS/DOE study took a more comprehensive view of potential energy effects, adding solvent services to the refrigeration and insulation applications covered earlier. It updated the engineering studies used to predict energy effects. Serious problems still remained in pinning down these effects.

First, as noted repeatedly above, the elimination of ODCs is generating many different responses, each of which has specific implications for energy use, among other things. It would be impossible to document the range of these effects in a summary study of this kind, even if ideal data were available for each response.

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[8] Oak Ridge National Laboratory and Arthur D. Little, Inc., conducted the study, which is documented in Fischer et al., 1991.

Second, ideal data were not available. Actual experience with substitutes for ODCs remains quite limited. Detailed engineering work on specific responses is typically proprietary. And the technology continues to move, opening new responses continually. In the face of these problems, the AFEAS/DOE study does a credible job of defining the likely scope of near-term responses and compiling the best engineering data currently available on these responses in a form that does not compromise their proprietary sources.

The AFEAS/DOE results confirm the sense of the earlier Oak Ridge National Laboratory study that overall energy effects are likely to be small, especially in the areas of greatest interest to DoD. To see this, let us focus on results relevant to the two areas of greatest interest to DoD, centrifugal chillers and solvent services.

Centrifugal Chillers

The AFEAS/DOE study first surveys the existing literature on the likely effects of eliminating ODCs on energy efficiency. Table E.3 summarizes relevant results from a survey of information on energy requirements, measured in terms of kilowatts of electricity required per ton of refrigeration capacity, associated with a shift from CFC-11 to HCFC-123 in centrifugal chillers. The range of effects shown results from differences (often poorly specified in the source documents)

Table E.3

Change in Energy Requirements When Converting CFC-11 Centrifugal Chillers to HCFC-123

Source	Date	Change	Additional Comments
Oak Ridge	Feb 1989	+2%	
UNEP	Jun 1989	up to 5%	
Trane Corp.	Sep 1989	+1.8%	Based on cycle thermodynamics, heat transfer not included
Radian Corp.	Feb 1990	+5%	Can use same motor, but expect material compatibility problems
K. Reitz	Apr 1990	up to 5%	
M.R. Lorenz	Apr 1990	+7–5%	
Daikin Ind.	Mar 1991	+8.2%	For new 300 RT chiller
		+9.6%	For new 1000 RT chiller
ASHRAE	Mar 1991	+6–8%	Gear and/or motor changes needed
Oak Ridge	Mar 1991	+2.4%	Based on cycle thermodynamics, heat transfer not included
Daikin Ind.	Mar 1991	no change	New impeller
Clark et al.	Apr 1991	+0–15%	Based on six actual field retrofits
E.L. Smithart	Apr 1991	+3–5%	For retrofits

NOTE: See original for detailed citations. Fischer et al., 1991, pp. E.6–E.8

in applications, differences in methods used to measure the change, changes in technology over time, and perhaps most disconcerting, differences in initial investments to affect energy efficiency. Table E.4 summarizes analogous results from a survey of information on energy requirements associated with a shift from CFC-12 to CFC-134a in centrifugal chillers. To narrow the range of reported energy effects and understand the range that remained better, the AFEAS/DOE study selected several specific chiller sizes and then sought consistent information on technology available in mid-1990 and optimized each option considered. For example, it examined 1000-refrigeration-ton (RT) water-cooled chillers that used CFC-11, CFC-12, HCFC-22, HCFC-123, HFC-134a, and ammonia as refrigerants. It then optimized a 1000 RT chiller for each refrigerant, given that each chiller had to cost the same amount.[9] Hence, differences in energy use among alternative refrigerants reflect technical adjustments to optimize each system to each refrigerant, but not differences in initial investments specifically designed to affect energy efficiency.

Measures of such differences are not ideal for DoD's purposes. They are likely to understate the energy effects of retrofits and to overstate the energy effects of changes made in the mid to late 1990s when more mature technology and engineering will improve the energy efficiency of chillers that use new refrigerants. Nonetheless, these differences reflect the best effort to date to control for factors that might affect energy use so that we can understand how

Table E.4

Change in Energy Requirements When Converting CFC-12 Centrifugal Chillers to HFC-134A

Source	Date	Change	Additional Comments
Oak Ridge	Feb 1989	+2%	
A. Braswell	Apr 1989	+8–10%	
UNEP	Jun 1989	+5%	Requires impellor and/or gear change
Trane Corp.	Sep 1989	+1–8%	Based on cycle thermodynamics, heat transfer not included
Snyder General	Nov 1990	-4.1%	New gearset, lab test per ARI Std 550 on 100 RT machine
Snyder General	Feb 1991	"down"	Actual chiller retrofit, new gearset
ASHRAE	Mar 1991	+1–2%	New gearset
Oak Ridge	Mar 1991	+2.1%	Based on cycle thermodynamics, heat transfer not included
Clark et al.	Apr 1991	no change	Based on two actual field retrofits

NOTE: See original for detailed citations. Fischer et al., 1991, pp. E.9–E.10.

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[9] The data used are based on a survey of original equipment manufacturers who provided data in a way that masked sensitive data about their proprietary designs. For more detail, see Calm, 1991.

energy use might actually change as DoD switches from ODCs to alternatives in its chillers.

With that in mind, Table E.5 summarizes the AFEAS/DOE findings for chillers defined at the study's baseline initial cost in each size category. For our purposes, the most important numbers are those shown in parentheses for HCFC-123 and HFC-134a. These show the differences in energy use between CFC-11 and its likely substitute, HCFC-123, and between CFC-12 and its likely substitute, HFC-134a. The differences are uniformly small and often negative—the switch from one optimized design to another could actually reduce energy use. Actual differences will vary substantially from one installation to another, but the average effect on energy use is likely to be small.

Table E.5

Energy Consumption in Selected Chiller Applications

Refrigerant	300 RT Water Cooled	1000 RT Water Cooled	3000 RT Water Cooled
CFC-11	42.4	41.8	n.a.
CFC-12	42.4	41.2	46.1
HCFC-22	42.8	38.5	41.8
HCFC-123	43.4	40.7	n.a.
	(+2.4)	(-2.6)	
HFC-134a	42.8	41.2	45.7
	(+0.9)	(0)	(-0.9)

SOURCE: Calculations based on data presented in Fischer et al., 1991, Appendix G.

NOTES: Absolute values are shown in 1000 kWh/RT. Numbers in parentheses are percentage differences from relevant reference cases, where CFC-11 is the reference case for HCFC-123 and CFC-12 is the reference case for HFC-134a. N.A. is not applicable.

Solvents

Measuring the energy effects of eliminating the use of CFC-113 and methyl chloroform as industrial solvents presents a somewhat different challenge. On the one hand, we have much more experience with alternatives to these solvents. On the other, specific uses of these solvents are far more diverse than those for chillers and information about a solvent's use in one application need not be especially helpful in understanding its potential use in another application. Solvent applications often reflect a great deal of local knowledge that cumulatively optimizes cleaning activities in specific operations by changing temperatures, rates of exposure to solvents, details of direct physical removal of contaminants, and so on.

The AFEAS/DOE study could not hope to capture such diversity or the depth of local knowledge associated with it. Based on information from over 30 solvent users and manufacturers, it opted to define four generic solvent-based cleaning processes: batch and in-line metal cleaning, and batch and in-line electronic cleaning. It then optimized each of these generic processes for each of nine solvents.

Like the work on chillers above, this work is not a perfect match for DoD's needs. Most important, it does not indicate where one solvent can be effectively substituted for another. In many cases, current technology simply does not allow such substitution to produce the needed level of cleaning performance. Hence, it cannot be assumed that a solvent user can simply choose among all the options that AFEAS/DOE considers for any particular cleaning activity. In fact, the effective range of practical choices is likely to be quite narrow.

Even where substitution is possible, AFEAS/DOE does not optimize all systems for the same cleaning activity. Rather, it optimizes each for the activity where it is most likely to be used. This suggests that, when comparing two appropriate solvents in the same application, differences in energy use associated with them are likely to be larger than differences inferred directly from the AFEAS/DOE study results.

Finally, technology and engineering design are still rapidly advancing in this area. Hence, results based on currently available knowledge are likely to overstate the energy differences associated with comparisons of appropriate solvents when one might be substituted for another later in the decade.

Despite these difficulties, the AFEAS/DOE results give DoD the best basis for comparing the energy effects of using alternative solvents; the AFEAS/DOE study results simply must be applied with caution. Table E.6 summarizes the results of this analysis. It shows actual energy required per metric tonne of metal cleaning and per square meter of electronic cleaning; energy requirements are not meaningfully comparable across these applications. In parentheses, it shows percentage differences between the energy requirements associated with CFC-113 and all other solvents. Differences between energy requirements associated with methyl chloroform and other solvents can be approximated by subtracting the percentage shown for methyl chloroform in each column from the percentage shown for any other solvent.

Two important results stand out in Table E.6. First, reported energy effects of moving from CFC-113 or methyl chloroform to other chlorinated solvents, with the possible exception of trichloroethylene, are modest and actually appear to offer significant percentage energy savings in certain in-line electronics cleaning

Table E.6

Energy Consumption in Major Solvent Cleaning Services

Type of Cleaning Service	Metal cleaning		Electronic cleaning	
	Batch	In-line	Batch	In-line
CFC-113	60.1	35.1	2.73	9.60
	(0)	(0)	(0)	(0)
HCFC-141b	65.1	37.5	2.96	8.97
	(+8)	(+7)	(+8)	(-7)
HCFC-225ca	58.8	34.3	2.67	7.85
	(-2)	(-2)	(-2)	(-18)
HCFC-225cb	59.6	35.5	2.69	7.90
	(-1)	(+1)	(-2)	(-18)
HCFC-123	60.6	34.2	2.75	8.52
	(+1)	(-3)	(+1)	(-12)
Methyl chloroform	64.8	35.8	2.94	7.82
	(+8)	(+2)	(+8)	(-19)
Trichloroethylene	73.0	41.3	—	—
	(+21)	(+18)		
Aqueous cleaning	126.1	40.9	11.8	22.2
	(+110)	(+17)	(+332)	(+132)
Semi-aqueous cleaning	109.7	36.7	10.4	13.1
	(+82)	(+5)	(+279)	(+37)

SOURCE: Calculations based on data presented in Fischer et al., 1991, Appendices Y and Z.

NOTE: Absolute numbers are shown in kWh/tonne metal for metal cleaning and kWh/square meter board for electronic cleaning. Numbers in parentheses are percentage differences from CFC-113, the primary reference case.

processes. Second, moving to aqueous or semi-aqueous processes entail substantial energy penalties in all areas but in-line metal cleaning. The analysis indicates that two factors contribute to these penalties.

First, aqueous and semi-aqueous systems simply clean items more slowly than the other alternatives in batch processes. Throughput for these systems is only about a third that of chlorinated solvents in batch metal cleaning and a fifth that of chlorinated solvents in batch electronic cleaning. Hence, even where systems have similar energy demands per hour, this slower flow rate penalizes the aqueous and semi-aqueous options.

Second, aqueous and semi-aqueous systems impose heating and drying loads far higher than those for chlorinated solvents and far higher than the energy requirements unique to chlorinated solvents—to operate chillers and stills, for example. Innovative use of heat pumps and waste heat recovery methods can reduce the energy demands of all of these systems; such innovations are not reflected in the numbers reported. But they do not offset the large energy penalties associated with moving from chlorinated solvents to aqueous or semi-aqueous alternatives.

We cannot conclude from these results that aqueous and semi-aqueous alternatives should be discouraged or even avoided. In fact, there is growing enthusiasm for these methods despite these problems. They help users avoid many health, safety, and environmental problems associated with the use and disposal of many of the chlorinated solvents and uncertainties about these associated with new solvents like HCFC-225. The costs of these problems are high enough relative to the cost of energy so that aqueous and semi-aqueous systems should not be discouraged unless energy use imposes a far larger penalty than most users and regulators associate with it.

That said, these results suggest that eliminating ODCs as solvents could have a significant percentage effect on energy use. No one knows the extent to which eliminating ODCs will increase the use of energy-intensive aqueous and semi-aqueous processes. Where it does increase, energy use in solvent services will rise. Even if it does rise, however, effects on total energy use could be small because energy use in solvent services is small to begin with.

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