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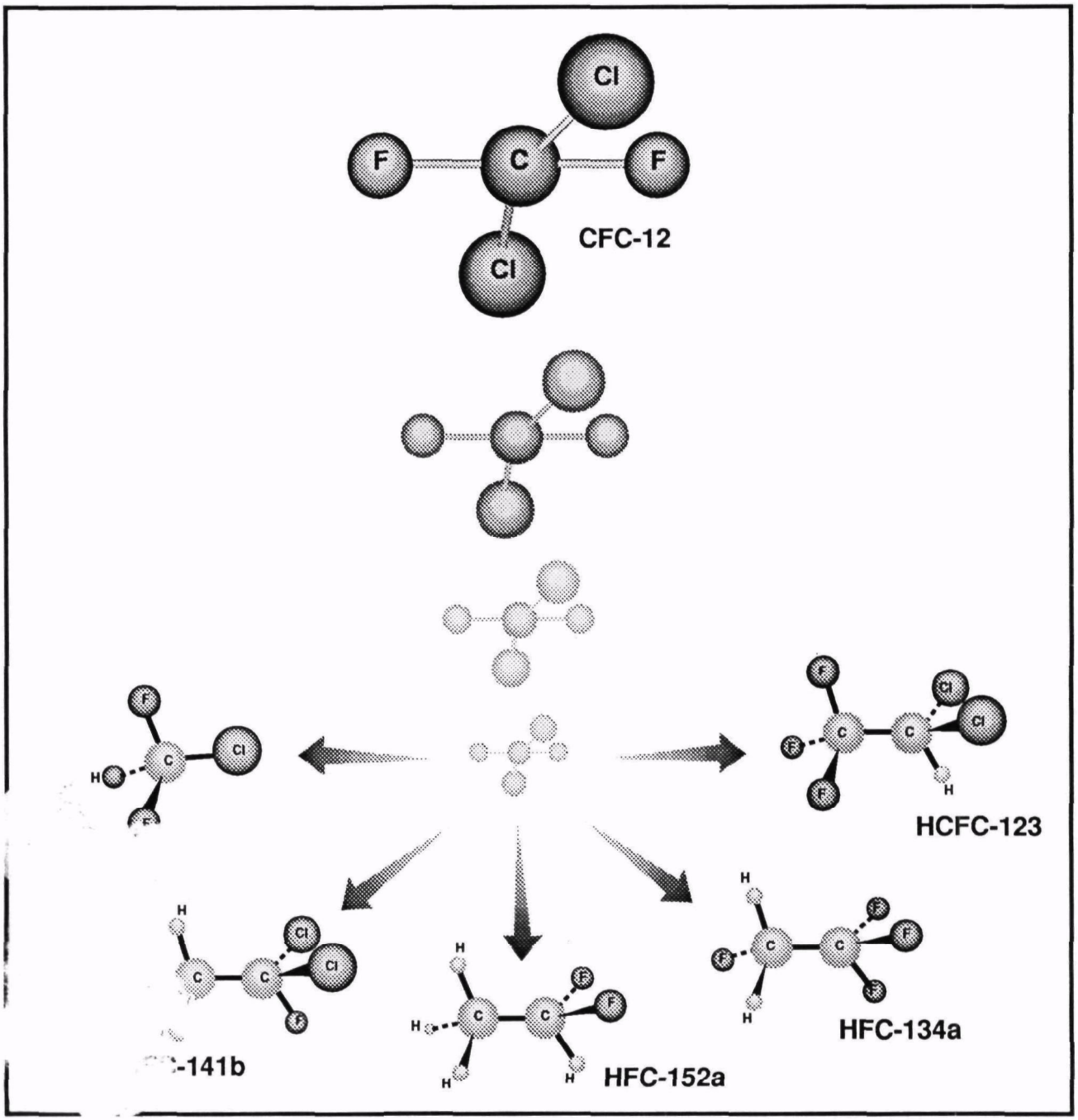

ANALYSIS OF THE ENVIRONMENTAL IMPLICATIONS OF THE FUTURE GROWTH IN DEMAND FOR PARTIALLY-HALOGENATED CHLORINATED COMPOUNDS

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DISCLAIMER

The U.S. Environmental Protection Agency does not endorse the performance, environmental acceptability, or commercial viability of any of the potential substitutes for chlorofluorocarbons (CFCs) discussed in this report. Mention of trade names also does not represent an endorsement.

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EXECUTIVE SUMMARY

This report focuses on the potential impact of substitutes for chlorofluorocarbons (CFCs) (1) on future stratospheric chlorine levels[1]; (2) as greenhouse gases; and (3) on energy efficiency and the subsequent costs and indirect greenhouse impacts. The findings of this analysis are summarized below:

(1) Regardless the stringency of the regulatory policy adopted, a near-term increase in stratospheric chlorine from present levels cannot be prevented. Causes include the eventual emission of "banked" (already used but not emitted) CFCs that cannot be recycled or destroyed, the long atmospheric residence times of CFCs, transport delays of the compounds from the troposphere to the stratosphere, and emissions of chlorinated compounds that would occur from uses until the earliest feasible start date of a phaseout.

(2) Stratospheric chlorine levels will continue to increase significantly even with a complete phaseout of fully-halogenated chlorofluorocarbons if growth in carbon tetrachloride and methyl chloroform use is not limited.[2] Increases could exceed 6.5 ppb by 2075.[3]

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[1] Estimates of stratospheric chlorine levels are used in this analysis as surrogates for potential ozone depletion. Chlorine and bromine levels are thought to be the primary, although not the sole, determinants of ozone depletion. See Chapter 1, page 1-5 for a more detailed explanation of this convention.

[2] The IUPAC name for methyl chloroform is 1,1,1 trichloroethane.

[3] The assumed growth rates for carbon tetrachloride and methyl chloroform underlying these results are fully discussed in Chapter 2, page 2-7.

(3) Projected stratospheric chlorine levels can be reduced to just below current levels by the middle to end of the next century. This could occur with a phaseout of fully-halogenated CFCs, a phaseout of both methyl chloroform and carbon tetrachloride, and sufficient development of non-chlorine based substitutes to limit the growth of hydrochlorofluorocarbon (HCFC) substitutes to no more than 35 percent (using a combination of HCFCs with an average ODP of 0.02) of the market growth in CFC use (or 20 percent of the market with an average ODP of 0.05) that would have occurred without future regulation.[4,5]

(4) To return chlorine to pre-Antarctic ozone levels, a phaseout of the HCFCs would also be necessary. Because of their relatively short atmospheric lifetimes, HCFCs can be phased out sometime in the 2020-2040 time frame without affecting the timing of Clx returning to pre-Antarctic ozone hole levels.

(5) Depending on the substitution scenario, HCFCs used to replace CFCs could contribute from 0.02 ppb (the prudent use of HCFCs) to 1.25 ppb (an extreme case of HCFC use) to atmospheric chlorine levels by 2075 with a phaseout of CFCs by the year 2000. In three of the four substitution scenarios examined, the phaseout of CFCs was accomplished with less than

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[4] "HCFC" stands for "hydrochlorofluorocarbon", a chlorofluorocarbon with a hydrogen atom. The hydrogen atom reduces the amount of chlorine transported to the stratosphere by increasing the oxidation rate in the lower atmosphere.

[5] The controls on carbon tetrachloride and methyl chloroform as well as the limits on CFC replacements do not reflect EPA policy positions. Rather, they represent the assumptions modeled in evaluating the types and stringency of reductions necessary to return future chlorine concentrations to current (1985) levels.

a 0.4 ppb contribution to chlorine concentrations from HCFCs. Among the HCFCs, the largest contributors of chlorine would be HCFC-141b and HCFC-22. It is reasonable to expect that recycling HCFCs and the use of low ODP HCFCs in high emission uses could reduce chlorine by significant amounts.

(6) The degree to which the greenhouse effect is diminished or exacerbated as a result of the transition from CFCs depends on the substitutes chosen to replace fully-halogenated compounds. Between possible substitution scenarios, the combined indirect energy and direct greenhouse effects could result in as much as 4.0 percent (extreme case) or as little as -1.06 percent (i.e. a reduction in warming) (best case) of the total greenhouse warming by 2075. By comparison, doubling new automobile fuel efficiency worldwide would reduce global warming in 2075 by 7 percent, rapid reforestation would reduce warming by 6 percent, and increased use of nuclear power would reduce warming by 5 percent.[6] The analysis also illustrates that the direct greenhouse properties of the substitutes contribute significantly more to calculated global warming than do indirect greenhouse properties (e.g., energy impacts) associated with the partially halogenated CFC replacements, except for the substitutes applied in refrigerators, where energy effects tend to dominate. Expanded use of ammonia could result in reductions of chlorine contribution, energy use, and greenhouse warming. The

[6] These policies to reduce global warming are more thoroughly explained in Chapter 3, page 3-60.

acceptability of such expanded use would be dependent on careful demonstration of safety.

(7) The effects of HCFCs on stratospheric chlorine levels depend on current atmospheric science as described in 1985 WMO assessments. Uncertainties exist in lifetimes due to uncertainties about kinetics, chemistry, and also the sizes of sources and sinks. Increases in the estimates of compound lifetimes from current estimates would reduce the estimates of the speed of recovery and, if large enough, prevent reduction of stratospheric chlorine levels. Alternatively, reductions in these estimates would speed up atmospheric recovery.

(8) In the United States, the difference in total energy use attributable to various patterns of CFC substitution could range from an increase of 28 quads from 1989 to 2075 (worst case) to a 62 quad reduction over the same period (best case).[7] Globally the difference could be as large as an 129 quad increase and a 444 quad reduction. Implementation of the most energy efficient alternatives would require expedited investments in alternatives and systems in which to use them.

(9) Of the options evaluated as CFC replacements, those applicable to the residential refrigeration end use represent the best opportunity for reducing greenhouse warming and energy use. The use of HCFCs with high ozone depletion potentials and radiative forcing properties in rigid foams constitute the greatest risk of increased contributions to stratospheric chlorine. The use of HCFCs in aerosol applications also

[7] Quads are quadrillion (10^{15}) British thermal units (Btus).

comprise a potential chlorine and warming risk. Finally, chillers represent a CFC market segment in which the differences between options, in terms of warming and chlorine contributions, could also be very significant. The combined differences between the "worst" and "best" case CFC substitution options for these four applications represent a potential reduction of four percent of the greenhouse effect and 0.5 ppb in chlorine concentrations.

CHAPTER ONE

THE HCFC ISSUE: BACKGROUND AND CONTEXT

In September 1987, 24 nations signed the "Montreal Protocol on Substances that Deplete the Ozone Layer" (Montreal Protocol). The primary objective of this international agreement is the protection of human welfare from ozone depletion. Since the creation of the Protocol, a variety of scientific studies, including the report of the Ozone Trends Panel[1] and the EPA's report Future Concentrations of Stratospheric Chlorine and Bromine[2] have demonstrated to the governments of the world that current restrictions on chlorofluorocarbons are inadequate.

As a result, governmental and non-governmental organizations, as well as, industry representatives have called for additional steps to prevent ozone depletion. The most significant manifestation of support for such action is the non-binding Helsinki declaration in which 77 nations called for a phaseout in the production of regulated chemicals by the year 2000.

Despite the agreement, however, concern has been expressed regarding several possible issues: the speed of a phaseout of the currently regulated chemicals; the possible need to include carbon tetrachloride and methyl chloroform reductions in the Montreal Protocol; and the potential increase of and restrictions on hydrochlorofluorocarbons (HCFCs) used as substitutes for CFCs. Questions have also been raised about the impacts of CFC substitutes on

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[1] U.S. National Aeronautics and Space Administration, Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report, Washington, D.C., August 1988.

[2] U.S. EPA, Future Concentrations of Stratospheric Chlorine and Bromine, July 1988.

energy efficiency and their contribution to global warming as greenhouse gases.

A number of studies are currently underway to resolve many of these issues, including the United Nations Environment Programme (UNEP) Montreal Protocol Technology and Economics Assessments (Technical Progress on Protecting the Ozone Layer), and industry sponsored investigations on the environmental impacts of substitutes under the auspices of The Alternative Fluorocarbon Environmental Acceptability Study (AFEAS). The EPA has also undertaken two major studies concerning these issues: this analysis of the environmental consequences of potential substitutes for chlorofluorocarbon (CFCs) and a companion study (the "vintaging analysis") which focuses on the timing, costs and benefits of a CFC and halon phaseout. While this report on CFC substitutes considers costs to a limited extent (i.e., it examines energy costs), its primary focus is on the chlorine and greenhouse impacts of replacements for CFCs, especially HCFCs. Although uncertainties will remain about the consequences of substitutes, and other issues such as toxicity and air/water quality impacts must be considered, the analysis contained in this report should assist in clarifying the environmental differences that accompany various patterns of substitution for CFCs in the future.

1.1 THE MONTREAL PROTOCOL

The Montreal Protocol restricts the production and consumption of five fully-halogenated chlorofluorocarbon compounds (Group I compounds: CFC 11, 12, 113, 114, 115) and three halon compounds (Group II compounds: Halon 1211, 1301, and 2402). Under the Protocol, the production and consumption of the

Group I compounds are to be reduced to 50 percent of 1986 levels by 1998. This is to be achieved by instituting a 20 percent reduction by 1993 and a further 30 percent reduction by 1998. The production and consumption of Group II compounds are to be frozen by 1992 at 1986 levels.[3] On January 1, 1989, the Montreal Protocol entered into force, with 34 nations having ratified it. As of January 1, 1990, about 50 nations had ratified the Protocol.

1.2 SCIENTIFIC DEVELOPMENTS SINCE THE PROTOCOL

Since the signing of the Montreal Protocol, studies have indicated that the atmospheric projections which formed the basis for the Protocol could be understatements of risk associated with increasing levels of stratospheric chlorine and bromine, thereby rendering the current international agreement insufficient to protect the ozone layer. When the agreements were reached in Montreal, the models of stratospheric chemistry used to project ozone depletion predicted that almost no depletion should have occurred from CFC emissions to date and that no more than 2.5 percent depletion would occur by 2060 under the restrictions required by the Protocol.

In March following the Protocol signing, a report examining ozone trends was released by an international group of over one hundred scientists chaired by NASA.[4] The report summarized the results of an 18-month review of ground-

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[3] On August 12, 1988, EPA promulgated a final rule that implements the United States' obligation under the Montreal Protocol (53 FR 30566). EPA has created a quota system under which production and consumption rights are allocated over time.

[4] See: U.S. National Aeronautics and Space Administration, Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report, Washington, D.C., August 1988.

based and satellite data of total column ozone and vertical profiles of ozone. It concluded that stratospheric ozone in the northern mid-latitudes had been depleted by 1.7 to 3 percent between 1969 and 1986, and that "the observed changes may be due wholly, or in part, to the increased atmospheric abundance of trace gases, primarily chlorofluorocarbons (CFCs)." The Panel also stated that: "The weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in ozone within the polar vortex." With the release of the Panel's findings it became clear that the atmospheric models used by negotiators in the Protocol underestimated the link between CFCs, chlorine, and ozone depletion. Protocol negotiators had not accounted for the recently documented observed depletion of total column ozone over the northern mid-latitudes during the past decade or for the Antarctic ozone hole.

In fact, in comparing satellite and other data on depletion of total column ozone with the results of atmospheric models used to estimate depletion in column ozone, the panel noted that actual depletion in total column ozone at northern mid-latitudes during the period from 1969 to 1987 was two to three times greater than estimates developed using 2-D predictive models of the atmosphere.

Efforts are now underway in the scientific community to better explain the relationship between chlorine levels and ozone depletion. However, uncertainties regarding the impacts of heterogeneous chemistry (the leading hypothesis for explaining the discrepancy between observations and observed trends) are likely to remain for some time and the subsequent refinement of

the atmospheric models are not likely to produce definitive estimates of the relationship of chlorine levels and ozone depletion in the near term.

To cope with the limitations of existing atmospheric models, the EPA issued a report, Future Concentrations of Stratospheric Chlorine and Bromine, which projected chlorine levels in the future, using chlorine and bromine as surrogates for ozone depletion risk.[5] An update of this report was presented by the U.S. government at the first meeting of the Protocol parties in Helsinki. Although imperfect as a measure of risk, the estimation of stratospheric chlorine and bromine levels as a means of assessing the potential for ozone depletion can serve as a surrogate for risk since chlorine and bromine concentrations are thought to be the primary (but not the sole) determinants of ozone depletion. Thus in this report, concentrations of atmospheric chlorine under various substitution scenarios are estimated to determine the environmental risks of various phase-out scenarios; ozone depletion levels are not explicitly evaluated.[6]

1.3 THE HELSINKI DECLARATION

Nations throughout the world have reacted to the new data on ozone depletion by proposing a phaseout of fully-halogenated CFCs. In April of 1989 at the first meeting of the Montreal Protocol Parties, approximately 77 nations concurred with the non-binding document adopted as the Helsinki Declaration which includes the following language:

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[5] Op. cit.

[6] Bromine concentrations from halons and the subsequent potential for ozone depletion are not considered in this analysis.

"The Governments and the European Communities represented at the First Meetings of the Parties to the Vienna Convention and the Montreal Protocol ...

ENCOURAGE all states that have not done so to join the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol.

AGREE to phase out the production and the consumption of CFC's controlled by the Montreal Protocol as soon as possible but not later than the year 2000 and for that purpose to tighten the timetable agreed upon in the Montreal Protocol taking due account of the special situation of developing countries.

AGREE to both phase out halons and control and reduce other ozone-depleting substances which contribute significantly to ozone depletion as soon as feasible.

AGREE to commit themselves, in proportion to their means and resources, to accelerate the development of environmentally acceptable substituting chemicals, products and technologies.

AGREE to facilitate the access of developing countries to relevant scientific information, research results and training and to seek to develop appropriate funding mechanisms to facilitate the transfer of technology and replacement of equipment at minimum cost to developing countries."

The declaration clearly endorses the positions of a CFC phaseout by the year 2000 taken by President Bush, the European Community, and others prior to the meeting.

1.4 ANALYTICAL ISSUES REGARDING CFC SUBSTITUTES

A variety of questions must be considered in evaluating policies to protect stratospheric ozone. There exist at least three possible goals for phase-out policies, ranging from: (1) accepting the additional risk associated with higher chlorine levels once the levels are stabilized; (2) restoring stratospheric chlorine concentrations to 1985 levels; and (3) reducing chlorine levels to below those that led to current depletion (e.g., pre-Antarctic ozone hole levels). Each policy could have different implications for the ozone layer and for CFC substitutes. Stabilizing chlorine at 1985 levels, for example, presumes the permanent acceptance of an Antarctic ozone hole, whereas reducing chlorine from 2.7 ppb (1985 levels) to 2.0 ppb would likely be necessary to eventually eliminate the presence of the hole.

In addition to the continued contribution of chlorine to the stratosphere from substitutes for fully-halogenated CFCs, other significant environmental effects should be considered in evaluating CFC replacements. To varying degrees, compounds that could replace CFCs are "greenhouse gases" and thus will directly contribute to global warming through their radiative characteristics. Because CFCs have historically been used in energy intensive applications, substitutes for CFCs could also affect the amount of energy used and thus indirectly contribute to increased or decreased fossil fuel use.

Such changes could subsequently alter both carbon dioxide (CO_2) and methane (CH_4) emissions. Of course, changes in fossil fuel use could also contribute to other forms of air pollution, such as the emissions of nitrogen oxides.

Due to the concern about their potential chlorine contribution and greenhouse effects, HCFC substitutes for CFCs have been a focus of major public concern. Potential HCFC substitutes have been identified for most of the major applications in which CFCs are used. Although these compounds have lower ozone depletion values than CFCs, concern has been raised that emissions of HCFCs will contribute to stratospheric chlorine concentrations and could contribute to global warming either through their direct radiative characteristics or through indirect emissions of greenhouse gases caused by changes in the energy efficiency of equipment using the HCFC alternatives. The problem is even more complex than generally recognized because trade-offs between these effects are probable. For example, one HCFC substitute may increase chlorine more than some other HCFC (or HFC) substitute, but may produce significantly more energy efficiency and, thus, reduce other greenhouse gas emissions.

The purpose of this report is to evaluate the environmental implications of the increased use of partially-halogenated HCFCs and HFCs that could occur under a total, world-wide phaseout of CFC production by the year 2000. This evaluation includes a discussion of the trade-offs between different environmental objectives. Due to the significant complexities involved in such an evaluation, this analysis has been broken into the following key steps.

In **Chapter** 2, an analysis of total stratospheric chlorine is performed for methyl chloroform and carbon tetrachloride along with various scenarios of HCFC use. This chapter demonstrates how different restrictions on carbon tetrachloride and methyl chloroform, combined with various levels of HCFC use, would influence total chlorine loadings over time. The chapter also examines the range of actions needed to achieve reductions in chlorine concentrations to and below 1985 levels.

Chapter 3 presents estimates of the environmental effects associated with four CFC phaseout substitution scenarios that have been chosen to provide insight into how different CFC replacement patterns might influence future environmental conditions:

Scenario 1: assumes use of HCFC substitutes in end uses based on "conventional wisdom" (i.e., HFC-134a is used as a substitute for CFC-12 and HCFC-123 is used for CFC-11 in most applications). This scenario provides a baseline of changes assuming the chemicals most prominently considered as new substitutes are adopted.

Scenario 2: assumes use of substitutes with high contributions to stratospheric chlorine. This scenario allows exploration of what could happen if HCFCs (including those with the highest ozone depletion potentials) are used whenever possible, even where other substitutes may be available.

Scenario 3: assumes prudent use of HCFCs in different applications, with a high degree of recycling, usage bans, and product substitutes (e.g., substitute aqueous solutions for CFC-113 in solvent applications) to reduce emissions.

Scenario 4: assumes substitutes are chosen which result in a low greenhouse effect and energy impact. This scenario relies on a broad range of technological options, some of which are in their early stages of development or commercialization (e.g., vacuum panels) or which involve safety issues that would have to be resolved (e.g., the use of ammonia in refrigeration applications).

While many other scenarios are possible, those chosen illustrate important potential differences resulting from various paths of substitute development. In evaluating how to proceed in selecting CFC replacements, governments and industry will want to consider these differences. As will become evident, there are trade-offs among chlorine contribution, energy consumption, and global warming that could be of considerable importance in evaluating choices among CFC substitutes.

Chapter 4 examines these differences in more detail, considering the major potential substitutes for CFCs in specific energy intensive end uses in more detail. The analysis examines the possible trade-offs in chlorine contributions, direct global warming and indirect global warming associated with individual options for specific applications. This information should assist decision makers in recognizing the importance of accelerating research and development on options, altering institutional constraints that could

block the selection of certain substitutes, and avoiding premature commitments to less than optimal substitution choices.

1.5 CAVEATS

This report does not attempt to present all the information necessary to fully evaluate CFC replacement options. In addition to concerns about the chlorine, greenhouse and energy implications of using HCFCs and HFCs that are covered here, there are other environmental, safety and economic considerations that need to be considered but are not evaluated in this report. In addition, the direct costs of substitution, which include the costs of retrofitting the existing capital stock for HCFC use, or the cost of abandoning existing capital stock if HCFC substitutes are not commercialized, are not considered in this analysis. The chemical costs of different HCFCs or other alternatives also are not considered.

The report does analyze the energy cost implications associated with implementing substitutes. Changes in energy costs will occur because some of the substitutes for CFCs are more energy efficient than CFCs and some are less energy efficient.[7] However, there is still much uncertainty regarding the energy efficiency of these substitutes, and it is unlikely that these uncertainties will be resolved for several years. Future reports will consider the broader economic aspects of substitution choices more completely. Finally, this report does not contain a complete analysis of the toxicity or other health and environmental impacts of CFC substitutes. An investigation

[7] The evaluation of energy implications of HCFC and HFC use does not include analysis of the energy required to manufacture the compounds.

of these issues is being undertaken by EPA separately. The industry-sponsored Program for Alternate Fluorocarbon Toxicity Testing (PAFT) and AFEAS efforts also are investigating these issues.

Despite these limitations, this report contains critical information about key environmental and economic factors: stratospheric chlorine, greenhouse warming, and energy use.

CHAPTER TWO

AGGREGATE EVALUATION OF FUTURE CHLORINE LEVELS

A critical issue in evaluating options for strengthening the Montreal Protocol involves examining the likely sources of future increases in aggregate stratospheric chlorine. An aggregate analysis is appropriate because from the perspective of ozone depletion, the specific source of chlorine contributions is unimportant.

To evaluate fully how different scenarios of future compound use and controls influence aggregate chlorine levels in the stratosphere, this chapter focuses on examining three critical issues:

(1) Uncontrolled Compounds: An evaluation of the influence of emissions of two ozone-depleting compounds that are not currently regulated, carbon tetrachloride and methyl chloroform. The effects of these compounds are analyzed because restrictions on their use are currently under consideration for inclusion in the Montreal Protocol.

(2) Aggregate HCFC Use: An analysis of the changes in stratospheric chlorine concentrations (Clx) that result from different assumptions about the use of HCFCs to replace CFCs.

(3) Average HCFC Characteristics: An analysis of the changes in chlorine concentrations resulting from the use of HCFCs with different average ozone depletion potentials.

By considering these three issues in detail, it is possible to understand how different policies can lead to different aggregate effects on

stratospheric chlorine levels and to understand the relative importance of different factors in terms of the highest chlorine levels reached and the effects of stabilizing or restoring chlorine levels to or below 1985 concentrations.[1]

2.1 ESTIMATION OF STRATOSPHERIC CHLORINE LEVELS

To estimate stratospheric chlorine levels, this report uses a model utilized in prior negotiations that led to the Montreal Protocol. The model estimates stratospheric chlorine concentrations based on the use and subsequent emissions of chlorinated compounds.[2]

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[1] This chapter examines the influence of substitutes on stratospheric chlorine concentrations. Later in the report, when the analysis is expanded to evaluations of greenhouse warming and energy impacts from the CFC replacements, HFCs and other chemical substitutes are included in the analysis.

[2] This method is taken from P.S. Connell, A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere, Lawrence Livermore National Laboratory, Livermore, California (1986). The model used is a parameterized version of the LLNL 1-D model which involves a simplified representation of the exponential decay in the abundances of each compound. The rate of decay is defined by an estimate of each compound's lifetime. The model is summarized in Appendix I.

This method also recognizes that each compound has a different "efficiency" with which its chlorine can perturb the stratospheric ozone. The greater the compound's efficiency, the larger the impact its chlorine will have on stratospheric ozone. For example, HCFC-22 dissociates (and consequently injects its chlorine) at a different altitude than does CFC-11. As a result, its chlorine is less efficient at depleting stratospheric ozone. The estimates of chlorine abundances in this method adjust for these relative efficiencies so that the total change in chlorine abundance across all compounds is a consistent measure of the potential impact on stratospheric ozone.

Recent work by Prather and Watson has utilized a simpler method of estimating total (not stratospheric) chlorine levels. See Prather, M.J. and R.T. Watson, Transient Scenarios for Atmospheric Chlorine and Bromine, Annex 2, (Draft report), 1989.

In the model used, the amount of chlorine added to the stratosphere by a CFC or a substitute depends on two factors: (1) the amount of chlorine contained in the compound, and (2) the stability of the compound in the troposphere. These two factors are represented by two parameters, atmospheric lifetime and conversion factors. The lifetimes represent the period of time that the chlorine associated with the compounds remains in the atmosphere.[3] Atmospheric lifetimes can range from about 2 years (HCFC-123) to 680 years (CFC-115). Exhibit 2-1 presents the lifetimes of several HCFC and HFC substitutes.[4] All chlorine containing compounds theoretically pose some risk to the stratosphere. HCFCs, however, pose less of a long term risk than CFCs due primarily to their shorter lifetimes and the subsequent release of their chlorine atoms below the stratosphere. As illustrated in Exhibit 2-1a, the atmosphere can recover from chlorine contributed from HCFCs more quickly than from that resulting from CFC use. In fact, the shorter lifetimes of the HCFCs mean that the recovery times can be measured in decades rather than centuries.

The conversion factors reflect the number of chlorine atoms per molecule, the molecular weight of the molecule, the relative efficiency of the compound's chlorine at depleting ozone, and a factor related to the total atmospheric volume. The conversion factors are used to transform emissions in millions of kilograms into ppbv of chlorine and to adjust for the relative efficiencies of the compounds to supplying ozone depleting chlorine to the atmosphere.

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[3] The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the stratosphere is 1/e or about 37 percent of the original value.

[4] "HFC" stands for "hydrofluorocarbon". These compounds contain no chlorine atoms and, therefore, have no calculated effect on stratospheric ozone.

EXHIBIT 2-1

ESTIMATES OF LIFETIMES OF POSSIBLE CFC SUBSTITUTES[1, 2]

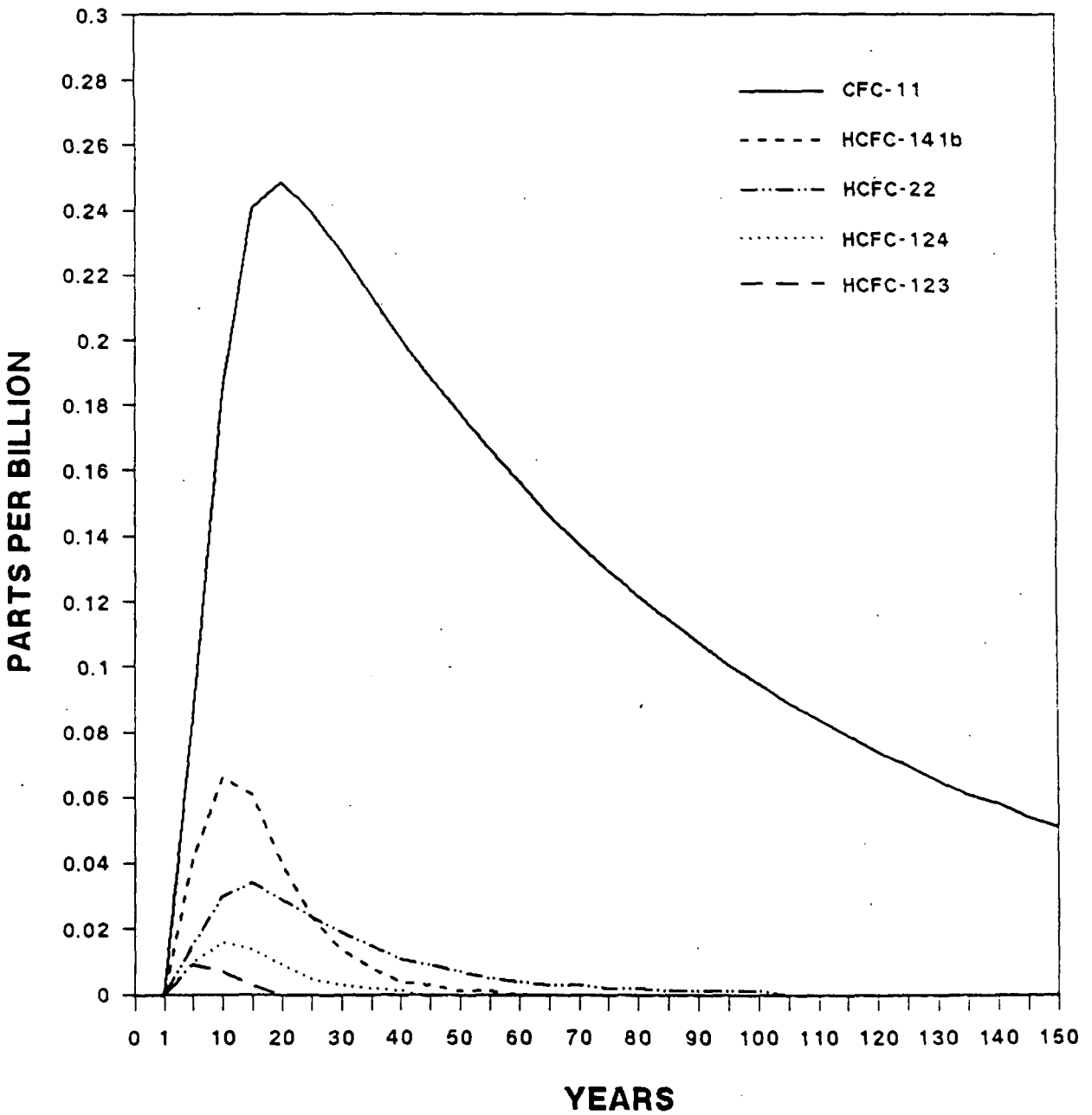
COMPOUND	LIFETIME (years)
HCFC-123	2
HFC-152a	2
HCFC-124	8
HCFC-141b	9
HCFC-22	20
HFC-134a	21
HCFC-142b	25
HFC-125	37

[1] Lifetime estimates are from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

[2] There are uncertainties associated with the estimates of the HCFC lifetimes. The primary factor contributing to this uncertainty is the uncertainty in estimates of the HCFCs' rate coefficients, with estimates of the abundance now and in the future of the hydroxyl radical (OH), and with estimates of other sinks. Changes in the compounds' lifetimes will affect their contributions to Clx levels and subsequently their ozone depletion potentials. Appendix G presents a sensitivity analysis of results from Chapter 3 estimated assuming a range of compound lifetimes.

EXHIBIT 2-1A

PROJECTED CHLORINE CONCENTRATIONS FROM CFC-11 AND SELECTED HCFCS FROM HYPOTHETICAL ONE YEAR EMISSIONS OF 300 MILLION KILOGRAMS



In this analysis, the assumption is made that background chlorine levels remain unchanged. The estimated background levels, therefore, are not incorporated in estimates of changes in chlorine from present levels. For the analyses in this chapter, values for chlorine levels are all reported as increases relative to current (1985) levels. The chlorine concentration for 1985 is assumed to be 2.7 ppb. All scenarios are modeled assuming a phaseout of fully-halogenated CFCs by the year 2000, 100 percent global participation in the reductions, and no controls on baseline (i.e., current) uses of HCFC-22.

2.2 RESULTS OF AN AGGREGATE ANALYSIS OF THE INFLUENCE OF CFC SUBSTITUTES ON CHLORINE LEVELS

This section presents estimates of stratospheric chlorine levels (Clx) under a range of assumptions regarding controls on methyl chloroform and carbon tetrachloride, the rate of HCFC substitution and the average ozone depletion potential of the HCFC substitutes under conditions of a CFC phaseout in 2000. For each set of assumptions examined, an exhibit is provided depicting Clx profiles and concentrations of stratospheric chlorine over time.

2.2.1 Evaluation of Controls on Methyl Chloroform and Carbon Tetrachloride

Emissions of carbon tetrachloride and methyl chloroform, if uncontrolled, would contribute to increases in stratospheric chlorine. Although not currently regulated under provisions of the Montreal Protocol, both of these compounds have recently attracted significant international attention particularly in light of new scientific information suggesting that

the risks of stratospheric ozone depletion are greater than had previously been thought.

The influence of emissions of methyl chloroform and carbon tetrachloride on stratospheric chlorine levels is examined in this analysis based on estimates of the current use and projections of future emissions of the two compounds. Carbon tetrachloride use is assumed to remain constant (no growth) at 1986 levels over the time period analyzed. Although in previous EPA analysis [including the Agency's presentation to the Montreal Protocol parties in Helsinki (1989)] carbon tetrachloride use was assumed to grow in the future, this analysis assumes that CFC producers will not "dump" excess carbon tetrachloride feedstocks on global markets and that independent carbon tetrachloride use will not in fact increase.[5] While possibilities exist for increased carbon tetrachloride use, such growth is now assumed unlikely given toxicity concerns.

For purposes of this analysis, methyl chloroform use is assumed to grow at an annual rate of 4.7 percent per year from 1986 to 1992, at 2.78 percent annually during the period 1992 to 2000, at 2.50 percent annually during the period 2000 to 2050, and to remain constant after 2050.[6] If methyl chloroform were used as a substitute for CFCs and other regulated chlorinated solvents

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[5] Carbon tetrachloride feedstocks refer to the use of the compound in the manufacture of fully-halogenated CFCs.

[6] Some industry sources maintain that, even in the absence of regulation, methyl chloroform use will not increase over time. If this were the case, the scenario in Exhibit 2-2, which represents the methyl chloroform freeze, would illustrate industry's implied baseline.

(e.g., methylene chloride in pesticides), its emissions in the short term could possibly increase beyond those assumed in this evaluation.

The effects of various control scenarios for phasing out fully-halogenated CFCs and for limiting the use of methyl chloroform and carbon tetrachloride on stratospheric chlorine levels are presented graphically in Exhibit 2-2.[7] This exhibit illustrates the incremental reductions in chlorine levels achieved by each of the controls. That is, the second curve, "Carbon Tetrachloride Phaseout," represents chlorine levels projected to occur following adoption of the Montreal Protocol and the complete elimination of the use of carbon tetrachloride by 2000. Similarly, the third curve reveals the reductions in chlorine concentrations resulting from a freeze on the use of methyl chloroform combined with the reductions included in the Protocol and a carbon tetrachloride phaseout by 2000.

As shown in Exhibit 2-2, if no additional steps are undertaken to reduce the use of chlorinated compounds and if the growth in compound use occurs at the assumed rates, by 2100 chlorine levels would <u>increase</u> from current levels to 10.0 ppb. Phasing out carbon tetrachloride yields reductions in chlorine of 0.7 ppb in 2075 relative to the Montreal Protocol case.

Curves 3 and 4 on Exhibit 2-2 illustrate the reductions in chlorine levels achievable via the implementation of controls on methyl chloroform. If methyl chloroform use is frozen at 1986 levels (or, alternatively, if emissions remain constant at 1986 levels), by 2075 projected chlorine levels

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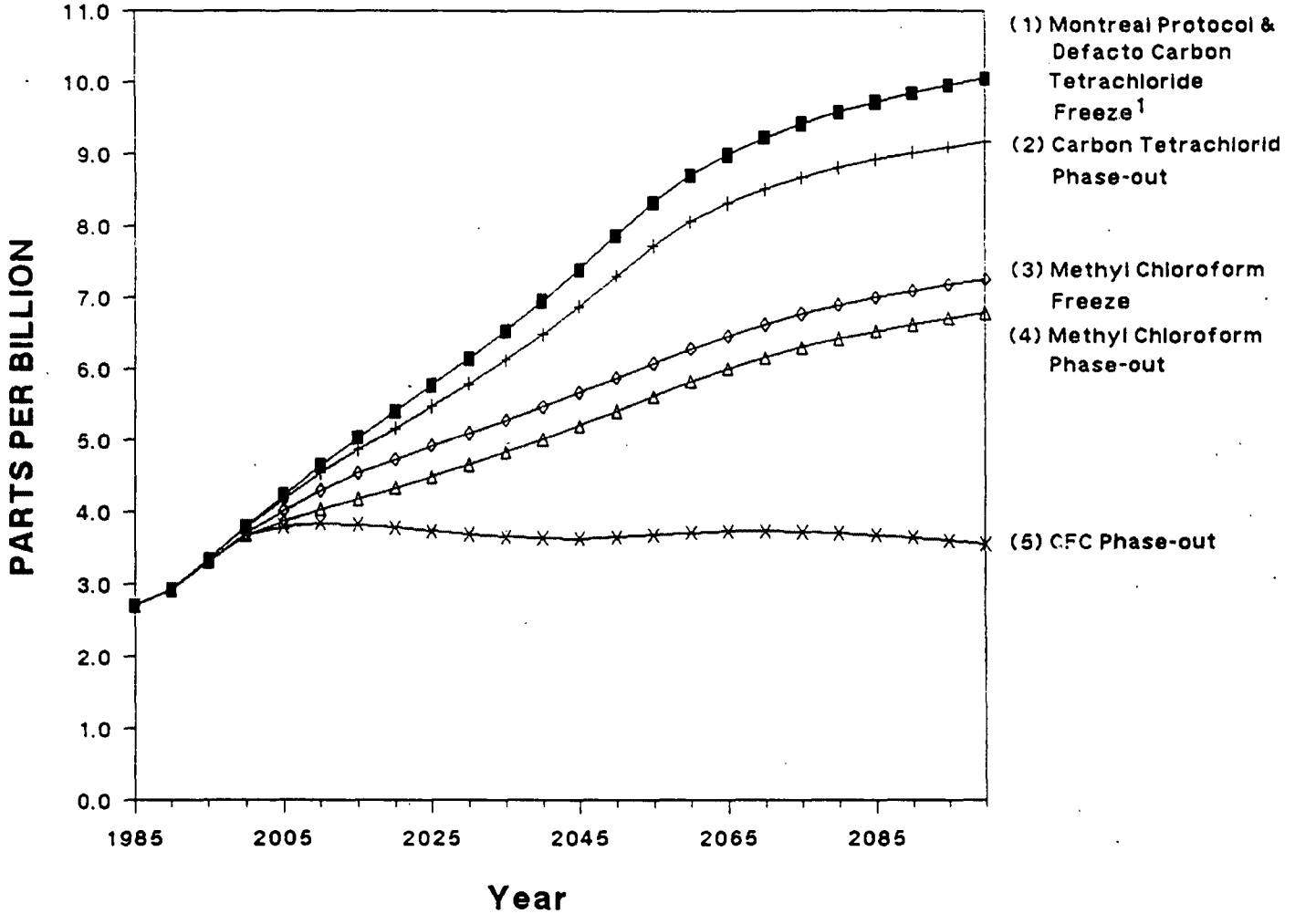
[7] The control assumptions for methyl chloroform and carbon tetrachloride were developed solely to illustrate the types and stringency of reductions necessary to return future chlorine concentrations to 1985 levels. These assumptions should not be interpreted as official policy positions.

Exhibit 2-2
METHYL CHLOROFORM AND CARBON TETRACHLORIDE CONTROLS
TOTAL Clx CONCENTRATIONS
1985 Through 2100



Assumptions:
- o HCFCs Capture 50% of What CFC Market Would Have Been
- o HCFCs Average an ODP of 0.05
- o 100% Global Participation

Notes:
[1] In earlier drafts, (including EPA's presentation in Helsinki to Montreal Protocol parties (1989)), these policies (Montreal Protocol and Carbon Tetrachloride Freeze) were shown as two separate controls. In this analysis, the two are combined based on the assumption that CFC producers will not "dump" carbo tetrachloride feedstock (that would have been used to produce CFCs) on global markets and that indepe dent carbon tetrachloride use will not in fact increase.

will decline by approximately 2 ppb from the uncontrolled methyl chloroform baseline. By instituting a complete phaseout of methyl chloroform use, chlorine levels in 2075 will decline by approximately 0.5 ppb from the methyl chloroform freeze case. This 0.5 ppb reduction in chlorine concentrations is independent of any future growth assumptions (i.e., it represents the reduction achieved by phasing out from 1986 levels).

As was the case for the carbon tetrachloride controls, reductions in methyl chloroform use result in a slowing of the rate of increase in chlorine concentrations. Even if a phaseout of both of these compounds were added to the Montreal Protocol reductions, however, chlorine concentrations would continue to increase through 2100 due to the continued use of CFCs. As shown by curve 5 in Exhibit 2-2, a complete phaseout of fully-halogenated CFCs in 2000 following the phased reductions called for in the Montreal Protocol through 1998, in combination with a complete elimination of methyl chloroform and carbon tetrachloride use, is sufficient to stabilize chlorine levels over time at just under 4 ppb assuming HCFC substitution of 50 percent with an average ozone depletion potential of 0.05. Phasing out the fully-halogenated CFCs results in an absolute decrease in chlorine concentrations of greater than 5.5 ppb from chlorine levels estimated to occur in 2075 following worldwide implementation of the Montreal Protocol controls.

2.2.2 Evaluation of Potential Growth Rates for CFC Substitutes

The first step in estimating the global demand for HCFCs as replacements for CFCs is to define the total potential market for all CFC substitutes (e.g., HCFCs, product substitutes, recycling) over the period 1985 to 2165. To estimate the demand for CFC replacements, the demand for CFCs that would

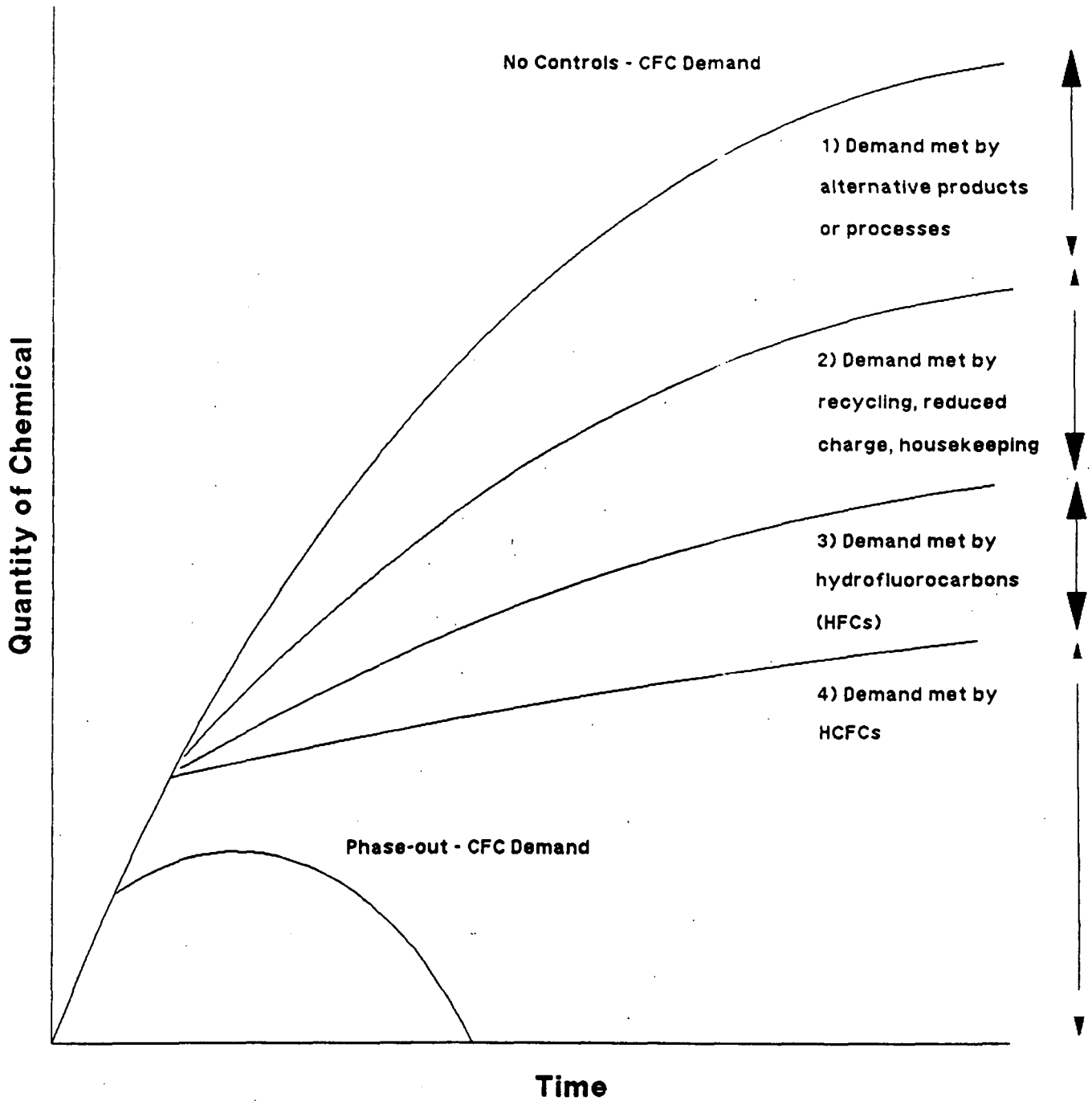
have existed without regulation must be determined. This CFC market is based on the demand for products and services that consume and/or use CFCs (e.g., refrigerators, insulating foams, solvent cleaning of metal and electronic components). As the production of CFCs is reduced and ultimately eliminated (to meet the schedule of reductions adequate for a phaseout by 2000), the demand for the ultimate products and services to which CFC contributed will not cease. Rather, some types of alternatives will be adopted to satisfy the market. This analysis focuses on HCFCs, one group of substitutes that could partially satisfy the market.

The upper bound of the total market for HCFCs as replacements for CFCs is represented schematically by the "No Controls" line in Exhibit 2-3. By definition, this line represents the demand for CFCs if the rate of HCFC substitution is a one-to-one replacement of CFCs. This unrestricted growth in demand for CFCs is based on assumptions about the rate at which demand for the compounds would grow in the future in the absence of any restrictions on production or consumption including controls specified by the Montreal Protocol. Such estimates of the CFC market are based on assumptions regarding the rate at which the demand for products and services which use CFCs is expected to increase. As the demand for these products increase over time, so too does the demand for CFCs.

In this analysis, unrestricted global demand for CFCs is projected to grow at an annual rate of approximately 4.0 percent between 1986 and 2000, and

Exhibit 2-3

SCHEMATIC REPRESENTATION OF POTENTIAL MARKET FOR CFC SUBSTITUTES



an annual rate of 2.5 percent from 2000 to 2050 and to remain constant after 2050.[8]

It is unlikely, however, that HCFCs will be the sole replacements for foregone CFCs (i.e., capture the entire potential market for CFC replacements). Among the factors which will limit the use of HCFCs are:

- Reduced charge sizes within the capital stock (e.g., mobile air conditioners), due to potentially higher costs of HCFCs;
- Use of product substitutes for CFC-based products (e.g., paper packaging) and processes that eliminate the need for CFCs (e.g., no-clean electronic components);
- More efficient use of HCFCs through the incorporation of blends;
- Use of HFCs (e.g., HFC-134a) and other non-chlorine containing compounds (e.g., the use of aqueous solutions or alcohols for solvent cleaning applications); and
- Improved housekeeping and recycling.

Hence, reductions in the use of fully-halogenated CFCs can and will be accomplished through a variety of means. Some of the substitutes (e.g., technical controls such as process modifications and product substitutes, and some alternative chemicals such as HFCs) will not contribute to stratospheric chlorine levels. The reduction in total possible market potential for HCFCs

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[8] Baseline future consumption of HCFC-22 (growth in current uses rather than growth in uses as a substitute for CFCs) is assumed to follow a pattern similar to that of the other substances. HCFC-22 is expected to grow at an average annual rate of 4.37 percent for the period 1985 to 2000, 2.74 percent between 2000 and 2050, and to be constant after 2050. The assumption that CFC and HCFC growth levels off after 2050 is important, as demonstrated in EPA's Future Concentrations of Stratospheric Chlorine and Bromine. The results presented here depend on this assumption.

from any of these non-chlorine CFC replacements is represented by areas (1) "Demand met by alternative products or processes," (2) "Demand met by recycling, reduced charge size and housekeeping," and (3) "Demand met by hydrofluorocarbons (HFCs)" in Exhibit 2-3. The remaining substitutes (e.g., HCFCs) will contribute to stratospheric chlorine levels. This potential market is represented by area (4) "Demand met by hydrochlorofluorocarbons (HCFCs)" in Exhibit 2-3. Different assumptions about the size of this HCFC market form the basis for the analysis of chlorine loadings that follows.[9]

Exhibit 2-4 graphically depicts changes in chlorine concentrations resulting from HCFC substitution relative to 1985 levels for four CFC replacement rates. The reader should note that this exhibit presents only the chlorine contributions of the HCFC substitutes. The impacts on chlorine concentrations from the continued use of CFCs according to the Montreal Protocol reduction requirements as well as the contributions from methyl chloroform, carbon tetrachloride and baseline HCFC-22 have all been excluded from this exhibit in order to isolate the effect of the HCFC substitution rates. This exhibit also assumes the HCFCs have an average ozone depletion potential (ODP) of 0.05 (based on HCFC-22).

As shown in Exhibit 2-4, in all cases, chlorine concentrations are projected to increase through 2100 reflecting the continued demand for

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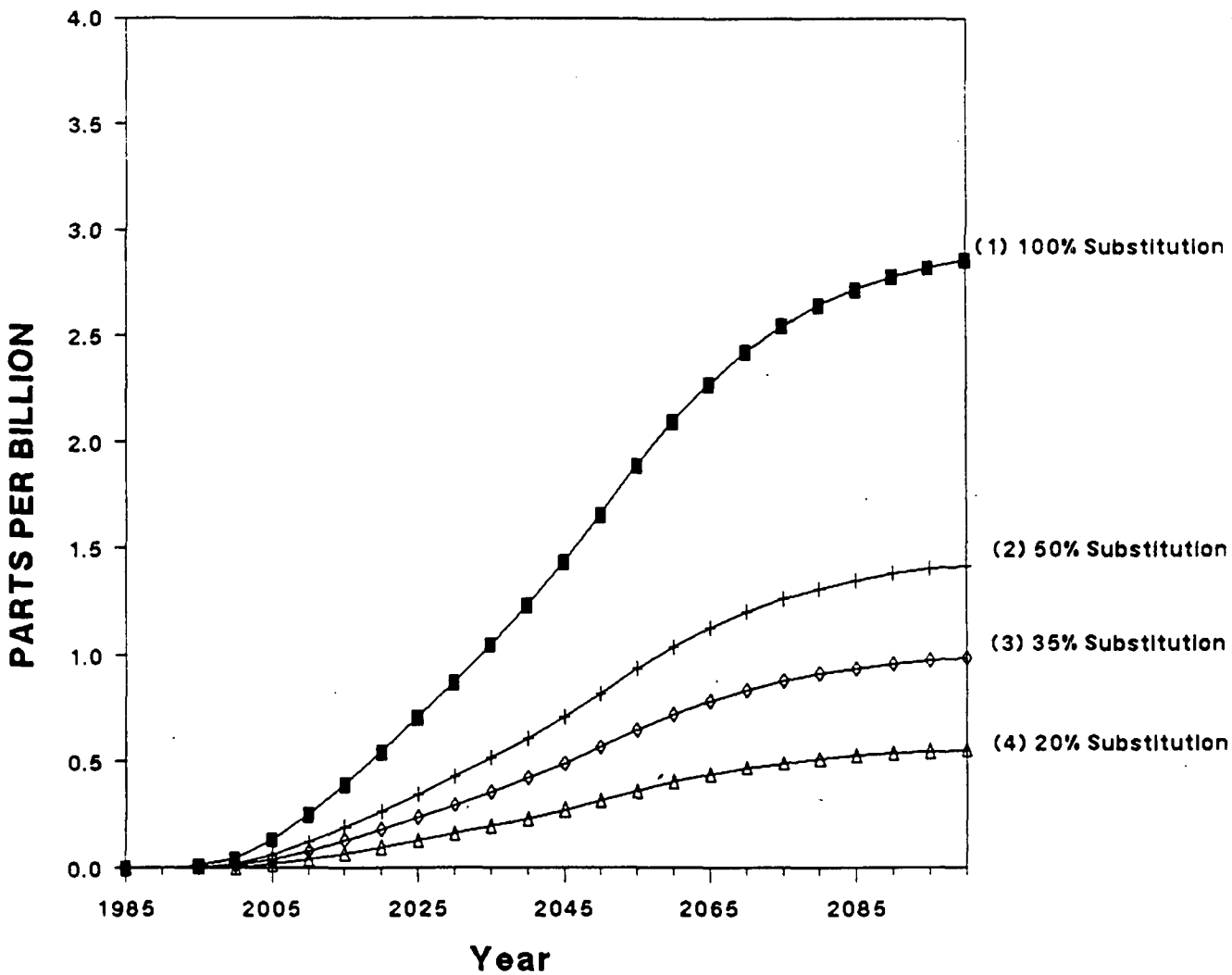
[9] The approach employed in this analysis of aggregate chlorine loadings for estimating stratospheric chlorine levels based on emissions is also used in the scenario based evaluations discussed in Chapter 3 and the trade-off analysis of Chapter 4. In addition, the above methodology for determining the rate of growth for various CFC replacements is also employed in Chapter 3. In Chapter 3, the rate of HCFC substitution is estimated more precisely by focusing on individual end uses and the likelihood of various non-chlorine containing substances (e.g., product and processes changes, and HFCs) being adopted. A full discussion of the methodology used in this report is presented in Appendix A.

Exhibit 2-4

INFLUENCE OF THE SUBSTITUTION RATE INCREMENTAL Clx CONCENTRATIONS FROM HCFC SUBSTITUTES 1985 Through 2100



Assumptions:

- 2000 Phase-out of Fully Halogenated CFCs
- 100% Global Participation
- HCFCs Average an ODP of 0.05

products and services which use CFCs being met (at least partially) through the use of HCFCs. However, as the rate of substitution is reduced, the increase in Clx levels is less rapid.

If HCFCs are used as substitutes for CFCs on a one-to-one basis (100 percent case), the replacements will contribute approximately 2.6 ppb to overall chlorine concentrations by 2075. By limiting HCFC substitution to a 50 percent replacement rate, an incremental decline of roughly 1.3 ppb from the full substitution scenario is projected to occur. Further, the 35 percent and 20 percent substitution scenarios yield reductions of 1.7 and 2.1 ppb respectively in 2075, relative to the 100 percent substitution case.

2.2.3 Evaluation of Varying Atmospheric Characteristics of CFC Substitutes

In addition to the uncertainty concerning the rate at which HCFCs will replace foregone CFCs, uncertainty exists about the specific HCFC substitutes that will be used. The future mix of HCFCs used is an important factor in assessing the contribution of CFC substitutes to stratospheric chlorine levels because the HCFCs have different chemical and physical characteristics. These characteristics determine the degree to which the substitutes contribute chlorine to the atmosphere.

Exhibit 2-5 displays ozone depletion potentials for several potential CFC substitutes. Ozone depletion potentials (ODPs) are a measure of the calculated effect of one compound on stratospheric ozone compared to the calculated effect of CFC-11 (on an equal mass basis). These indices serve as simplified expressions of the chemical and physical characteristics of the compounds and as a useful measure of each compound's potential effect on stratospheric ozone.

EXHIBIT 2-5

OZONE DEPLETION POTENTIALS OF POSSIBLE CFC SUBSTITUTES[1,2]

COMPOUND	ODP
HCFC-22	0.05
HCFC-123	0.02
HCFC-124	0.02
HCFC-141b	0.08
HCFC-142b	0.06
HFC-125	0.00
HFC-134a	0.00
HFC-152a	0.00

[1] The estimates of ozone depletion potential used in this analysis have been updated from previous EPA analyses to reflect recent information on HCFC lifetimes. For example, the ODP for HCFC-141b has been changed from 0.10 to 0.08 (personal communication, Connell).

[2] As indicated in Exhibit 2-1, the uncertainties associated with HCFC lifetimes affect the compounds' potential Clx contribution as well as estimated ODPs. Lengthening a compound's lifetime results in a greater Clx contribution, while shortening the lifetime would reduce the Clx contribution. For example, if the uncertainty of the lifetime of HCFC-22 is 20 percent, the corresponding range for its ODP is 0.05, plus or minus 0.01.

In this evaluation, assumptions are made regarding average ozone depletion potential of the mix of HCFC substitutes likely to be used to replace CFCs. Average ozone depletion potentials will be influenced by two factors: (1) the mix of substitutes used, and (2) the portion of total CFC demand that is replaced through the use of each substitute. Examples of different mixes of chemicals and associated average ODPs are shown in Exhibit 2-6. As demonstrated in the exhibit a range of mixes can give the same average ozone depletion potential and a range of average ozone depletion potentials are possible for the same quantity of chemical use (but different mix). In this evaluation a range of average ODP is used to bound the uncertainty concerning the exact substitutes that might be used to replace CFCs: 0.02; 0.05; and 0.08. In this segment of the analysis, the substitution rate of HCFCs for foregone CFCs is held constant at 50 percent in order to illustrate clearly the effect of varying the characteristics of the substitutes.[10]

Exhibit 2-7 presents an illustration of the influence of the average ozone depletion potentials of the mix of substitutes used to replace CFCs on stratospheric chlorine concentrations. In this segment of the analysis, the substitution rate of HCFCs for foregone CFCs is held constant at 50 percent to illustrate clearly the effect of varying the characteristics of the

[10] In Chapter 3, the average ozone depletion potential for each substitution scenario is estimated based on assessment of specific substitutes for different applications.

EXHIBIT 2-6

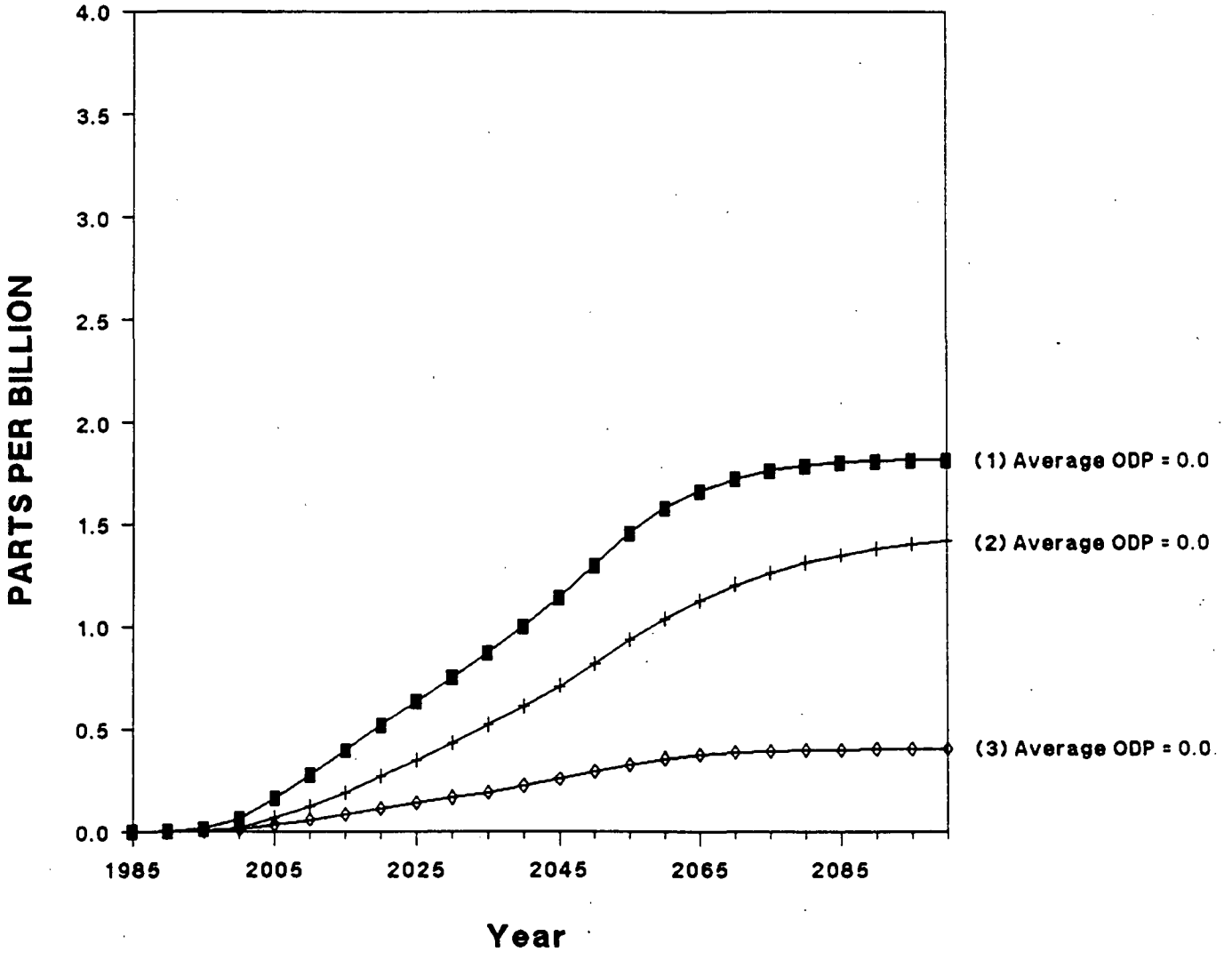
EXAMPLES OF AVERAGE OZONE DEPLETION POTENTIAL ESTIMATES[1]

COMPOUND	PERCENT OF CFC DEMAND CAPTURED			
	EXAMPLE A	EXAMPLE B	EXAMPLE C	EXAMPLE D
HCFC-22	100	50	50	0
HCFC-123	0	25	50	0
HCFC-141b	0	25	0	100
Average ODP	0.05	0.05	0.035	0.08

[1] This exhibit presents a simplified illustration of the estimation of average ozone depletion potentials for a set of HCFC substitutes. The compounds and substitution rates above are not intended to represent actual CFC replacement scenarios. As indicated in the text, HCFCs will not be the sole substitutes for CFCs.

Exhibit 2-7

INFLUENCE OF AVERAGE ODP OF HCFC SUBSTITUTES
INCREMENTAL Clx CONCENTRATIONS FROM HCFC SUBSTITUTES
1985 Through 2100



Assumptions:

- 2000 Phase-out of Fully Halogenated CFCs
- 100% Global Participation
- HCFCs Capture 50% of What CFC Market Would Have Been

substitutes.[11] As in Exhibit 2-2, these increments of chlorine concentrations represent only the contributions of the HCFC substitutes. The influence of the remaining CFCs, methyl chloroform and carbon tetrachloride have all been removed from consideration in order to isolate the impact of the atmospheric characteristics of the HCFCs.

For all three cases evaluated, chlorine levels would increase through 2100 as HCFCs are used to replace 50 percent of the CFC demand over time. As the average ozone depletion potential of the mix of HCFC substitutes declines, this increase in chlorine levels relative to 1985 concentrations becomes less pronounced.

Assuming the mix of substitutes has an average ozone depletion potential similar to that of HCFC-141b (0.08), HCFCs would contribute 1.8 ppb chlorine by 2075.[12] By altering the mix of CFC replacements such that the average ozone depletion potential of the substitutes is 0.05 or 0.02, chlorine contributions from the HCFCs are shown to decline to 1.3 and 0.4 ppb respectively in 2075.

Uncertainties in the lifetimes of HCFCs can have an effect on the compound's ozone depletion potential. The uncertainties about the reactions of HCFCs with other species can lead to assumptions of a greater or lesser

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[11] In Chapter 3, the average ozone depletion potential for each substitution scenario is estimated based on assessment of specific substitutes for different applications.

[12] In the absence of controls, CFCs would contribute approximately 21.816 ppb to chlorine levels in 2075. Under the provisions of the Montreal Protocol, CFCs would contribute 2.864 ppb chlorine and substitutes for foregone CFCs (assuming a 50 percent rate of substitution and an average ozone depletion potential of 0.05) would add 1.147 ppb to chlorine concentrations in 2075.

lifetime. Uncertainties about sinks could also have effects on estimates of HCFC lifetimes. Wine recently reported the possibility of methyl chloroform having a sink other than the hydroxyl radical (OH^-) of 20 percent (hydrolysis).[13] Coupled with uncertainty about the lifetime of methyl chloroform, on which OH abundance and hence HCFC lifetimes are benchmarked, this uncertainty about sinks could lead to uncertainties in the ODPs of HCFCs of up to 40 percent. Thus the mix of HCFCs or level of HCFC use consistent with any chlorine path could be altered in the future if current estimates prove inaccurate.

2.2.4 Summary of the Policies Required to Reduce Stratospheric Chlorine Levels

Exhibit 2-8 presents a summary of the policy options available for reducing stratospheric chlorine levels to or below 1985 concentrations (i.e., stabilizing or reducing ozone depletion risks). Chlorine concentrations are projected to increase through 2010 in every control scenario. This result occurs because of several factors: the continued use of CFCs in all scenarios to the year 2000; the release of banked CFCs; the long atmospheric residence times of the CFCs; and the delay in the transport of the compounds to the stratosphere. In essence, it appears inevitable that for the next 25 years, there will be an increase of chlorine from present levels.

Curve 1 on Exhibit 2-8 reveals that even with 100 percent global participation in the current Montreal Protocol, chlorine concentrations would increase quite significantly with a notable contribution to the rise in Clx levels from CFCs, methyl chloroform and carbon tetrachloride. In fact,

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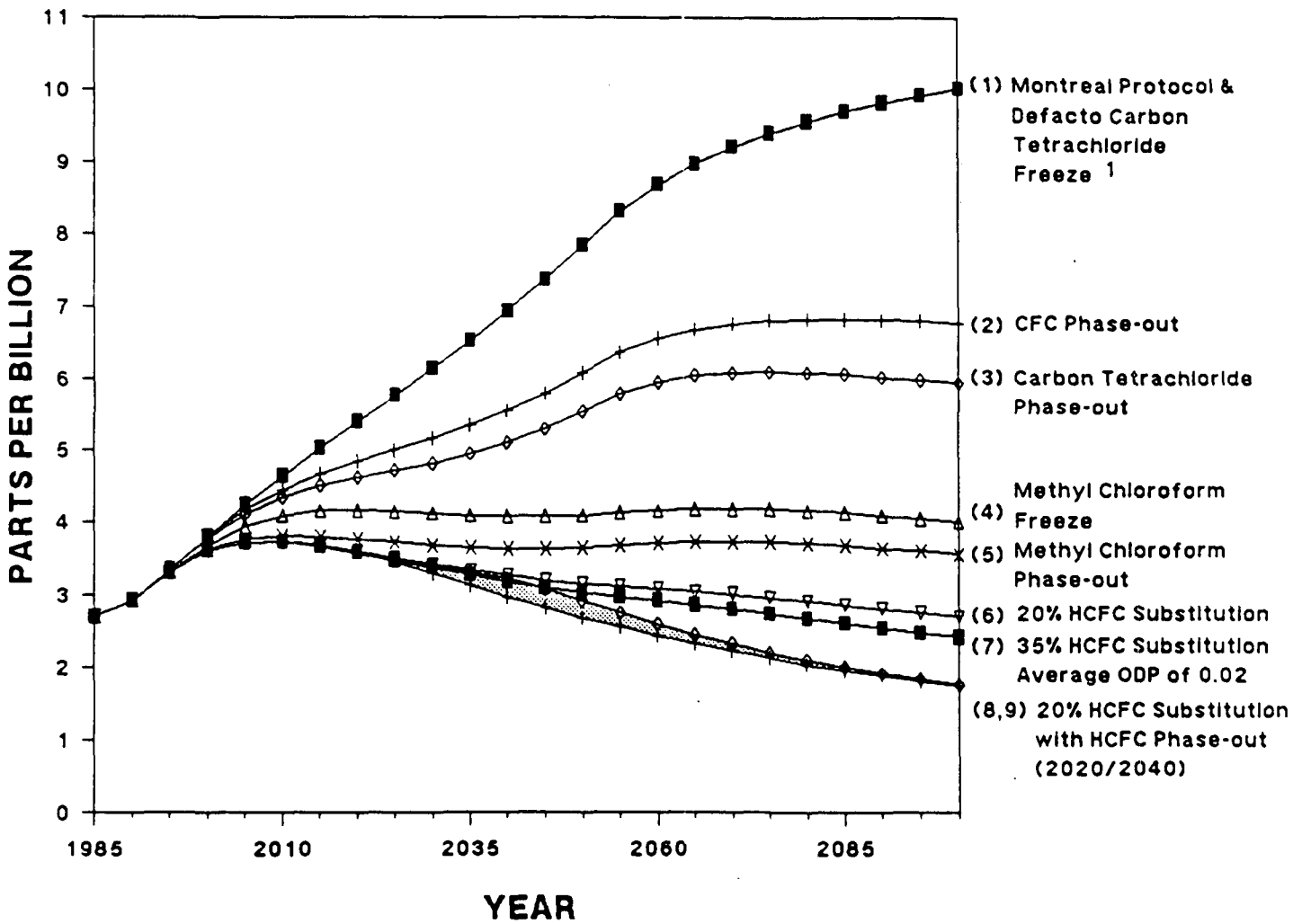
[13] Personal communication with Dr. Paul Wine.

Exhibit 2-8
SUMMARY REDUCTIONS - POLICIES NEEDED TO REDUCE CHLORINE CONCENTRATIONS TOTAL Clx CONCENTRATIONS 1985 Through 2100



Assumptions:

- HCFCs Capture 50% of What CFC Market Would Have Been (Except 6-9)
- HCFCs Average an ODP of 0.05 (Except Curve 7)
- 100% Global Participation

Notes:

[1] In earlier drafts, (including EPA's presentation in Helsinki to Montreal Protocol parties (1989)), these policies (Montreal Protocol and Carbon Tetrachloride Freeze) were shown as two separate controls. In this analysis, the two are combined based on the assumption that CFC producers will not "dump" carbon tetrachloride feedstock (that would have been used to produce CFCs) on global markets and that independent carbon tetrachloride use will not in fact increase. While possibilities exist for an increase in use to occur, such growth is unlikely given the awareness of carbon tetrachloride's potential contribution to stratospheric ozone depletion.

stratospheric Clx levels could increase approximately 7 ppb by 2075 from 1985 levels following full implementation of the current Protocol.

Phasing out fully-halogenated CFCs by themselves would reduce chlorine levels by 2.6 and 3.2 ppb in 2075 and 2100, respectively, relative to the Montreal Protocol case (see Curve 2).[14] Nevertheless, under the CFC phase-out scenario, stratospheric chlorine concentrations could still climb to approximately 4 ppb above 1985 levels in 2075 and continue to increase through 2100.

The addition of carbon tetrachloride and methyl chloroform controls to the phase out policy will result in further reductions of chlorine levels. In 2075 the incremental benefits (2.0 ppb) of freezing the use of methyl chloroform is of the same magnitude as the reductions achievable through a CFC phase out (2.6 ppb from the Protocol case). Phaseouts of carbon tetrachloride and methyl chloroform would reduce chlorine levels by approximately another 1.2 ppb in 2075. This latter estimate is independent of the growth estimates of these compounds.

The analysis shows that an HCFC substitution rate equal to 20 percent of the original CFC market (measured from an assumed baseline rate of 50 percent) combined with carbon tetrachloride and methyl chloroform controls would be consistent with a reduction in chlorine concentrations to 1985 levels by 2100. If the average ozone depletion potential of the mix of CFC substitutes were

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[14] As was the case for Exhibit 2-2, this graph presents <u>incremental</u> reductions in chlorine levels achieved by implementation of each of the controls. For example, the second curve, "CFC Phase Out", represents chlorine levels projected to occur following adoption of the Montreal Protocol and the complete elimination of CFC use in 2000.

0.02 (not 0.05) and the HCFC substitution rate increased to 35 percent, chlorine levels would be 0.3 ppb lower in 2100 than the levels estimated in that year for the 0.05 ODP/20 percent substitution case.

Recent discussions have focused on the possibility of phasing out HCFCs around 2020-2040. Exhibit 2-8 shows the incremental effects of these policies and demonstrates that a phaseout in this time frame would eliminate their contribution to total chlorine levels by 2075. The additional phaseout of HCFC substitutes and baseline HCFC-22 by 2020-2040 would return Clx to below pre-Antarctic ozone hole levels of 2.0 <u>before</u> 2100.

The results presented in Exhibit 2-8 demonstrate that stratospheric chlorine can be reduced below 1985 concentrations if a phaseout of fully-halogenated CFCs begins in 2000 and is accompanied by a phaseout of both methyl chloroform and carbon tetrachloride, and the prudent use of HCFCs (e.g., a 20 percent or lower rate of substitution and an average ozone depletion potential of 0.05). A return to pre-Antarctic ozone hole levels also requires that HCFC use be eliminated.

CHAPTER THREE

AN ANALYSIS OF FOUR AGGREGATE HCFC SUBSTITUTION SCENARIOS

The previous chapter focused on potential changes in stratospheric chlorine levels from the continued use of CFCs and from other chlorinated compounds not currently regulated by the Montreal Protocol. It also illustrated the potential reductions in chlorine levels that could be reached under various limits on these compounds and highlighted the potential contribution to chlorine levels from various use scenarios for the HCFCs. This chapter focuses in detail on the potential use of HCFCs. It develops scenarios based on the specific use of these chemicals to replace CFCs across applications in the context of a phaseout of the fully-halogenated CFCs by the year 2000. It then examines the implications of each CFC substitution scenario for:

- -- increases in stratospheric chlorine levels;
- -- increases in greenhouse gases, and, therefore, projected global warming; and
- -- changes in energy efficiency, and, therefore, indirect impacts on global warming through increased use of fossil fuels (referred to as the "indirect" greenhouse effect).

Given the rapid pace of technological development related to CFC substitutes, developing scenarios for HCFC use over time is an inherently uncertain undertaking. For example, chemical substitutes that appeared promising only a few months ago have been surpassed by new substitutes or have fallen out of favor as testing is completed and more is learned about their

attributes in particular applications. Given the rapid pace of development, and the existing uncertainties in such areas as the results of long-term toxicity and ozone-depletion potential, any analysis of future use of HCFCs will remain uncertain. These uncertainties apply both to the selection of CFC substitutes in the United States and worldwide. For example, while alcohol-based cleaners appear to be the substitutes being adopted by many electronics firms in Europe, U.S. companies are exploring the use of aqueous and terpene cleaners and Japanese firms are developing a new branch of the HCFC family. It is too soon to determine whether electronics firms worldwide will continue down these different paths or whether they will converge on a primary substitute. Consequently, the analyses in this report will require periodic updates.

3.1 THE ANALYTICAL FRAMEWORK

To examine the range of substitutes that could be used to replace CFCs, this chapter attempts to set bounds on their implications on chlorine levels and direct and indirect greenhouse impacts by examining four aggregate substitution scenarios. Chapter 4 presents a more detailed analysis of implications for alternative substitutes within each of the major CFC use sectors that have important energy implications.

3.1.1 Scenarios Used

The four scenarios examined in this chapter are:

Scenario 1: Conventional Wisdom: assumes the leading candidates to replace CFCs based on industries' research efforts over the past several years

(e.g., HCFCs, HFCs, product substitutes, along with recycling and improved housekeeping) are actually adopted.

Scenario 2: High Use of HCFC Compounds with Maximum ODPs: provides an "upper bound" on chlorine increases from HCFCs by assuming that industry replaces CFCs with HCFCs wherever possible and chooses those HCFCs with the highest ODPs. Such a scenario is plausible since at least several of these chemicals are already commercially available including HCFC-22 and HCFC-142b.

Scenario 3: Prudent HCFC Use: assumes that industry moves to HCFCs only when reasonable non-HCFC alternatives (e.g., product substitutes or HFCs) are not available and that recycling and the use of HCFCs with lowest ODP is chosen whenever possible.

Scenario 4: Minimum Greenhouse and Energy Impacts: assumes substitutes are selected with the goal of decreasing direct and indirect greenhouse impacts [e.g, uses short life fluorine based compounds and alternative refrigerants (ammonia) and products (vacuum panels) when they reduce greenhouse effects].

Each scenario is discussed in greater detail below.

3.1.2 End Use Categories Examined

Within each scenario, this analysis breaks down CFC use into 20 end use categories. These represent the vast majority of total CFC consumption and include specific use categories for each of the major energy-consuming sectors to enable a detailed look at both energy efficiency and energy cost impacts. For the purposes of this analysis, the remaining CFC use falling outside these

categories was distributed evenly across all other uses.[1] Exhibit 3-1 provides a list of the 20 end use categories and the type of CFC used in each category.

Because of the differences in global use patterns, technological preferences, and energy supply, the analysis also divides the world into 4 regions:

-- the United States;

-- Western industrialized countries;

-- Centrally-planned economies; and

-- Other developing countries (Rest of the World).

3.1.3 Description of CFC Reduction Technologies

To eliminate the use of CFCs by the year 2000, the analysis draws on a wide range of reduction options including: chemical substitutes (e.g., HCFCs, HFCs, alcohol and others); product substitutes (e.g., spray pumps, vacuum panels); and recycling and housekeeping practices. Because of the differences in the assumptions underlying the scenarios, each relies on a different mix of these chemical substitutes/product substitutes and recycling activities.

Exhibit 3-2 provides a summary of the contribution of different reduction technologies to the achievement of the phaseout in each use category for each of the scenarios. This exhibit illustrates the distinctions between each of the scenarios. For example, in Scenario 2 there is extensive use of HCFCs in

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[1] EPA has conducted research into distributing total CFC use among specific end uses. There is, however, some use that is unaccounted for. To the greatest extent possible, total use has been allocated to the appropriate use areas.

EXHIBIT 3-1

TWENTY END-USE CATEGORIES

END-USE CATEGORIES	CFCS USED CURRENTLY
1. Mobile Air Conditioners	CFC-12
2. Residential Refrigeration[a]	CFC-12
3. Chillers	CFC-11, CFC-12, CFC-114
4. Process Refrigeration	CFC-12, CFC-115[b]
5. Cold Storage Warehouses	CFC-12, CFC-115
6. Retail Food Storage	CFC-12, CFC-115
7. Other Refrigeration[c]	CFC-12, CFC-115
8. Refrigerated Transport[c]	CFC-12, CFC-115
9. Rigid Polyurethane Foam (residential refrigeration)	CFC-11, CFC-12
10. Rigid Polyurethane Foam (other refrigeration)	CFC-11
11. Rigid Polyurethane Foam (refrigerated transport)	CFC-11
12. Rigid Polyurethane Foam (structure insulation)	CFC-11, CFC-12
13. Rigid Polyurethane Foam (packaging)	CFC-11, CFC-12
14. Flexible Foam	CFC-11
15. Rigid Non-Polyurethane Foam (structure insulation)	CFC-12
16. Rigid Non-Polyurethane Foam (packaging)	CFC-11, CFC-12, CFC-114
17. Aerosols	CFC-11, CFC-12
18. Solvent Cleaning (cold cleaning)	CFC-113
19. Solvent Cleaning (vapor degreasing)	CFC-113
20. Sterilization	CFC-12

[a] Includes CFC-12 used as a working fluid in domestic refrigerators and freezers only. CFC use associated with insulation of refrigerators and freezers is categorized under Rigid Polyurethane Foam (refrigeration).

[b] References to CFC-115 are as a component of HCFC-502.

[c] Use of CFC-12 and CFC-115 in other refrigeration and refrigerated transport applications represent the use of these compounds as a working fluid. CFC use associated with insulation is categorized under Rigid Polyurethane Foam (other refrigeration) and (refrigerated transport).

Descriptions of these end-use areas are presented in U.S. EPA, Regulatory Impact Analysis: Protection of Stratospheric Ozone, Volume III, August 1, 1988.

Exhibit 3-2
HCFC/HFC and Not-in-Kind Market Potentials for the Substitution Scenarios

End Use	Control Options	Percent Market Potential Conventional Wisdom	Percent Market Potential Maximum HCFC Use	Percent Market Potential Prudent HCFC Use	Percent Market Potential Minimize Greenhouse Energy Impact
Mobile Air Conditioners	Recovery at Service/Quality Engineering	20	20	20	20
	HCFCs/HFCs	80	80	80	80
	Total	100	100	100	100
Residential Refrigeration	Recovery at Service, Rework, and Disposal	-	-	7	-
	Alternate Leak Test Procedure	-	-	1	-
	HCFCs/HFCs	100	100	92	100
	Total	100	100	100	100
Chillers	Recovery at Service and Disposal	19	19	32	19
	Alternate Leak Test Procedure	1	1	1	1
	Ammonia	20	20	20	35
	HCFCs/HFCs	60	60	47	4[illegible]
	Total	100	100	100	10[illegible]
Process Refrigeration	Recovery at Service and Disposal	-	-	34	-
	Ammonia	16	16	16	16
	HCFCs/HFCs	84	84	50	84
	Total	100	100	100	100
Cold Storage Warehouses	Recovery at Service and Disposal	-	-	30	-
	Alternate Leak Test Procedure	1	1	1	1
	Ammonia	18	18	18	38
	HCFCs/HFCs	81	81	50	61
	Total	100	100	100	100
Retail Food Storage	Recovery at Service and Disposal	15	15	28	15
	Alternate Leak Test Procedure	1	1	1	1
	Ammonia	9	9	9	35
	HCFCs/HFCs	75	75	62	49
	Total	100	100	100	100
Other Refrigeration Appliances	Recovery at Service and Disposal	4	4	9	4
	Alternate Leak Test Procedure	1	1	1	1
	HCFCs/HFCs	95	95	90	95
	Total	100	100	100	100
Refrigerated Transport	Recovery at Service and Disposal	4	4	9	4
	Alternate Leak Test Procedure	1	1	1	1
	HCFCs/HFCs	95	95	90	95
	Tota	100	100	100	100

Exhibit 3-2
HCFC/HFC and Not-in-Kind Market Potentials for the Substitution Scenarios

End Use	Control Options	Percent Market Potential Conventional Wisdom	Percent Market Potential Maximum HCFC Use	Percent Market Potential Prudent HCFC Use	Percent Market Potential Minimize Greenhouse Energy Impact
Rigid Polyurethane Foam (Refrigeration)	Thick Fiberglass Batts	-	-	-	-
	Water Blown Foam	-	-	24/40 (1)	-
	Vacuum Panels	-	-	20	100
	HCFCs/HFCs	100	100	56/40 (2)	-
	Total	100	100	100	100
Rigid Polyurethane Foam (Other Refrigeration Appliances)	Thick Fiberglass Batts	-	-	-	5
	Water Blown Foam	-	-	20/32 (3)	-
	Vacuum Panels	5	5	35	95
	HCFCs/HFCs	95	95	45/33 (4)	-
	Total	100	100	100	100
Rigid Polyurethane Foam (Refrigerated Transport)	Thick Fiberglass Batts	-	-	-	5
	Water Blown Foam	-	-	20/32 (3)	-
	Vacuum Panels	5	5	35	95
	HCFCs/HFCs	95	95	45/33 (4)	-
	Total	100	100	100	100
Rigid Polyurethane Foam (Insulation)	Thick Fiberglass Batts	10	10	10	10
	Water Blown Foam	-	-	6	-
	Fiberboard	10	10	10	10
	Expanded Polystyrene Bead Boards	20	20	40	20
	HCFCs/HFCs	60	60	34	60
	Total	100	100	100	100
Rigid Polyurethane Foam (Packaging)	Other Packaging Material	40	40	50	20
	Expanded Polystyrene Beads	40	40	50	80
	HCFCs/HFCs	20	20	-	-
	Total	100	100	100	100
Flexible Foam	CO2 Process/Harder Foams	20	20	20	20
	Engineered Plastic Cushioning	20	20	20	20
	Water Blown Foams	20	20	40	40
	Latex Foams	20	20	20	20
	HCFCs/HFCs	20	20	-	-
	Totals	100	100	100	100
Rigid Non-polyurethane Foam (Insulation)	Thick Fiberglass Batts	20	20	20	20
	Expanded Polystyrene	40	40	50	40
	HCFCs/HFCs	40	40	30	40
	Total	100	100	100	100

Exhibit 3-2
HCFC/HFC and Not-in-Kind Market Potentials for the Substitution Scenarios

End Use	Control Options	Percent Market Potential Conventional Wisdom	Percent Market Potential Maximum HCFC Use	Percent Market Potential Prudent HCFC Use	Percent Market Potential Minimize Greenhouse Energy Impact
Rigid Non-polyurethane Foam (Packaging)	Alternative Packaging Material	40	40	100	30
	Expanded Polystyrene Beads	30	30	-	70
	HCFCs/HFCs	30	30	-	-
	Total	100	100	100	100
Cold Cleaning	Engineering Controls	13	20	30	13
	Organic Solvents	20	37	39	20
	Aqueous Cleaning/Semi-Aqueous	67	-	31	67
	HCFCs/HFCs	-	43	-	-
	Total	100	100	100	100
Vapor Degreasing	Engineering Controls	13	20	30	13
	Organic Solvent	20	37	39	20
	Aqueous Cleaning/Semi-Aqueous	67	-	31	67
	HCFCs/HFCs	-	43	-	-
	Total	100	100	100	100
Sterilization	Condensation/Reclamation	4	4	14	14
	Nitrogen Purge/Ethylene Oxide	4	4	14	14
	10/90 Ethylene Oxide/Carbon Dioxide	20	20	72	72
	HCFCs/HFCs	72	72	-	-
	Total	100	100	100	100
Aerosols	Hydrocarbons/Pumps/Other Delivery Systems	75	75	100	100
	HCFCs/HFCs	25	25	-	-
	Total	100	100	100	100

Notes

(1) For the U.S., CPE, and ROW 24 percent of the CFCs and for the WIC 40 percent of the CFCs are replaced by water blown foams.
(2) For the U.S., CPE, and ROW 56 percent of the CFCs and for the WIC 40 percent of the CFCs are replaced by HCFCs.
(3) For the U.S., CPE, and ROW 20 percent of the CFCs and for the WIC 32 percent of the CFCs are replaced by water blown foams.
(4) For the U.S., CPE, and ROW 45 percent of the CFCs and for the WIC 33 percent of the CFCs are replaced by HCFCs.

refrigeration and foams, whereas in Scenario 4 there is somewhat more use of ammonia as a refrigerant and of vacuum panels and other insulating materials as foam substitutes because of their higher energy efficiency. In contrast, Scenario 3 makes use of HCFCs in more limited areas than Scenario 1 and shows greater reliance on recycling.

A more detailed description of the environmental characteristics of the HCFC and HFC substitutes applied under the scenarios is presented in Appendix B. That appendix presents estimates of the following parameters for each of these compounds:

- Chemical formula and molecular weight;
- Ozone depletion potential;
- Direct greenhouse contribution;
- Flammability;
- Toxicity status;
- Current uses; and
- Areas of potential substitution.

The reader should note that there exists a great deal of uncertainty concerning many important characteristics of these substitutes. The information reported in the appendix is believed to represent the best currently available data and therefore is incorporated in this analysis, but these estimates should not be misinterpreted as definitive findings.

Appendix C summarizes the applicability of potential chemical substitutes in the 20 end uses considered in this analysis. In addition, the matrices indicate the currently available substitutes, those considered the leading candidates to replace the foregone CFCs in the long term, whether the

substitute is applicable to only new equipment or both new and existing units, the replacement factor (e.g., whether more or less is required to replace the CFCs), and the anticipated changes in the energy efficiency of the equipment resulting from the use of the alternative.

3.1.4 Use Specifications of CFC Alternatives

In addition to defining the technological alternatives to CFCs that are employed to achieve a phaseout, the scenarios also specify the following characteristics:

- The HCFC/HFC substitute(s) used in existing and new capital stock;
- The replacement factors for new and exiting capital stock, representing the number of kilograms of a substitute needed to replace one kilogram of CFC;
- The year in which the substitutes are assumed first to be introduced into new and existing capital stock;
- The percentage change in energy consumption[2] associated with the use of the substitute in new and existing capital stock (negative numbers represent reductions in energy consumption); and
- The "market penetration" term which specifies the amount of the total market for CFCs that is captured by HCFCs change under a phaseout.

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[2] Several options that reduce energy use, such as cascading HCFC-22 systems in retail refrigeration, are not included in this draft. These options will be considered in other analyses.

It is important to note that the substitutes applied in each end use area under the four scenarios described below have been chosen to comply with the overarching specification of each scenario (i.e., the substitutes applied under Section 2 represent those currently identified substitutes that have maximum chlorine content). The controls that actually will be adopted by industry are very uncertain. In some cases, significant technical problems remain to be resolved for specific controls, and within many end use areas, there are a number of competing substitutes that could prove practical. EPA will continue its evaluation of substitutes over time. Readers must recognize, therefore, that the scenarios presented here represent paths defined for analytical purposes.

3.2 DESCRIPTION OF SUBSTITUTE SCENARIOS

3.2.1 Scenario 1 - Conventional Wisdom

This scenario illustrates the use of HCFCs and HFCs that have been examined by industry over the past several years (less in some cases) and currently appear to be the leading candidates to replace the fully-halogenated CFCs. As shown in Exhibit 3-3, the alternatives employed in this scenario include reliance on HCFC-22 (to replace CFC-12) and HCFC-123 (to replace CFC-11) in most foam applications, the use of HFC-134a in automobile air conditioning, the use of a near azeotropic refrigerant material (e.g., a blend

Exhibit 3-3

Chemical Substitution Assumptions for Scenario 1
Conventional Wisdom

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Mobile Air Conditioners	CFC-12	Mixture(1)	HFC-134a	1.07(2)	0.9	1993	1993	-2.0	(+6.7 to +1.0)(3) +3.0	80
Residential Refrigeration	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0(3)	-3.0(3)	100
Chillers	CFC-11	HCFC-123	HCFC-123	1.0	1.0	1992	1992	+1.0 (3)	+1.0 (3)	60
	CFC-12	HFC-134a	HFC-134a	1.0	1.0	1992	1992	(+6.7 to +1.0)(3) +3.0	(+6.7 to +1.0)(3) +3.0	60
	CFC-114	HFC-124	Mixture(1)	1.0	1.0	1992	1993	(+6.7 to +1.0)(4) +3.0	-3.0(3)	60
Process Refrigeration	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0(3)	-3.0(3)	84
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	84
Cold Storage Warehouses	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0(3)	-3.0(3)	81
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	81
Retail Food Storage	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0(3)	-3.0(3)	75
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	75
Other Refrigeration Appliances	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0(3)	-3.0(3)	95
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	95
Refrigerated Transport	CFC-12	Mixture(1)	Mixture(1)	1.07(2)	1.07(2)	1993	1993	-2.0	-2.0	95
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	95
Rigid Polyurethane Foam (refrigeration)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	100
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	0.0	100
Rigid Polyurethane Foam (other refrigeration appliances)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	95
Rigid Polyurethane Foam (refrigerated transport)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	95
Rigid Polyurethane Foam (insulation)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+10.0	60
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	0.0	60

(Continued on the next page)

Exhibit 3-3

Chemical Substitution Assumptions for Scenario 1
Conventional Wisdom

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Rigid Polyurethane Foam (packaging)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	N/A	20
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	N/A	20
Flexible Foam	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1992	N/A	N/A	20
Rigid Non-polyurethane Foam (insulation)	CFC-12	N/A	HCFC-22/HCFC-142b	N/A	1.0	N/A	1989	N/A	+0.0	40
Rigid Non-polyurethane Foam (packaging)	CFC-11	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
	CFC-12	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
	CFC-114	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
Cold Cleaning	CFC-113	HCFC-141b/HCFC-123 (5)	Non-HCFC/HFC	1.0	NA	1992	1989	N/A	N/A	67
Vapor Degreasing	CFC-113	HCFC-141b/HCFC-123 (5)	Non-HCFC/HFC(6)	1.0	NA	1992	1989	0.0	+150.0	67
Sterilization	CFC-12	Prop(7)	Prop(7)	1.0	1.0	1992	1992	N/A	N/A	72
Aerosols	CFC-11	NA	HCFCs/HFCs(8)	NA	1.0	NA	1992	N/A	N/A	25
	CFC-12	NA	HCFCs/HFCs(8)	NA	1.0	NA	1992	N/A	N/A	25

Notes:

(1) Represents a near-azeotropic ternary blend of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124. There may be other azeotropic and near-azeotopic blends with equivalent energy and capacity for low and high temperature applications.
(2) Takes into consideration blend lost due to hose permeation. Obtained from "Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants," SAE Technical Paper, February 1989.
(3) Provided by industrial source.
(4) Due to absence of data on energy implications of HCFC-124, assumed to be same as those for HFC-134a used to replace CFC-12 in this application.
(5) Assumes a mixture of 62 percent HCFC-141b, 36 percent HCFC-141b, and 2 percent methanol.
(6) CFC-113 replaced by Aqueous/Semi-Aqueous cleaning resulting in energy loss of 150 percent.
(7) Proprietary componds assumed to have chemical & physical properties similar to HCFC-22.
(8) Assumed a mixture with an ODP of 0.02 and a lifetime of 8 years.

of HCFC-22, HCFC-124 and HCFC-152a) in other refrigeration applications, the use of aqueous cleaners, terpenes and alcohols as solvents, and some use of HCFCs as aerosol substitutes. The scenario also includes the use of a moderate amount of recycling in the refrigeration and air conditioning sectors and includes retrofitting in each of these use categories for the existing capital stock (through the use of a near azeotrope, HCFC-124, HFC-125 or HFC-134a as applicable). Each of the four scenarios include similar chemical substitutes used in retrofitting (primarily refrigeration and air conditioning sectors) because of the more limited options available for retrofitting existing capital.

The purpose behind this scenario is to demonstrate the potential contribution from HCFCs to chlorine and the energy impacts of the substitutes selected, assuming choices were made based on considerations of technical feasibility absent strong consideration of other environmental or energy impacts.

3.2.2 Scenario 2: Maximum Use of HCFCs with Maximum Chlorine Content

The purpose of this scenari is to show a "worst case" for impacts of CFC substitutes on stratospheric chlorine levels. As shown in Exhibit 3-4, to define this "upper bound," the refrigeration and air conditioning sectors make maximum use of HCFC-22 (except the use of a near azeotropic refrigerant mixture in automobile air conditioners) which has a substantially higher ozone depletion potential than any of the non-azeotropic refrigerant mixtures (NARMs) under consideration and used in other scenarios. As stated above, refrigerants similar to those used in Scenario 1 are used for the purposes of

Exhibit 3-4

Chemical Substitution Assumptions for Scenario 2
Maximum HCFCs Use

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Mobile Air Conditioners	CFC-12	Mixture (1)	Mixture (1)	1.07(2)	1.07(2)	1993	1993	-2.0	-2.0	80
Residential Refrigeration	CFC-12	Mixture (1)	Mixture(3)	1.0	1.0	1993	1993	-3.0(4)	-20.0	100
Chillers	CFC-11	HCFC-123	HCFC-22	1.0	1.0	1992	1991	+1.0(4)	(+0.0 to +8.0)(4) +4.0	60
	CFC-12	HFC-134a	HCFC-22	1.0	1.0	1992	1991	+3.0	(+0.0 to +8.0)(4) +4.0	60
	CFC-114	HFC-124	HCFC-22	1.0	1.0	1992	1991	+3.0(5)	(+0.0 to +8.0)(4) +4.0	60
Process Refrigeration	CFC-12	Mixture (1)	HCFC-22	1.0	1.0	1993	1992	-3.0(4)	+4.0 (6)	84
	CFC-115	HFC-125	HCFC-22	1.0	1.0	1993	1992	+0.0	+4.0 (6)	84
Cold Storage Warehouses	CFC-12	Mixture (1)	HCFC-22	1.0	1.0	1993	1992	-3.0(4)	(0.0 to -5.0)(4) -2.5	81
	CFC-115	HFC-125	HCFC-22	1.0	1.0	1993	1992	+0.0	(0.0 to -5.0)(4) -2.5	81
Retail Food Storage	CFC-12	Mixture (1)	HCFC-22	1.0	1.0	1993	1992	-3.0(4)	-3.1 (7)	75
	CFC-115	HFC-125	HCFC-22	1.0	1.0	1993	1992	+0.0	-3.1 (7)	75
Other Refrigeration Appliances	CFC-12	Mixture (1)	HCFC-22	1.0	1.0	1993	1992	-3.0(4)	+4.3(7)	95
	CFC-115	HFC-125	HCFC-22	1.0	1.0	1993	1992	+0.0	+4.3(7)	95
Refrigerated Transport	CFC-12	Mixture (1)	Mixture (1)	1.07(2)	1.07(2)	1993	1993	-2.0	-2.0	95
	CFC-115	HFC-125	HCFC-22	1.0	1.0	1993	1992	+0.0	+4.3(7)	95
Rigid Polyurethane Foam (refrigeration)	CFC-11	N/A	HCFC-141b	N/A	0.94(8)	N/A	1993	N/A	0.0(8)	100
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	0.0	100
Rigid Polyurethane Foam (other Refrigeration appliances)	CFC-11	N/A	HCFC-141b	N/A	0.94(8)	N/A	1993	N/A	0.0(8)	95
Rigid Polyurethane Foam (refrigerated Transport)	CFC-11	N/A	HCFC-141b	N/A	0.94(8)	N/A	1993	N/A	0.0(8)	95
Rigid Polyurethane Foam (insulation)	CFC-11	N/A	HCFC-141b	N/A	0.94(8)	N/A	1993	N/A	0.0(8)	60
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	0.0	60

(Continued on the next page)

Exhibit 3-4

Chemical Substitution Assumptions for Scenario 2
Maximum HCFCs Use

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Rigid Polyurethane Foam (packaging)	CFC-11	N/A	HCFC-141b	N/A	0.85	N/A	1993	N/A	N/A	20
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	N/A	20
Flexible Foam	CFC-11	N/A	HCFC-141b	N/A	0.85	N/A	1992	N/A	N/A	20
Rigid Non-polyurethane Foam (insulation)	CFC-12	N/A	HCFC-22/HCFC-142b	N/A	1.0	N/A	1989	N/A	0.0	40
Rigid Non-polyurethane Foam (packaging)	CFC-11	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
	CFC-12	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
	CFC-114	N/A	HCFC-22	N/A	0.8	N/A	1989	N/A	N/A	30
Cold Cleaning	CFC-113	HCFC-141b/HCFC-123 (9)	HCFC-141b/HCFC-123 (9)	1.0	1.0	1992	1992	N/A	N/A	43
Vapor Degreasing	CFC-113	HCFC-141b/HCFC-123 (9)	HCFC-141b/HCFC-123 (9)	1.0	1.0	1992	1992	0.0	0.0	43
Sterilization	CFC-12	Prop (10)	Prop (10)	1.0	1.0	1992	1992	N/A	N/A	72
Aerosols	CFC-11	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	N/A	25
	CFC-12	N/A	HCFC-22	N/A	1.0	N/A	1989	N/A	N/A	25

Notes:
(1) Represents a near-azeotropic ternary blend of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124. There may be other azeotropic or near-azeotropic mixtures with equivalent energy and capacity for low and high temperature applications.
(2) Takes into consideration blend lost due to hose permeation. Obtained from "Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants," SAE Technical Paper Series, February 1989.
(3) Assumes a binary near-azeotropic mixture is developed with an ODP similar to HCFC-22/HFC-152a mixture (75%/25%).
(4) Obtained from industrial source.
(5) Due to absence of data on energy implications of HCFC-124, energy implications assumed to be similar to those for HFC-134a used to replace CFC-12 in this application.
(6) Due to lack of data assumes energy efficiency for process refrigeration similar to chillers.
(7) Energy-Use Impact of Chlorofluorocarbon Alternatives, Oak Ridge National Laboratory, February 1989.
(8) Assumes attempts to optimize (i.e., improvements in cell density, cell size, etc.) are unsuccessfull and that foam thickness is increased sufficiently to achieve equivalent energy efficiency.
(9) Assumes a mixture of 62 percent HCFC-141b, 36 percent HCFC-123, and 2 percent methanol
(10) Proprietary compound assumed to have chemical and physical properties similar to those of HCFC-22.

retrofitting existing capital stock. In the foam sector, this scenario relies more heavily on HCFC-141b which has an ozone depletion potential which is roughly four times that of HCFC-123. Both are still under consideration by the foam industry to determine possible trade-offs in product quality, production costs and energy efficiency. In the solvents sector, HCFC-141b captures over 40 percent of what the market for CFC-113 would have been, thus contributing significantly more to chlorine levels than aqueous cleaners, terpenes or alcohols used in Scenario 1. Finally in the aerosol category, one-quarter of the market goes to HCFC-22 with its relatively high ODP.

3.2.3 Scenario 3: Prudent HCFC Use

The purpose of this scenario is to illustrate the amount of chlorine from the use of a "minimum amount" of HCFCs consistent with phasing out the fully-halogenated CFCs. As a result, as shown in Exhibit 3-5, this scenario is specified to use HFC-134a extensively in the air conditioning and refrigeration use sectors for new equipment despite possible losses in energy efficiency. The amount of recycling that occurs is also increased, thus reducing the demand for HCFCs used in servicing. In the foam sectors, the scenario relies extensively on HCFC-123 over HCFC-141b because of the significant differences in their ODPs. In the solvent sector, non-HCFC substitutes, including terpenes, aqueous cleaners and alcohols, are used. In the aerosol sector, product substitutes and hydrocarbon propellants are used instead of HCFCs.

This scenario focuses exclusively on the selection of substitutes based on their chlorine content and not on their energy impacts. As a result, it

Exhibit 3-5

Chemical Substitution Assumptions for Scenario 3
Prudent HCFC Use

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Mobile Air Conditioners	CFC-12	Mixture (1)	HFC-134a	1.07(2)	0.9	1993	1993	-2.0	(+6.7 to +1.0)(3) +3.0	80
Residential Refrigeration	CFC-12	Mixture (1)	HFC-134a	1.0	1.0	1993	1992	-3.0(3)	(+6.7 to +1.0)(3) +3.0	92
Chillers	CFC-11	HCFC-123	HCFC-123	1.0	1.0	1992	1992	+1.0 (3)	+1.0 (3)	47
	CFC-12	HCFC-134a	HFC-134a	1.0	1.0	1992	1992	+3.0(3)	(+6.7 to +1.0)(3) +3.0	47
	CFC-114	HCFC-124	HCFC-124	1.0	1.0	1992	1993	(+6.7 to +1.0)(4) +3.0	(+6.7 to +1.0)(4) +3.0	47
Process Refrigeration	CFC-12	Mixture (1)	HFC-134a	1.0	1.0	1993	1992	-3.0(3)	(+6.7 to +1.0)(3) +3.0	50
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	50
Cold Storage Warehouses	CFC-12	Mixture (1)	HFC-134a	1.0	1.0	1993	1992	-3.0(3)	(+6.7 to +1.0)(3) +3.0	50
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	50
Retail Food Storage	CFC-12	Mixture (1)	HFC-134a	1.0	1.0	1993	1992	-3.0(3)	(+6.7 to +1.0)(3) +3.0	62
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	62
Other Refrigeration Appliances	CFC-12	Mixture (1)	HFC-134a	1.0	1.0	1993	1992	-3.0(3)	(+6.7 to +1.0)(3) +3.0	90
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	90
Refrigerated Transport	CFC-12	Mixture (1)	HFC-134a	1.07(2)	0.9	1993	1992	-2.0	(+6.7 to +1.0)(3) +3.0	90
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	90
Rigid Polyurethane Foam (refrigeration)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	56/40 (5)
	CFC-12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
Rigid Polyurethane Foam (other refrigeration appliances)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	45/33 (7)
Rigid Polyurethane Foam (refrigerated transport)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+5.0	45/33 (7)
Rigid Polyurethane foam (insulation)	CFC-11	N/A	HCFC-123	N/A	1.15	N/A	1993	N/A	+10.0	34
	CFC-12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)

(Continued on the next page)

Exhibit 3-5

Chemical Substitution Assumptions for Scenario 3
Prudent HCFC Use

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Equipment	Year of Introduction for Existing Equipment	Year of Introduction for New Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Assumptions Used & Estimated Ranges for Percent Change in Energy Consumption with Substitutes for Existing Equipment	Market Potential (%)
Rigid Polyurethane Foam (packaging)	CFC-11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
	CFC-12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
Flexible Foam	CFC-11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
Rigid Non-polyurethane Foam (insulation)	CFC-12	N/A	HFC-134a	N/A	0.8	N/A	1992	N/A	+10.0(3)	40
Rigid Non-polyurethane Foam (packaging)	CFC-11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
	CFC-12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
	CFC-114	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0(6)
Cold Cleaning	CFC-113	HCFC-141b/HCFC-123 (8)	Non-HCFC/HFC	1.0	N/A	1992	1989	N/A	N/A	31
Vapor Degreasing	CFC-113	HCFC-141b/HCFC-123 (8)	Non-HCFC/HFC(9)	1.0	N/A	1990	1989	0.0	+150.0	31
Sterilization	CFC-12	Non-HCFC/HFC	Non-HCFC/HFC	NA	NA	1992	1992	N/A	N/A	72
Aerosols	CFC-11	NA	Non-HCFC/HFC	NA	NA	NA	1992	N/A	N/A	25
	CFC-12	NA	Non-HCFC/HFC	NA	NA	NA	1992	N/A	N/A	25

Notes:

(1) Represents a near-azeotropic ternary blend of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124. There may be other azeotropic or near-azeotropic mixtures with equivalent energy and capacity for low and high temperature applications.
(2) Takes into consideration blend lost due to hose permeation. Obtained from "Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants," SAE Technical Paper, February 1989.
(3) Obtained from industrial source.
(4) Due to absence of data on energy implications of use of HCFC-124, energy impliaction assumed to be same as those for HFC-134a used to replace CFC-12 in this application.
(5) For the U.S., CPE, ROW 56 percent of the CFCs and for the WIC 40 percent of the CFCs are replaced by HCFCs.
(6) Zero market potential results from the use of new non-chemical technologies like vacuum panels for regid PU foam (refrigeration), optimized foam cells for rigid PU foam for insulation, and new packaging materials for rigid PU foam for packaging applications.
(7) For the U.S., CPE, ROW 45 percent of the CFCs and for the WIC 33 percent of the CFCs are replaced by HCFCs.
(8) Replaced by a mixture of 62 percent HCFC-141b, 36 percent HCFC-123, and 2 percent methanol.
(9) CFC-113 replaced in vapor degreasing by aqueous/semi-aqueous resulting in a 150 percent loss in energy.

provides insight into the energy losses that might occur if selections were based only on this criterion.

3.2.4 Scenario 4: Minimum Greenhouse Effect and Energy Impacts

The purpose of Scenario 4 is to focus on greenhouse and energy impacts and to determine what greenhouse gains may be possible if CFC substitutes are selected primarily on the basis of their ability to reduce global warming. As shown in Exhibit 3-6, this scenario introduces several chemical and product substitutes not included in prior scenarios. For example, in many of the refrigeration use categories, a combination of ammonia and a NARM with a low ODP and an average atmospheric lifetime of 6 years is specified. The use of ammonia in certain refrigeration applications introduces additional questions of flammability and consumer acceptance which would have to be quickly resolved for this option to become viable. Thus this scenario presents the beneficial implications, in terms of greenhouse warming and energy impacts, that could be realized if barriers such as those mentioned here were overcome. For foams used in the walls of refrigerators and other appliances, this scenario employs vacuum panels, which have the advantage of being both chlorine-free and significantly more energy efficient than other substitutes. While substantial research has gone into the development of reliable vacuum panels, additional efforts will be required before widespread commercialization would be possible. This scenario employs the use of HCFC-123 with shards as a substitute for rigid polyurethane foam; this process also must undergo further development before this energy efficient option could be commercialized.

Exhibit 3-6

Chemical Substitution Assumptions for Scenario 4
Minimized Greenhouse/Energy Impacts

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Uses Equipment	Year of Introduction Existing Equipment	Year of Introduction New Equipment	in Energy Consumption With Substitute for Existing Equipment	in Energy Consumption With Substitute for Existing Equipment	Market Potential (%)
Mobile Air Conditioners	CFC-12	Mixture(1)	Mixture(2)	1.07(3)	1.0	1993	1994	-2.0	-5.0	80
Residential Refrigeration	CFC-12	HCF-152a	HCF-152a	1.0	1.0	1993	1994	-7.0(4)	-7.0(4)	100
Chillers (5)	CFC-11	HCFC-123	25% Non-HCFC/HFC(6)/ 75% Mixture(2)	1.0	1.0	1992	1994	+1.0 (4)	-10.0/-15.0 (4)	60
	CFC-12	HCFC-134a	25% Non-HCFC/HFC(6)/ 75% Mixture(2)	1.0	1.0	1992	1994	+3.0 (4)	-10.0/-15.0 (4)	60
	CFC-114	HFC-124	25% Non-HCFC/HFC(6)/ 75% Mixture(2)	1.0	1.0	1992	1994	(+6.7 to +1.0)(7) +3.0	-10.0/-15.0 (4)	60
Process Refrigeration	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0 (4)	-3.0 (4)	84
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	84
Cold Storage Warehouses	CFC-12	Mixture(1)	25% Non-HCFC/HFC(6)/ 75% Mixture(2)	1.0	1.0	1993	1994	-3.0 (4)	-10.0/-15.0 (4)	81
	CFC-115	HFC-125	25% Non-HCFC/HFC(6)/ 75% Mixture(2)	1.0	1.0	1993	1994	0.0	-10.0/-15.0 (4)	81
Retail Food Storage	CFC-12	Mixture(1)	35% Non-HCFC/HFC(6)/ 65% Mixture(2)	1.0	1.0	1993	1994	-3.0 (4)	-10.0/-15.0 (4)	75
	CFC-115	HFC-125	35% Non-HCFC/HFC(6)/ 65% Mixture(2)	1.0	1.0	1993	1994	0.0	-10.0/-15.0 (4)	75
Other Refrigeration Appliances	CFC-12	Mixture(1)	Mixture(1)	1.0	1.0	1993	1993	-3.0 (4)	-3.0 (4)	95
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	95
Refrigerated Transport	CFC-12	Mixture(1)	Mixture(2)	1.07(3)	1.0	1993	1993	-2.0	-5.0	95
	CFC-115	HFC-125	HFC-125	1.0	1.0	1993	1993	0.0	0.0	95
Rigid Polyurethane Foam (refrigeration)	CFC-11	N/A	Non-HCFC/HFC(8)	N/A	N/A	N/A	1994	N/A	-25.0	100
	CFC-12	N/A	Non-HCFC/HFC(8)	N/A	N/A	N/A	1994	N/A	0.0	100
Rigid Polyurethane Foam (other Refrigeration appliances)	CFC-11	N/A	Non-HCFC/HFC(8)	N/A	N/A	N/A	1994	N/A	-25.0	95
Rigid Polyurethane Foam (refrigerated Transport)	CFC-11	N/A	Non-HCFC/HFC(8)	N/A	N/A	N/A	1994	N/A	-25.0	95
Rigid Polyurethane Foam (insulation)	CFC-11	N/A	Shards (HCFC-123) With Optimized Foam Cells	N/A	1.0	N/A	1992	N/A	-1.0	60
	CFC-12	N/A	Shards (HCFC-123) With Optimized Foam Cells	N/A	1.0	N/A	1992	N/A	0.0	60

(Continued on the next page)

Exhibit 3-6

Chemical Substitution Assumptions for Scenario 4
Minimized Greenhouse/Energy Impacts

End Use	CFC Used	Partially-Halogenated Compound Used for Existing Equipment	Partially-Halogenated Compound Used for New Equipment	Replacement Factor for Existing Equipment	Replacement Factor for New Uses Equipment	Year of Introduction Existing Equipment	Year of Introduction New Equipment	in Energy Consumption With Substitute for Existing Equipment	in Energy Consumption With Substitute for Existing Equipment	Market Potential (%)
Rigid Polyurethane Foam (packaging)	CFC-11	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	20
	CFC-12	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	20
Flexible Foam	CFC-11	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	20
Rigid Non-polyurethane Foam (insulation)	CFC-12	N/A	Shards(HFC-134a) With Optimized Foam Cells	N/A	1.0	N/A	1992	N/A	-1.0	40
Rigid Non-polyurethane Foam (packaging)	CFC-11	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	30
	CFC-12	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	30
	CFC-114	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	30
Cold Cleaning	CFC-113	HCFC-141b/HCFC-123 (9)	Non-HCFC/HFC	1.0	N/A	1992	1989	N/A	N/A	67
Vapor Degreasing	CFC-113	HCFC-141b/HCFC-123 (9)	Non-HCFC/HFC(10)	1.0	N/A	1992	1989	0.0	150	67
Sterilization	CFC-12	Non-HCFC/HFC	Non-HCFC/HFC	N/A	N/A	1990	1990	N/A	N/A	72
Aerosols	CFC-11	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	100
	CFC-12	N/A	Non-HCFC/HFC	N/A	N/A	N/A	1992	N/A	N/A	100

Notes:

(1) Represents a near-azeotropic ternary blend of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124. There may be other azeotropic of near-azeotropic mixtures with equivalent energy and capacity for low and high temperature applications.
(2) Assumes a Non-Azeotropic Refrigerant Mixture with an ODP of 0.01 and a lifetime of 6 years
(3) Takes into consideration blend lost due to hose permeation. Obtained from "Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants," SAE Technical Paper, February 1989.
(4) Based on a presentation by Ken Taulbee, White Industries at the International Conference of CFC & Halon Alternatives, Washington D.C., October 10 & 11, 1989.
(5) Higher capacity of CFC-11 and CFC-12 chillers assumed to switch to Ammonia moving the unit to roof tops of structure. Lower capacity chillers switch to near-azeotropic refrigerant mixtures that has been sufficiently buffered with non-flammable agents to eliminate safety concerns.
(6) Chillers, Cold Storage Warehouses, & Retail Food Storage Applications replaced by Ammonia resulting in energy improvements of 10 percent.
(7) Due to absence of data on energy implications of use of HCFC-124, energy implication assumed to be same as those for HFC-134a used to replace CFC-12 in this application.
(8) Rigid Polyurethane Foam Refrigeration Applications replaced by Vacuum Panels resulting in a 25 percent energy improvement.
(9) Based on a 62 percent HCFC-141b, 36 percent HCFC-123, and 2 percent methanol mixture.
(10) CFC-113 Use in Vapor Degreasing replaced by Aqueous/Terpenes resulting in an energy penalty of 150 percent.

3.3 IMPACT OF SUBSTITUTE SCENARIOS ON CHLORINE LEVELS, ENERGY USE AND COSTS, AND GLOBAL WARMING

For each of these scenarios, the model used in this analysis calculates:

- contributions from HCFCs to stratospheric chlorine levels;
- changes in energy consumption, based on the energy efficiency of the substitutes employed in the scenario and the supply of energy for that particular use in that particular region;
- changes in energy costs due to increased or decreased demand for each use sector; and
- contributions to global warming both from the direct radiative properties of the substitutes employed and from the changes in emissions from fossil fuel use due to shifts in energy efficiency.

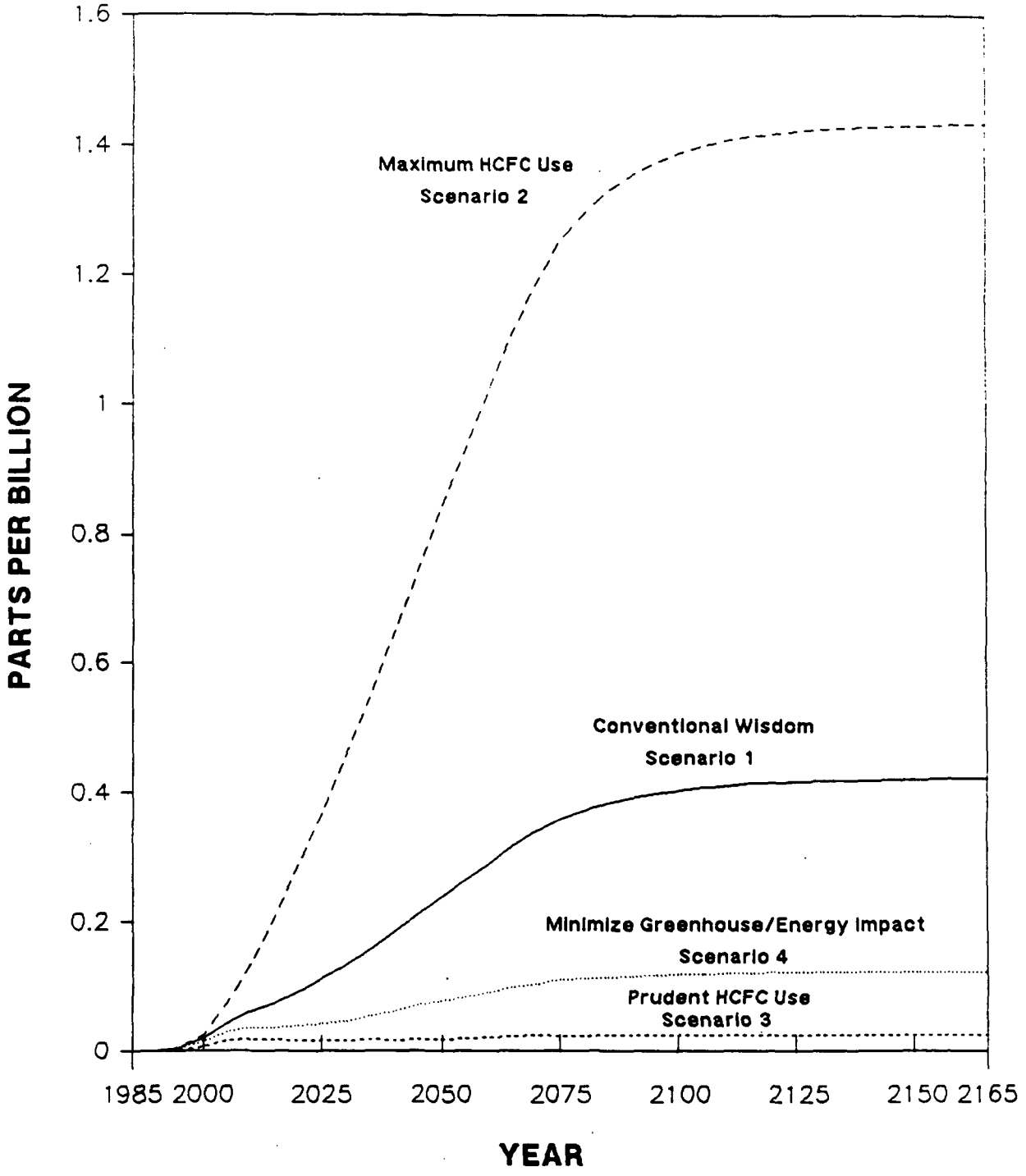
Appendix A documents the "no controls" scenario against which these results are compared. Appendix D presents the energy consumption and costs assumed in this report.

3.3.1 Impacts on Stratospheric Chlorine (Clx) Concentrations

Exhibit 3-7 shows the contributions from each of the four scenarios to stratospheric chlorine levels. This exhibit focuses only on the contributions from the substitutes used in each scenario. In contrast to the results presented in Chapter 2, this exhibit does not demonstrate what total Clx levels are estimated to be under each scenario with methyl chloroform and carbon tetrachloride use.

Chlorine concentrations increase up to approximately 1.25 ppb in Scenario 2, the high HCFC use case by 2075. The increases under Scenario 1

EXHIBIT 3-7
Clx INCREASE DUE TO HFC/HCFC SUBSTITUTION



and Scenario 4, both of which rely extensively on product substitutes, alternative refrigerants and recycling, are estimated to be relatively small (0.36 ppb and 0.11 ppb, respectively) for the same year. Scenario 3, the prudent use case, results in Clx increases of about 0.02 ppb in 2075.

Chapter 2 examined the potential contributions from HCFCs assuming market penetrations of 20 percent, 35 percent and 50 percent of what the market for CFCs would have been and assuming average ODPs of 0.02 and 0.05. The assumptions used in the four scenarios evaluated in this chapter provide even different mixes of these two critical factors. Scenario 1 (conventional wisdom) would result in HCFCs capturing 35.5 percent of the market with an average ODP of 0.03. In contrast, Scenario 2 (use of HCFCs with maximum chlorine contribution) results in these chemical substitutes capturing 48.7 percent of the market, with an average ODP of 0.056. In both Scenarios 3 and 4, the prudent HCFC use and the minimum greenhouse gas cases, respectively, there is substantially lower market penetration rates and lower average ozone depletion potential. The two scenarios have market penetrations rates of 9.2 percent and 17.4 percent, and ODPs of 0.02 and 0.024, respectively.

Exhibits 3-8 to 3-11 show the contributions of each of the HCFCs to chlorine concentrations for each of the four scenarios in the year 2075. This one year comparison provides a "snapshot" of the relative importance of the various HCFCs in contributing to Clx. Estimates are reported for 2075 because that year represents a point well after substitutes used on an interim basis to service existing capital stock have been eliminated. They illustrate the dominant role of HCFC-141b in contributing to chlorine due to its extensive use in foam categories and as a solvent, as well as the large contribution

EXHIBIT 3-8

CONTRIBUTION OF HCFC/HFC SUBSTITUTES TO Clx INCREASES IN 2075 - CONVENTIONAL WISDOM

Scenario 1

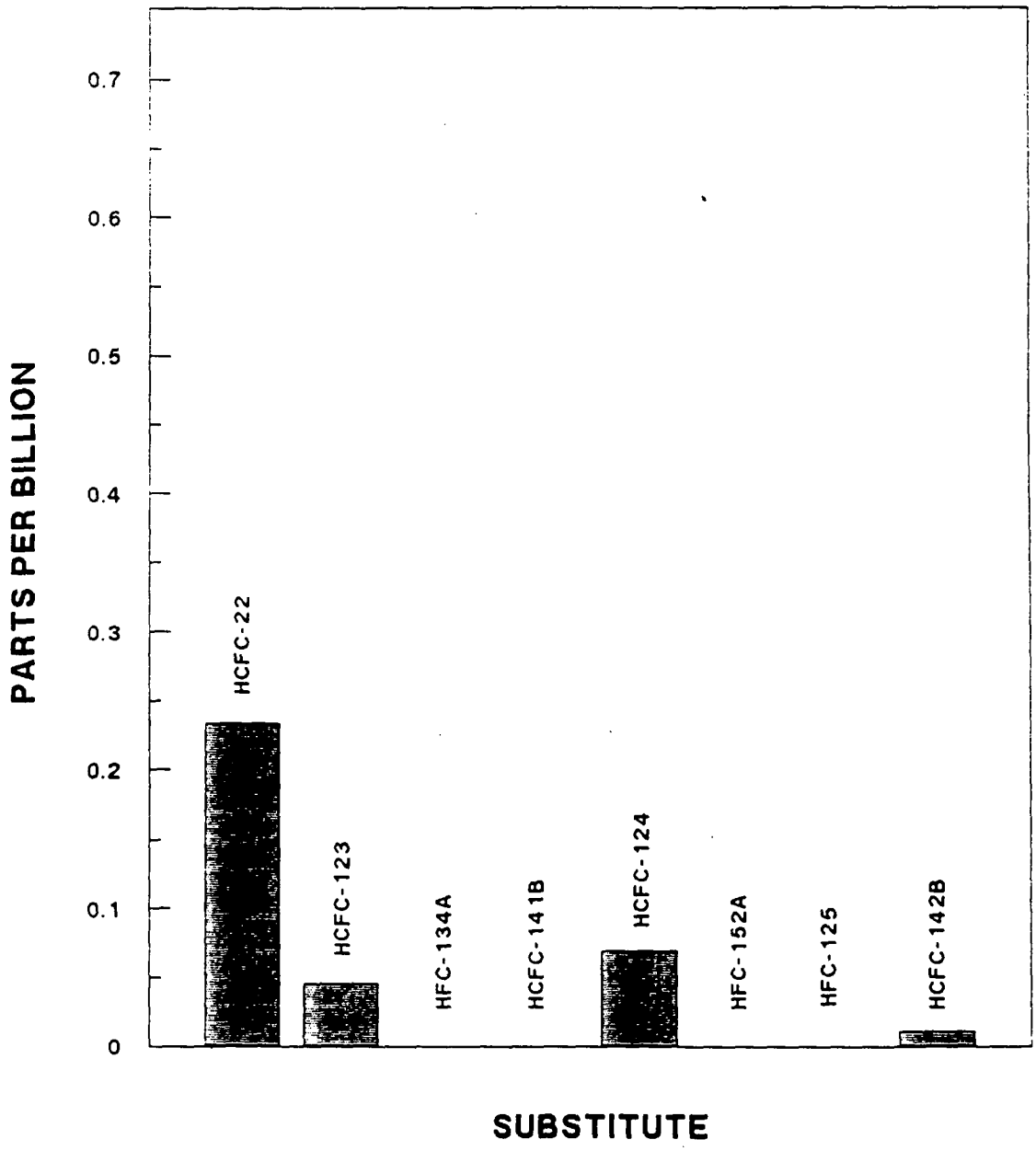


EXHIBIT 3-9

CONTRIBUTION OF HCFC/HFC SUBSTITUTES TO Clx INCREASES IN 2075 - MAXIMUM HCFC USE

Scenario 2

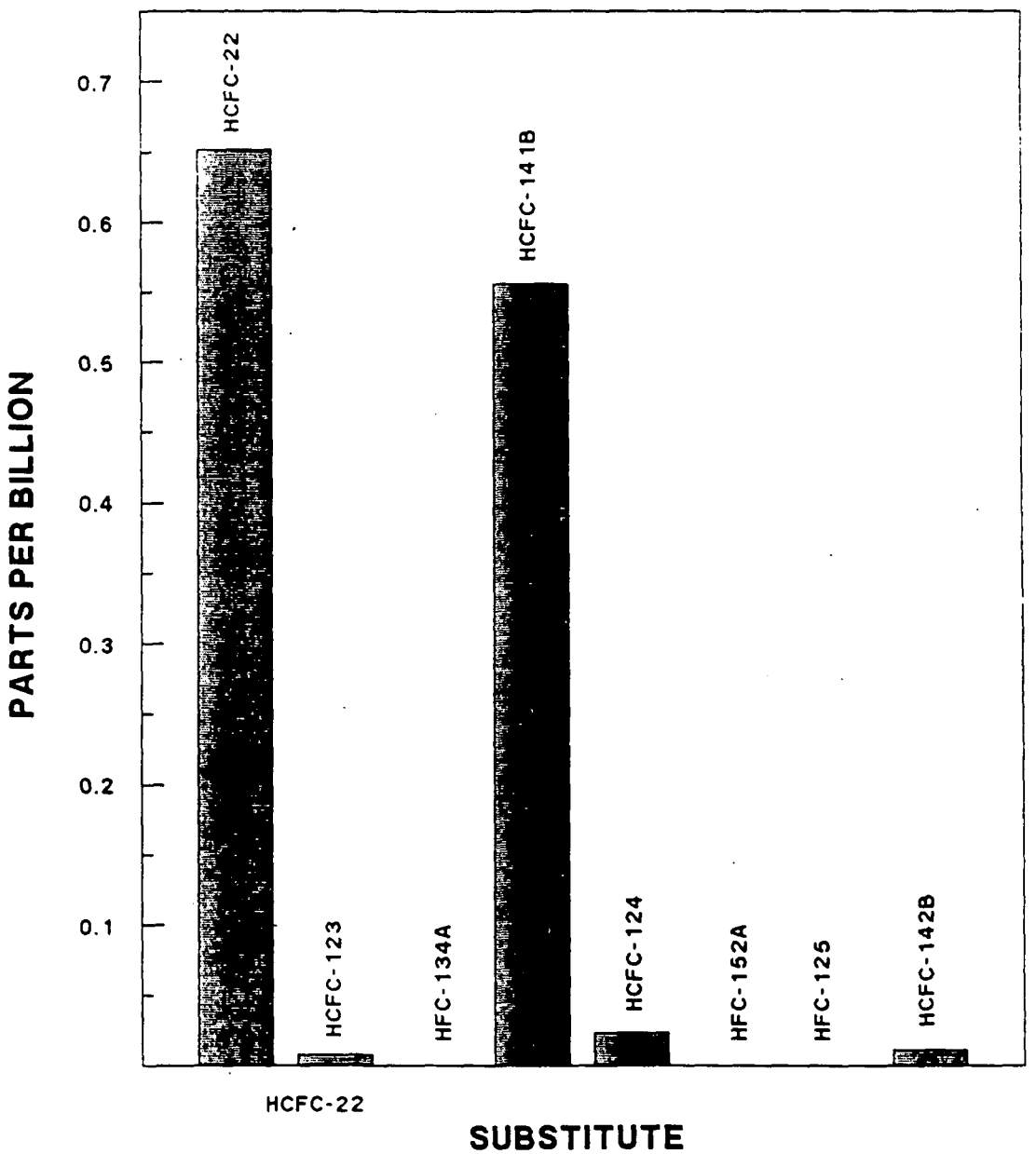


EXHIBIT 3-10

CONTRIBUTION OF HCFC/HFC SUBSTITUTES TO Clx INCREASES IN 2075 - PRUDENT HCFC USE

Scenario 3

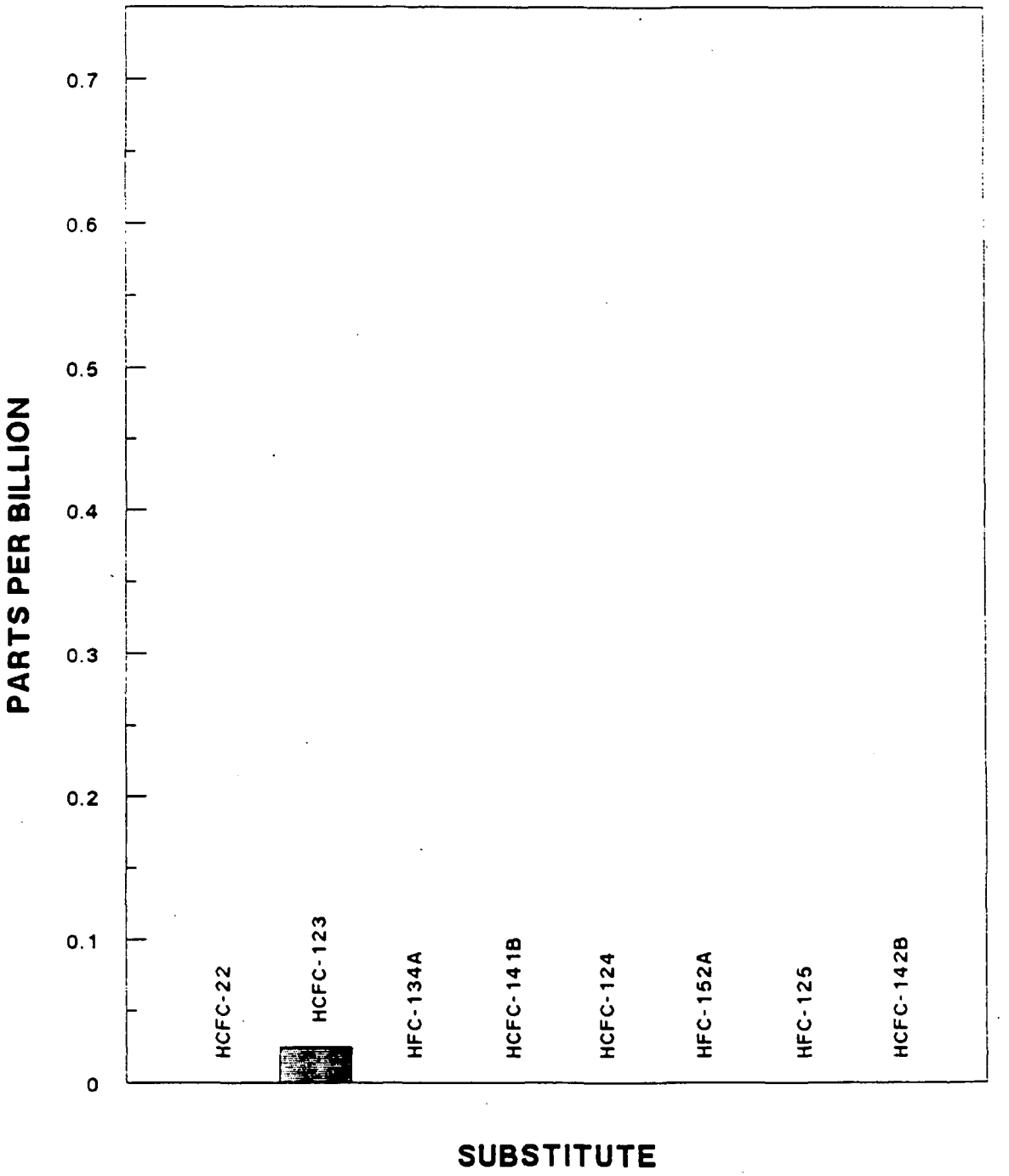
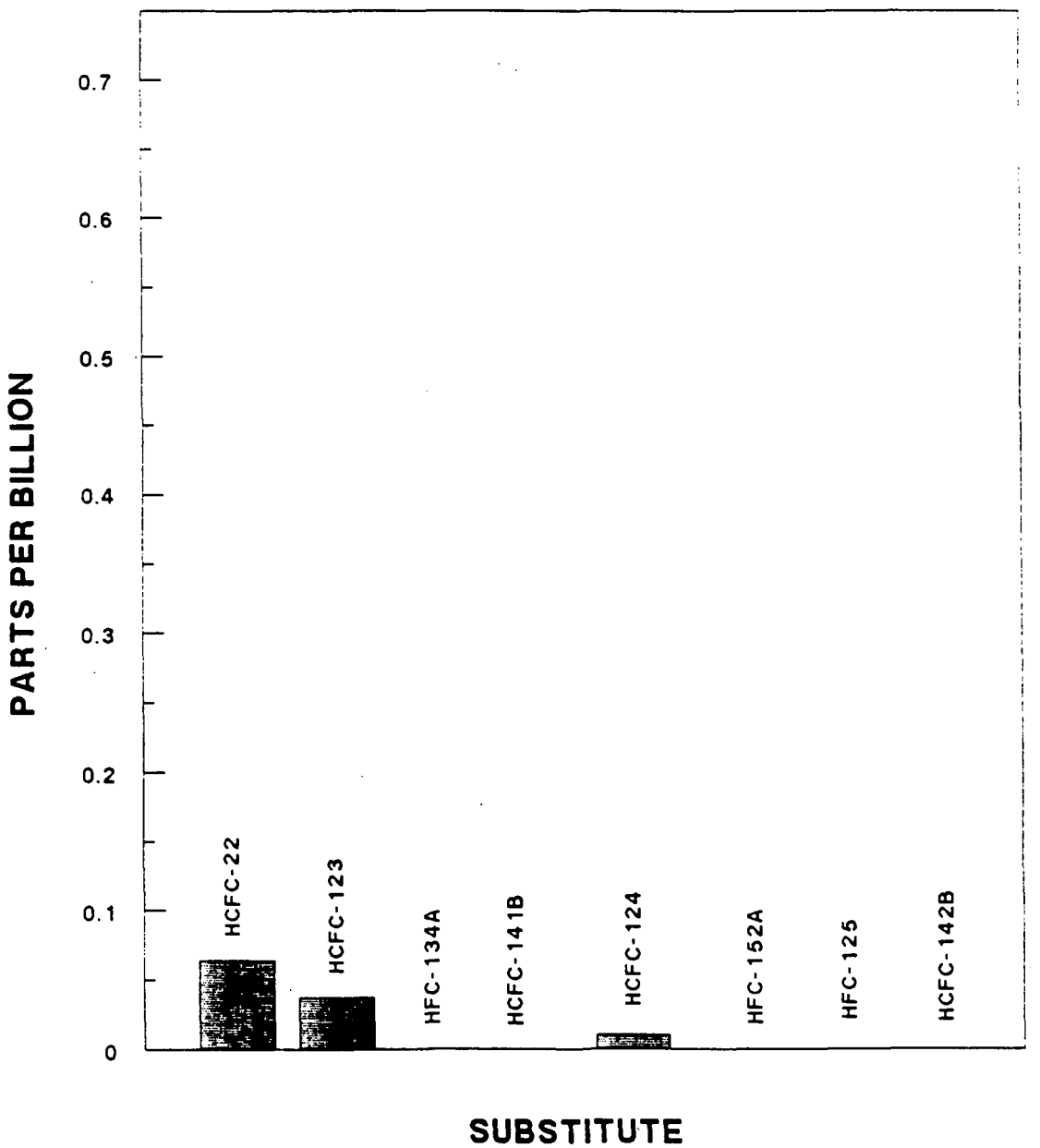


EXHIBIT 3-11

CONTRIBUTION OF HCFC/HFC SUBSTITUTES TO Clx INCREASES IN 2075 - MINIMIZE GREENHOUSE/ENERGY IMPACT

Scenario 4



from HCFC-22 used in refrigeration and air conditioning in Scenario 2. In Scenario 1 HCFC-22 also contributes significant amounts as a result of its use in foam applications.

Exhibit 3-12 provides an overview of the percentage of Clx from HCFCs for each of the use categories for each scenario. It shows that approximately 40 percent of the Clx comes from insulating foam and aerosol use in the conventional wisdom scenario. HCFCs used in insulating foam in construction, vapor degreasing, and aerosols contribute to over half of the Clx increase in Scenario 2. Since aqueous cleaners, terpenes, and alcohols replace HCFC-141b in solvent use in Scenario 3, by far the single largest source of Clx is the use of HCFC-123 in the insulation market. While this is a very high percentage of total Clx in Scenario 3, it represents a substantially smaller amount in absolute terms from the insulating foam category in Scenario 2 where HCFC-141b is used. In Scenario 4, where total Clx increases are low, process refrigeration (where a NARM is used) and insulating foam (where HCFC-123 is used) are the largest contributors. Exhibits 3-13 to 3-16 further illustrate the conclusions by showing the absolute contributions to Clx from each of the use categories for each of the scenarios.

3.3.2 Impacts on Energy Consumption and Costs

CFCs had been used across a broad range of products in part because of their contribution to improved energy efficiency. As a result, the energy implications of any shifts away from these compounds could be significant both in terms of energy usage and in terms of the overall costs of phasing out of CFCs.

EXHIBIT 3-12

CLx INCREASES IN TWENTY END USE AREAS IN 2075 DUE TO SUBSTITUTION OF HCFCS

	Distribution Clx Increases in 2075			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Clx Increase (ppb)	0.358	1.249	0.024	0.111
Mobile Air Conditioners	0.00%	3.24%	0.00%	9.23%
Residential Refrigeration	5.53%	1.92%	0.00%	0.00%
Chillers	2.76%	9.95%	31.25%	12.31%
Process Refrigeration	9.22%	4.44%	0.00%	30.77%
Cold Storage Warehouses	6.91%	3.84%	0.00%	4.62%
Retail Food Storage	5.53%	5.28%	0.00%	6.15%
Other Refrigeration Appliances	1.38%	0.48%	0.00%	4.62%
Refrigerated Transport	7.37%	2.04%	0.00%	6.15%
Rigid Polyurethane Foam - Refrigeration	2.30%	6.83%	18.75%	0.00%
Rigid Polyurethane Foam - Other Appliances	0.00%	0.36%	0.00%	0.00%
Rigid Polyurethane Foam - Refrigerated Transport	0.46%	1.20%	0.00%	0.00%
Rigid Polyurethane Foam - Insulation	29.49%	22.78%	50.00%	26.15%
Rigid Polyurethane Foam - Packaging	1.38%	0.84%	0.00%	0.00%
Flexible Foams	0.92%	2.52%	0.00%	0.00%
Rigid Non-Polyurethane Foam - Insulation	4.61%	1.20%	0.00%	0.00%
Rigid Non-Polyurethane Foam - Packaging	7.37%	1.92%	0.00%	0.00%
Cold Cleaning	0.00%	2.16%	0.00%	0.00%
Vapor Degreasing	0.00%	18.47%	0.00%	0.00%
Sterilization	2.76%	0.72%	0.00%	0.00%
Aerosol	11.98%	9.83%	0.00%	0.00%
Total	100.00%	100.00%	100.00%	100.00%

EXHIBIT 3-13

ClX INCREASE IN 2075 DUE TO HCFC SUBSTITUTION

CONVENTIONAL WISDOM

Scenario 1

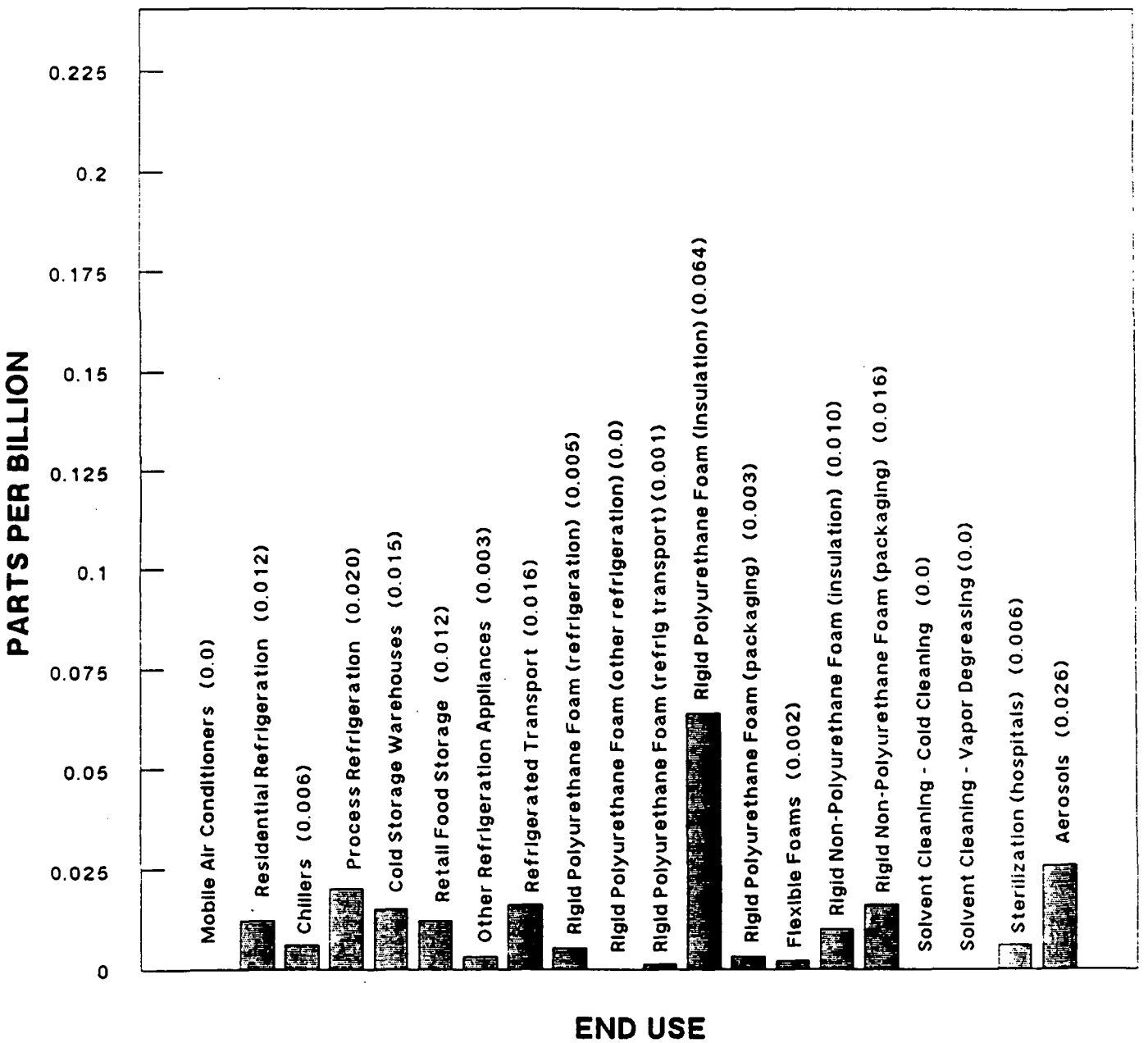


EXHIBIT 3-14

Clx INCREASE IN 2075 DUE TO HCFC SUBSTITUTION
MAXIMUM HCFC USE
Scenario 2

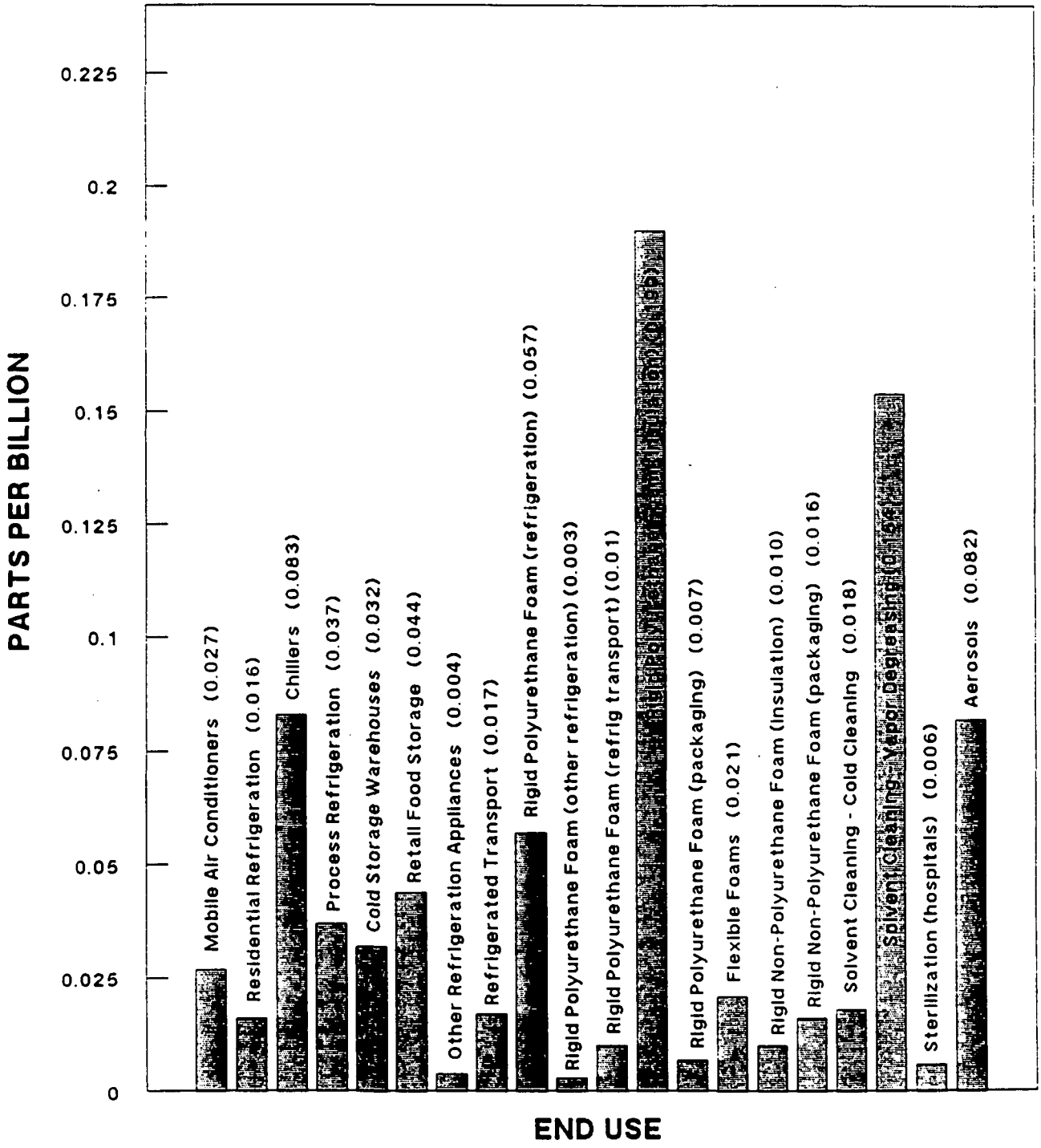


EXHIBIT 3-15

Clx INCREASE IN 2075 DUE TO HCFC SUBSTITUTION
PRUDENT HCFC USE
Scenario 3

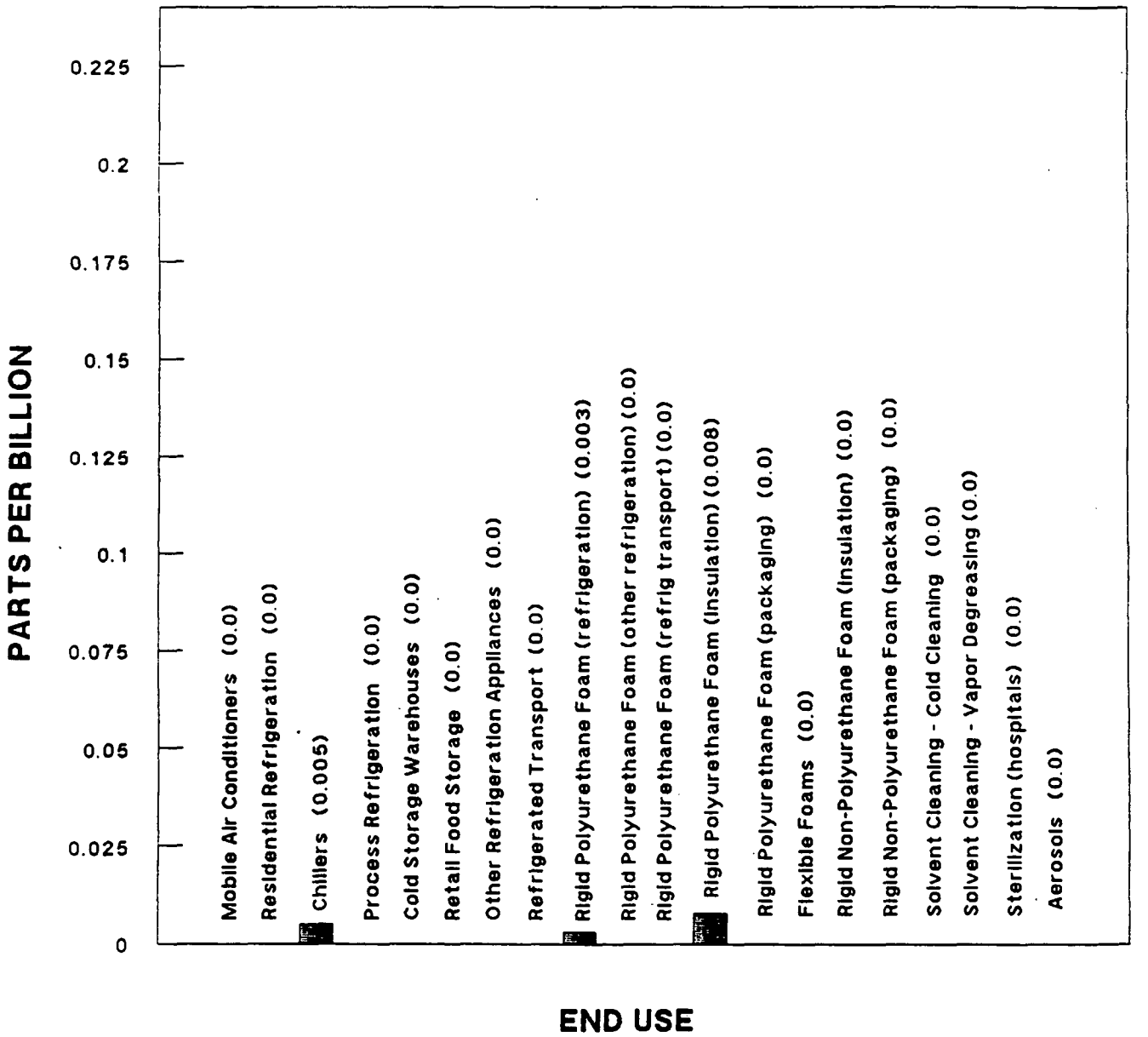
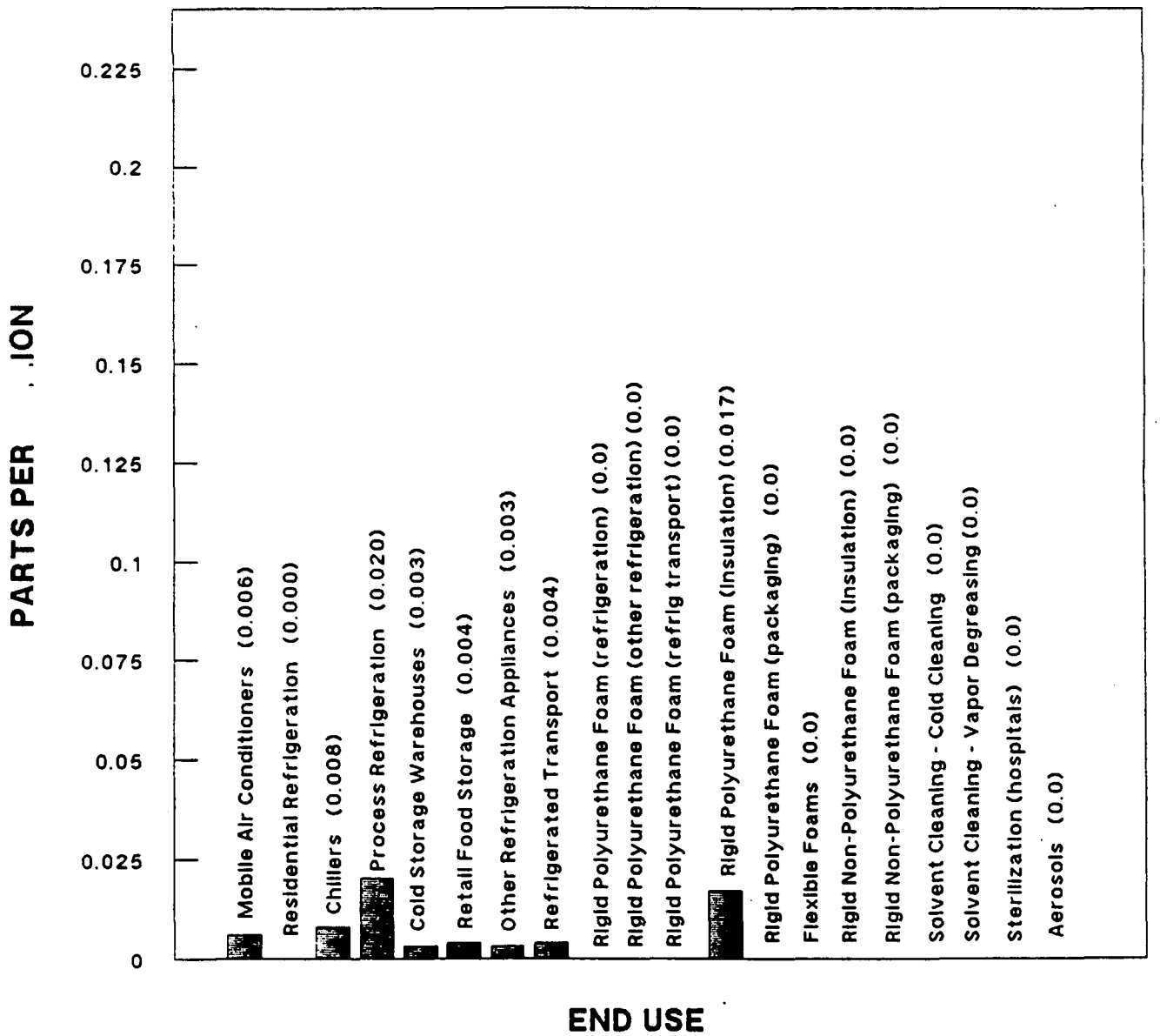


EXHIBIT 3-16

Clx INCREASE IN 2075 DUE TO HCFC SUBSTITUTION
MINIMIZE GREENHOUSE/ENERGY IMPACT
Scenario 4



Exhibits 3-17 to 3-25 show estimated changes in U.S. and global energy consumption associated with these use categories and the various CFC alternatives for the period 1989 to 2075.[3] Because large uncertainties exist both in the quantity of CFC-related energy used around the world and in the energy efficiency implications of particular substitutes, the estimates shown in this report should be interpreted only as indicating the range of possible energy impacts and not as exact estimates.

As shown in Exhibit 3-17, energy savings (i.e., improved energy efficiency) are estimated to be realized in the U.S. and globally under Scenarios 2 and 4. In the U.S., cumulative energy impacts for the period 1989 to 2075 range from a reduction in use of 62.04 quads (shown as -62.04 quads) under Scenario 4 to an increase in energy consumption of approximately 28.16 quads under Scenario 3. Although in absolute terms these are relatively large changes, when compared to estimated total U.S. energy consumption of 12,410 quads over the 1989 to 2075 period, the maximum increase in energy use in the U.S. represents approximately 0.2 percent of total U.S. energy use while the maximum reduction in energy use represents 0.5 percent.[4] The cumulative global energy impacts between 1989 and 2075 range from an energy savings of

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[3] The reader should note that for several of the refrigeration applications (e.g., residential refrigeration) CFC consumption has been divided into that used as the refrigerant working fluid and that used to produce the foam insulation. Because the different uses within these applications were analyzed independently, the energy implications of the assumed design changes are not additive and have been reported separately in this report.

[4] The estimates of total energy use in the U.S. and worldwide were developed using standard industry estimates through 2000 then were projected to 2075 assuming an annual growth rate of 1.3 percent in all regions.

EXHIBIT 3-17

COMPARISON OF ENERGY IMPACTS BY SCENARIO (1989-2075)

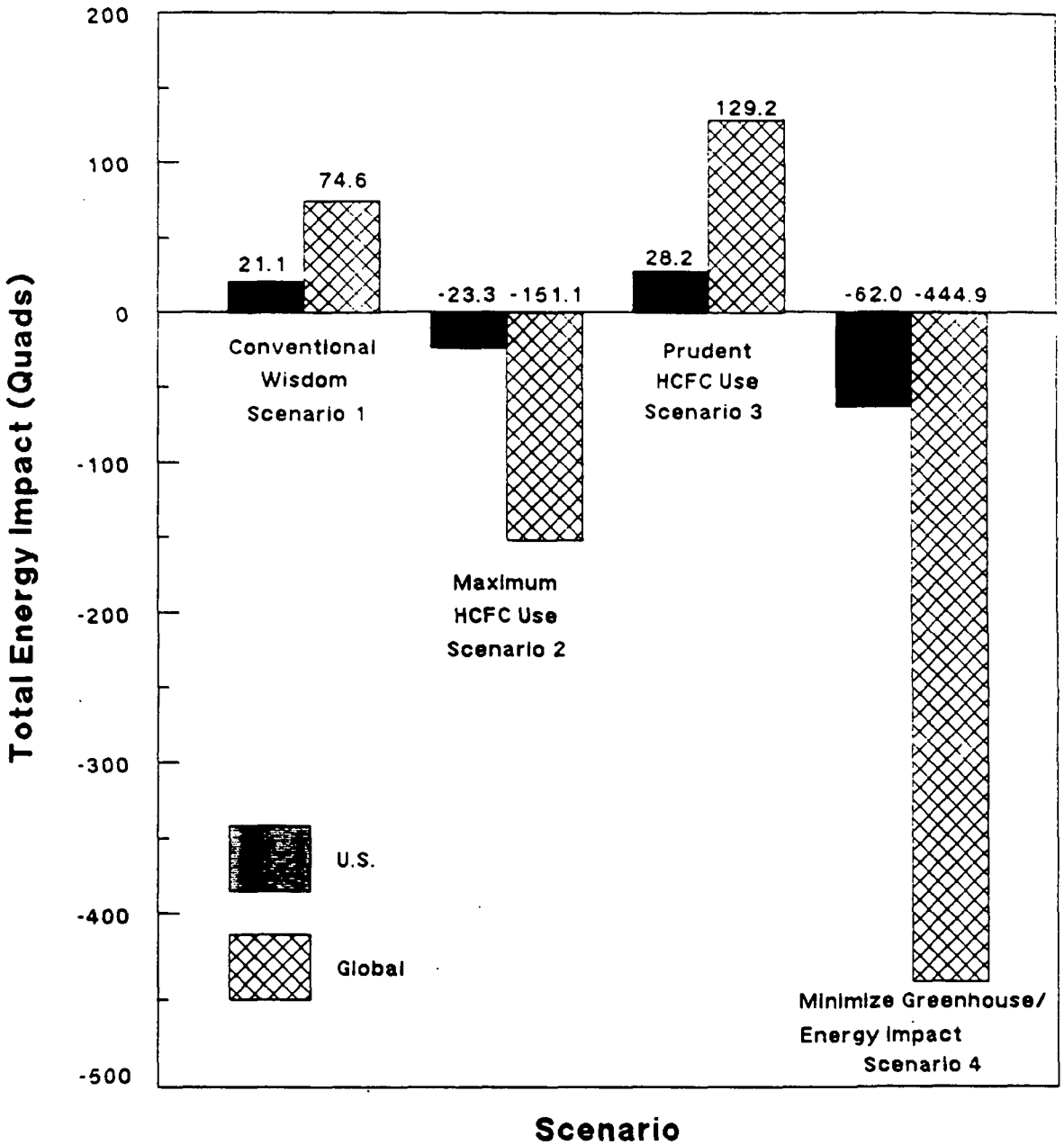


EXHIBIT 3-18
U.S. CUMULATIVE ENERGY IMPACTS - BY END USE
CONVENTIONAL WISDOM (1989 - 2075)
Scenario 1

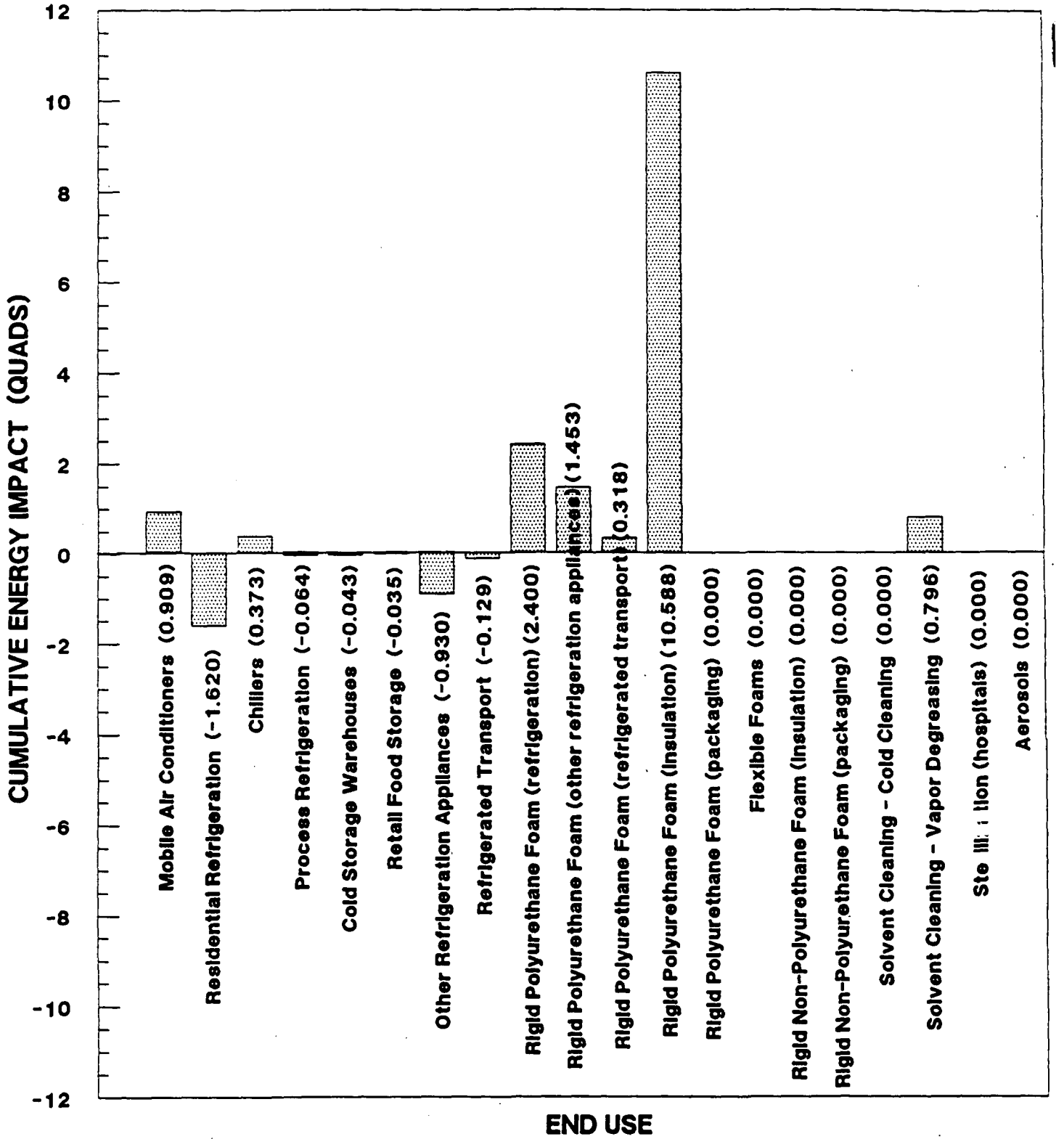


EXHIBIT 3-19

U.S. CUMULATIVE ENERGY IMPACTS - BY END USE
MAXIMUM HCFCs USE (1989 - 2075)
Scenario 2

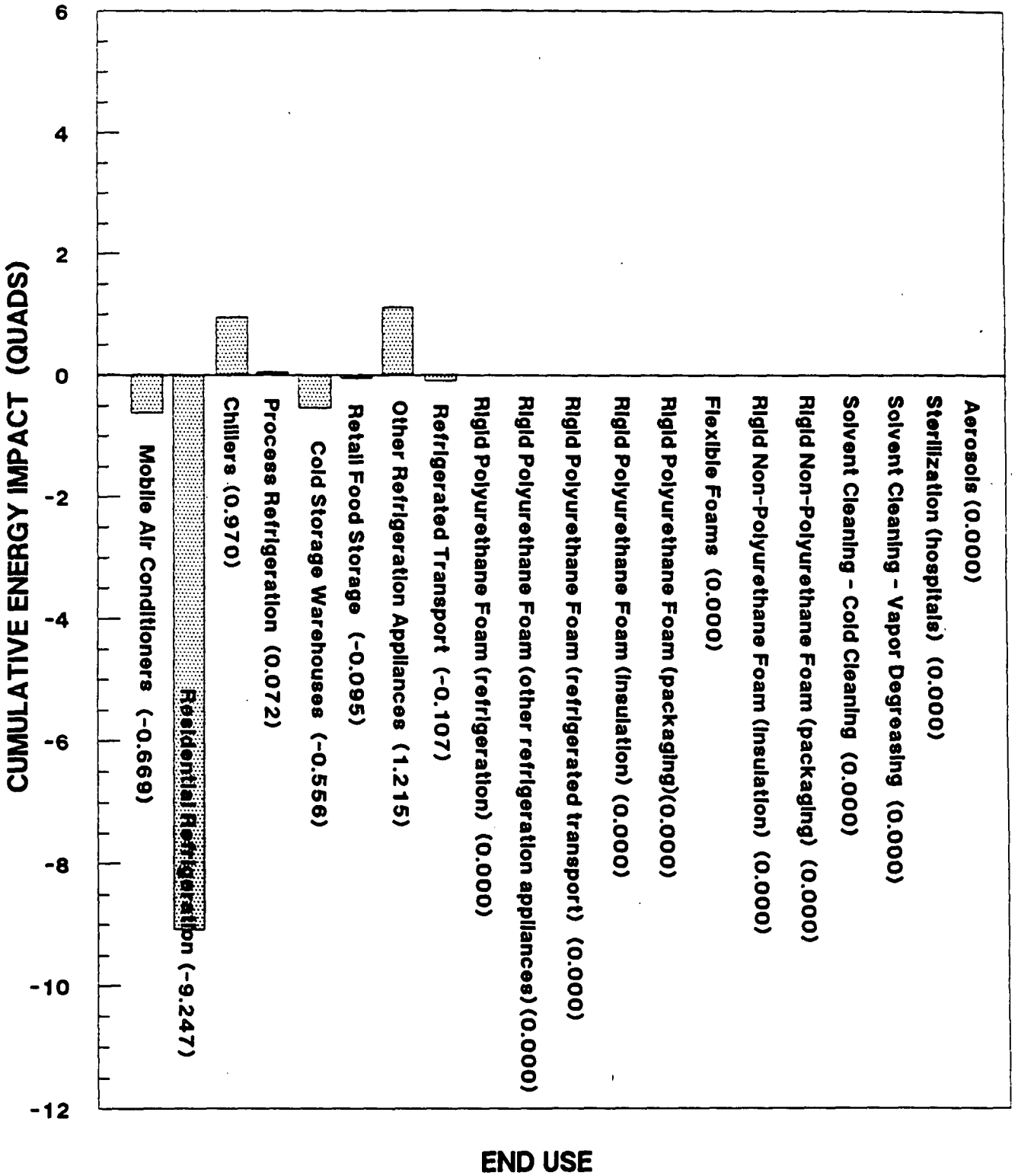


EXHIBIT 3-20
U.S. CUMULATIVE ENERGY IMPACTS - BY END USE
PRUDENT HCFCs USE (1989 - 2075)
Scenario 3

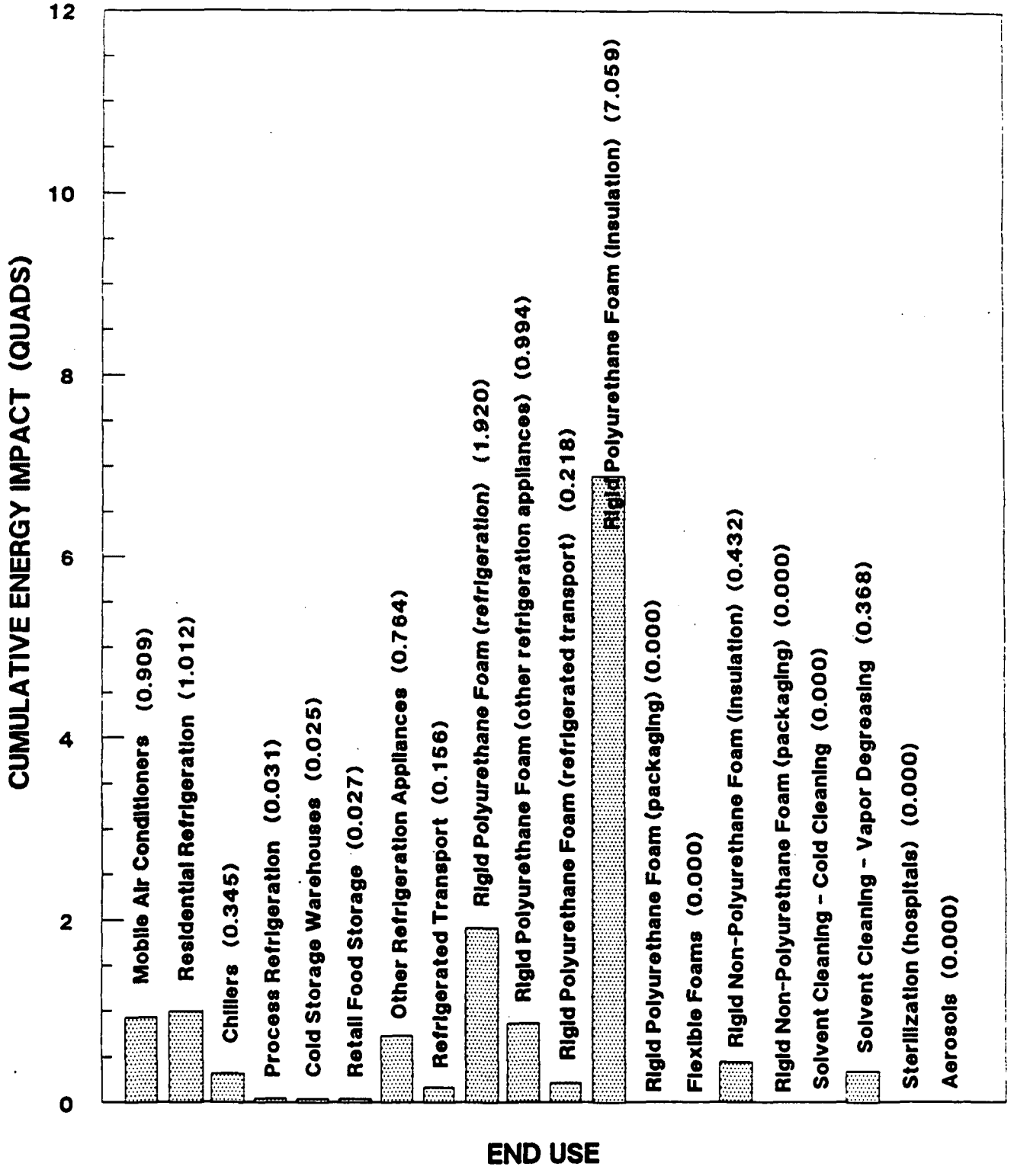


EXHIBIT 3-21

U.S. CUMULATIVE ENERGY IMPACTS - BY END USE
MINIMIZE GREENHOUSE/ENERGY IMPACTS (1989 - 2075)
Scenario 4

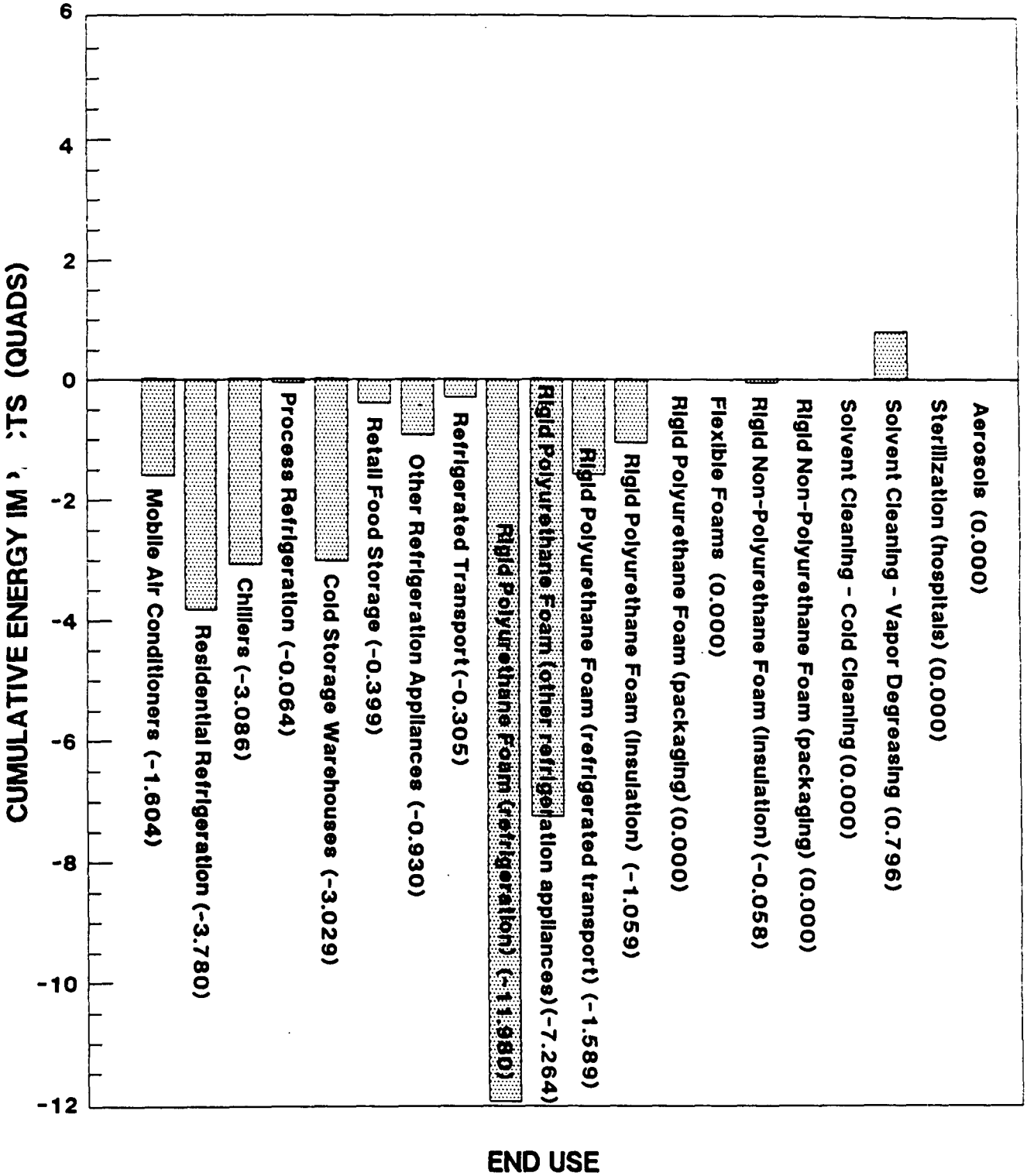


EXHIBIT 3-22

GLOBAL CUMULATIVE ENERGY IMPACTS -- BY END USE
CONVENTIONAL WISDOM (1989-2075)
Scenario 1

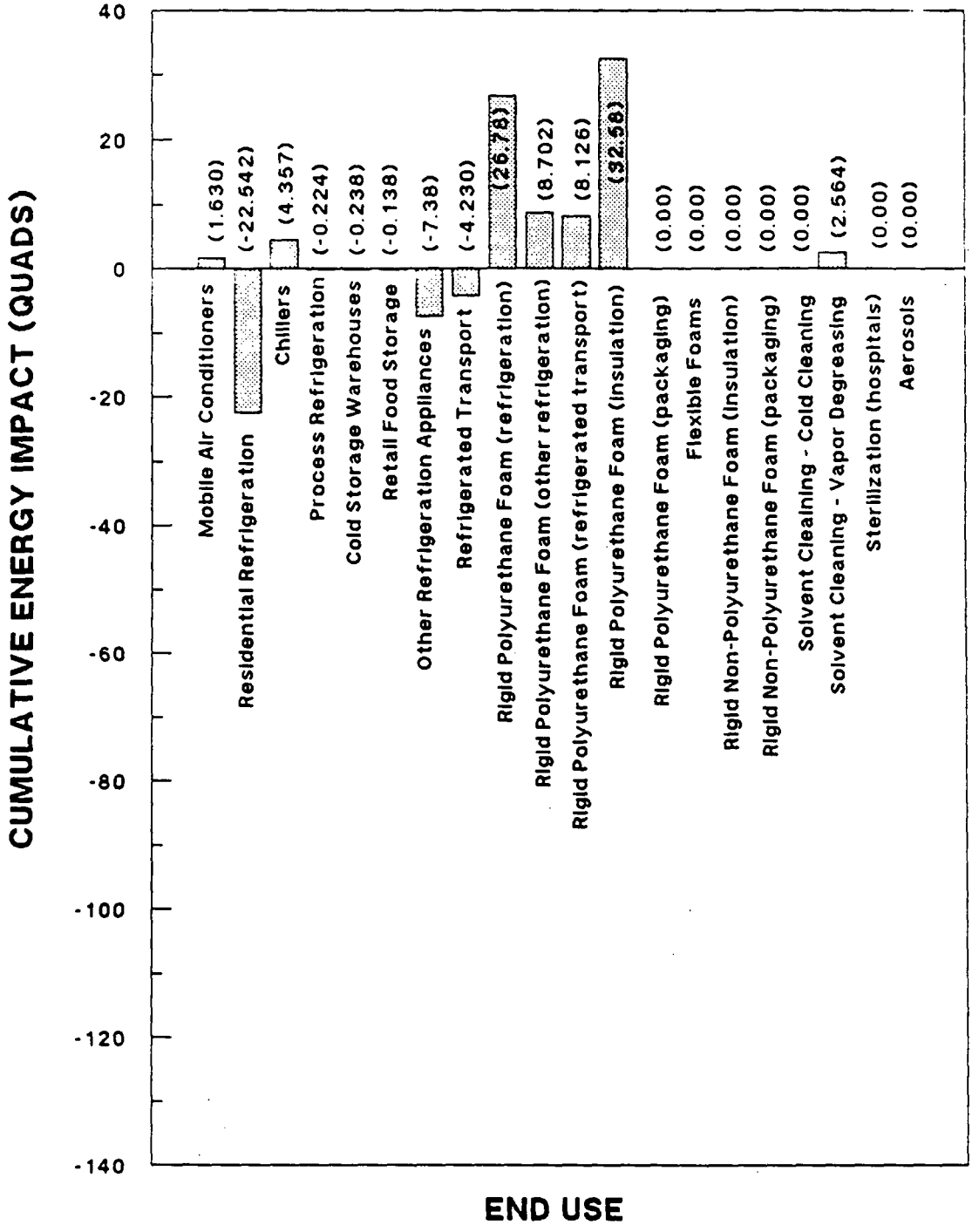


EXHIBIT 3-23

GLOBAL CUMULATIVE ENERGY IMPACTS -- BY END USE
MAXIMUM HCFCs USE (1989-2075)
Scenario 2

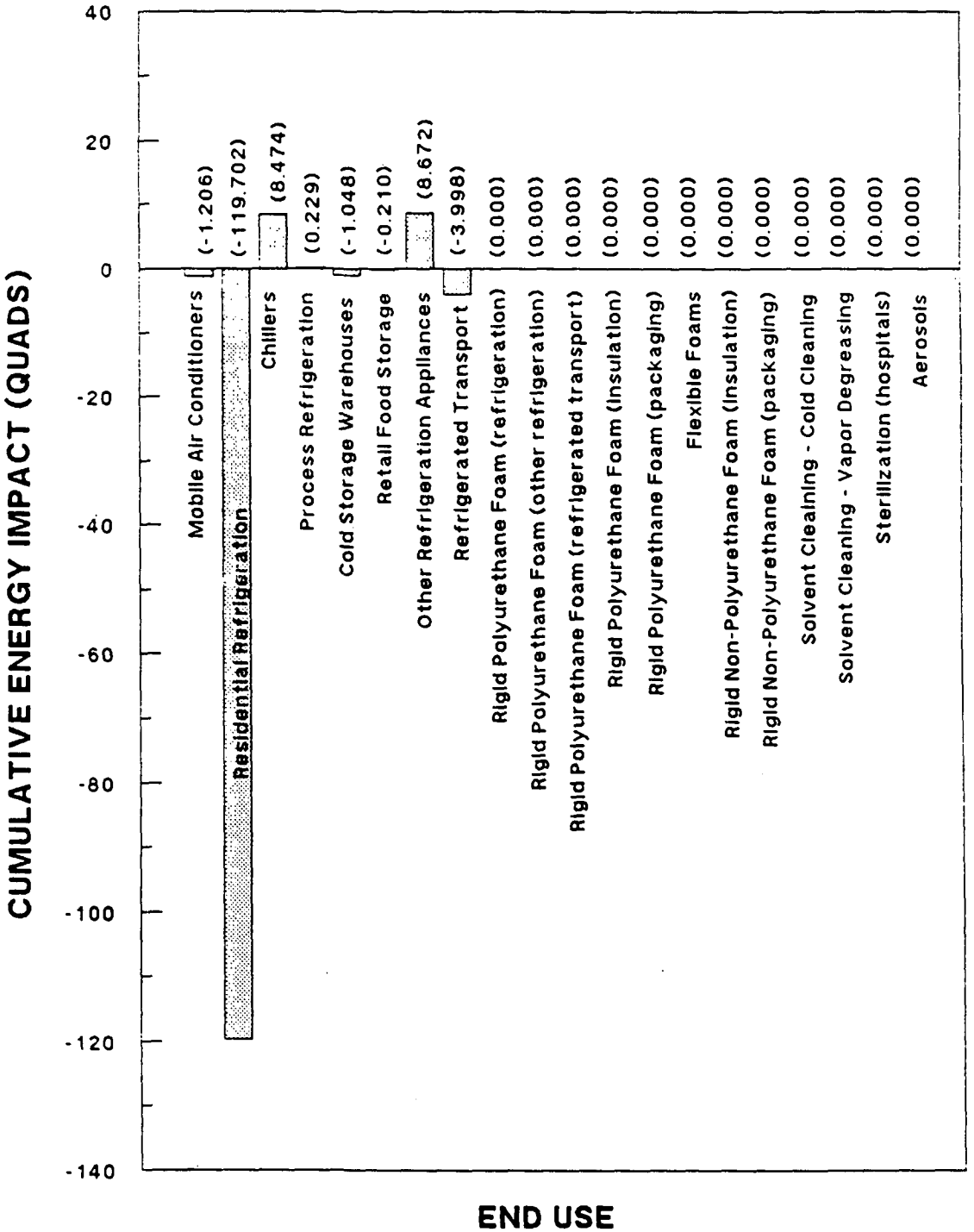


EXHIBIT 3-24

GLOBAL CUMULATIVE ENERGY IMPACTS -- BY END USE
PRUDENT HCFCs USE (1989-2075)

Scenario 3

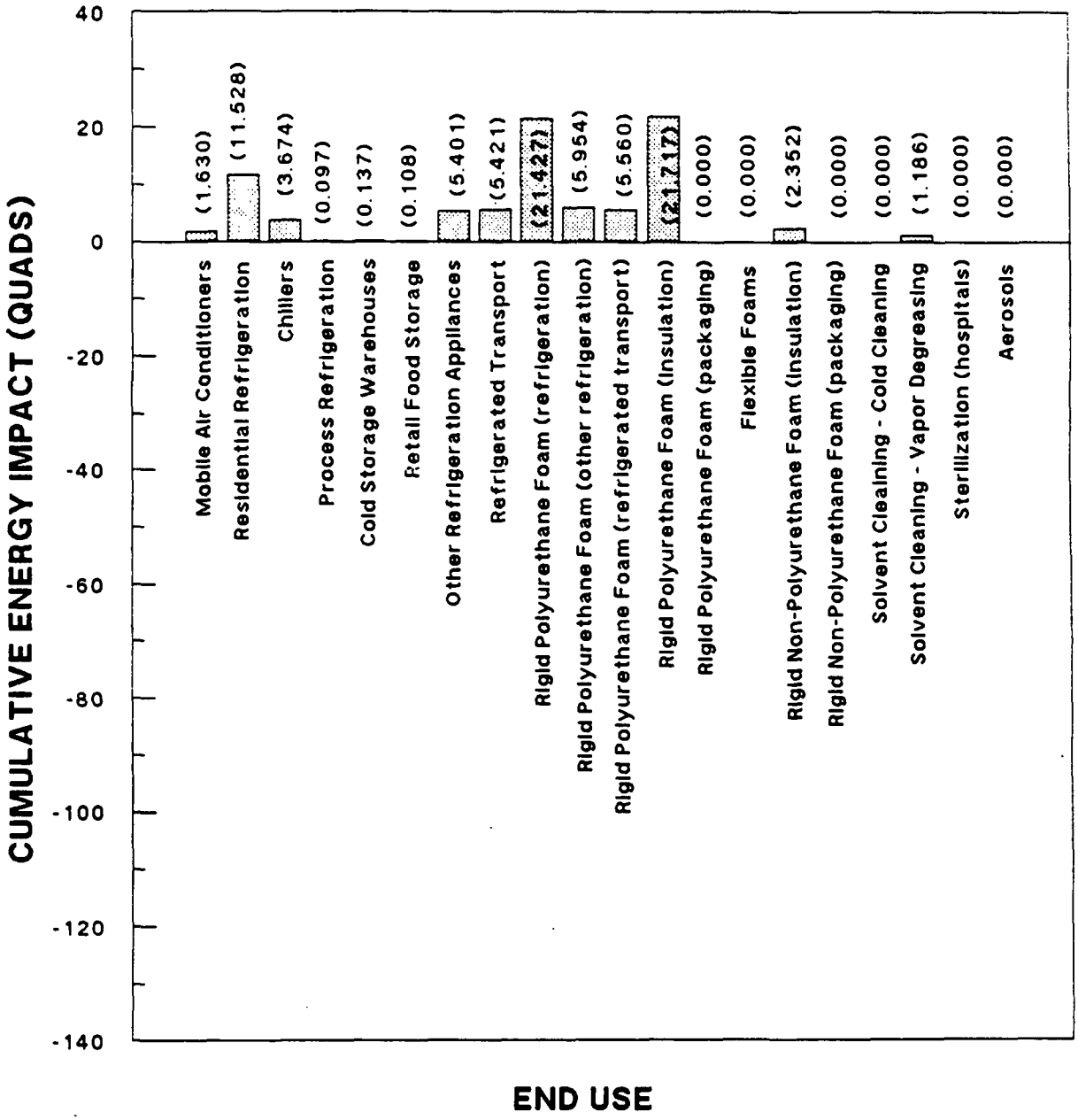
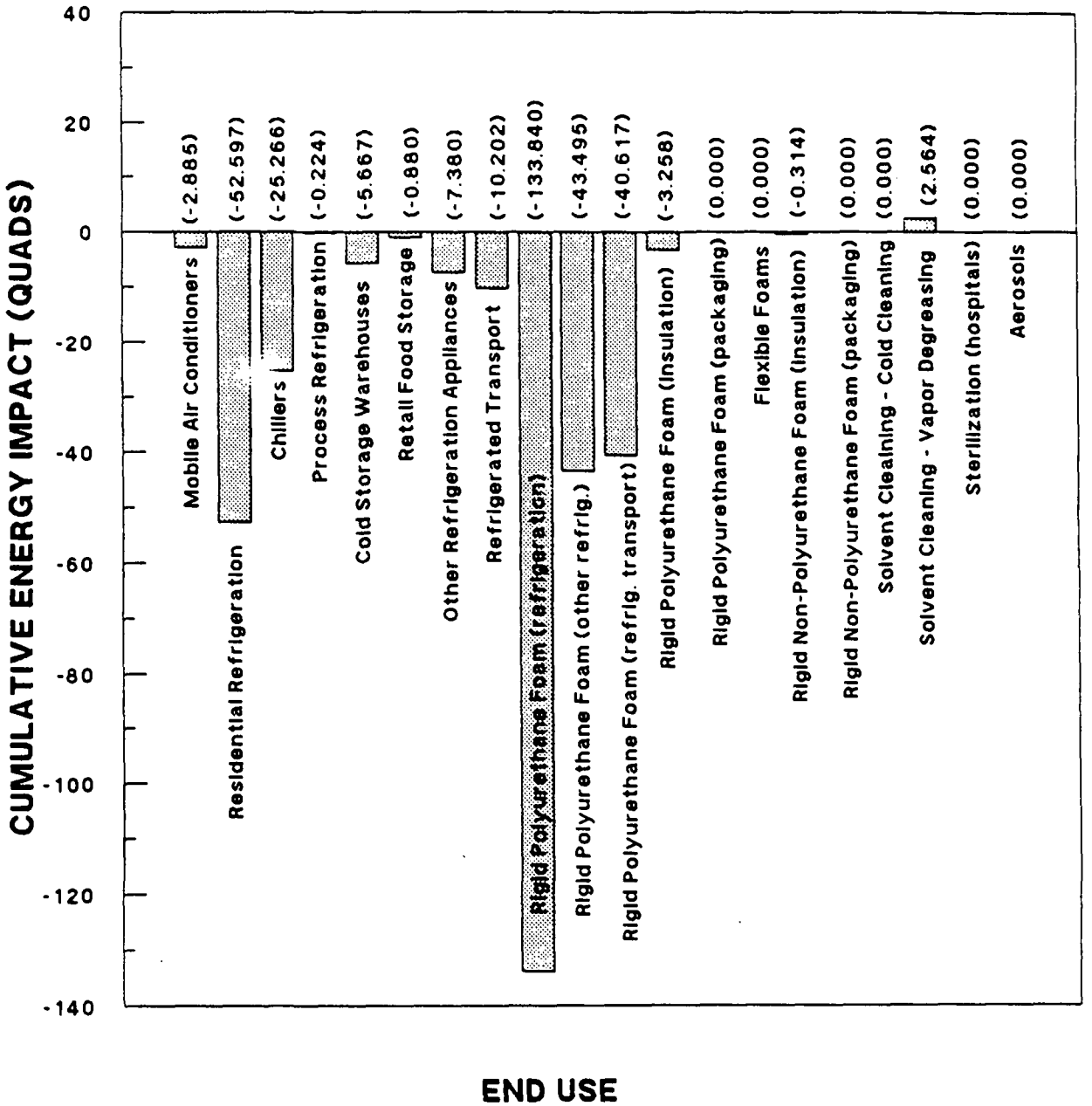


EXHIBIT 3-25

GLOBAL CUMULATIVE ENERGY IMPACTS -- BY END USE
MINIMUM GREENHOUSE/ENERGY (1989-2075)
Scenario 4



END USE

444.9 quads to an increase in energy use of 129.154 quads. When compared to total global energy consumption over the same period (roughly 54,464 quads), global energy impacts represent no more than a 0.24 percent increase in global energy consumption or a 0.8 percent decrease in consumption.

The largest U.S. and global energy savings are estimated to occur under Scenario 4. This result is consistent with the specification of this scenario as one in which energy impacts are minimized through the extensive use of ammonia as a refrigerant and energy efficient, "not-in-kind" substitutes such as vacuum panels in the insulation end uses. Scenario 2 is estimated to result in the next greatest energy savings, reducing global energy use by over 151 quads. Although the substitutes applied in Scenario 2 are relatively energy efficient, as presented above, this same scenario is expected to result in the highest Clx contributions of the four scenarios estimated. This result is an indication of the types of trade-offs that occur in selecting among alternatives to CFCs.

Exhibits 3-18 to 3-25 present breakdowns of the contributions of the substitutes applied in each end use to the cumulative energy impacts estimated for each scenario. As noted in Appendix D to this report, no energy impacts are estimated for CFC substitutes in several end uses. Impacts are not evaluated because either: (1) there is no energy consumption associated with the CFC end use, or (2) the energy impacts due to CFC substitution are expected to be negligible. CFC end uses for which no energy impacts are estimated include flexible foam, rigid non-polyurethane packaging foams, sterilization, and aerosols.

Under Scenario 4, the greatest reduction in U.S. and global energy use is estimated to result in the rigid polyurethane foam refrigeration end use area. As shown in Exhibit 3-6, the vacuum panels assumed to be used under this scenario are estimated to reduce energy use in this area by 25 percent. Under Scenarios 1, 2, and 4, substantial U.S. and global energy savings are estimated to occur in the residential refrigeration end use. Under these three scenarios, the substitutes used in this end use were estimated to decrease energy consumption by 3 to 20 percent in most current and new applications. The estimated energy savings from global baseline energy use (1989 through 2075) in the residential refrigeration application range from 119.7 quads under Scenario 2 to approximately 22.54 quads under Scenario 1. In the U.S. alone, estimates of the energy savings within this end use range from 9.2 quads under Scenario 2 to 1.6 quads under Scenario 1.[5] These results reflect not only the energy efficiency assumptions specified under each scenario, but also the fact that this end use is estimated to represent approximately 25 percent of the U.S. and global annual, baseline CFC-related energy consumption through the period of analysis.

The energy effects of other end uses can vary substantially across scenarios. The rigid polyurethane foam insulation end use also accounts for approximately 25 percent of baseline CFC-related energy use. The substitutes in this end use result in increases in U.S. energy consumption under Scenarios 1 and 3, have no contribution to energy changes under Scenario 2, and contribute to energy savings under Scenario 4.

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[5] These estimates include only changes due to substitution of the refrigerant.

Exhibits 3-26 through 3-34 present estimates of the cumulative changes in U.S. and global energy costs estimated to result under each scenario through 2010. The cost estimates are presented only through 2010 due to uncertainties associated with projecting these costs. The cumulative costs associated with these energy consumption changes are estimated to range from cost increases of $5.69 billion to cost savings of $72.32 billion in the U.S. and from cost increases of $22.3 billion to savings of $378.04 billion worldwide. It is important to remember that this analysis does not take into consideration differences in the direct costs of alternatives to CFCs (e.g., vacuum panels may cost more than HCFC-blown insulation) and are not net costs (or savings).

3.3.3 Impacts of CFC Substitution Scenarios on Global Warming

Exhibits 3-35 to 3-41 present the incremental global warming impacts under each of the four substitution scenarios.[6] To develop estimates of global warming through 2075, estimates of the energy impacts, and the associated emissions of energy-related trace gases, are projected through 2075.[7]

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[6] Estimates of global warming impacts for the four substitution scenarios are reported as increments of warming from the CFC replacements only and are expressed as changes relative to a phase out of CFCs in 2000 assuming no substitutes.

[7] To forecast these energy effects, energy use in the baseline is assumed to grow proportionally with baseline CFC emissions projected through 2075 and the fuel shares and emissions factors specified in Appendix D are held constant starting in 2010. The projected time scenarios of U.S. and global energy impacts used to develop estimates of energy-related trace gas emissions for each scenario are presented in Appendix D.

EXHIBIT 3-26

COMPARISON OF ENERGY COSTS BY SCENARIO (1989-2010)

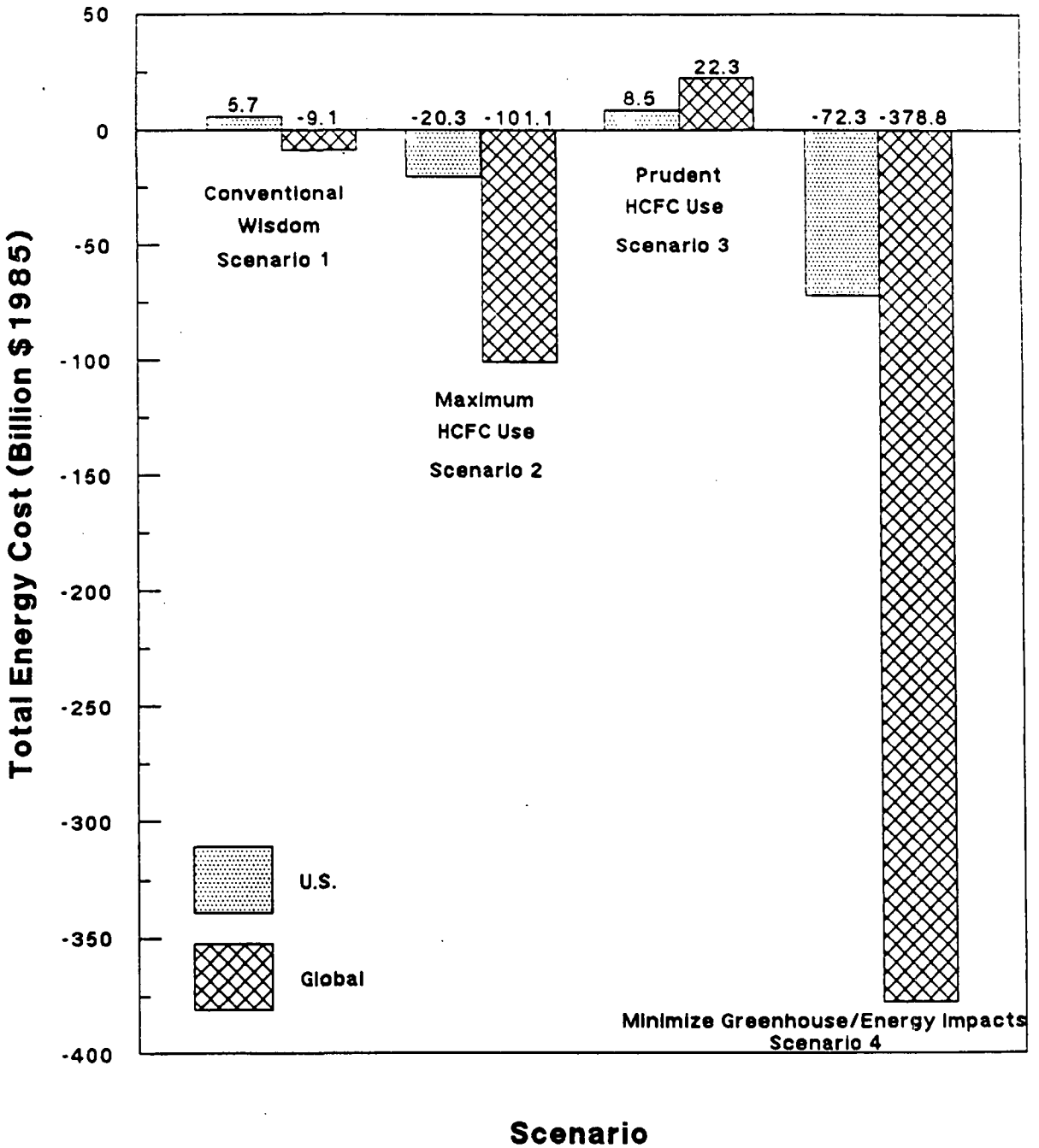
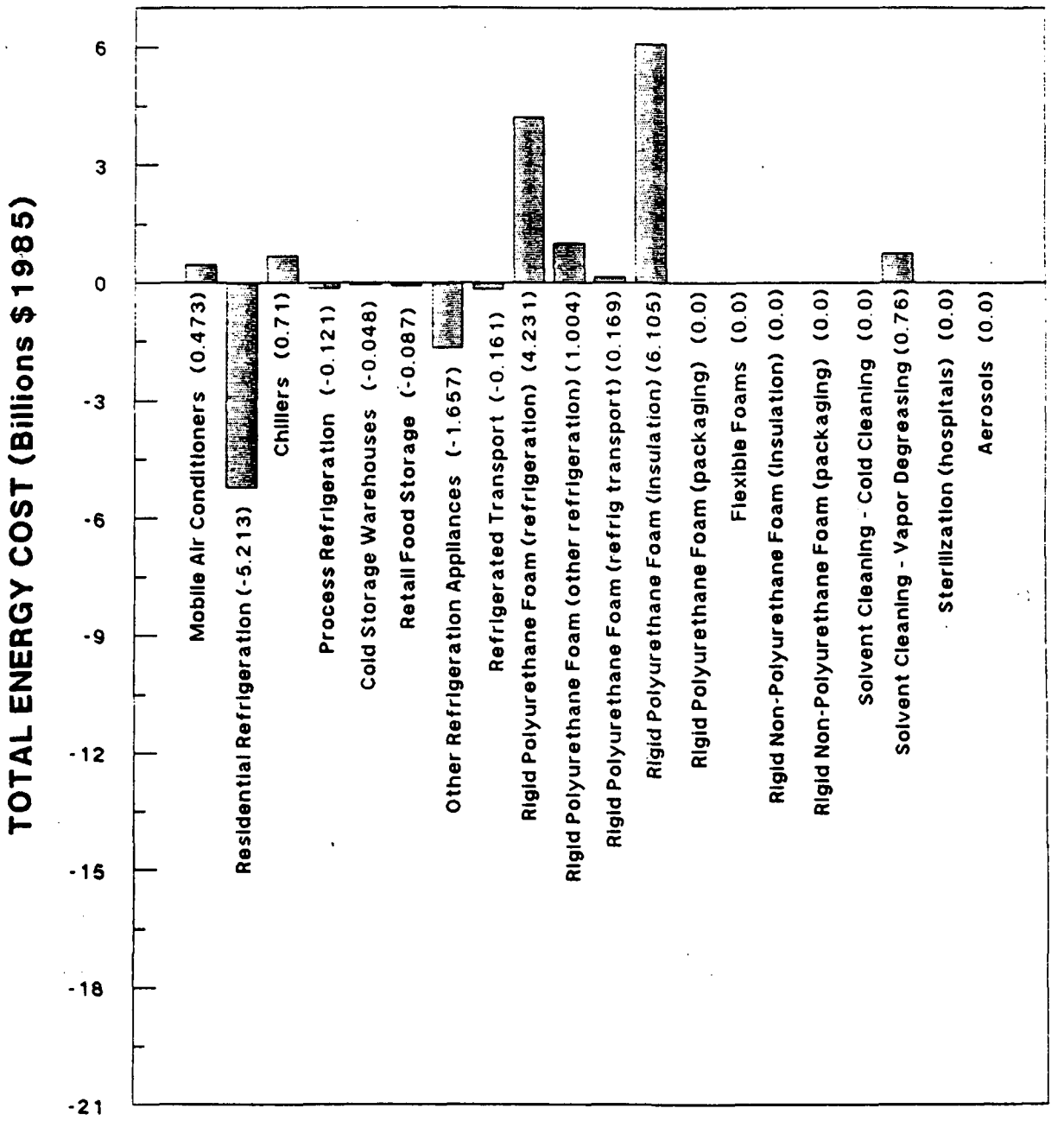


EXHIBIT 3-27

U.S. CUMULATIVE ENERGY COSTS BY END USE
CONVENTIONAL WISDOM (1989 - 2010)
Scenario 1



END USE

EXHIBIT 3-28

U.S. CUMULATIVE ENERGY COSTS BY END USE
MAXIMUM HCFC USE (1989 - 2010)
Scenario 2

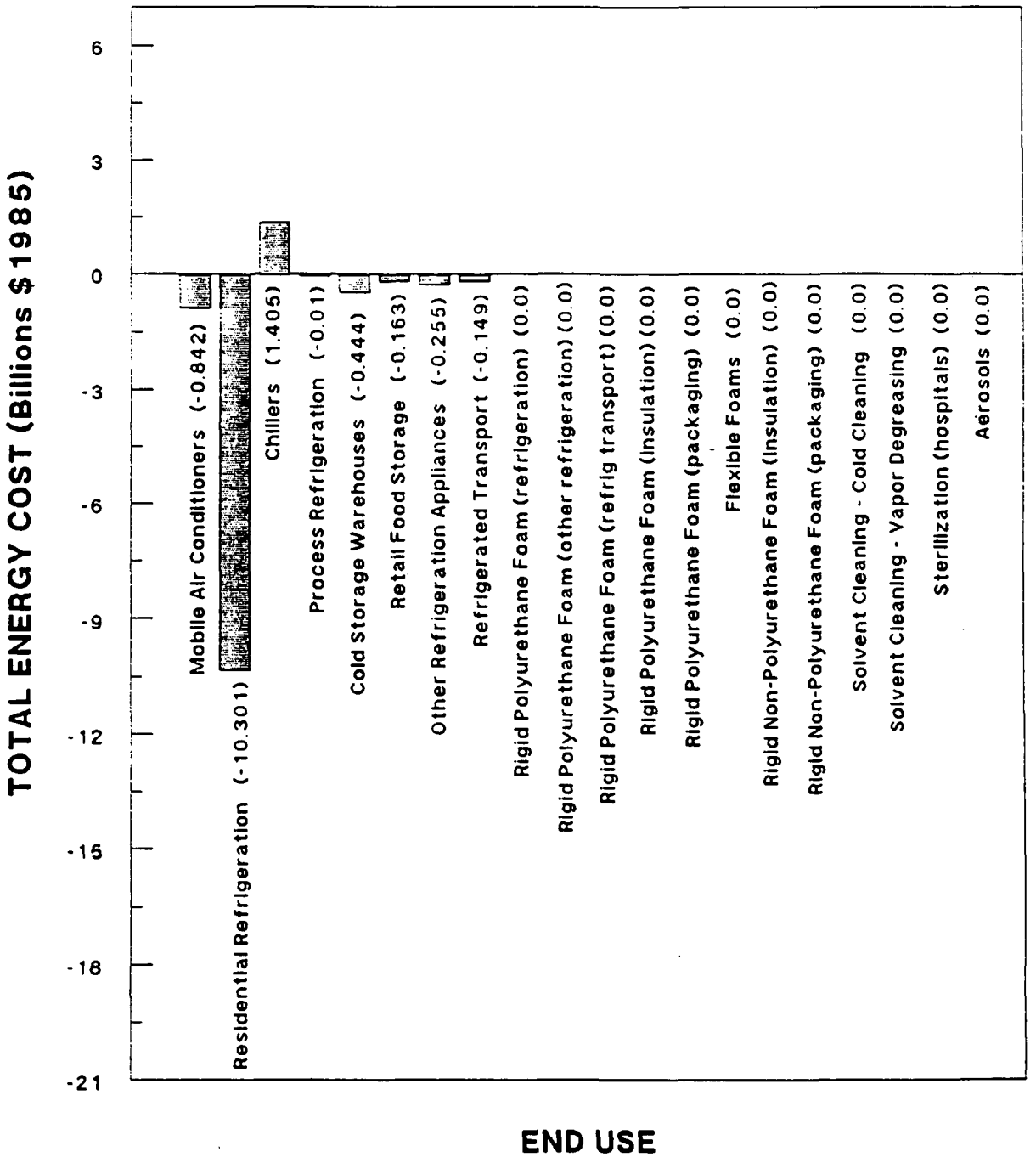


EXHIBIT 3-29

U.S. CUMULATIVE ENERGY COSTS BY END USE
PRUDENT HCFC USE (1989 - 2010)
Scenario 3

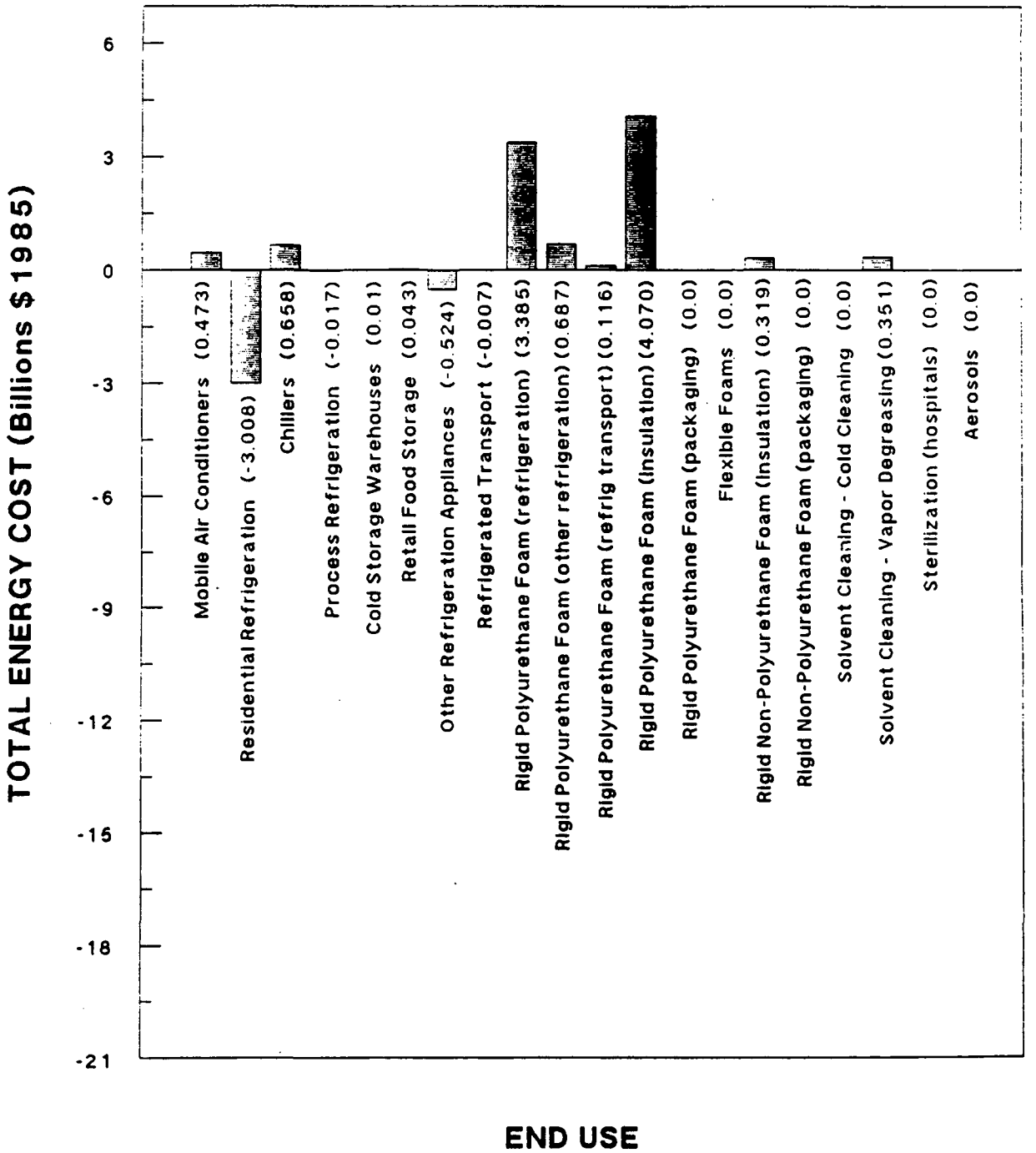


EXHIBIT 3-30

U.S. CUMULATIVE ENERGY COSTS BY END USE
MINIMIZE GREENHOUSE/ENERGY IMPACT (1989 - 2010)
Scenario 4

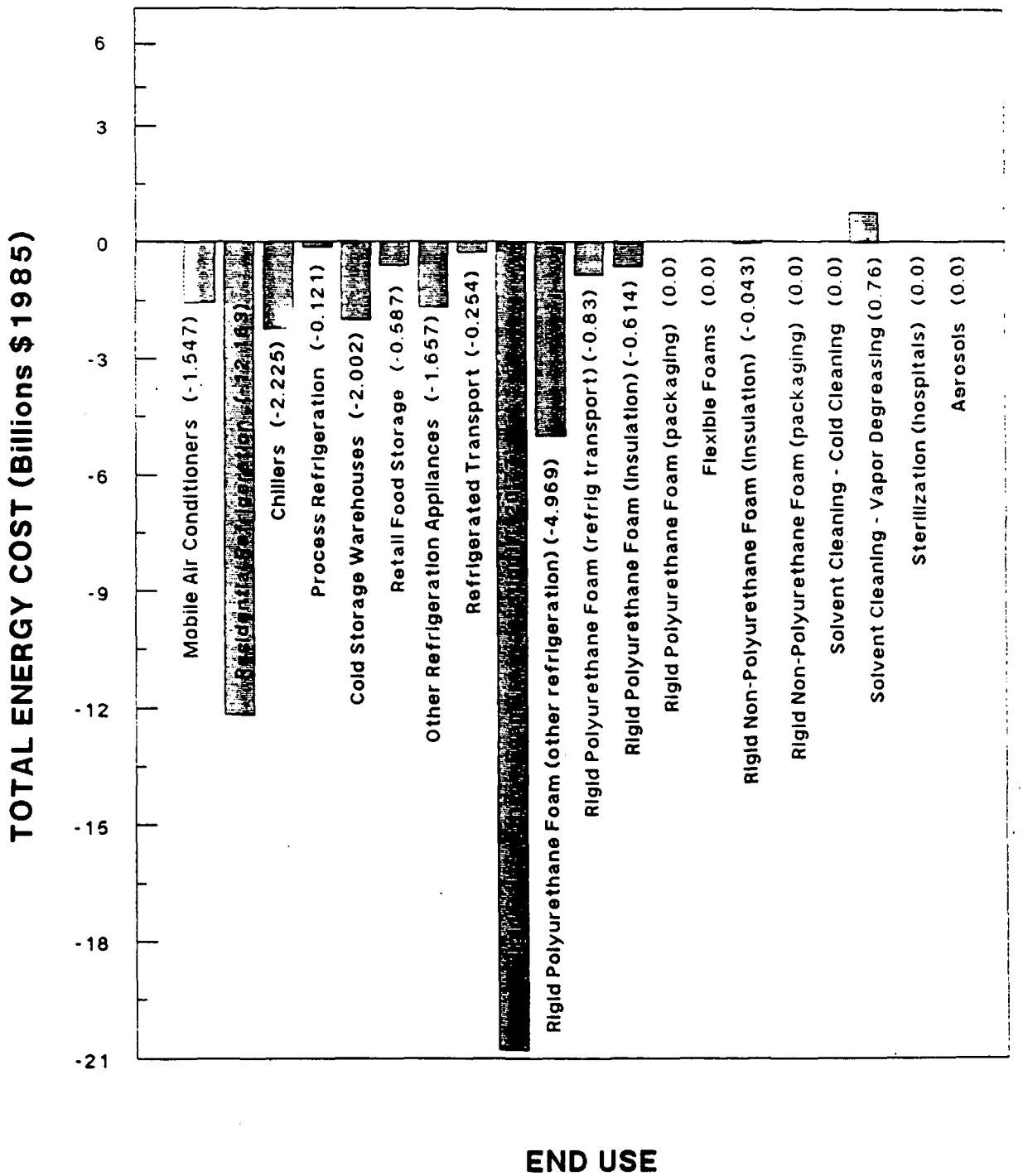


EXHIBIT 3-31

GLOBAL CUMULATIVE ENERGY COST BY END USE
CONVENTIONAL WISDOM (1989 - 2010)
Scenario 1

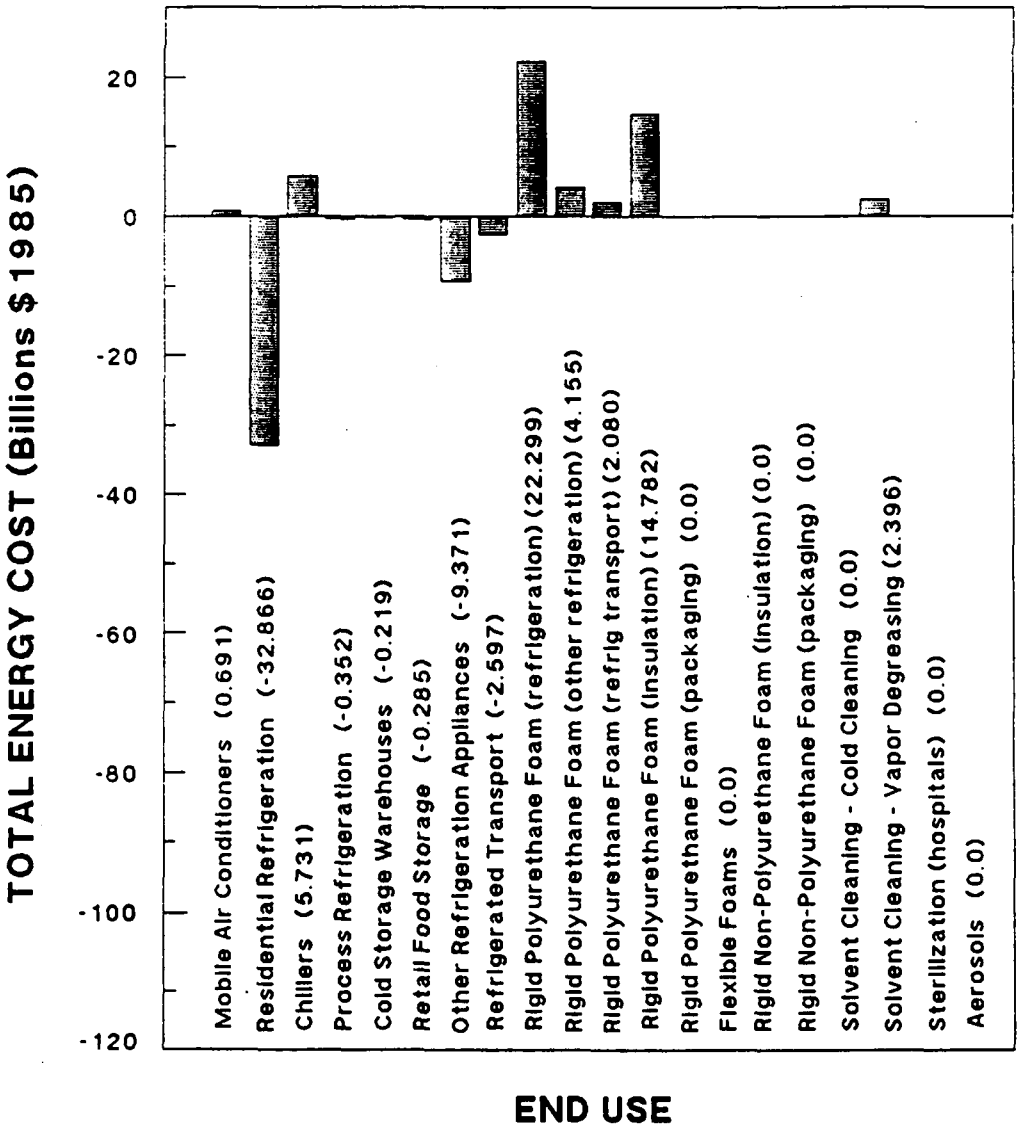
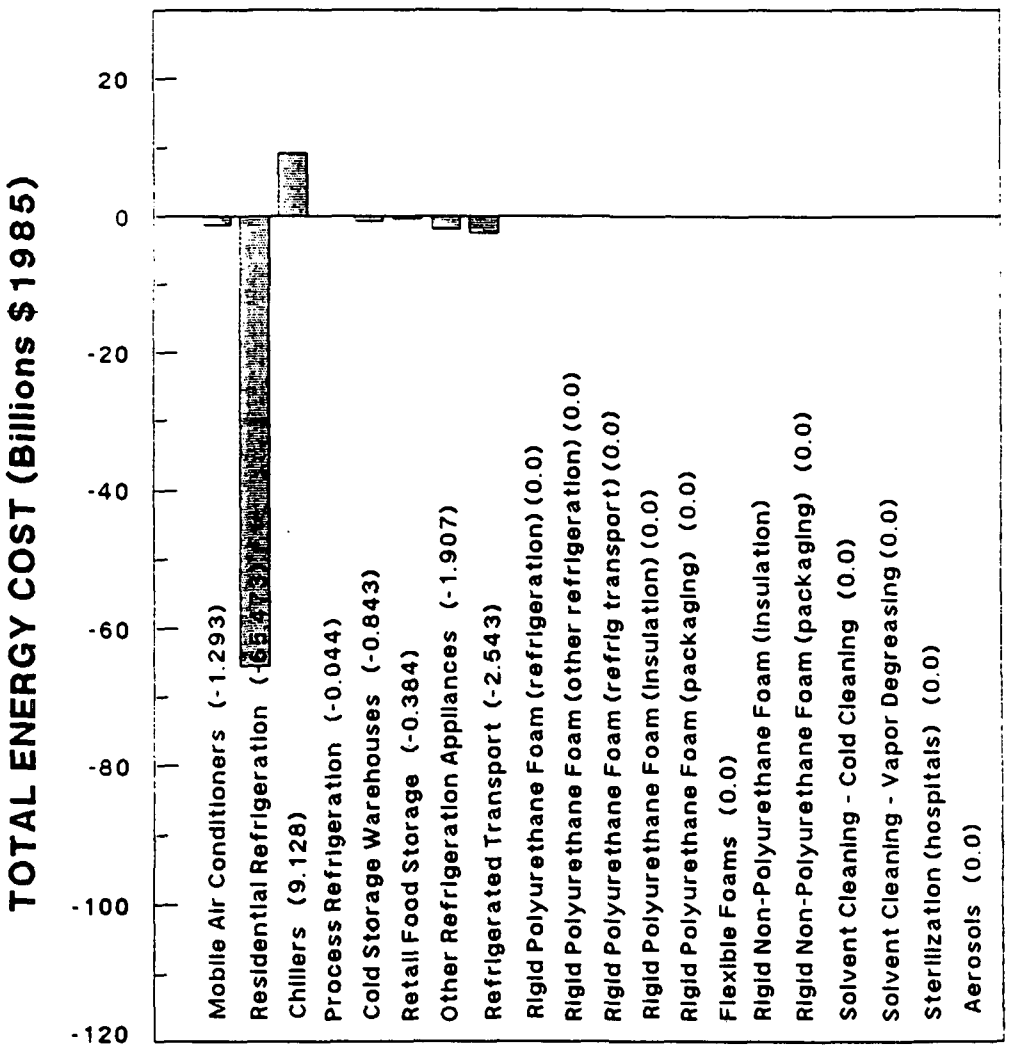


EXHIBIT 3-32

GLOBAL CUMULATIVE ENERGY COST BY END USE
MAXIMUM HCFC USE (1989 - 2010)
Scenario 2



END USE

EXHIBIT 3-33

GLOBAL CUMULATIVE ENERGY COST BY END USE
PRUDENT HCFC USE (1989 - 2010)
Scenario 3

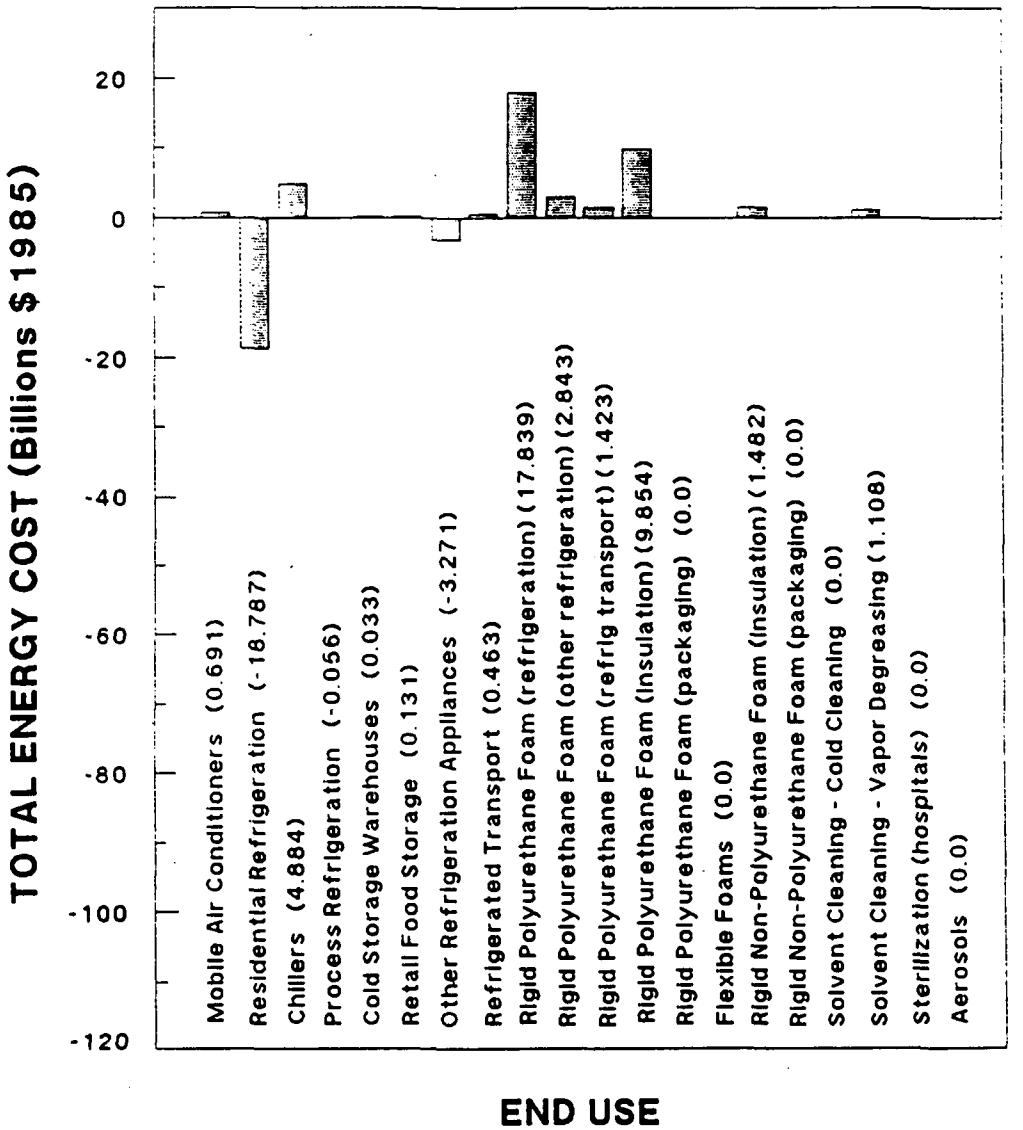
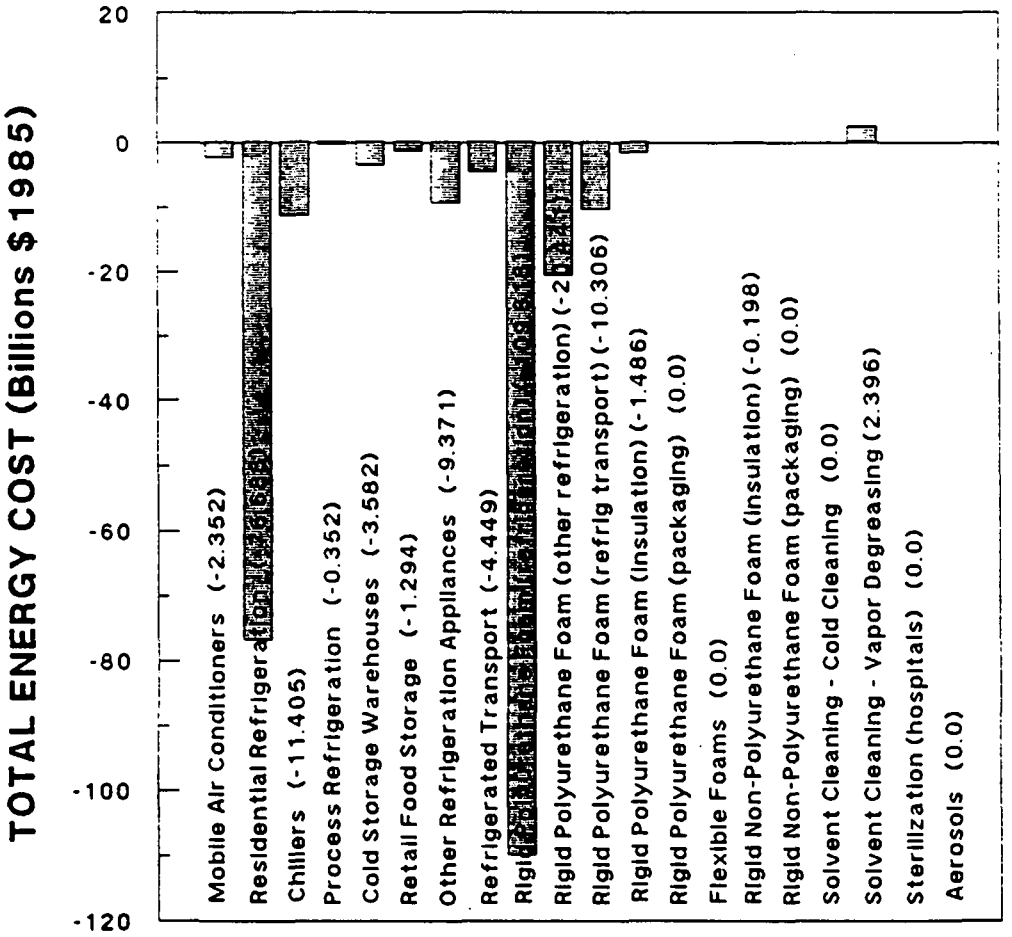


EXHIBIT 3-34

GLOBAL CUMULATIVE ENERGY COST BY END USE
MINIMIZE GREENHOUSE/ENERGY IMPACT (1989 - 2010)
Scenario 4



END USE

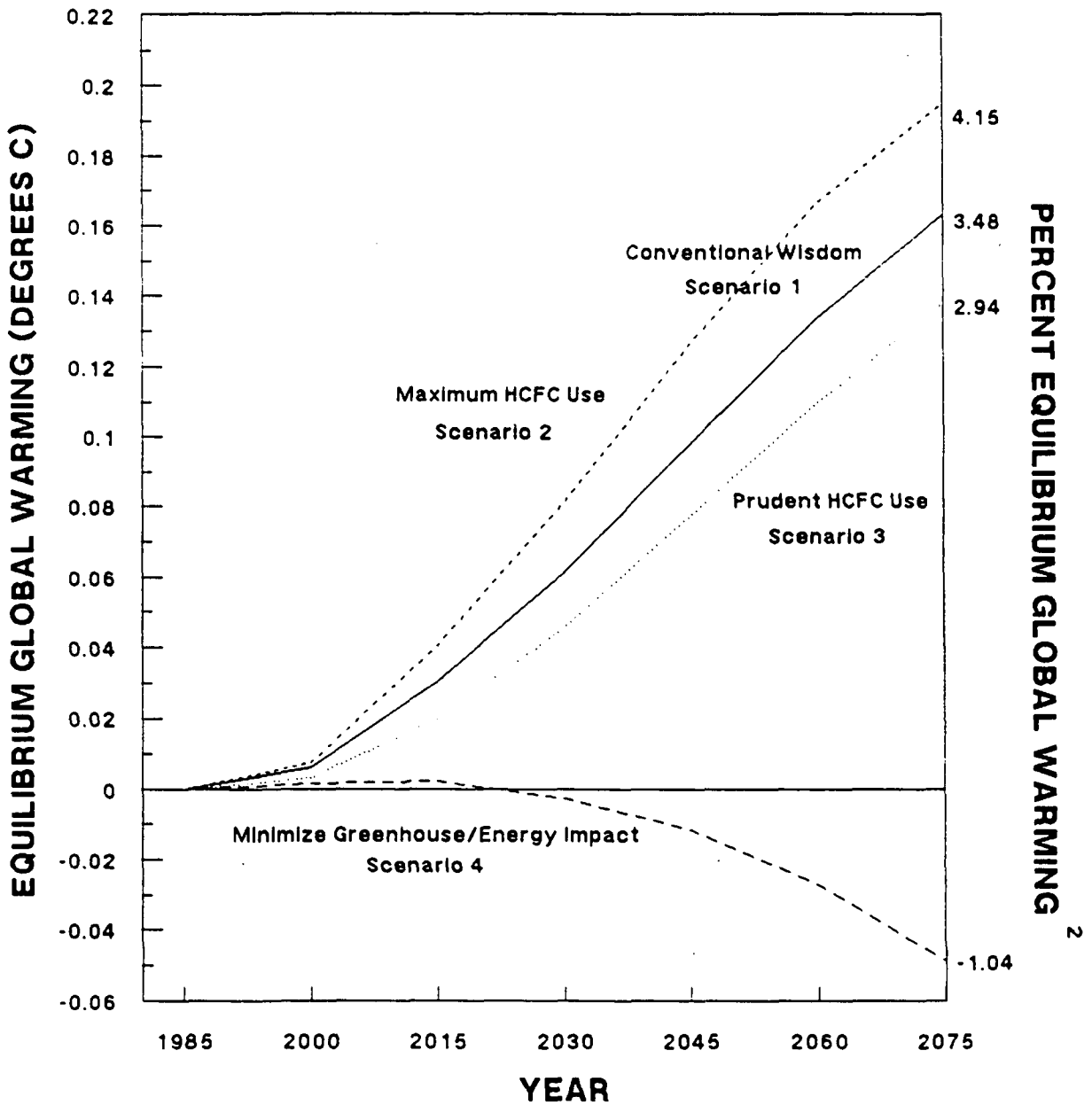
Substitution for CFCs can influence global warming both through the direct radiative properties of the substitutes and through changing the energy efficiency of the equipment and products using the substitutes. These changes in energy efficiency can result in changes in fossil fuel demand and therefore the emissions of other greenhouse gases (e.g., CO_2).

Exhibit 3-35 isolates the total contribution of the CFC substitution scenarios to global warming from 1985 through 2075. These contributions range from a positive 0.194°C under Scenario 2 to a -0.049°C under Scenario 4 (i.e., slightly reduced warming). CFC-11 and CFC-12 are estimated to have contributed to approximately 14 percent of global warming during the 1980s. If CFCs were not curtailed, their continued use would have resulted in their contributing to approximately 30 percent of the greenhouse warming in 2075. In contrast, CFC substitutes contribute only approximately 3.4 percent to the total estimated rate of warming under Scenario 1, 4.0 percent in Scenario 2, and 2.9 percent in Scenario 3. In Scenario 4, CFC replacements actually decrease global warming by approximately 1 percent. Furthermore, the total projected global warming rates under each HCFC scenario are approximately 2°C lower than the estimated warming assuming CFC use had continued uncontrolled.

These numbers must be compared to other options to reduce global warming as shown in Exhibit 3-36. As illustrated by this exhibit, the contribution of individual methods for reducing global warming are quite small as a percentage of total realized warming. Even a step such as doubling the fuel efficiency of the global automobile fleet would have only a 7 percent effect in 2075 on

EXHIBIT 3-35

GLOBAL WARMING DUE TO HCFC/HFC SUBSTITUTION BY SCENARIO: 1985-2075 [1]

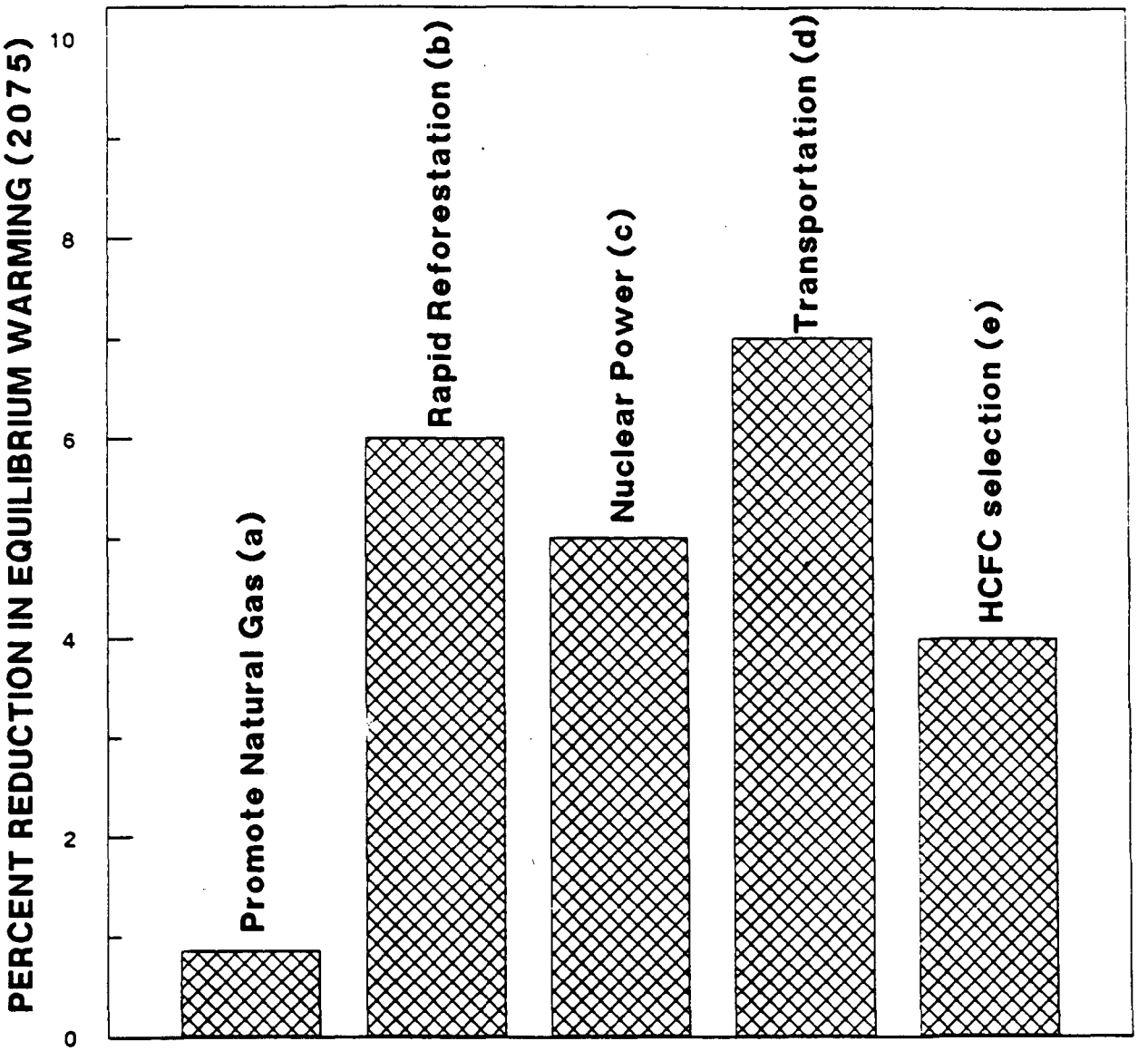


1 This exhibit illustrates global warming associated with both the direct radiative forcing of the substitutes and changes in the emission of greenhouse gases due to changes in energy efficiency.

2 Percent equilibrium global warming in 2075 due to HCFC/HFC substitution

EXHIBIT 3-36

COMPARISON OF REDUCTIONS IN EQUILIBRIUM WARMING FROM VARIOUS POLICIES



Notes: (1) All estimates, except "HCFC Selection", taken from: U.S. EPA, "Policy Options for Stabilizing Global Climate", Draft Report to Congress, February 1989 and personal communication with Craig Ebert, ICF, Inc. These estimates are all relative to the Rapidly Changing World (RCW) baseline scenario of the report. This report is currently under review.

(2) "HCFC Selection" represents the reduction achievable by moving from the scenario of maximum warming contribution to the least warming contribution. This estimate does not include the positive feedbacks (e.g. methane increase yields decreases in hydroxyl radical concentrations and increases in tropospheric ozone, both of which contribute to the greenhouse effect) included in the projections for the policies against which it is compared.

(3) Policies are described on the following page.

EXHIBIT 3-36 (continued)

COMPARISON OF REDUCTIONS IN EQUILIBRIUM WARMING FROM VARIOUS POLICIES

Policy Descriptions:

(a) Promote Natural Gas: Assumes economic incentives accelerate exploration and production of natural gas. The cost of locating and producing natural gas is reduced by an annual rate of 0.5% relative to the RCW scenario. Incentives for gas use for electricity generation increase gas share by 5% in 2025 and 10% thereafter.

(b) Rapid Reforestation: Assumes reforestation sufficiently rapid to make terrestrial biosphere a net source for CO_2 by 2000. Such a change necessitates reforesting 2.1×10^6 square miles by 2015 and 4.4×10^6 square miles by 2100.

(c) Nuclear Power: Assumes the promotion of nuclear power through technological improvements in nuclear design which reduce costs by approximately 0.5% annually.

(d) Transportation: Assumes that the fuel efficiency of new cars in the U.S. increases to 40 mpg in 2000, and global fleet average fuel efficiency increases to 50 mpg by 2050.

(e) HCFC Selection: Represents difference in equilibrium global warming for scenarios 2 and 4, expressed as a percent of equilibrium warming in 2075.

reducing warming.[8] This suggests that the quantity of warming associated with options for replacing CFCs may be relatively important (i.e., of the same magnitude as other reduction options).

Exhibit 3-37 distributes the total contribution to equilibrium warming of the CFC substitutes under each substitution scenario between the direct effects from the compounds themselves and the indirect effects resulting from changes in energy consumption under each scenario. Under Scenarios 1 2 and 3, the direct radiative effects of the HCFC and HFC substitutes are more significant than the indirect effects associated with emissions of energy-related greenhouse gases. For example, even though Scenario 3 decreases energy efficiency while Scenario 2 increases efficiency, because the substitutes applied in Scenario 3 have lower direct greenhouse effects, this scenario presents less of a greenhouse problem overall than does Scenario 2. Under Scenario 4, the negative contribution of indirect energy-related greenhouse gases associated with use of CFC substitutes is greater than the radiative effect of the substitutes themselves, which is slightly positive.

As shown in Exhibits 3-38 through 3-41, no single end use consistently contributes a substantial portion of the warming estimated to occur under each scenario. In Scenario 1, four end uses -- rigid polyurethane foam (insulation), chillers, retail food storage, and mobile air conditioning -- contribute to over 50 percent of the estimated increase in warming attributable to CFC substitutes under the scenario. In Scenario 2, chillers, rigid polyurethane foam insulation, and aerosols are significant contributors

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[8] U.S. EPA, Policy Options for Stabilizing Global Climate, Draft report to Congress, February 1989. This report is currently under review.

EXHIBIT 3-37

EQUILIBRIUM WARMING BY 2075 DUE TO HCFC/HFC SUBSTITUTION

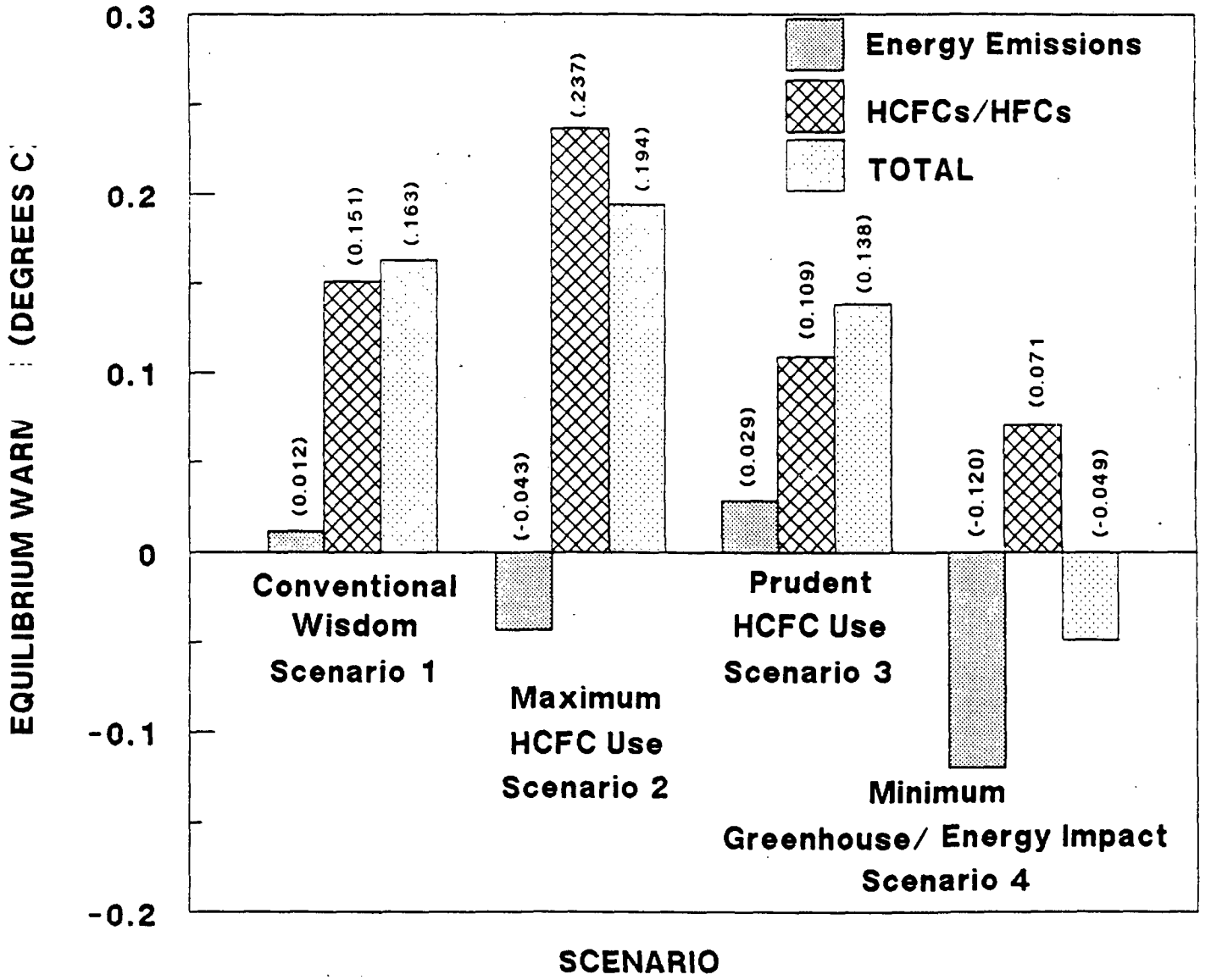


EXHIBIT 3-38

CONTRIBUTION OF CFC END USES TO WARMING IN 2075

CONVENTIONAL WISDOM

Scenario 1

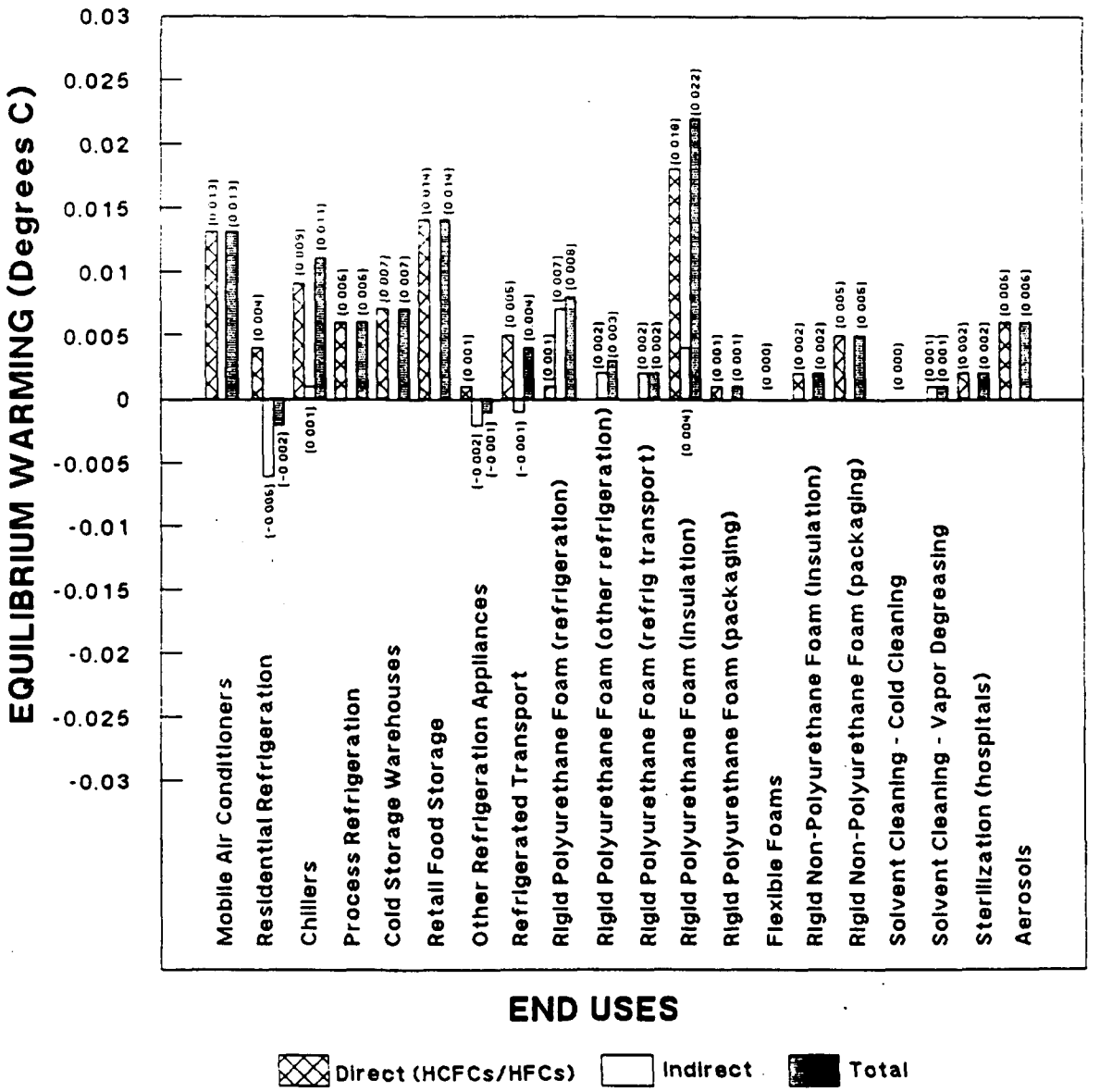


EXHIBIT 3-39

CONTRIBUTION OF CFC END USES TO WARMING IN 2075
MAXIMUM HCFC USE
Scenario 2

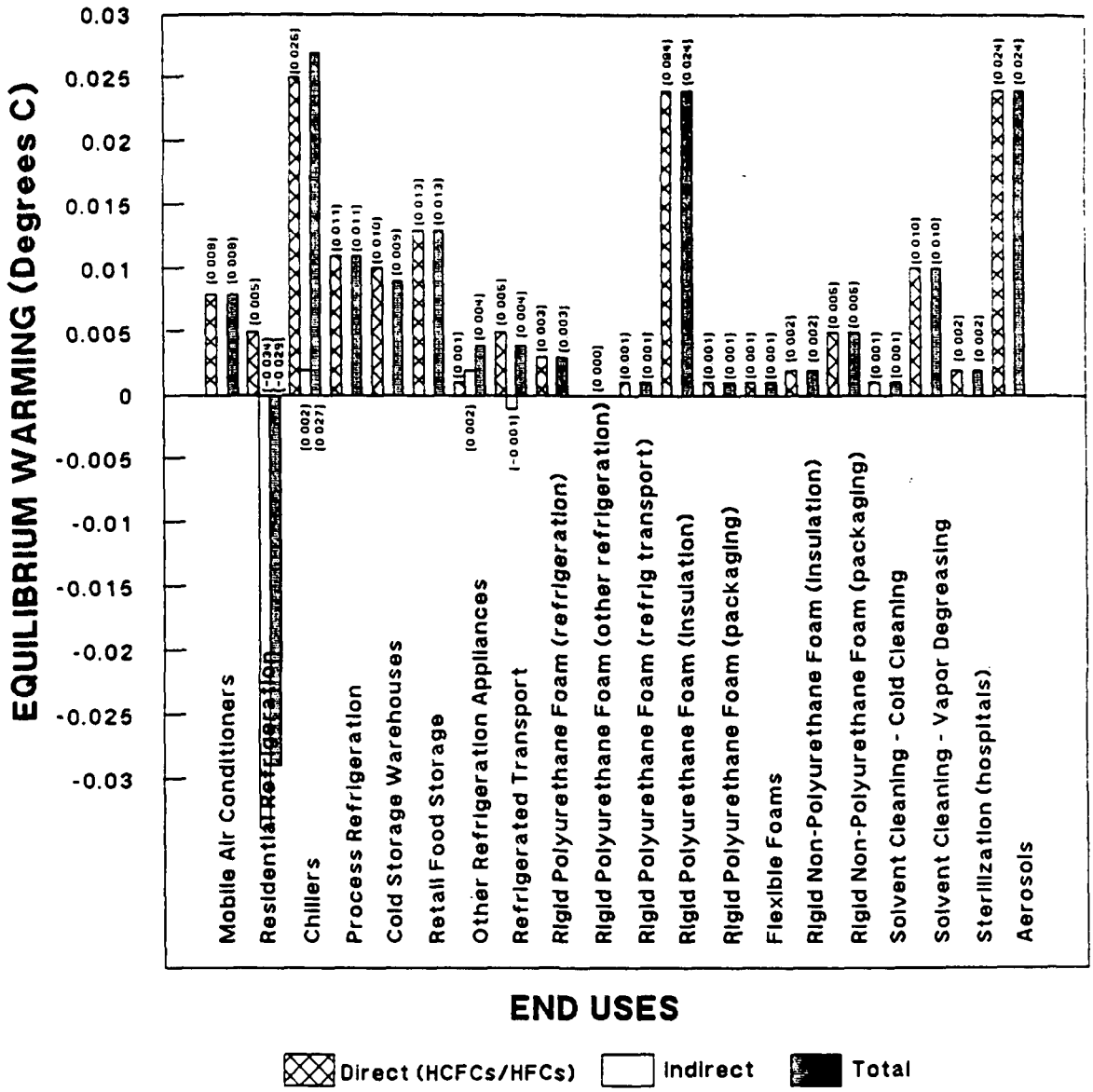


EXHIBIT 3-40

CONTRIBUTION OF CFC END USES TO WARMING IN 2075

PRUDENT HCFC USE

Scenario 3

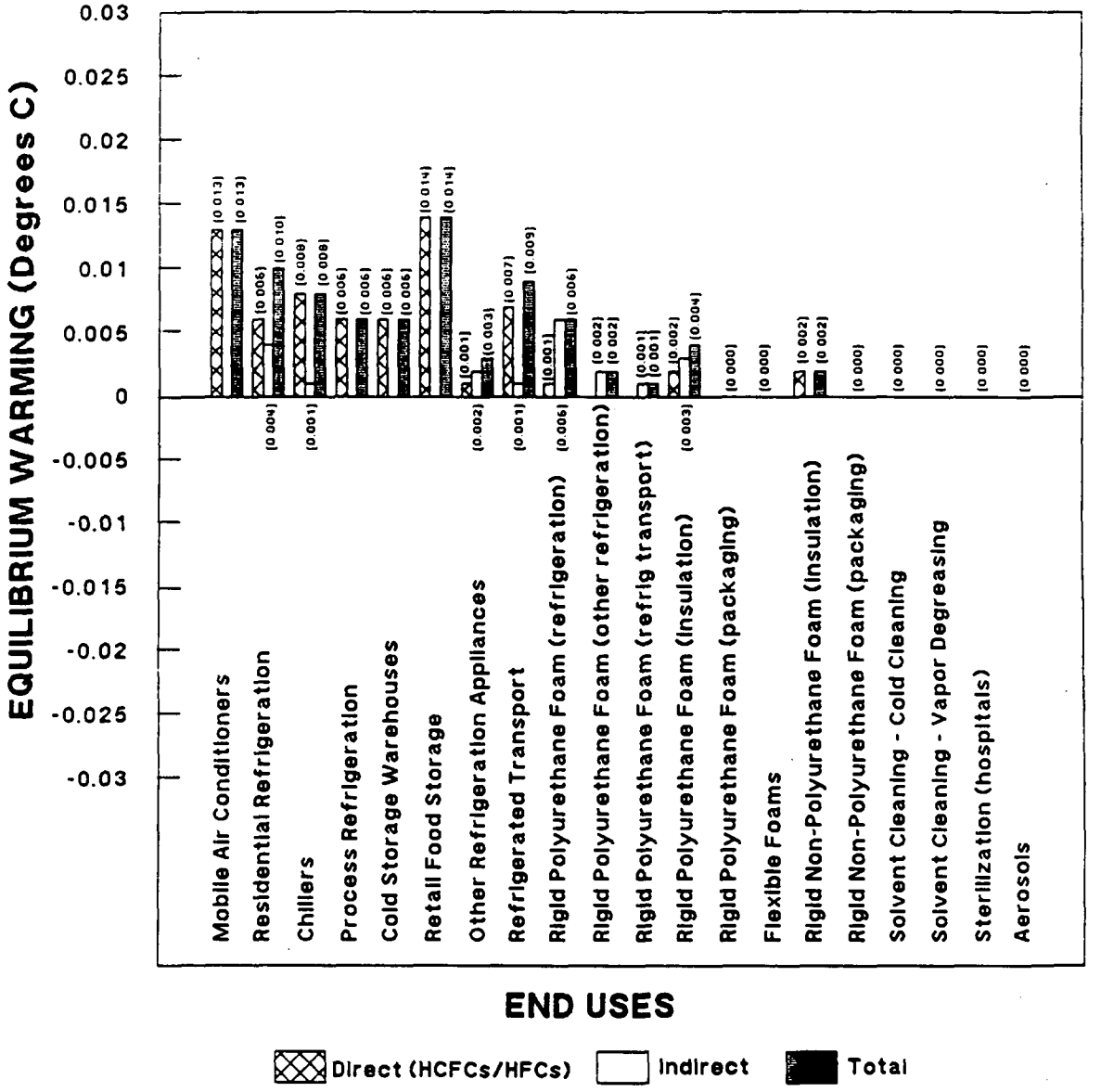
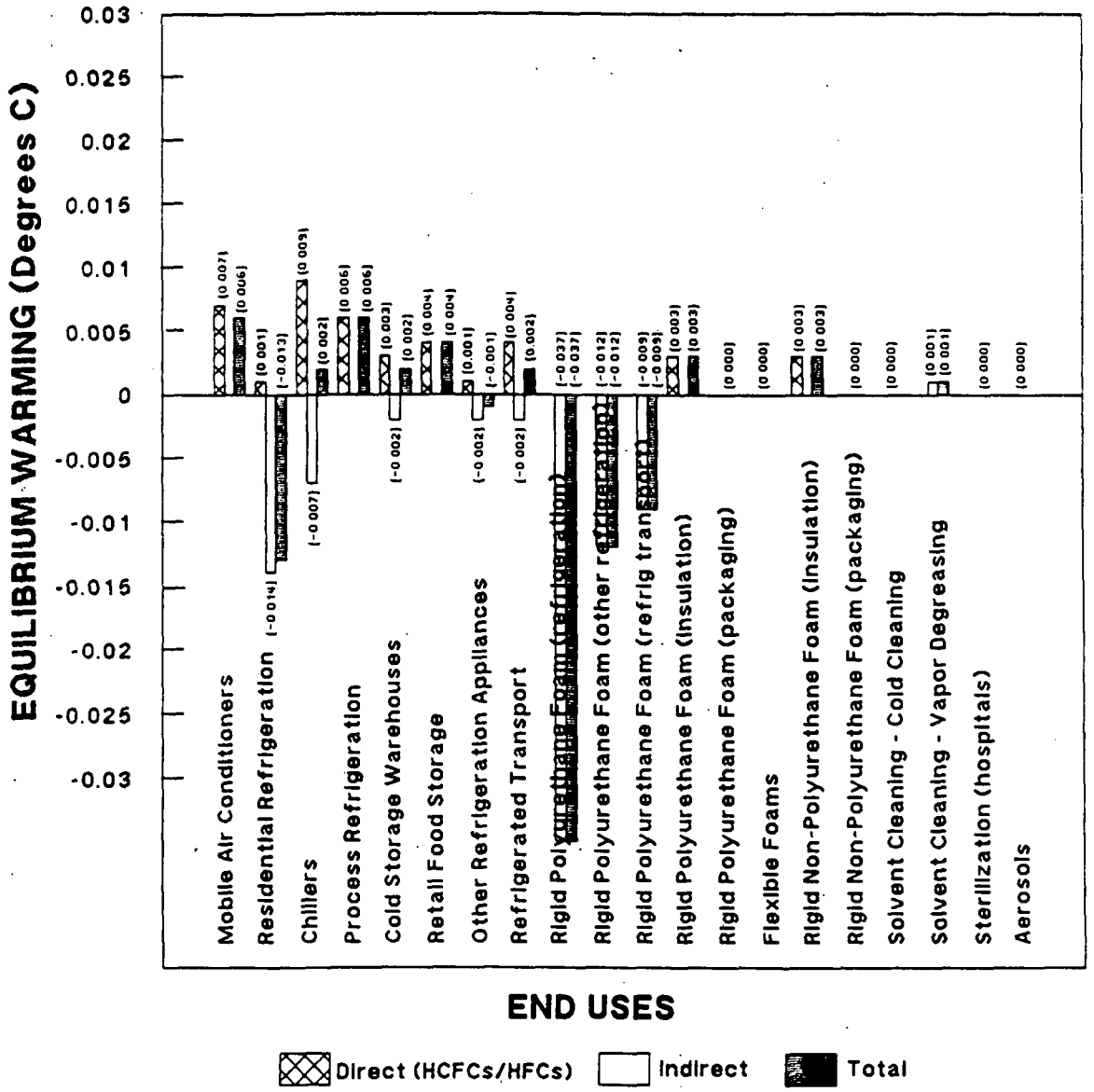


EXHIBIT 3-41

CONTRIBUTION OF CFC END USES TO WARMING IN 2075
MINIMIZE GREENHOUSE/ENERGY IMPACT
Scenario 4



to warming, contributing to approximately 50 percent of the estimated increase.

In Scenario 3, mobile air conditioning, residential refrigeration, retail food storage, and refrigerated transport contribute approximately 50 percent of the increase in global warming associated with the CFC substitutes. Finally, in Scenario 4, which was specified such that substitutes with the minimum greenhouse effect would be used, the greatest contributions to warming are from the following end use areas: mobile air conditioning, process refrigeration, retail food storage, rigid non-polyurethane foam insulation, and rigid polyurethane foam insulation.

The CFC substitutes used in the residential refrigeration end use make negative contributions to global warming in each scenario except Scenario 3 where HFC-134a is used to minimize total chlorine levels.

Exhibits 3-38 through 3-41 also disaggregate these total effects into the contribution attributable to energy emissions estimated for the end use and the contribution estimated for the CFC substitutes themselves. In six end use areas which are not expected to realize changes in energy efficiency due to CFC substitution, there is no contribution to warming from energy-related greenhouse gases. These six application areas are rigid polyurethane foam packaging, flexible foams, rigid non-polyurethane foam packaging, cold cleaning, sterilization, and aerosols.

In eight of the other end use areas, the contributions to global warming of the substitute compounds themselves are greater than the contributions from energy-related greenhouse gases under each scenario. These end uses are mobile air conditioning, chillers, process refrigeration, cold storage, retail

food storage, refrigerated transport, and rigid non-polyurethane foam insulation, and rigid non-polyurethane foam insulation.

Chapter Four examines options within energy consuming applications in more detail in terms of their greenhouse potential and chlorine contribution.

3.4 CONCLUSIONS

This chapter examined the impact of four alternative scenarios of CFC substitution on future chlorine levels, energy usage and costs, and greenhouse warming. These scenarios were defined in an effort to place bounds on the possible impacts on these environmental considerations that could result from a phaseout of CFCs by the year 2000. The scenarios also reflect the substantial uncertainties inherent in projecting which CFC substitutes will actually be employed and their percentage market share on a world-wide basis. In addition, substantial uncertainties also exist concerning the energy efficiency of alternatives now under review. Only as more testing and development work occurs, will more accurate information become available on the energy impacts of various alternatives. Finally, technological developments to replace CFCs are occurring at a rapid rate and many of the actual substitutes available in the year 2000 may not be considered in these scenarios.

Despite these uncertainties, the results of the scenarios analyzed in this chapter provide useful insights into the potential impacts on chlorine levels and energy use from CFC substitution.

(1) Increases in chlorine levels from the market penetration of HCFCs are less than 0.4 ppb under all scenarios except the maximum HCFC use

scenario. Under both the prudent use case (Scenario 3) and maximum energy efficiency case (Scenario 4), Clx increases are 0.02 and 0.1 ppb, respectively, through 2075. Future chlorine increases from HCFCs would only be significant if extensive use of the highest ODP substitutes (e.g. HCFC-141b) occurs in such areas as foam insulation and solvent cleaning.

(2) Large potential energy efficiency gains appear possible if alternative refrigerants including non-azeotropic materials that incorporate HCFCs are developed. Even more substantial gains could be possible through the added use of ammonia in more applications. Sizable energy efficiency gains are also possible through the use of vacuum panel insulation in refrigeration appliances. Relatively small energy losses would be experienced through the use of HFC-134a in auto air conditioning, the use of HCFC-123 in foam applications, and through the use of aqueous and terpene cleaners as solvents.

(3) Changes in energy efficiency occurred for all the scenarios. The economic gains from improved energy efficiency could substantially reduce the overall costs associated with reducing the use of CFCs (though this analysis did not consider the possible increased costs of using some substitutes compared with others.) While the savings resulting from reductions in energy use in the U.S. appeared large in absolute dollars, the estimated declines in energy use in the U.S. are less than 1 percent of total U.S. energy use estimated for the period under examination.

(4) The substitution scenarios varied significantly in their contributions to global warming. Scenario 4, by substantially improving energy efficiency and limiting the use of greenhouse gases, would actually

slightly slow global warming. In contrast Scenario 2 would contribute 0.2°C in 2075 to equilibrium warming. This represents about 4 percent of the total projected greenhouse warming by that date. In general, the direct greenhouse properties of the substitutes would have a substantially greater impact on global warming than indirect or energy efficiency impacts with the exception of refrigerator's working fluids.

CHAPTER FOUR

A PARTIAL ENVIRONMENTAL ANALYSIS OF OPTIONS WITHIN SPECIFIC APPLICATIONS

As discussed in earlier chapters, the question of understanding the environmental implications of HCFC and HFC use has a variety of aspects.

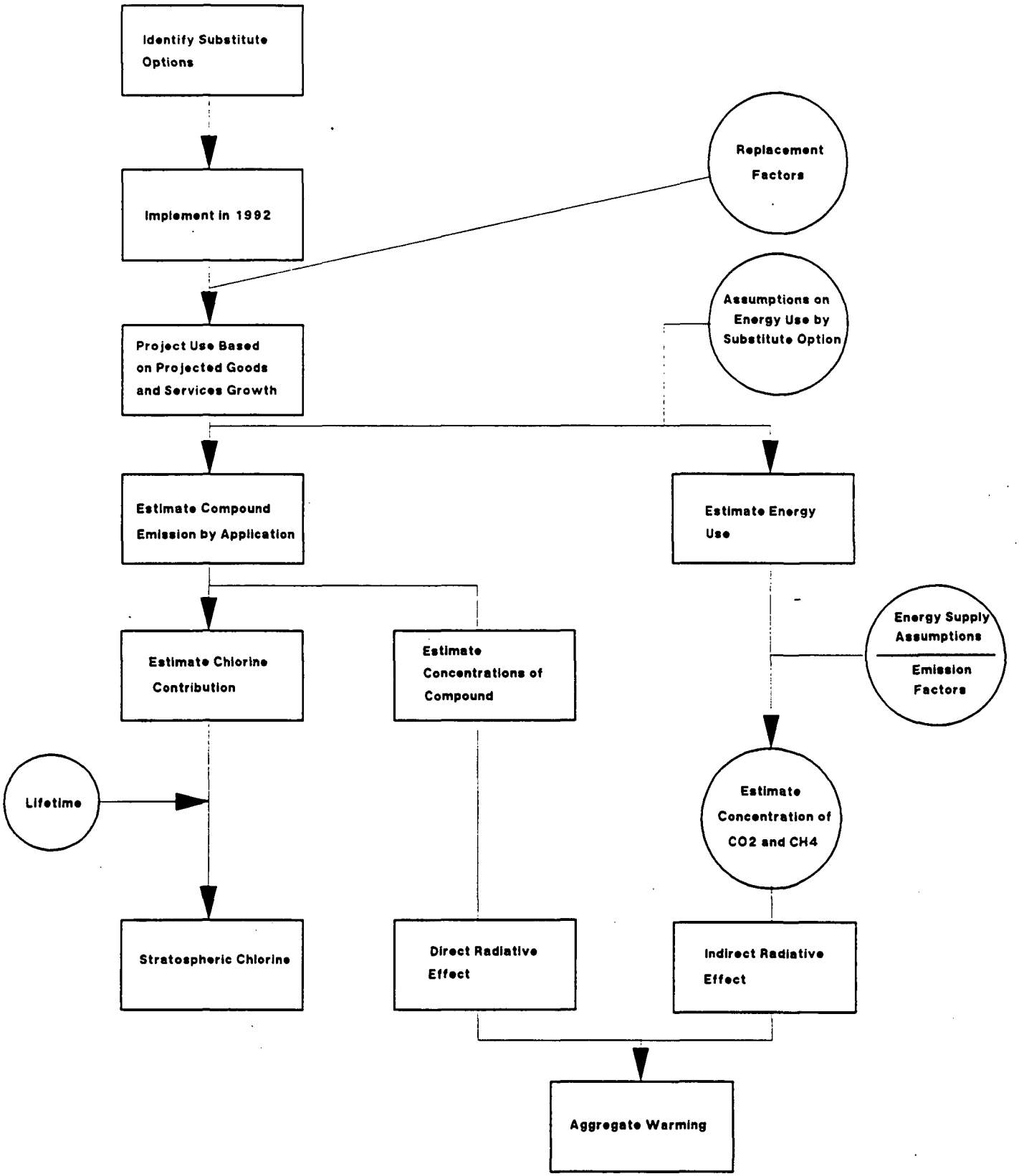
Chapter 2 examined the effect of using different aggregate levels of various HCFCs on stratospheric chlorine. Chapter 3 then examined various "scenarios" for future HCFC and HFC use assuming different market penetration in key applications. The analysis showed that future chlorine, greenhouse warming, and energy use can vary between scenarios by significant amounts. Chapter 3 also demonstrated that for certain uses, such as aerosols, HCFCs could contribute significantly to chlorine without concomitant advantages in terms of energy reduction.

In this chapter certain key uses are analyzed more closely to determine possible chlorine and greenhouse tradeoffs between different CFC substitute options. While incomplete, this analysis does provide critical insight into possible risks and opportunities associated with various choices of CFC substitutes in energy intensive uses. EPA plans to follow this report with more focused analyses on individual uses.

4.1 METHODOLOGY USED IN THIS ANALYSIS

To understand the tradeoffs between options, it is important to make a series of assumptions about options and to calculate effects through a sequence of models. Exhibit 4-1 summarizes the methodology used here. First, for each application, substitute options are identified. In addition, for

EXHIBIT 4-1
APPROACH USED IN THIS ANALYSIS



each use area, good use practices, such as recycling, tightened systems that reduce emissions, etc., are assumed to be used.

To simplify the analysis, full scale implementation of every option is assumed to occur in 1992, even though substitution would actually occur gradually over a longer time period.[1]. This simplifying assumption has a slight effect on estimates of aggregate impacts. As discussed earlier, replacement factors are determined for each option. Combined with projected growth in use sectors, these yield options for uses by application. With assumptions on energy use, supply, and emission factors, it is then possible to calculate contributions to chlorine and to global warming of each HCFC compound, and CO2 and CH4 that result from each application/substitute option. The end result is that the greenhouse effect is computed by considering two sources of global warming: the direct radiative effects of emissions, and the indirect effect of increased carbon dioxide and methane emissions associated with the energy used.[2]

4.1.1 Limitations of the Analysis

There are several limitations to this analysis. First, some options are not considered. Secondly, assumptions about energy use, replacement factors,

---

[1] This simplifying assumption of full implementation of all substitutes in 1992 is made in order to introduce consistency in comparisons across alternatives within applications and across applications. This assumption eliminates all influence of start dates, rates of penetration and market penetration and subsequently isolates the differences in physical and chemical characteristics between the CFC replacements.

[2] The emissions factors assumed are for a typical mixture of fuels used currently to supply energy use (details are provided in Appendix D). Clearly the actual fuels used to provide energy could change over time, as could energy use.

lifetimes, etc. could be altered and will change as more is learned about the use of HCFCs in specific applications. Finally, not all of the options considered may prove feasible; more research and development is needed for some. Despite these issues, the underlying conclusion of this chapter -- that there are significant impacts from the different options -- is quite robust.

4.2 OPTIONS ANALYSIS FOR END USE AREAS

4.2.1 Refrigerators

Residential refrigerators constitute an important end use because of their high energy consumption. Two areas need consideration, replacements of CFC-12 as the refrigerant and for CFC-11 as an insulator.

Evaluation of Options for Refrigerants

HFC-134a had been conventionally viewed as the most likely refrigerant replacement. More recently, a ternary blend has been proposed that is a near azeotrope (HCFC-22 - 40 percent, HFC-152a - 20 percent; HCFC-124 - 40 percent). In addition, in the 1970's, Lorenz et al. developed a two-evaporator model that achieved 20 percent gains in energy efficiency using a NARM with a 26°C temperature glide (78°C difference in boiling points).[3] A wide variety of compounds exist that could be used as NARMs in refrigerators (Exhibit 4-2). At least three research groups are now examining over 10 mixtures in an attempt to achieve similar gains with chemicals that are more environmentally attractive than those Lorenz used.

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[3] Fourteenth International Congress of Refrigeration, proceedings published by the International Institute for Refrigeration, Moscow 1975.

EXHIBIT 4-2

Boiling Point Difference for Selected 50/50 Weight Percent Compositions (°C)

Expected Temperature Glide = 1/3 (Boiling point difference)

R-141b (32)																
5	R-123 (27)															
23	18	R-21 (9)														
37	32	14	R-143 (-5)													
42	37	19	5	R-142b (-10)												
44	39	21	7	2	R-124 (-12)											
44	39	21	7	2	0	Isobutane (-12)										
52	47	29	15	10	8	8	R-134 (-20)									
57	52	34	20	15	13	13	5	DME (-25)								
57	52	34	20	15	13	13	5	0	R-152a (-25)							
59	54	36	22	17	15	15	7	2	2	R-134a (-27)						
73	68	50	36	31	29	29	21	16	16	14	R-22 (-41)					
74	69	51	37	32	30	30	22	17	17	15	1	Propane (-42)				
80	75	57	43	38	36	36	28	23	23	21	7	6	R-143a (-48)			
81	76	58	44	39	37	37	29	24	24	22	8	7	1	R-125 (-49)		
84	79	61	47	42	40	40	32	27	27	25	11	10	4	3	R-32 (-52)	
114	109	91	77	72	70	70	62	57	57	55	41	40	40	33	30	R-23 (-82)

In evaluating options for refrigerants, the examination of substitution possibilities has been reduced to four distinct cases, as shown in Exhibit 4-3. Exhibit 4-4 shows aggregate chlorine (Clx) and warming associated with these options.[4]

Analysis of Results

Because of the high energy use and relatively low emissions of refrigerators, there is a significant greenhouse difference between Options 1 and 4 (the two options with 20 percent energy gains over CFC-12) and Options 2 and 3. The fact that between Options 1 and 4 (two options with high energy efficiency but HCFCs of different lifetimes) there is little greenhouse difference indicates that for options which would provide much greater energy efficiency, a significant greenhouse advantage will exist regardless of the lifetime of the HCFCs or HFCs used.

In terms of chlorine, the difference between the higher and lower ODP mixtures for the high energy efficiency options is 0.01 ppb, a relatively small difference.

Examining the difference between HFC-134a and the ternary mixture, the gain in greenhouse warming is slightly more than 0.01°C (or approximately 0.2 percent of estimated global warming in 2075), while the use of the ternary results in an additional contribution to chlorine concentrations of only 0.012 ppb.

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[4] The detailed results for the evaluations presented in the chapter are provided in Appendix F.

EXHIBIT 4-3

OPTIONS FOR REPLACING CFC-12 IN RESIDENTIAL REFRIGERATORS

CFC USED		DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-12	Option 1	NARM[1]	1.0	-20
CFC-12	Option 2	MIX[2]	1.0	-3[a]
CFC-12	Option 3	HFC-134a	1.0	+3[a]
CFC-12	Option 4	NARM[3]	1.0	-20

[1] A non-azeotropic refrigerant mixture with a good temperature glide, and a high percentage of HCFC-22 as a component; an ODP of 0.025 is assumed.

[2] A near-azeotropic ternary mixture of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124.

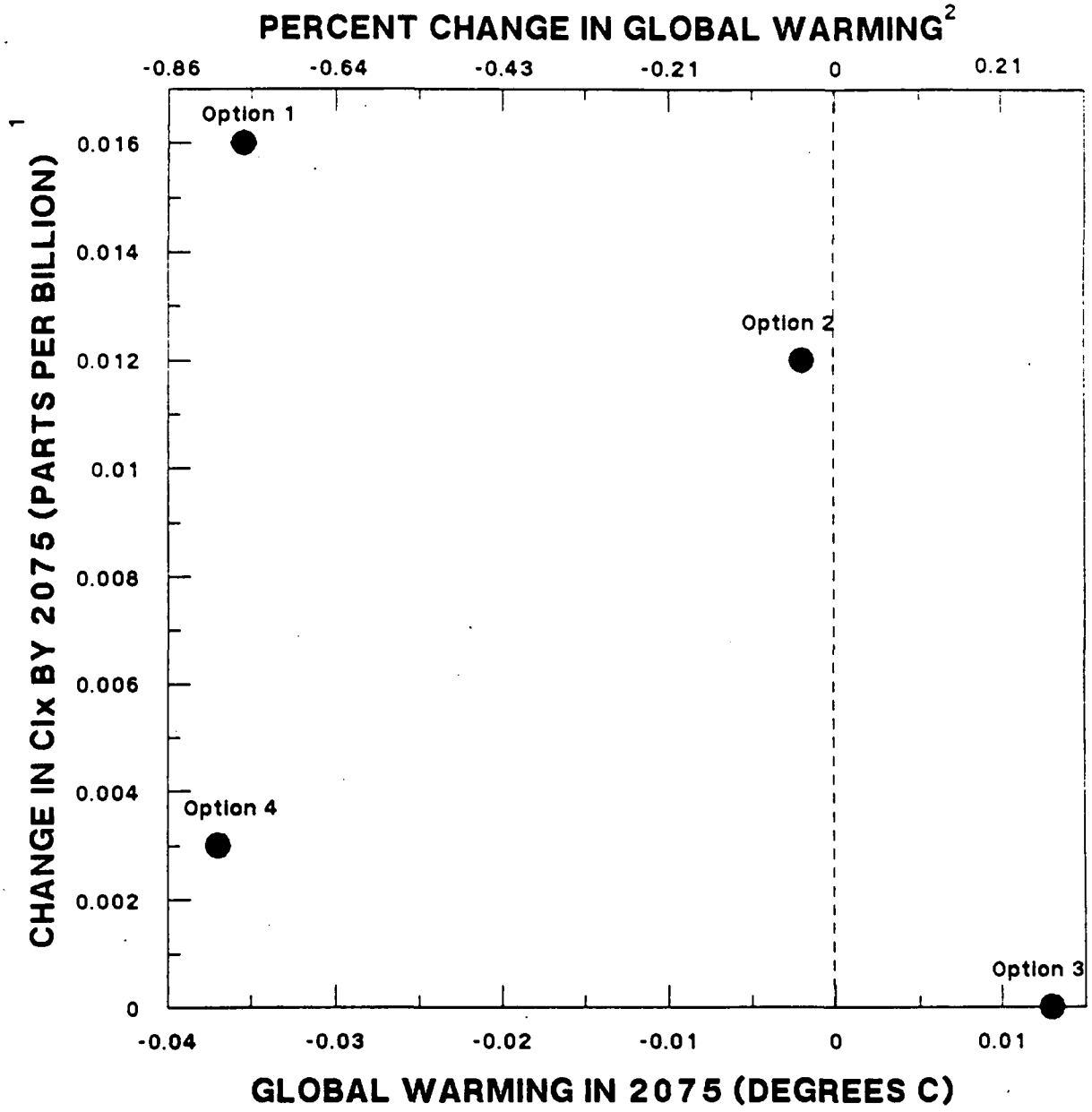
[3] A non-azeotropic refrigerant mixture with a good temperature glide in which both components have low ODP; therefore an ODP of 0.01 is assumed.

[a] Provided by an industry source.

EXHIBIT 4-4

TRADEOFF ANALYSIS

RESIDENTIAL REFRIGERATION



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

Evaluation of Options for Insulation in Refrigerators

HCFC-123 and HCFC-141b are generally viewed as the leading candidates to replace CFC-11 in insulating foams for refrigerators. Generally, industry would prefer that the thickness of refrigerator walls remain the same. If the "K" or "R" values of foam (i.e., the insulating capability) are assumed to dictate energy use, there could be a 5.0 percent energy loss for foam blown with HCFC-123 and for foam blown with HCFC-141b without thicker walls. Attempts are being made, however, to optimize foam blowing regimes in order to eliminate any energy loss associated with HCFC-123 or HCFC-141b foam.[5]

Other options also exist for avoiding energy loss. In testimony to the U.S. Department of Energy, General Electric (GE) demonstrated that in the U.S. the thickening of unit side walls or tops and bottoms (but not increasing depth) would allow retention of energy efficiency.[6] GE calculated that in such situations the changes in heights or widths would be small enough that their current models would still be able to service 76 percent of the market (instead of 88 percent now served) given current kitchen configurations and cabinet openings in the U.S. Of course, increasing the depth several inches is another alternative that could allow some brands to service existing markets in which widening the unit or adding height is infeasible.

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[5] The optimization of foam manufactured using HCFC-123 and HCFC-141b and used to insulate residential refrigerators in order to achieve a zero energy efficiency change relative to CFC-11 blown foam appears feasible by 1993.

[6] GE Appliances Response to Department of Energy Notice of Proposed Rulemaking Regarding Refrigerators, Refrigerator-Freezers and Freezers, January 31, 1989 (Docket No. CE-RM-87-102).

A more advanced technological option for replacing CFC-11 blown foam is vacuum insulation. Several technologies are now under development, including fine particles, aerosols, hard vacuums, and diatomaceous earth. While uncertainties remain about the practicality of any of these options, they could potentially improve energy performance up to 35 percent (R values of 60-70 and 80 per inch). Exhibit 4-5 summarizes the options that are considered in this analysis, while Exhibit 4-6 shows the results of the trade-off analysis.

Analysis of Results

Clearly vacuum panels are much better than any of the other insulating alternatives, reducing greenhouse warming by 0.048°C (approximately 1.03 percent of the warming projected to occur by 2075) and Clx by as much as 0.057 ppb from the levels estimated for the other options.

There are differences in the contributions to greenhouse warming and stratospheric chlorine levels from the use of HCFC-123 and HCFC-141b in this foam application. Given the current thickness, HCFC-141b contributes approximately 0.046 ppb more to Clx and 0.002°C more to warming than does HCFC-123. By increasing the thickness of HCFC-141b foam, an incremental increase in Clx of 0.006 ppb is estimated relative to the current thickness. Similarly, increasing the thickness of HCFC-123 foam results in minor increases in Clx. The effect on global warming, however, is a decrease in warming of 0.007°C and 0.008°C, respectively, for HCFC-141b and HCFC-123.

EXHIBIT 4-5

REPLACEMENTS FOR CFCS IN RIGID POLYURETHANE FOAM (Refrigeration)

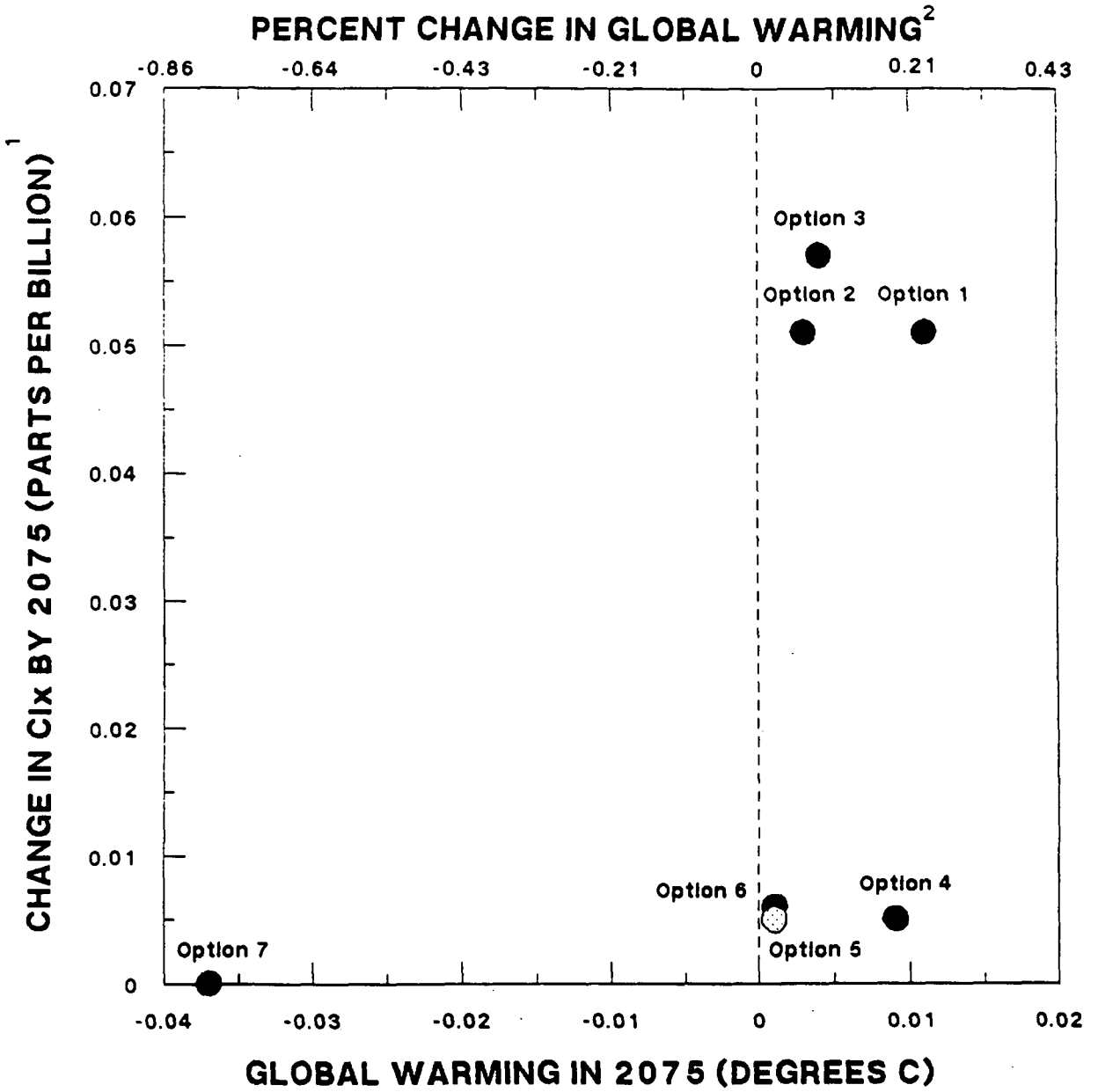
CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-11	1	HCFC-141b - same thickness	0.85	+5.0
CFC-12		HCFC-22	1.00	0.0
CFC-11	2	HCFC-141b Optimized	0.85	0.0[a]
CFC-12		HCFC-22	1.00	0.0
CFC-11	3	HCFC-141b - increased thickness	0.94	0.0
CFC-12		HCFC-22	1.00	0.0
CFC-11	4	HCFC-123 - same thickness	1.15	+5.0
CFC-12		HCFC-22	1.00	0.0
CFC-11	5	HCFC-123 Optimized	1.15	0.0[a]
CFC-12		HCFC-22	1.00	0.0
CFC-11	6	HCFC-123 - increased thickness	1.21	0.0
CFC-12		HCFC-22	1.00	0.0
CFC-11	7	Vacuum Panels	N/A	-25.0
CFC-12		Vacuum Panels	N/A	0.0

[a] Assumes that the foam has been optimized (e.g., by improving cell density, cell thickness, etc.) to provide same energy efficiency. See "Energy-Use Impact of Chlorofluorocarbon Alternatives," Oak Ridge National Laboratory, February 1989.

EXHIBIT 4-6

TRADEOFF ANALYSIS

RIGID POLYURETHANE FOAM (REFRIGERATION)



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

4.2.2 Mobile Air Conditioning

Mobile air conditioners use a large quantity of CFC-12 because of the sizable number of units and their very high leakage rate. A typical automobile air conditioner will currently emit 3.7 kgs of CFC-12 over 15 years, compared to 0.35 kgs from a refrigerator.[7]

HCFC-22 is an option that few automobile companies are now considering due to its high pressure requirements, its possibly lower energy efficiency and the need for total unit redesign.

HFC-134a is the leading candidate for replacing CFC-12, although lubrication and desiccants have to be changed in order for the compound to be used in current units. HFC-134a is assumed in this analysis to result in a 3 percent increase in energy consumption.

The ternary blend (40 percent - HCFC-22, 20 percent - HFC-152a, 40 percent HFC-124) would have a higher leakage rate (7 percent), with a better energy efficiency (2 percent gain) than CFC-12.[8] The possibility of using a blend that has a low ODP and better energy use (5 percent) is also considered. Several such possibilities exist, including HFC-152a blended with HFC-134a and HCFC-22.

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[7] The estimates are based on assumptions concerning the initial charge of these applications as well as the quantity of CFCs used to service each. This approach accounts for automobile air conditioning emissions that are greater than the initial charge. The releases from refrigerators include those from insulating foam as well as those from the refrigerant.

[8] The assumed leakage rate accounts for losses due to hose permeation. See "Evaluation of Fluorocarbon Blends as Automotive Air Conditioning Refrigerants," SAE Technical paper, February 1989.

Exhibit 4-7 summarizes the options considered here. The differences between the options are shown in Exhibit 4-8.

Analysis of Results

Because of the high emissions of car air conditioners, the greenhouse potential of HFC-134a is relatively high, totalling 0.016°C. The greenhouse effect of HCFC-22 would be worse, however, (0.019°C) because it would result in higher emissions. The ternary mixture would produce a greenhouse effect of 0.01°C (0.006°C less than HFC-134a) due to the lower radiative properties of the blend. An option with even a shorter lifetime and lower ODP, however, would save a more significant fraction of greenhouse warming 0.008°C (0.2 percent of total estimated warming in 2075). As long as the blend as a whole contains a low ODP (0.01, for example) total chlorine contribution could be kept low.

An important conclusion of this analysis is that, in automobile air conditioning, the use of any compound with more than a one or two year lifetime could contribute significantly to global warming if current emissions levels are not reduced (e.g., if tighter hoses and recycling are not introduced). It is worth noting that the use of HFC-134a would result in a net positive contribution to global warming (compared to no emissions), an amount of warming that a 4 percent improvement in global fuel efficiency would eliminate.[9]

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[9] Estimates based on potential reduction achievable through improvements in transportation fuel efficiency. See U.S. EPA, Policy Options for Stabilizing Global Climate, Draft Report to Congress, February 1989.

EXHIBIT 4-7

REPLACEMENTS FOR CFC-12 IN MOBILE AIR CONDITIONING

CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-12	1	HCFC-22	1.0	+8.9[a]
CFC-12	2	MIX[1]	1.07	-2.0
CFC-12	3	HCFC-134a	0.9	+3.0[b]
CFC-12	4	NARM[2]	1.0	-5.0

[1] A near azeotropic ternary mixture of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124.

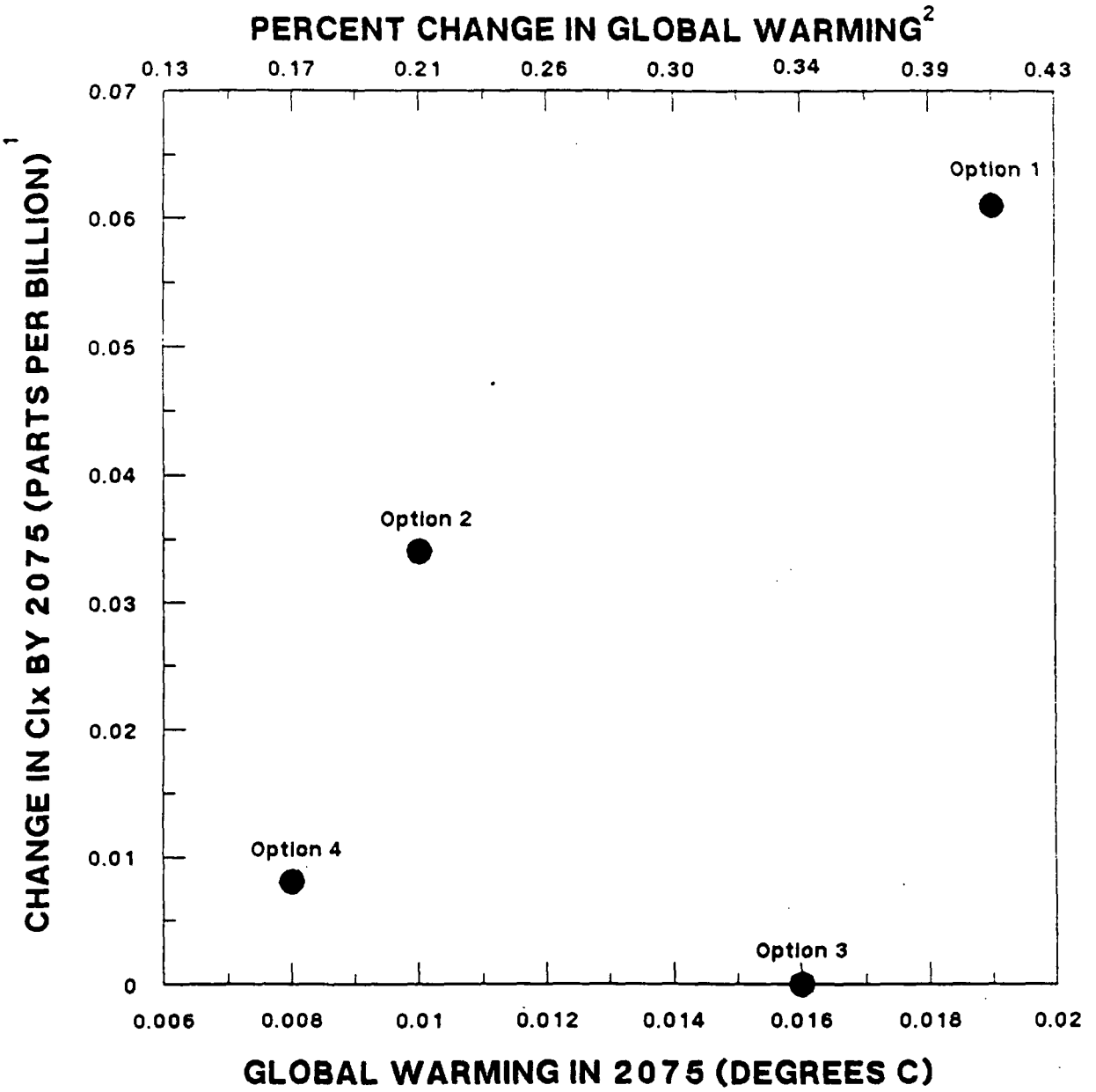
[2] A non-azeotropic refrigerant mixture with a good temperature glide in which both components have low ODP; therefore an ODP of 0.01 is assumed.

[a] Obtained from Energy-Use Impacts of Chlorofluorocarbon Alternatives, Oak Ridge National Laboratory, February 1989.

[b] Provided by an industry source.

EXHIBIT 4-8

TRADEOFF ANALYSIS
MOBILE AIR CONDITIONERS



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

4.2.3 Chillers

Chillers use large quantities of CFC-11, smaller quantities of CFC-12, and even less of CFC-114. The largest single market is that of centrifugal CFC-11 chillers. The leading candidate for replacing CFC-11 is HCFC-123. Energy performance of this option appears similar to that of the original refrigerant with perhaps a 1 percent loss in efficiency, although changes in design will have to be made to achieve capacity equal to that of CFC-11 machines.

The leading candidate for replacing CFC-12 is HFC-134a. Initial tests suggest that this option will result in higher energy use (an increase of approximately 3 percent is applied in our scenario), but additional tests may show that no losses are incurred when the system is optimized.[10]

For CFC-114, HCFC-124 is the leading candidate as a replacement option.[11] In this analysis, the use of HCFC-124 is assumed to result in a 3 percent reduction in energy use.

Other options also exist for all three of the compounds currently used. For example, ammonia may be a reliable replacement for current chemicals in individual building units or in district cooling centers. Non-azeotropic mixtures might also become viable substitutes.[12] Consequently, the analysis assumes a combination incorporating ammonia and a NARM as one of the options.

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[10] Personal communication with Howard Sibley, Carrier, Inc.

[11] Due to concern expressed by some reviewers of an earlier draft of this report, EPA is continuing to review and evaluate this assumption.

[12] Personal communication with Didion, NITS.

This combination is included as a surrogate for a whole set of similar options with the potential for an increase in energy efficiency of 10 to 15 percent.

Another option considered is a total switch to HCFC-22 chillers. This would be accomplished by replacing single HCFC-11 chillers with multiple HCFC-22 chillers. A 4 percent increase in energy efficiency is assumed for this option. Finally, the possibility of replacing CFC-12 and CFC-114 with a ternary blend that increases energy efficiency by 3 percent is considered. Exhibit 4-9 shows these options. Exhibit 4-10 shows the differences in the warming effects and chlorine concentrations estimated for each of these options.

Analysis of Results

The results show a significant difference between the HCFC-22 option and all others in terms of both chlorine (0.139 ppb) and warming (0.046°C). This large difference results from the long lifetime, increased emissions, and higher energy use of HCFC-22 chillers. In fact, even if the energy inefficiencies of HCFC-22 were eliminated through design changes, wholesale replacement by HCFC-22 chillers would result in increases of 0.042°C (approximately 0.9 percent) in estimated warming in 2075. Even with these design changes warming from use of HCFC-22 would be more than twice that estimated for HCFC-123 use.

Between the other options listed, there are still considerable differences in performance. Ammonia clearly reduces both greenhouse and chlorine effects because its emissions do not contribute to either and because of its improvements in energy efficiency. The difference between Option 1

EXHIBIT 4-9

CHILLER OPTIONS

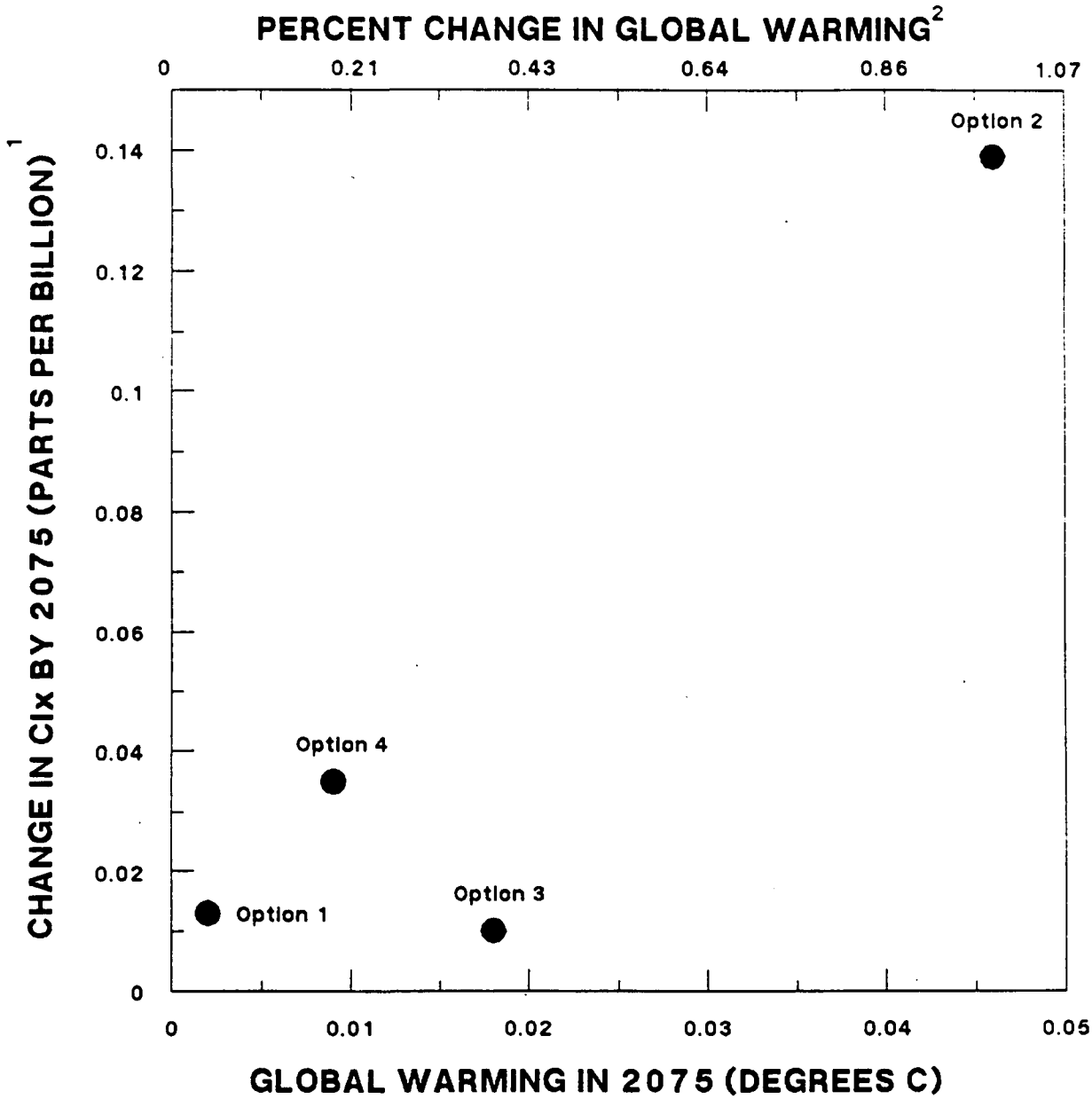
CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-11	1	25% Ammonia/75% NARM[1]	1.0	-10.0/-15.0[a]
CFC-12		25% Ammonia/75% NARM[1]	1.0	-10.0/-15.0[a]
CFC-114		25% Ammonia/75% NARM[1]	1.0	-10.0/-15.0[a]
CFC-11	2	HCFC-22	1.0	+4.0[a]
CFC-12		HCFC-22	1.0	+4.0[a]
CFC-114		HCFC-22	1.0	+4.0[a]
CFC-11	3	HCFC-123	1.0	+1.0[a]
CFC-12		HFC-134a	1.0	+3.0[a]
CFC-114		HCFC-124	1.0	+3.0[a]
CFC-11	4	HCFC-123	1.0	+1.0[a]
CFC-12		MIX[2]	1.0	-3.0[a]
CFC-114		MIX[2]	1.0	-3.0[a]

[1] A non-azeotropic refrigerant mixture with a good temperature glide in which both components have low ODP; therefore an ODP of 0.01 is assumed.

[2] A near-azeotropic ternary mixture of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124.

[a] Provided by an industry source.

EXHIBIT 4-10
TRADEOFF ANALYSIS
CHILLERS



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

(ammonia and low ODP NARMs) and Option 4 (HFC-123 and ternary) also illustrates that high emissions from chillers (at least as currently operating) make the average ODP an important factor in terms of the chlorine contribution.

4.2.4 Retail Food Storage

Retail food refrigerators use CFC-12 and CFC-115 which is a component of HCFC-502. HCFC-22 can be a replacement for both of these compounds. An option which combines use of ammonia in some situations and a NARM in others is also considered. The analysis assumes a 10 to 15 percent energy efficiency gain for this combination. Finally, HFC-125 is under evaluation as a replacement for CFC-115. Exhibit 4-11 summarizes the options considered here.

Analysis of Results

Exhibit 4-12 summarizes the results of the options in terms of chlorine and greenhouse warming. In this case, the use of HCFC-22 results in the highest Clx contributions estimated for the use area, 0.059 ppb. This option contributes as much as 0.054 ppb more to chlorine levels than the other two options considered. Option 3 results in the highest contribution to warming (0.019°C); this is 0.001°C higher than Option 2 and 0.014°C higher than Option 1.

There are also differences in performance between the other options themselves. The ammonia used in Option 1 reduces greenhouse and chlorine effects below those estimated under Option 3, because ammonia emissions do not contribute to either effect and because of the relative energy efficiency estimated for the mixture.

EXHIBIT 4-11

RETAIL FOOD STORAGE OPTIONS

CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-12	1	35% Ammonia/65% NARM[1]	1.0	-10.0/-15.0[a]
CFC-115		35% Ammonia/65% NARM[1]	1.0	-10.0/-15.0[a]
CFC-12	2	HCFC-22	1.0	-3.1[b]
CFC-115		HCFC-22	1.0	-3.1[b]
CFC-12	3	MIX[2]	1.0	-3.0
CFC-115		HFC-125	1.0	+0.0[a]

[1] A non-azeotropic refrigerant mixture with a good temperature glide in which both components have low ODP; therefore an ODP of 0.01 is assumed.

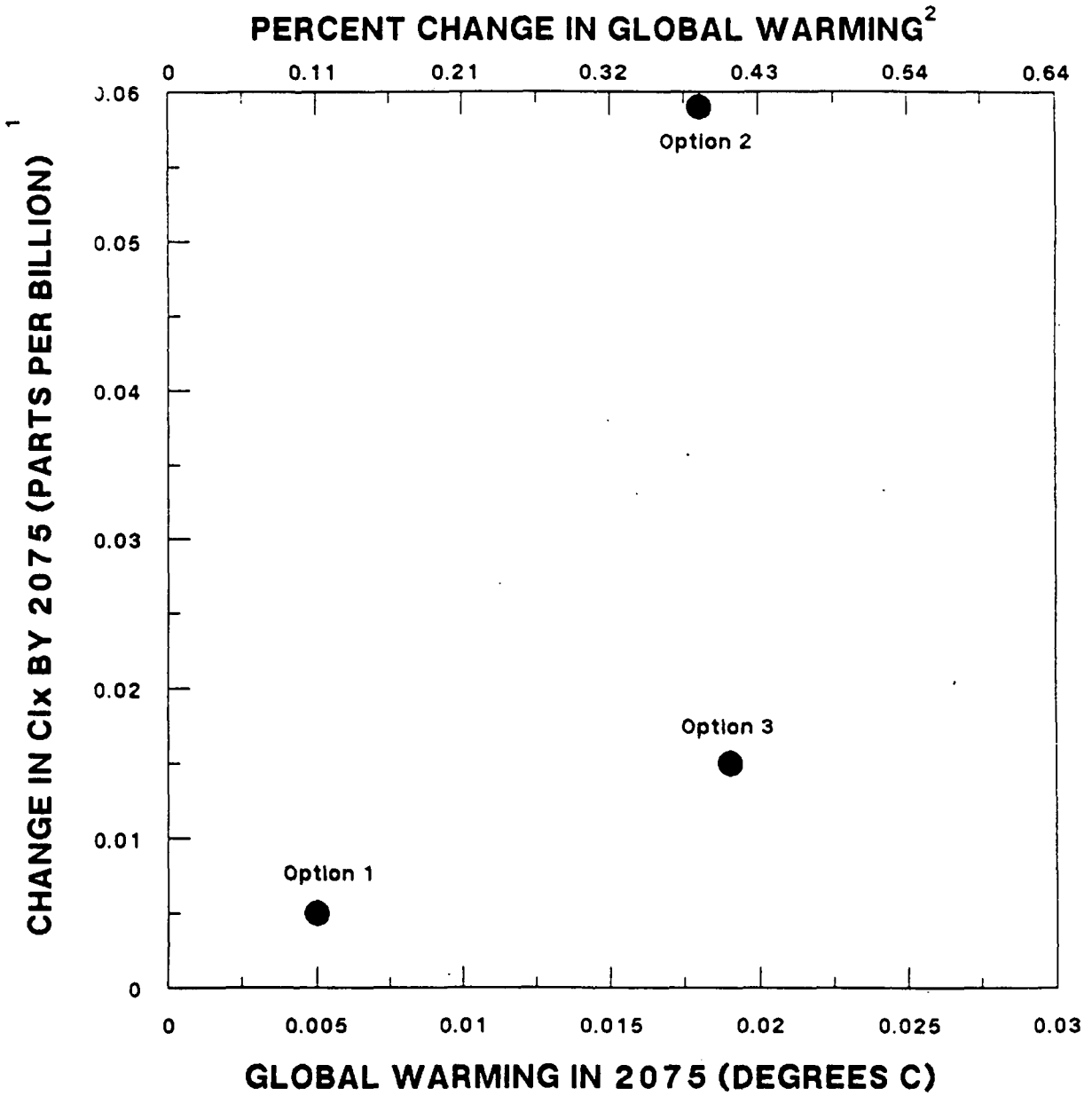
[2] A near-azeotropic ternary mixture of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124.

[a] Provided by an industry source.

[b] Obtained from Energy-Use Impacts of Chlorofluorocarbon Alternatives, Oak Ridge National Laboratory, February 1989.

EXHIBIT 4-12

TRADEOFF ANALYSIS
RETAIL FOOD STORAGE



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

4.2.5 Process Refrigeration

CFC-12 and CFC-115, which is a component of HCFC-502, are also used in process refrigeration applications. HCFC-22 can be a replacement for both of these compounds; when applied in this analysis, it is assumed to increase energy consumption by 4 percent. An option which combines the use of ammonia and HCFC-22 also is being considered as a replacement f· both compounds. The energy impacts of this combined option are assumed to be a 10 percent decrease in energy use associated with the ammonia and a 4 percent increase in energy use associated with using HCFC-22. Finally, a NARM and HFC-125 are under evaluation as replacements. Exhibit 4-13 summarizes the options considered here.

Analysis of Results

The results of the analysis in Exhibit 4-14 again highlight the relatively high contribution of HCFC-22 to warming (0.013°C) and chlorine concentrations (0.044 ppb). In addition, the results for the other options considered are consistent with the effects estimated in the analyses of the retail food storage and chillers end uses. That is, Option 1, which is comprised of 80 percent ammonia, reduces the chlorine and warming contribution by 0.014 ppb and 0.004°C compared to Option 3, which applies the ternary mixture and HFC-125.

4.2.6 Rigid Polyurethane Foam Insulation

CFC-11 has been the primary compound used in insulation, although CFC-12 is also used as a frothing agent. HCFC-123 and HCFC-141b both have been proposed as replacements for CFC-11 in this application. Because the "K"

EXHIBIT 4-13

PROCESS REFRIGERATION OPTIONS

CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-12	1	80% Ammonia/20% HCFC-22	1.0	-10.0/+4.0[a]
CFC-115		80% Ammonia/20% HCFC-22	1.0	-10.0/+4.0[a]
CFC-12	2	HCFC-22	1.0	+4.0[a]
CFC-115		HCFC-22	1.0	+4.0[a]
CFC-12	3	MIX[1]	1.0	-3.0[b]
CFC-115		HFC-125	1.0	0.0

[1] A near-azeotropic ternary mixture of 40 percent HCFC-22, 20 percent HFC-152a, and 40 percent HCFC-124.

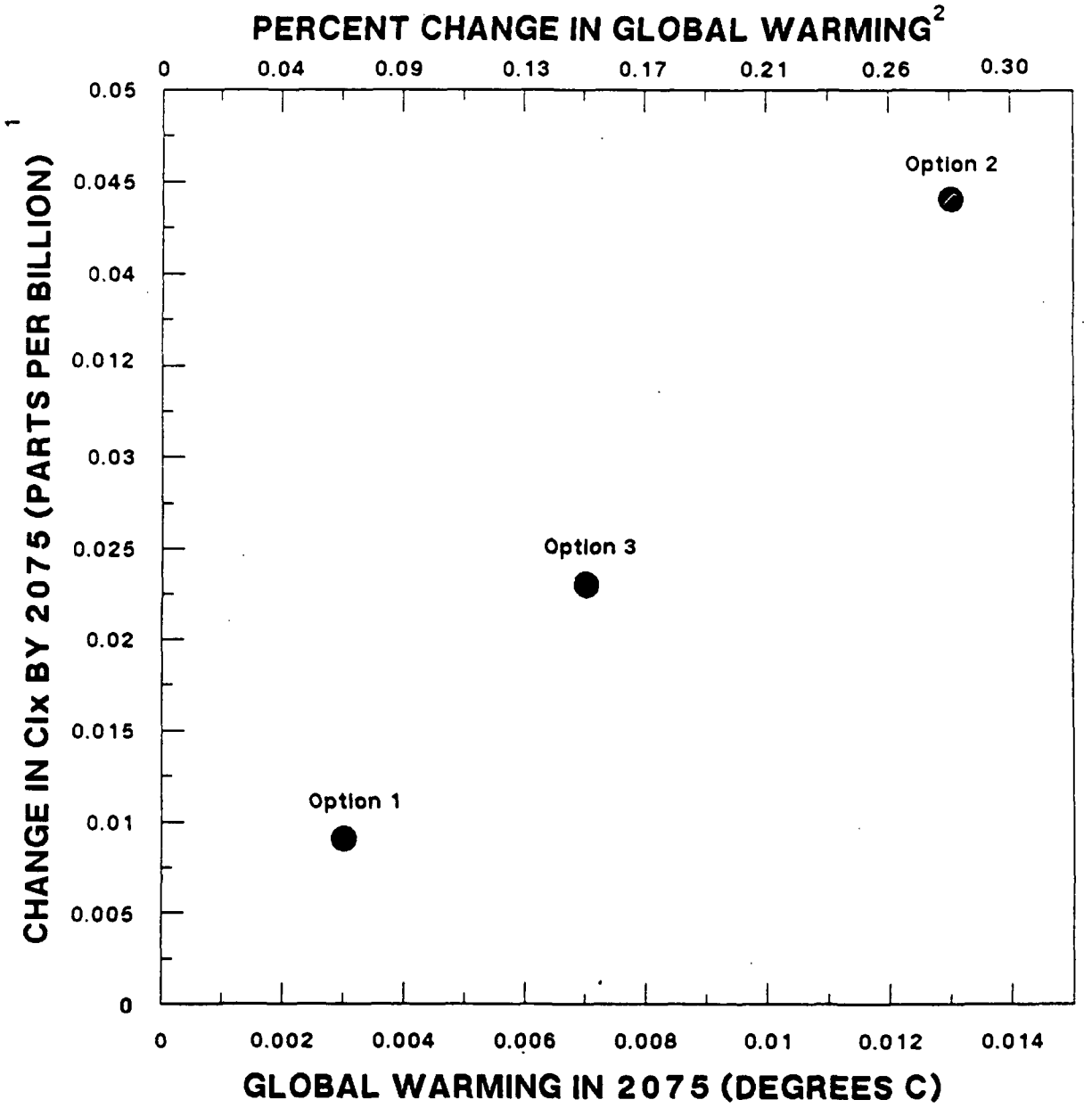
[a] In absence of application-specific data assume energy-efficiency is equivalent to chillers.

[b] Provided by an industry source.

EXHIBIT 4-14

TRADEOFF ANALYSIS

PROCESS REFRIGERATION



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

values (conductivity) of HCFC-141b and HCFC-123 are 10 percent higher than that for foam blown with CFC-11, unless they are improved by modifying the cell structure in foam or adding shards that reduce radiative losses, the energy loss associated with their use could reach 10 percent. Optimization of foam formulations could, if successful, eliminate any energy loss. Furthermore, the addition of materials to eliminate radiative losses could even produce a 1 percent gain in energy efficiency. Finally, in many uses the thickness of HCFC-123 or HCFC-141b foam could be increased to compensate for higher "K" values. Exhibit 4-15 shows these options.

Analysis of Results

Exhibit 4-16 shows the changes in global warming and chlorine concentrations estimated for each option. Clearly the most significant difference between options is with HCFC-123 and HCFC-141b, with the latter contributing approximately 0.2 ppb more to Clx. This difference is approximately half of the reduction in stratospheric chlorine contribution achieved by moving from a methyl chloroform freeze to a phaseout. Increasing the thickness of the insulation increases chlorine by 0.001 ppb for HCFC-123 and 0.02 ppb for HCFC-141b, but reduces the warming effect by approximately 0.007°C (roughly 0.15 percent of total estimated warming by 2075) in both cases. Clearly the energy savings resulting from increasing insulation thickness significantly offsets the direct greenhouse effects of additional emissions in both cases.

Additional reductions in warming, beyond those estimated for thicker insulation stock, are estimated for the use of HCFC-123 with shards. The

EXHIBIT 4-15

RIGID POLYURETHANE FOAM OPTIONS
(Insulation)

CFC USED	OPTION	DESCRIPTION	REPLACEMENT FACTOR	PERCENTAGE CHANGE IN ENERGY USE
CFC-11	1	HCFC-123 - same thickness	1.15	+10.0[a]
CFC-12		HCFC-22	1.0	0.0[a]
CFC-11	2	HCFC-123 - Optimized	1.15	0.0[b]
CFC-12		HCFC-22	1.0	0.0
CFC-11	3	HFC-123 - increased thickness	1.21	0.0
CFC-12		HCFC-22	1.0	0.0
CFC-11	4	HCFC-141b - same thickness	0.85	+10.0
CFC-12		HCFC-22	1.0	0.0
CFC-11	5	HCFC-141b Optimized	0.85	0.0[b]
CFC-12		HCFC-22	1.0	0.0
CFC-11	6	HCFC-141b - increased thickness	0.94	0.0
CFC-12		HCFC-22	1.0	0.0
CFC-11	7	Shards (HCFC-123) with Optimized Foam Cells	1.0	-1.0
CFC-12		Shards (HCFC-123) with Optimized Foam Cells	1.0	0.0

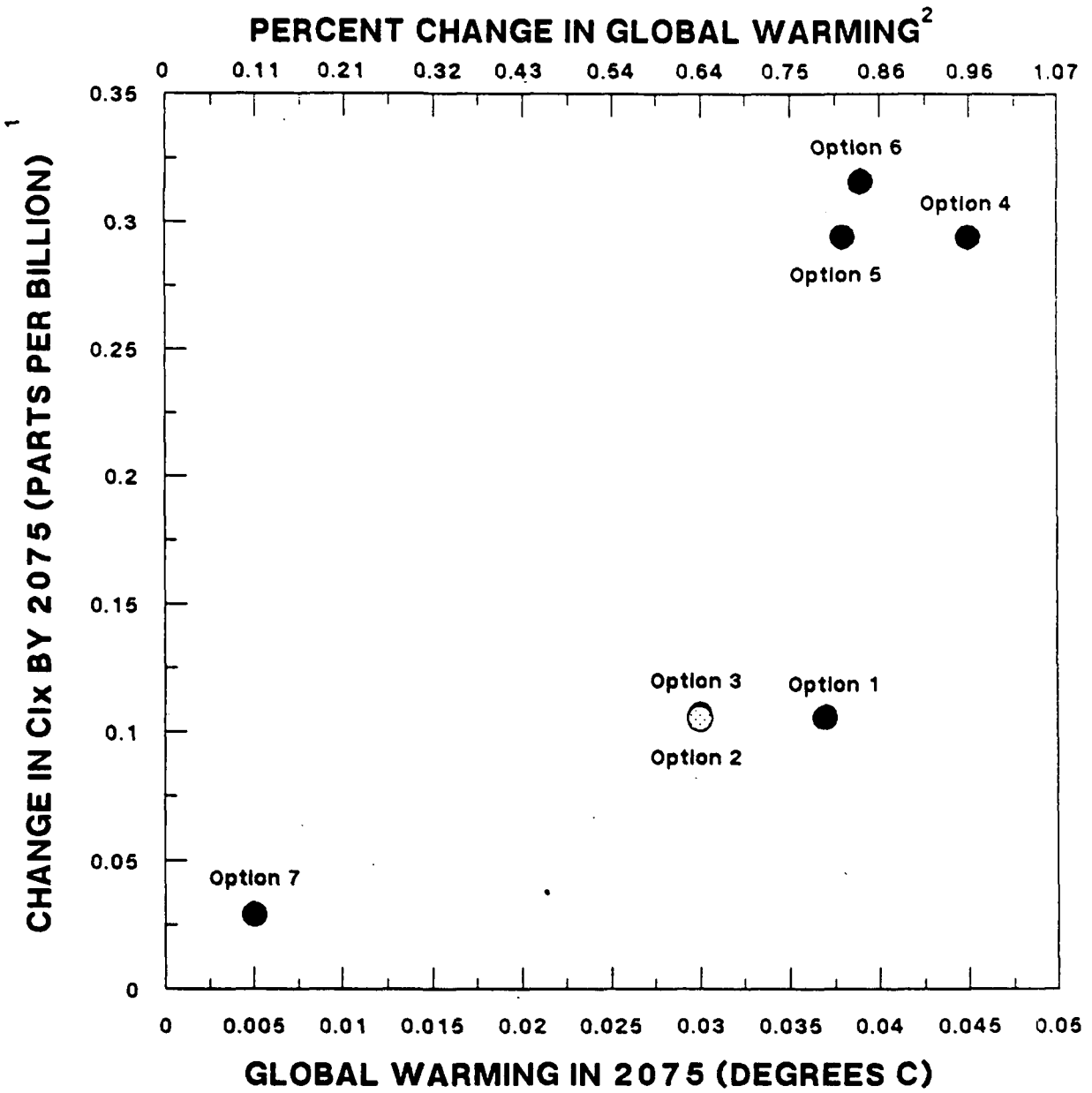
[a] Obtained from an industry source.

[b] Assumes that the foam has been optimized (e.g., by improving cell density, cell thickness, etc.) to provide same energy efficiency.

EXHIBIT 4-16

TRADEOFF ANALYSIS

RIGID POLYURETHANE FOAM (INSULATION)



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

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gains in energy efficiency and relatively low direct effect of HCFC-123 used in conjunction with shards results in an estimated total warming contribution of 0.005°C. This warming contribution is accompanied by a Clx contribution of approximately 0.03 ppb.

4.3 SUMMARY ANALYSIS OF END USE AREAS CONSIDERED

A closer look at the different applications has revealed that there are substantial differences in the contributions of different options to chlorine and the greenhouse effect. Exhibit 4-17 shows the relative contributions of each option to chlorine concentrations and Exhibit 4-18 to global warming.

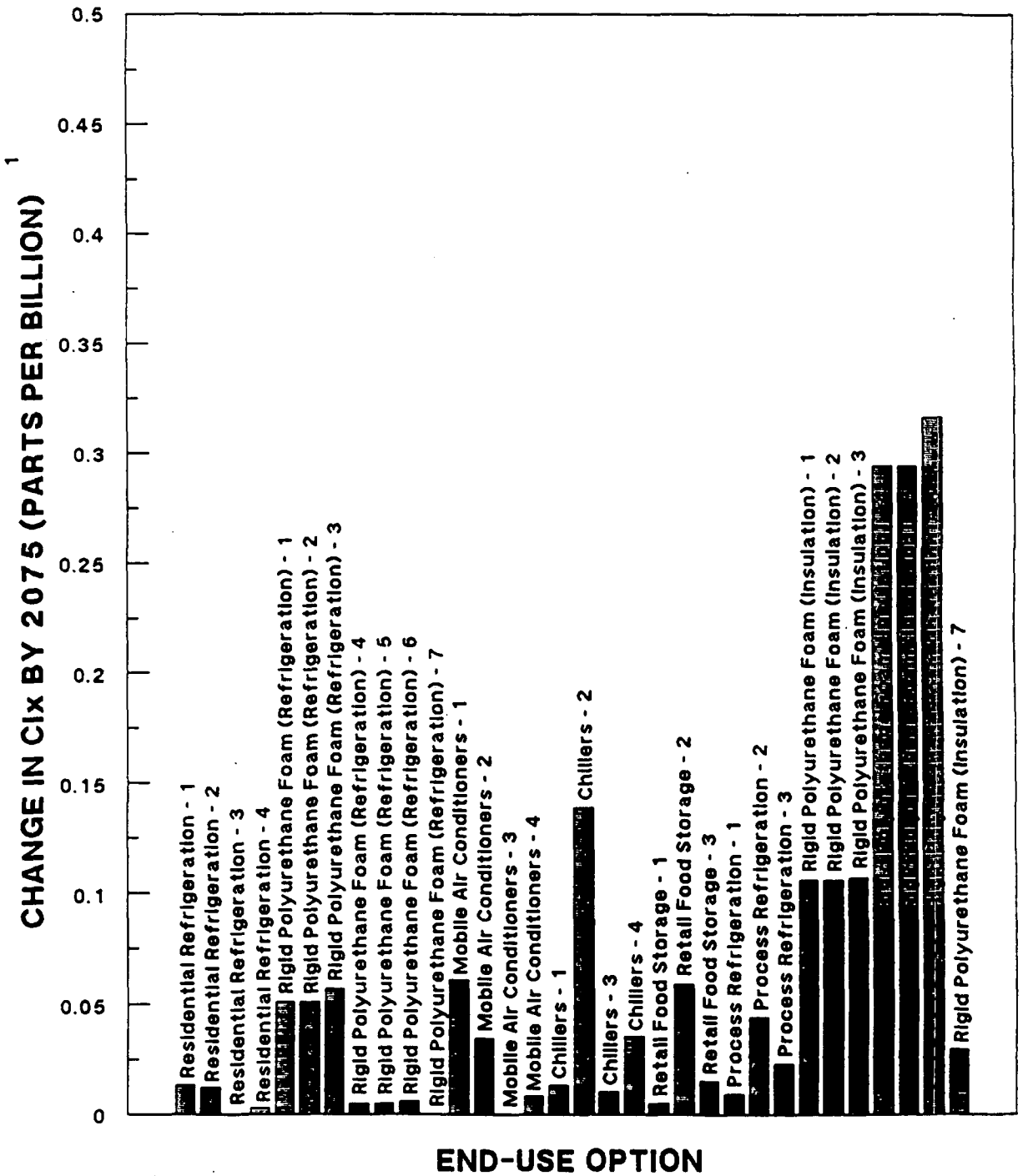
Clearly the compounds that could most significantly contribute to additional chlorine are HCFC-141b and HCFC-22. Those that could have the least effect on chlorine include HFC-134a and ammonia, neither of which contribute to chlorine levels.

Similarly HCFC-141b and HCFC-22 could do the most to increase the global warming effect, while the use of ammonia, vacuum panels and certain NARMs could do the most to decrease it.

Exhibit 4-19 plots the chlorine and warming values for all the options considered in this trade-off analysis. By moving from one option to another, the relative tradeoffs within each application area can be compared. In general, there are only a few cases in which an increase in chlorine is the trade-off required for a reduction in greenhouse effect or energy use. In those cases, (e.g., refrigerators) the greenhouse and energy use improvements are relatively large in contrast to the requisite chlorine increase. The

EXHIBIT 4-17

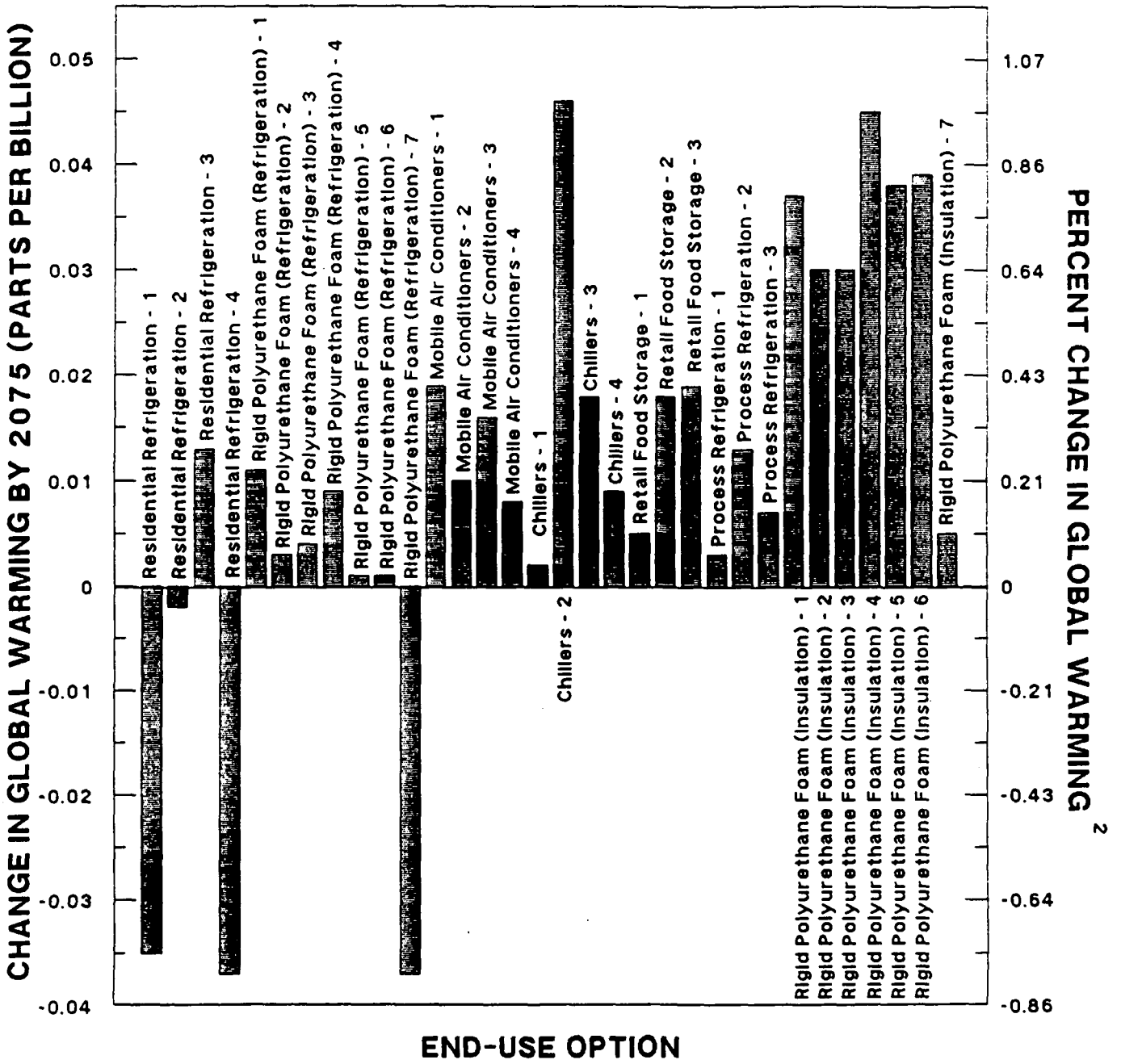
TRADEOFF ANALYSIS
ClX INCREASE



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs

EXHIBIT 4-18

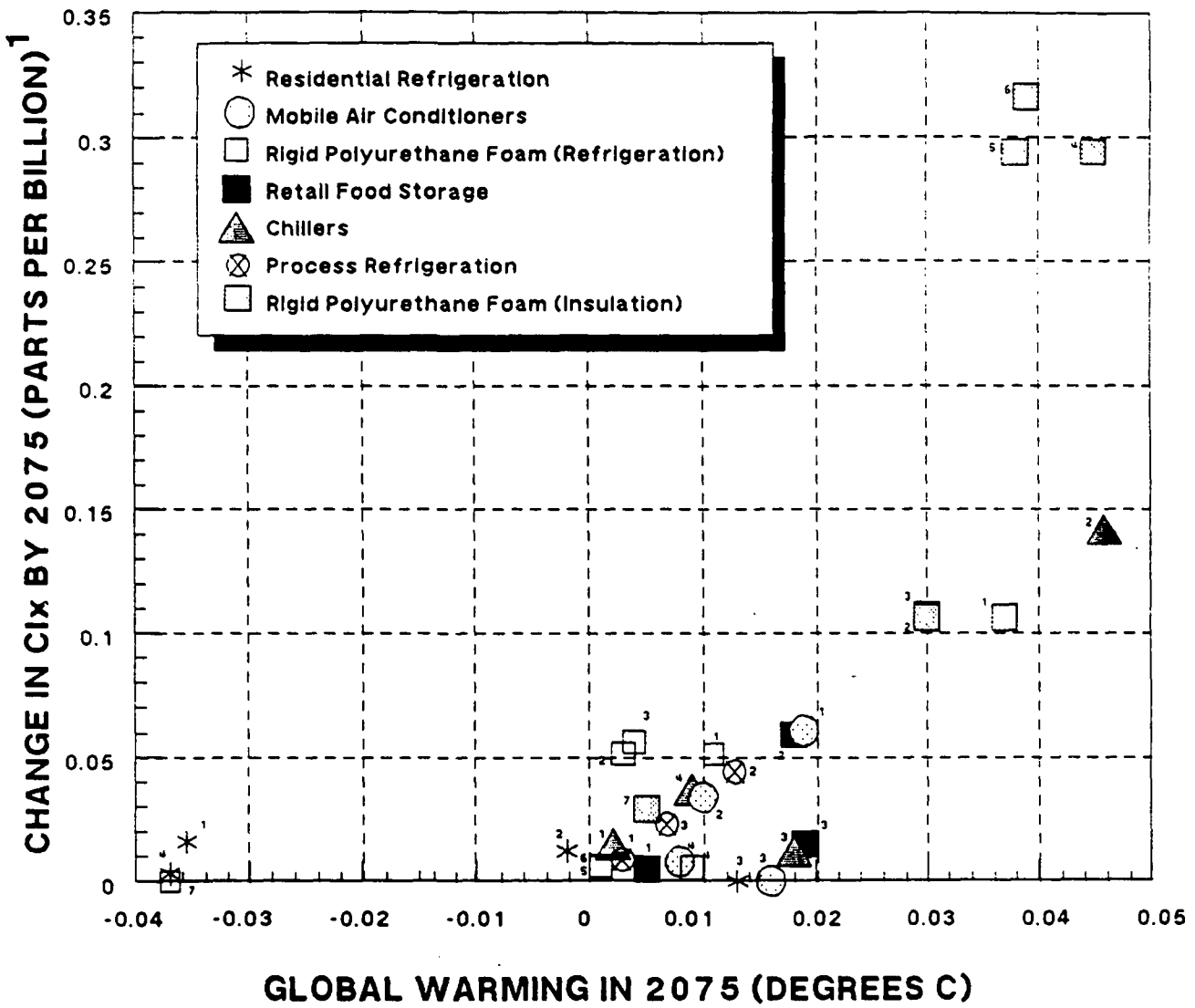
TRADEOFF ANALYSIS
GLOBAL WARMING



2 Estimates represent percentage changes in global warming from a baseline of 4.674 degrees C (equilibrium) which assumes temperature increases from changes in emissions of carbon dioxide, methane, and nitrogen oxides, a phase-out of fully halogenated CFCs and no substitutes that contribute to global warming

EXHIBIT 4-19

TRADEOFF ANALYSIS
ALL END USES



1 Estimates represent changes from a baseline that assumes no HCFC substitution for CFCs.

results also indicate that reductions in emissions similar to those in Scenario 3 of Chapter 3 could decrease greenhouse effects by comparatively great amounts.

APPENDIX A

METHODS FOR ESTIMATING DEMAND, EMISSIONS, AND ENVIRONMENTAL EFFECTS ASSUMING NO CONTROLS ON CFC USE AND A PHASEOUT OF CFC USE

APPENDIX A

METHODS FOR ESTIMATING DEMAND, EMISSIONS, AND ENVIRONMENTAL EFFECTS ASSUMING NO CONTROLS ON CFC USE AND A PHASEOUT OF CFC USE

This appendix presents the methods used to estimate the potential future demand for and emissions of HCFC and HFC substitutes for fully-halogenated CFCs that are phased out as a result of concerns regarding the impacts that CFCs have on stratospheric ozone and global climate change. The major assumptions applied in estimating total CFC demand and emissions assuming there are no controls on CFC use and assuming a phaseout in CFC use by the year 2000 that does not use HCFC substitutes are presented here. These estimates are used in Chapters 2, 3, and 4 of this report to develop and evaluate various substitution and tradeoff scenarios.

1.1 THE APPROACH USED TO ESTIMATE GLOBAL DEMAND FOR AND EMISSIONS OF HCFCs

This section explains the methods used to estimate the total demand for and emissions of HCFCs. Additional assumptions applied in developing estimates of chlorine concentrations, global warming, and energy impacts also are presented.

1.1.1 Methods for Estimating Global Demand for HCFCs

The first step in estimating global demand for HCFCs under the parametric analysis of chlorine in Chapter 2 of this report, the substitution scenarios analysis in Chapter 3, and the trade-off analysis in Chapter 4 is to estimate the total potential market for all CFC substitutes (e.g., HCFCs, other compounds) over the period from 1985 to 2165. The estimation approach is depicted graphically in Exhibit A-1. This future market is bounded by:

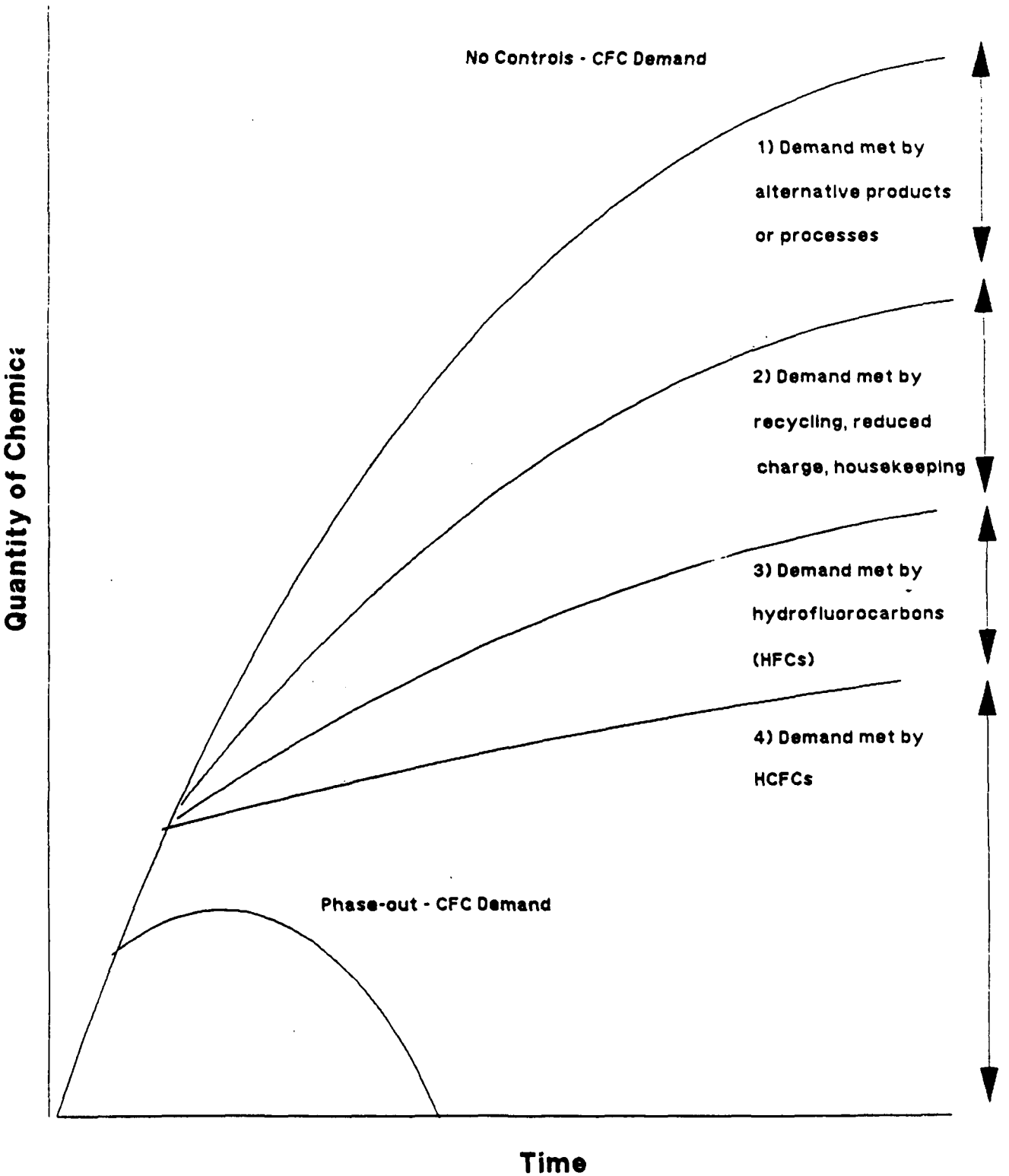
- The size of the CFC market that would have existed in the absence of any controls on production or consumption; and
- The size of the CFC market assuming a phaseout of CFCs.

The maximum market for CFC substitutes is represented by the level of CFC demand estimated assuming that CFC use is allowed to grow without any controls placed on production or consumption of the compounds, including the controls specified by the Montreal Protocol. This level of demand is represented by the No Controls line on Exhibit A-1. The lower boundary of demand for HCFCs is estimated assuming a phaseout of CFC use that does not employ HCFC substitutes. This phaseout is defined to follow the Montreal Protocol through 1998, with a complete phaseout by the year 2000. Demand under the phaseout is represented by the Phaseout line in Exhibit A-1.

The difference between the market for CFCs assuming no controls on use and assuming a phaseout represent an estimate of the total possible market for all CFC substitutes under a phaseout. The methods followed to estimate

Exhibit A-1

SCHEMATIC REPRESENTATION OF POTENTIAL MARKET FOR CFC SUBSTITUTES



total global demand for and emissions of CFCs assuming no controls on CFC use and assuming a CFC phaseout under which HCFCs are not applied are presented below.

1.1.2 Estimating Global Demand Assuming No Controls on Future CFC Use

The methods used to develop demand and emissions estimates assuming there are no controls on CFC use are based on previous EPA work presented in the Regulatory Impact Analysis (RIA) supporting the August 12, 1988 final rule on stratospheric ozone protection.[1] This scenario identifies the anticipated future global use and emissions of CFCs 11, 12, 113, 114, and 115 in the absence of any regulatory intervention. Due to the Montreal Protocol and its assumed extension to a complete phaseout, use of these compounds will, in fact, not be permitted to grow as anticipated under these no controls estimates. However, the estimates developed assuming no controls reflect the underlying demand for refrigeration applications, foam products, etc., which now use CFCs.

Estimates of the demand for CFCs were divided among the following four regions:

- United States (U.S.);
- Western Industrialized Countries;
- Centrally-Planned Economies; and
- Developing Countries (Rest of the World/ROW).

These four regions are an aggregation of the eight regions used in the analysis presented in the RIA as follows:

- U.S. estimates are a function of U.S. data only;

- Western industrial country estimates are derived from data on the following regional categories: members of the European Economic Community, Canada, Japan, Australia, New Zealand, and other developed nations;

- Centrally planned economy estimates are derived from data on the USSR and Eastern Europe; and

- Rest of the world estimates are derived from data on the following nations: China, India, and other lesser developed countries, and nations which produce less than 0.2 kilograms of CFCs per capita.

Within these regions, CFC demand is further distributed among 20 end-use areas. These end-use areas were selected to differentiate the types of HCFCs and HFCs that may be substituted for CFCs under a phaseout and, therefore, the environmental and energy impacts associated with substitutes in each of these end-use areas. These end-use areas are listed in Exhibit A-2.

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[1] U.S. EPA, Regulatory Impact Analysis: Protection of Stratospheric Ozone, August 1, 1988.

EXHIBIT A-2

TWENTY END-USE CATEGORIES

End-Use Categories	CFCs Used Currently
1. Mobile Air Conditioners	CFC-12
2. Residential Refrigeration[a]	CFC-12
3. Chillers	CFC-11, CFC-12, CFC-114
4. Process Refrigeration	CFC-12, CFC-115[b]
5. Cold Storage Warehouses	CFC-12, CFC-115
6. Retail Food Storage	CFC-12, CFC-115
7. Other Refrigeration[c]	CFC-12, CFC-115
8. Refrigerated Transport[c]	CFC-12, CFC-115
9. Rigid Polyurethane Foam (residential refrigeration)	CFC-11, CFC-12
10. Rigid Polyurethane Foam (other refrigeration)	CFC-11
11. Rigid Polyurethane Foam (refrigerated transport)	CFC-11
12 . Rigid Polyurethane Foam (structure insulation)	CFC-11, CFC-12
13. Rigid Polyurethane Foam (packaging)	CFC-11, CFC-12
14. Flexible Foam	CFC-11
15. Rigid Non-Polyurethane Foam (structure insulation)	CFC-12
16. Rigid Non-Polyurethane Foam (packaging)	CFC-11, CFC-12, CFC-114
17. Aerosols	CFC-11, CFC-12
18. Solvent Cleaning (cold cleaning)	CFC-113
19. Solvent Cleaning (vapor degreasing)	CFC-113
20. Sterilization	CFC-12

[a] Includes CFC-12 used as a working fluid in domestic refrigerators and freezers only. CFC use associated with insulation of refrigerators and freezers is categorized under Rigid Polyurethane Foam (refrigeration).

[b] References to CFC-115 are as a component of HCFC-502.

[c] Use of CFC-12 and CFC-115 in other refrigeration and refrigerated transport applications represent the use of these compounds as a working fluid. CFC use associated with insulation is categorized under Rigid Polyurethane Foam (other refrigeration) and (refrigerated transport).

Estimates of CFC demand and emissions assuming there are no controls on CFC use were divided among the 20 end uses using the following steps:

(1) Global CFC demand in 1985 was allocated to the CFC end uses based on estimates of the distribution of CFC use across the four regions and the 20 end-use areas;

(2) Growth rates were applied to the end-use demand estimates for 1985 to estimate CFC demand over time; and

(3) Release tables were applied for each end use area to estimate emissions from each over time.

1.1.3 CFC Consumption Patterns in 1985

Exhibit A-3 presents estimates of total CFC consumption in 1985. Exhibits A-4 through A-7 show estimated CFC consumption patterns for 1985 in the four geographic regions. The following sections explain the methods used to develop the consumption pattern estimates and compare the estimates to those in the RIA.

CFC Consumption in the U.S.

Exhibit A-4 presents estimates of the distribution of CFC consumption by end use in the United States in 1985. These estimates are based on previous EPA analysis documented in the August 1988 RIA and the draft 1989 EPA document entitled, "Documentation of Engineering and Cost Data Used in the Vintaging Analysis."

CFC Consumption in Western Industrialized Countries

Estimates of the distribution of CFC consumption in western industrialized countries in 1985 are shown in Exhibit A-5. These estimates are based on data in the RIA, but consumption is disaggregated into 20 end-use categories based on recent information supplied by industry sources and through analogies with U.S. consumption patterns. Specifically, estimates of CFC-11 and CFC-12 consumption in the rigid foam insulation applications (bothpolyurethane and non-polyurethane), and CFC-12 consumption for residential refrigeration and sterilization end uses have been increased from values in the RIA based on information supplied by an industry source.

Estimates of CFC consumption in MACs are derived from market saturation and CFC use data. There is a large variation in MAC market saturation estimates among western industrialized countries. For example, 90 percent of the cars in Japan are equipped with air conditioning, compared with only two percent in West Germany. On average, it is estimated that 20 percent of the cars in this region are equipped with air conditioning.

EXHIBIT A-3

GLOBAL CONSUMPTION OF CONTROLLED SUBSTANCES IN 1985
(millions of Kg)

	U.S.	WIC	CPE	ROW
CFC-11	79.5	173.0	42.4	73.2
CFC-12	136.9	153.7	88.7	75.4
CFC-113	68.5	85.3	10.6	12.6
CFC-114	4.0	5.1	2.0	2.4
CFC-115	4.5	2.2	0.8	1.0

Source: ICF analysis.

EXHIBIT A-4

ESTIMATED USE OF CFC COMPOUNDS IN THE U.S. IN 1985
(percent)

End-Use Categories	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115
Refrigeration:					
Mobile Air Conditioners	0.0	32.3			
Residential Refrigeration	0.0	2.0			
Chillers	10.1	1.6		13.0	
Process Refrigeration	0.0	15.7			4.5
Cold Storage Warehouse	0.0	4.0			36.5
Retail Food Storage	0.0	6.4			57.5
Refrigerated Transport	0.0	2.1			0.9
Other Refrigeration	0.0	2.4			0.4
Total Refrigeration	10.1	66.5		13.0	100.0
Blowing Agent for Foam:					
Rigid PU Foam (residential refrigeration)	8.5	0.0			
Rigid PU Foam (refrigerated transport)	4.5	0.0			
Rigid PU Foam (other refrigeration)	9.6	0.0			
Rigid PU Foam (structure insulation)	39.9	2.5			
Rigid PU Foam (packaging)	2.9	0.08			
Flexible Foam	18.4	0.0			
Rigid Non-PU Foam (packaging)	1.2	6.6		87.0	
Rigid Non-PU Foam (structure insulation)	0.0	2.5			
Total Foam	85.0	11.68		87.0	
Aerosol:					
Aerosols	4.7	5.6			
Total Aerosol	4.7	5.6			
Miscellaneous:					
Solvent Cleaning-Cold Cleaning	0.0	0.0	10.0		
Solvent Cleaning-Vapor Cleaning	0.0	0.0	90.0		
Sterilization	0.0	16.1	0.0		
Total Miscellaneous	0.0	16.1	100.0		
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0

Totals may not add to 100 due to rounding.

Source: ICF analysis.

EXHIBIT A-5

ESTIMATED USE OF CFC COMPOUNDS IN WESTERN INDUSTRIALIZED COUNTRIES (percent)

End-Use Categories	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115
Refrigeration:					
Mobile Air Conditioners	0.0	10.2			
Residential Refrigeration	0.0	2.6			
Chillers	6.1	3.2		13.0	
Process Refrigeration	0.0	7.5			4.5
Cold Storage Warehouse	0.0	2.4			36.5
Retail Food Storage	0.0	3.5			57.5
Refrigerated Transport	0.0	4.2			0.9
Other Refrigeration	0.0	0.4			0.5
Total Refrigeration	6.1	34.0		13.0	100.0
Blowing Agent for Foam:					
Rigid PU Foam (residential refrigeration)	9.5	0.0			
Rigid PU Foam (refrigerated transport)	1.0	0.0			
Rigid PU Foam (other refrigeration)	0.3	0.0			
Rigid PU Foam (structure insulation)	20.0	2.6			
Rigid PU Foam (packaging)	2.7	1.0			
Flexible Foam	17.5	0.0			
Rigid Non-PU Foam (packaging)	1.7	8.1		87.0	
Rigid Non-PU Foam (structure insulation)	0.0	2.6			
Total Foam	53.2	14.3		87.0	
Aerosol:					
Aerosols	40.7	50.8			
Total Aerosol	40.7	50.8			
Miscellaneous:					
Solvent Cleaning-Cold Cleaning	0.0	0.0	10.0		
Solvent Cleaning-Vapor Cleaning	0.0	0.0	90.0		
Sterilization	0.0	1.0	0.0		
Total Miscellaneous	0.0	1.0	100.0		
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0

Totals may not add to 100 due to rounding.

Source: ICF analysis.

CFC Consumption in Centrally Planned Economies

Exhibit A-6 presents estimates of the distribution of CFC consumption by end use in 1985 in centrally planned economies. These estimates are derived from the estimate of CFC consumption in the Soviet Union and Eastern Bloc nations presented in the RIA, in which total CFC consumption in this region was estimated to be seven percent of the total world consumption. For purposes of this analysis, this estimate was subdivided into the 20 end-use categories using assumptions about the effect that the relatively cooler climatic conditions in this region will have on demand for some products such as mobile air conditioners (expected to be lower than in the U.S.) and insulation applications (expected to be higher than in the U.S.).

CFC Consumption in the Rest of the World Region (ROW)

Exhibit A-7 presents estimates of the distribution of CFC consumption by end use in ROW nations. ROW nations include all developing countries. Data on CFC consumption in these countries are sparse. The Chemical Manufacturers Association (CMA), however, reports data on total CFC production serving all markets other than centrally planned economies (CMA 1986). These data are used in this analysis to derive an estimate of ROW consumption. Estimated ROW consumption of CFCs is calculated as the difference between total production data from CMA and the sum of estimated consumption of CFCs in the U.S. and western industrialized countries.

The production data from CMA are provided in five aggregate end-use categories. To disaggregate these estimates into the 20 end-use categories, two separate steps are taken. For MACs, recent industry-supplied market saturation data and CFC use rates are used to estimate CFC consumption. Industry sources estimate that ten percent of the cars driven in this region are equipped with air conditioning. This estimate is combined with recent data on the number of automobiles in these nations and CFC use per MAC unit, to derive CFC consumption in the MAC end use.

1.1.4 CFC Demand Growth Rates

Projections of CFC demand in each end use assuming there are no controls on CFC use were based on projections of compound use from the RIA, revised to reflect input from industry sources. Exhibits A-8 to A-11 show the demand growth rates assumed for each region of the world analyzed in this analysis. Growth rates are estimated for each end use through the year 2050; assuming no CFC controls demand is assumed to remain constant after 2050. The growth assumptions applied vary among end uses and across geographical regions. The growth rates reflect assumptions about the differences in demand for CFCs that result from important cross-regional differences. These include differences in the maturity of markets for various end uses, geographical differences, such as climate, which are key determinants of the demand for some products that use

EXHIBIT A-6

ESTIMATED USE OF CFC COMPOUNDS IN CPEs IN 1985
(percent)

End-Use Categories	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115
Refrigeration:					
Mobile Air Conditioners	0.0	3.5			
Residential Refrigeration	0.0	5.0			
Chillers	9.4	6.4		13.0	
Process Refrigeration	0.0	15.3			4.5
Cold Storage Warehouse	0.0	4.7			36.5
Retail Food Storage	0.0	7.9			57.6
Refrigerated Transport	0.0	5.5			0.9
Other Refrigeration	0.0	0.8			0.5
Total Refrigeration	9.4	49.1		13.0	100.0
Blowing Agent for Foam:					
Rigid PU Foam (residential refrigeration)	8.2	0.0			
Rigid PU Foam (refrigerated transport)	1.1	0.0			
Rigid PU Foam (other refrigeration)	0.3	0.0			
Rigid PU Foam (structure insulation)	34.1	20.2			
Rigid PU Foam (packaging)	2.2	1.1			
Flexible Foam	26.0	0.0			
Rigid Non-PU Foam (packaging)	1.1	7.4		87.0	
Rigid Non-PU Foam (structure insulation)	0.0	0.0			
Total Foam	73.0	28.7		87.0	
Aerosol:					
Aerosols	17.5	21.3			
Total Aerosol	17.5	21.3			
Miscellaneous:					
Solvent Cleaning-Cold Cleaning	0.0	0.0	10.0		
Solvent Cleaning-Vapor Cleaning	0.0	0.0	90.0		
Sterilization	0.0	0.9	0.0		
Total Miscellaneous	0.0	0.9	100.0		
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0

Totals may not add to 100 due to rounding.

Source: ICF analysis.

EXHIBIT A-7

ESTIMATED USE OF CFC COMPOUNDS IN ROW IN 1985
(percent)

End-Use Categories	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115
Refrigeration:					
Mobile Air Conditioners	0.0	4.6			
Residential Refrigeration	0.0	4.6			
Chillers	12.9	6.3		13.0	
Process Refrigeration	0.0	14.9			4.5
Cold Storage Warehouse	0.0	4.6			36.5
Retail Food Storage	0.0	7.8			57.6
Refrigerated Transport	0.0	5.4			0.9
Other Refrigeration	0.0	1.0			0.4
Total Refrigeration	12.9	49.2		13.0	100.0
Blowing Agent for Foam:					
Rigid PU Foam (residential refrigeration)	6.7	0.0			
Rigid PU Foam (refrigerated transport)	1.1	0.0			
Rigid PU Foam (other refrigeration)	0.3	0.0			
Rigid PU Foam (structure insulation)	7.7	0.7			
Rigid PU Foam (packaging)	1.5	0.5			
Flexible Foam	35.0	0.0			
Rigid Non-PU Foam (packaging)	0.5	4.1		87.0	
Rigid Non-PU Foam (structure insulation)	0.0	0.0			
Total Foam	52.8	5.3		87.0	
Aerosol:					
Aerosols	34.3	44.9			
Total Aerosol	34.3	44.9			
Miscellaneous:					
Solvent Cleaning-Cold Cleaning	0.0	0.0	10.0		
Solvent Cleaning-Vapor Cleaning	0.0	0.0	90.0		
Sterilization	0.0	0.6			
Total Miscellaneous	0.0	0.6	100.0		
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0

Totals may not add to 100 due to rounding.

Source: ICF analysis.

Exhibit A-8

Growth Rate Assumptions for the United States

End Use	Compound	1985-1990	1991-2000	2001-2010	2011-2050
MACS	CFC-12	1.0%	1.0%	1.0%	1.0%
Residential Refrigeration	CFC-12	1.0%	1.0%	1.0%	1.0%
Chillers	CFC-11	5.0%	4.0%	3.0%	3.0%
	CFC-12	5.0%	4.0%	3.0%	3.0%
	CFC-114	0.2%	0.2%	0.2%	0.1%
Process Refrigeration	CFC-12	1.0%	1.0%	1.0%	1.0%
	CFC-115	0.6%	0.6%	0.6%	0.5%
Cold Storage Warehouse	CFC-12	3.5%	3.5%	2.5%	2.5%
	CFC-115	3.5%	3.5%	2.5%	2.5%
Retail Food Storage	CFC-12	1.6%	1.6%	1.6%	1.5%
	CFC-115	3.5%	3.5%	2.5%	2.0%
Other Refrigeration	CFC-12	2.8%	2.8%	2.8%	2.5%
	CFC-115	6.0%	6.0%	5.0%	2.5%
Refrigerated Transport	CFC-12	2.8%	2.8%	2.8%	2.5%
	CFC-115	6.0%	6.0%	5.0%	2.5%
Rgd PU Foam Refrigeration	CFC-11	1.0%	1.0%	1.0%	1.0%
Rgd PU Foam - Other Refrigeration Appliances	CFC-11	2.8%	2.8%	2.8%	2.5%
Rgd PU Foam - Refrigerated Transport	CFC-11	2.8%	2.8%	2.8%	2.5%
Rgd PU Foam Insulation	CFC-11	8.0%	4.0%	3.0%	2.5%
	CFC-12	4.0%	2.0%	1.5%	1.3%
Rgd PU Foam Packaging	CFC-11	8.5%	4.0%	2.0%	2.0%
	CFC-12	8.5%	4.0%	2.0%	2.0%
Flexible Foam	CFC-11	3.6%	2.0%	1.5%	1.0%
Rgd-Non PU Foam Insulation	CFC-12	8.0%	5.0%	3.5%	3.5%
Rgd Non-PU Foam Packaging	CFC-11	3.4%	2.8%	2.0%	2.0%
	CFC-12	3.4%	2.8%	2.0%	2.0%
	CFC-114	3.4%	2.8%	2.0%	2.0%
Cold Cleaning	CFC-113	6.0%	5.0%	3.0%	2.5%
Vapor Degreasing	CFC-113	6.0%	5.0%	3.0%	2.5%
Sterilization	CFC-12	0.5%	0.5%	0.5%	0.5%
Aerosols	CFC-11	0.1%	0.1%	0.1%	0.1%
	CFC-12	0.1%	0.1%	0.1%	0.1%

Source: ICF analysis

Exhibit A-9

Growth Rate Assumptions for the Western Industrialized Countries

End Use	Compound	1985-1990	1991-2000	2001-2010	2011-2050
MACS	CFC-12	1.0%	1.0%	1.0%	1.0%
Residential Refrigeration	CFC-12	4.0%	3.0%	2.0%	1.0%
Chillers	CFC-11	5.0%	4.0%	3.0%	3.0%
	CFC-12	5.0%	4.0%	3.0%	3.0%
	CFC-114	0.1%	0.1%	0.1%	0.1%
Process Refrigeration	CFC-12	1.0%	1.0%	1.0%	1.0%
	CFC-115	0.4%	0.4%	0.4%	0.4%
Cold Storage Warehouse	CFC-12	3.5%	3.5%	2.5%	2.5%
	CFC-115	2.3%	2.0%	2.0%	1.5%
Retail Food Storage	CFC-12	1.6%	1.6%	1.6%	1.5%
	CFC-115	2.3%	2.0%	2.0%	1.5%
Other Refrigeration	CFC-12	2.8%	2.8%	2.8%	2.5%
	CFC-115	5.0%	5.0%	5.0%	2.5%
Refrigerated Transport	CFC-12	2.8%	2.8%	2.8%	2.5%
	CFC-115	5.0%	5.0%	5.0%	2.5%
Rgd PU Foam Refrigeration	CFC-11	4.0%	3.0%	2.0%	1.0%
Rgd PU Foam - Other Refrigeration Appliances	CFC-11	2.8%	2.8%	2.8%	2.5%
Rgd PU Foam - Refrigerated Transport	CFC-11	2.8%	2.8%	2.8%	2.5%
Rgd PU Foam - Insulation	CFC-11	8.0%	4.0%	3.0%	2.5%
	CFC-12	4.0%	2.0%	1.5%	1.3%
Rgd PU Foam Packaging	CFC-11	8.5%	4.0%	2.0%	2.0%
	CFC-12	8.5%	4.0%	2.0%	2.0%
Flexible Foam	CFC-11	3.6%	2.0%	1.5%	1.0%
Rgd-Non PU Foam Insulation	CFC-12	8.0%	5.0%	3.5%	3.5%
Rgd Non-PU Foam Packaging	CFC-11	3.0%	2.5%	1.5%	1.5%
	CFC-12	3.0%	2.5%	1.5%	1.5%
	CFC-114	2.8%	2.3%	1.5%	1.5%
Cold Cleaning	CFC-113	6.0%	5.0%	2.5%	2.5%
Vapor Degreasing	CFC-113	6.0%	5.0%	2.5%	2.5%
Sterilization	CFC-12	0.5%	0.5%	0.5%	0.5%
Aerosols	CFC-11	2.0%	1.0%	1.0%	0.5%
	CFC-12	2.0%	1.0%	1.0%	0.5%

Source: ICF analysis

Exhibit A-10

Growth Rate Assumptions for the Centrally Planned Economies

End Use	Compound	1985-1990	1991-2000	2001-2010	2011-2050
MACS	CFC-12	4.0%	2.0%	1.5%	1.0%
Residential Refrigeration	CFC-12	4.0%	2.0%	2.0%	2.0%
Chillers	CFC-11	3.0%	3.0%	2.0%	2.0%
	CFC-12	3.0%	3.0%	2.0%	2.0%
	CFC-114	1.0%	1.0%	0.5%	0.5%
Process Refrigeration	CFC-12	2.0%	1.5%	1.5%	1.0%
	CFC-115	2.0%	1.5%	1.5%	1.0%
Cold Storage Warehouse	CFC-12	5.0%	3.5%	3.5%	2.0%
	CFC-115	4.0%	3.0%	3.0%	2.0%
Retail Food Storage	CFC-12	4.0%	2.0%	1.5%	1.0%
	CFC-115	4.0%	3.0%	3.0%	2.0%
Other Refrigeration	CFC-12	5.0%	3.0%	2.5%	2.0%
	CFC-115	6.0%	4.0%	3.0%	2.0%
Refrigerated Transport	CFC-12	5.0%	3.0%	2.5%	2.0%
	CFC-115	6.0%	4.0%	3.0%	2.0%
Rgd PU Foam Refrigeration	CFC-11	4.0%	2.0%	2.0%	2.0%
Rgd PU Foam - Other Refrigeration Appliances	CFC-11	5.0%	3.0%	2.5%	2.0%
Rgd PU Foam - Refrigerated Transport.	CFC-11	5.0%	3.0%	2.5%	2.0%
Rgd PU Foam Insulation	CFC-11	4.0%	2.8%	2.0%	1.5%
	CFC-12	8.0%	5.5%	4.0%	3.0%
Rgd PU Foam Packaging	CFC-11	8.5%	5.0%	2.0%	2.0%
	CFC-12	8.5%	5.0%	2.0%	2.0%
Flexible Foam	CFC-11	5.0%	2.0%	1.5%	1.5%
Rgd-Non PU Foam Insulation	CFC-12	0.0%	0.0%	0.0%	0.0%
Rgd Non-PU Foam Packaging	CFC-11	3.4%	2.5%	1.5%	1.5%
	CFC-12	3.4%	2.5%	1.5%	1.5%
	CFC-114	3.0%	2.5%	1.5%	1.5%
Cold Cleaning	CFC-113	4.0%	3.0%	2.0%	1.0%
Vapor Degreasing	CFC-113	4.0%	3.0%	2.0%	1.0%
Sterilization	CFC-12	2.0%	2.0%	1.5%	1.0%
Aerosols	CFC-11	3.0%	3.0%	2.0%	2.0%
	CFC-12	3.0%	3.0%	2.0%	2.0%

Source: ICF analysis

Exhibit A-11

Growth Rate Assumptions for the Rest of the World

End Use	Compound	1985-1990	1991-2000	2001-2010	2011-2050
MACS	CFC-12	5.0%	4.0%	3.0%	3.0%
Residential Refrigeration	CFC-12	5.0%	4.0%	3.0%	3.0%
Chillers	CFC-11	5.0%	4.0%	4.0%	3.0%
	CFC-12	5.0%	4.0%	4.0%	3.0%
	CFC-114	1.0%	1.0%	1.0%	1.0%
Process Refrigeration	CFC-12	3.0%	2.0%	2.0%	1.0%
	CFC-115	1.0%	1.0%	1.0%	1.0%
Cold Storage Warehouse	CFC-12	4.0%	3.5%	3.5%	3.0%
	CFC-115	4.0%	3.0%	2.5%	2.5%
Retail Food Storage	CFC-12	3.0%	2.0%	2.0%	1.5%
	CFC-115	4.0%	3.0%	2.5%	2.5%
Other Refrigeration	CFC-12	3.0%	3.0%	3.0%	2.5%
	CFC-115	6.0%	6.0%	5.0%	5.0%
Refrigerated Transport	CFC-12	3.0%	3.0%	3.0%	2.5%
	CFC-115	6.0%	6.0%	5.0%	5.0%
Rgd PU Foam Refrigeration	CFC-11	5.0%	4.0%	3.0%	3.0%
Rgd PU Foam - Other Refrigeration Appliances	CFC-11	3.0%	3.0%	3.0%	2.5%
Rgd PU Foam - Refrigerated Transport	CFC-11	3.0%	3.0%	3.0%	2.5%
Rgd PU Foam Insulation	CFC-11	4.0%	2.0%	1.5%	1.5%
	CFC-12	8.0%	4.0%	3.0%	3.0%
Rgd PU Foam Packaging	CFC-11	8.5%	4.0%	2.0%	2.0%
	CFC-12	8.5%	4.0%	2.0%	2.0%
Flexible Foam	CFC-11	4.0%	2.0%	2.0%	1.5%
Rgd-Non PU Foam Insulation	CFC-12	0.0%	0.0%	0.0%	0.0%
Rgd Non-PU Foam Packaging	CFC-11	3.4%	2.5%	2.0%	1.5%
	CFC-12	3.4%	2.5%	2.0%	1.5%
	CFC-114	1.0%	1.0%	1.0%	1.0%
Cold Cleaning	CFC-113	7.0%	6.0%	3.5%	3.0%
Vapor Degreasing	CFC-113	7.0%	6.0%	3.5%	3.0%
Sterilization	CFC-12	3.0%	2.0%	1.5%	1.0%
Aerosols	CFC-11	6.0%	5.0%	3.0%	2.5%
	CFC-12	6.0%	5.0%	3.0%	2.5%

Source: ICF analysis

CFCs, such as chillers and insulation, and the different stages of economic development that various regions have attained and are expected to attain in the future. The end use growth rates applied here are based on the best available information in the U.S., however, the rates could be further refined with additional research into international markets. The assumptions supporting the growth rates for each region are summarized below.

In the U.S., the markets for refrigeration end uses such as MACs and residential refrigeration are near saturation. As a result, most of the future demand for CFCs in these end use areas is expected to be for replacement of existing capital stock as opposed to new growth; therefore, the growth rates in these end uses are assumed to be at relatively low rates of 1 percent annually. Growth rates for CFCs in foam applications are taken from the RIA. These growth rates reflect high demand in the building and construction industry. The growth in demand for CFC-113 for solvent applications is expected to be high because of the wide application of the compound in the growing electronics industry.

In general, the demand for CFCs in other western industrialized countries is assumed to grow at rates similar to those in the U.S. over the period of analysis. One notable difference is in the growth rate assumed for the aerosol end use. Prior to signing the Montreal Protocol, the U.S. had controlled non-essential uses of CFCs in this end use, however, European nations had not; growth in demand in this end use, therefore, is assumed to be higher in the WIC region than in the U.S. with an annual average of 1 percent growth in western industrialized countries verses a U.S. annual growth rate of 0.1 percent.

Growth rates in nations with centrally-planned economies and in the rest of the world generally are assumed to be higher than those in the U.S. and other western industrialized countries. As the nations in the former categories, such as India, China, and U.S.S.R., continue their economic development, the demand for items such as refrigerators should increase rapidly. For example, the growth in demand for refrigerators in these regions is assumed to be faster than that in the U.S. (approximately 4 percent annually versus 1 percent in the U.S.), because the U.S. refrigeration market has reached market maturity, and new residential refrigeration demand will be for replacement rather than growth. For the nations in the CPE category, the growth rates assumed for refrigeration, insulation, sterilization, and aerosol end uses also take into account the increase in production capacity of CFC-11, 12, 114, and 115 that was reported in the RIA to have occurred over the 1985-1990 period. CFC-113 growth rates are assumed to be lower in CPE nations than in the U.S., because the electronics industries are smaller in this region. In the ROW category, CFC-113 growth rate estimates are higher than in the U.S.

The growth rates applied in this analysis represent expectations based on current knowledge. Uncertainties about the future, however, make it difficult to balance aggregate rates of growth in demand for controlled substances with the growth rates specified for the end uses in which controlled substances are applied. Furthermore, it is difficult to project any new end uses to which CFCs could be applied in the future, and the growth in demand that would have resulted from those new uses.

For purposes of this analysis, future compound demand that is not allocated among the 20 end uses evaluated in this report has been taken into

account. Estimates of unallocated demand were developed by comparing the total demand for each controlled substance implicit in the end use growth rates specified above to estimates of total compound demand developed in the RIA. In most cases, the estimates of total demand in the RIA are higher than the estimates developed for this analysis, because of differences in the end uses evaluated, the regional categorization used, and the growth rates assumed. For purposes of this analysis, the differences in estimated total compound demand are assumed to represent the level of unallocated future demand. Using this approach, the estimates of total compound demand is the same here as in the RIA, however, the distribution of total demand is different.

1.1.5 *Estimating Demand Assuming a Phaseout in CFC Use*

CFC demand under a phaseout that does not employ HCFCs is estimated assuming that the use of all fully-halogenated CFCs, as projected assuming there are no controls on CFC use, is reduced following the provisions of the Montreal Protocol, and then eliminated by the year 2000. As allowed under the Protocol, developing countries are given an additional 10 years to achieve the complete phase out of CFCs. In addition, the U.S.S.R and Eastern Europe nations are assumed to freeze compound use in 1989 at 1989 levels rather than 1986 levels, and nations that produce 0.3 kilograms of CFCs per capita or less annually are assumed to freeze production at 1992 levels starting in 1992. For purposes of this analysis, it is also assumed that 100 percent participation and compliance with these use restrictions is achieved globally. Future demand for CFCs that is unallocated to existing uses also is phased out following the Protocol provisions.

1.1.6 Estimating Total Emissions Assuming No Controls on CFC Use and Assuming a Phaseout in CFC Use

Using the estimates of total compound demand in 20 end use areas and unallocated future demand, estimates of regional emissions of each compound from each end use are developed by applying release tables for each end use. The release tables used are presented in Exhibit A-12. Estimates of emissions over time are developed by applying release tables to the pattern of CFC use. The release tables indicate the estimated cumulative releases that occur following the initial year of compound use. For example, in the chillers end use, CFCs are assumed to be completely vented over a four year period. By the second year, 27 percent of the total amount of the chemical initially used has been vented. The final cumulative release rate of 1.0 in year four indicates that all of the compound used is vented by that year. In some end-use areas, such as aerosols and flexible foams, compounds are released immediately upon use. These end-uses have release rates of 1.0 in the first year.

With projections of emissions by region, end use, and compound, aggregate estimates of global compound emissions over the period 1985 to 2050

EXHIBIT A-12

RELEASE TABLES FOR EACH CFC END USE AREA

	Year of Release																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MACS	0.190	0.271	0.344	1.000																
Residential Refrigeration	0.094	0.107	0.121	0.134	0.147	0.160	0.172	0.185	0.197	0.209	0.221	0.233	0.244	0.255	0.267	0.278	1.000			
Chillers	0.190	0.271	0.344	1.000																
Process Refrigeration	0.190	0.271	0.344	0.410	0.469	0.522	0.570	0.613	0.651	0.686	0.718	0.746	0.771	0.794	0.815	0.833	1.000			
Cold Storage Warehouse	0.190	0.271	0.344	0.410	0.469	0.522	0.570	0.613	0.651	0.686	0.718	0.746	0.771	0.794	0.815	0.833	1.000			
Retail Food Storage	0.190	0.271	0.344	0.410	0.469	0.522	0.570	0.613	0.651	0.686	0.718	0.746	0.771	0.794	0.815	0.833	1.000			
Other Refrigeration	0.094	0.107	0.121	0.134	0.147	0.160	0.172	0.185	0.197	0.209	0.221	0.233	0.244	0.255	0.267	0.278	1.000			
Refrigerated Transport	0.037	0.095	0.152	0.209	0.264	0.319	0.374	0.428	0.482	0.535	0.589	0.642	1.000							
Rgd PU Foam Refrigeration	0.141	0.179	0.216	0.251	0.285	0.317	0.348	0.377	0.405	0.432	0.458	0.482	0.505	0.528	0.549	0.569	0.589	0.607	0.625	1.000
RFP -- Other Appliances	0.094	0.107	0.121	0.134	0.147	0.160	0.172	0.185	0.197	0.209	0.221	0.233	0.244	0.255	0.267	0.278	1.000			
RPF -- Refrig Transport	0.094	0.107	0.121	0.134	0.147	0.160	0.172	0.185	0.197	0.209	0.221	0.233	1.000							
Rgd PU Foam Insulation	0.141	0.179	0.216	0.251	0.285	0.317	0.348	0.377	0.405	0.432	0.458	0.482	0.505	0.528	0.549	0.569	0.589	0.607	0.625	1.000
Rgd PU Foam Packaging	0.141	0.179	0.216	0.251	0.285	0.317	0.348	0.377	0.405	0.432	0.458	0.482	0.505	0.528	0.549	0.569	0.589	0.607	0.625	1.000
Flexible Foam	1.000																			
Rgd-Non PU Foam Insulation	1.000																			
Rgd-Non-PU Foam Packaging	1.000																			
Cold Cleaning	1.000																			
Vapor Degreasing	1.000																			
Sterilization	1.000																			
Aerosols	1.000																			

Source: ICF Analysis

are developed. Exhibits A-13 and A-14, respectively, present estimates of total emissions assuming there are no controls on CFCs and a phaseout of CFCs, respectively. Under the phaseout, even though CFC use is assumed to end in the year 2000, emissions from banked sources continue until the sources are depleted.

1.2 ESTIMATING CHLORINE CONCENTRATIONS AND GLOBAL WARMING CONTRIBUTIONS ASSUMING NO CONTROLS AND A CFC PHASEOUT

A parameterized model, which has been used in previous EPA analyses of the stratosphere, is used to estimate chlorine concentrations over time. The method is taken from Connell[2], and translates emissions of the compounds into Clx levels using atmospheric lifetimes and conversion factors for each compound. The model is described in Appendix I. To evaluate the incremental Clx contributions of HCFCs, all Clx estimates are expressed as increases in Clx relative to 1985 levels of about 2.7 ppbv.

Calculations of global equilibrium warming are based on a model adapted from a one-dimensional radiative-convective model developed by the Goddard Institute for Space Studies (GISS) for estimating temperature increases associated with atmospheric CO_2 increases. The model, which has been used in previous EPA analyses of the stratosphere, such as the RIA, uses estimates of emissions of greenhouse gases and radiative forcing constants for each gas to compute changes in global equilibrium temperature.[3] For this report, the model was extended to evaluate the influence of previously-excluded CFCs (CFC-113, CFC-114, and CFC-115) as well as emissions of the HCFCs and HFCs.

1.2.1 Halons and Other Trace Gases

In addition to CFCs, emissions of other compounds and trace gases also have an important impact on stratospheric chlorine concentrations and global warming. Estimates of the emissions of these compounds are therefore necessary to project future trends in stratospheric chlorine and global warming. Therefore, in estimating environmental effects assuming no controls

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[2] P.S. Connell, A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere, Lawrence Livermore National Laboratory, Livermore, California.

[3] Equilibrium temperature change refers to the increase in the average global surface temperature that would be expected as the result of the changed radiative properties of the atmosphere associated with increases in concentrations of greenhouse gases. The estimates are called "equilibrium" increases because they assume that the Earth's climate system has equilibrated with the changed radiative properties of the atmosphere (i.e., that all positive and negative feedback associated with global warming have occurred.)

Exhibit A-13

TOTAL EMISSIONS ASSUMING NO CONTROLS ON CFC USE

Millions of Kilograms

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114	CFC-115	CCL4	CH3CCL3	Halon 1211	Halon 1301
1985	278.3	363.8	96.9	150.5	14.3	4.7	87.4	813.8	1.4	2.1
1990	399.3	481.7	136.5	240.6	18.0	7.3	118.8	738.1	3.3	3.8
1995	489.0	605.6	171.9	304.4	21.3	9.3	140.4	866.4	6.2	5.0
2000	584.1	743.6	208.5	371.5	24.5	11.5	162.0	992.9	9.9	5.8
2005	686.4	880.3	245.4	420.3	27.7	13.5	183.3	1123.4	14.8	6.9
2010	785.6	1004.3	280.3	475.5	31.4	15.4	207.4	1271.0	19.7	8.4
2015	890.8	1139.9	317.8	538.0	35.5	17.5	234.6	1438.1	24.2	9.8
2020	1008.5	1290.8	359.7	608.7	40.2	19.8	265.5	1627.0	29.0	11.3
2025	1141.1	1460.4	407.0	688.7	45.5	22.4	300.3	1840.9	33.6	13.1
2030	1291.0	1652.4	460.4	779.2	51.4	25.3	339.8	2082.8	38.9	15.0
2035	1460.6	1869.5	520.9	881.6	58.2	28.6	384.5	2356.5	45.0	17.3
2040	1652.6	2115.1	589.4	997.4	65.8	32.4	435.0	2666.1	52.0	20.1
2045	1869.7	2393.1	666.9	1128.5	74.5	36.6	492.1	3016.5	60.2	23.4
2050	2115.4	2707.5	754.5	1276.8	84.3	41.5	556.8	3412.9	69.6	27.4
2055	2189.5	2811.5	815.1	1276.8	85.3	44.8	556.8	3412.9	78.7	30.5
2060	2248.9	2862.5	852.2	1276.8	85.3	46.8	556.8	3412.9	86.7	33.1
2065	2298.0	2905.4	875.5	1276.8	85.3	48.1	556.8	3412.9	93.9	35.3
2070	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	99.4	37.3
2075	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.2	38.8
2080	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	39.6
2085	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.3
2090	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2095	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2100	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2105	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2110	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2115	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2120	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2125	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2130	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2135	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2140	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2145	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2150	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2155	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2160	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5
2165	2330.1	2919.9	879.1	1276.8	85.3	48.3	556.8	3412.9	100.8	40.5

Exhibit A-14

TOTAL EMISSIONS ASSUMING A CFC PHASEOUT*

Millions of Kilograms

YEAR	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114	CFC-115	CCL4	CH3CCL3	Halon 1211	Halon 1301
1985	278.3	363.8	96.9	150.5	14.3	4.7	87.4	813.8	1.4	2.1
1986	320.0	381.7	105.6	179.5	15.1	5.7	96.6	606.6	1.7	2.5
1987	338.5	400.8	113.2	200.9	15.8	6.0	102.6	642.0	2.0	2.9
1988	357.2	419.3	120.3	213.3	16.2	6.5	107.6	670.7	2.4	3.2
1989	352.8	422.6	128.5	198.3	15.7	6.6	103.1	635.9	2.8	3.5
1990	361.1	439.2	136.5	201.9	15.9	6.9	104.2	641.3	3.3	3.8
1991	370.8	450.5	141.4	205.8	16.1	7.1	105.4	646.6	3.8	4.1
1992	380.5	450.8	149.3	209.9	16.0	7.4	106.5	652.3	4.2	4.1
1993	342.7	413.0	156.7	175.0	14.0	7.2	90.6	655.0	4.7	4.2
1994	346.1	416.6	164.4	177.7	14.1	7.3	91.2	657.9	5.2	4.4
1995	350.9	420.7	171.9	180.6	14.1	7.3	91.8	660.9	5.7	4.5
1996	356.1	411.0	179.4	183.5	13.8	7.3	92.5	664.0	6.5	4.7
1997	360.3	416.5	186.7	186.5	13.8	7.3	93.2	667.2	6.8	4.8
1998	304.0	355.2	194.2	129.8	10.9	6.9	69.3	670.6	7.4	4.9
1999	299.7	360.6	201.4	129.7	10.6	6.9	67.6	664.0	8.1	5.0
2000	196.7	259.4	208.5	29.7	5.5	6.3	26.7	664.0	8.7	5.1
2001	194.5	240.2	215.5	29.7	4.8	6.0	26.7	664.0	9.4	5.3
2002	193.5	237.7	224.8	29.7	4.7	5.7	26.7	664.0	10.0	5.4
2003	178.3	186.6	231.5	23.8	3.1	5.2	21.3	664.0	10.6	5.5
2004	178.2	188.1	238.3	23.8	3.1	4.9	21.3	664.0	11.2	5.6
2005	180.2	183.7	245.4	23.8	3.1	4.4	21.3	664.0	12.5	5.8
2006	178.5	178.9	252.4	23.8	3.0	4.1	21.3	664.0	13.3	6.0
2007	176.4	176.4	259.3	23.8	3.0	3.8	21.3	664.0	13.9	6.1
2008	144.8	148.7	266.5	14.9	2.1	3.5	13.3	664.0	14.6	6.2
2009	139.3	138.4	273.3	14.9	2.0	3.0	13.3	664.0	15.2	6.3
2010	97.3	94.8	280.3	0.0	0.5	2.6	0.0	664.0	15.8	6.5
2011	92.5	86.4	287.5	0.0	0.3	2.4	0.0	664.0	15.3	6.6
2012	78.9	79.6	294.8	0.0	0.3	2.1	0.0	664.0	15.7	6.7
2013	75.0	70.3	302.3	0.0	0.0	1.9	0.0	664.0	16.0	6.9
2014	70.0	57.9	310.0	0.0	0.0	1.4	0.0	664.0	16.4	6.9
2015	66.5	54.5	317.8	0.0	0.0	1.3	0.0	664.0	16.8	7.0
2016	61.2	36.5	325.9	0.0	0.0	0.6	0.0	664.0	17.2	6.9
2017	45.2	31.2	334.0	0.0	0.0	0.5	0.0	664.0	17.6	6.9
2018	42.1	29.4	342.4	0.0	0.0	0.5	0.0	664.0	17.9	7.0
2019	17.6	19.4	350.9	0.0	0.0	0.4	0.0	664.0	18.3	7.1
2020	16.7	18.4	359.7	0.0	0.0	0.3	0.0	664.0	18.4	7.1
2040	0.0	0.0	589.4	0.0	0.0	0.0	0.0	664.0	18.0	7.1
2065	0.0	0.0	875.5	0.0	0.0	0.0	0.0	664.0	17.5	7.2
2070	0.0	0.0	879.1	0.0	0.0	0.0	0.0	664.0	17.5	7.3
2165	0.0	0.0	879.1	0.0	0.0	0.0	0.0	664.0	17.4	7.3

* Phaseout figures generated assuming a methyl chloroform freeze and a carbon tetrachloride phaseout.

and a phaseout, total emissions also include emissions of the following compounds.[4] In particular:

- HCFC-22, carbon tetrachloride, and methyl chloroform are used currently and contribute to chlorine and global warming;
- Halon 1211 and Halon 1301, compounds restricted under the Montreal Protocol, contribute to global warming[5]; and
- Other trace gases, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are greenhouse gases.

The following assumptions used in estimating total emissions assuming no controls and a phaseout of CFC use for these compounds and trace gases are summarized in Exhibits A-15 and A-16.

- For both scenarios, RIA estimates of global HCFC-22 demand were used to reflect future use of this compound in its current applications (i.e., not as a substitute for CFCs)[6].
- Demand for carbon tetrachloride, used as a feedstock in the production of some CFCs, is assumed to grow at rates presented in the RIA through 2050 when estimating emission assuming there are no controls on CFCs. For estimates assuming a phaseout, use of carbon tetrachloride is assumed to be phased out along with CFCs.[7]
- For estimating emissions assuming no controls, methyl chloroform demand is assumed to grow at rates presented in the RIA. For estimates assuming a phaseout, methyl chloroform use was assumed to be frozen at 1986 levels starting in 1989.

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[4] The assumptions presented here for a phase-out of these trace gases are applied in estimating total emissions and environmental effects of the substitution scenarios developed in Chapter 4 of this report.

[5] Halon 2402 also contributes to global warming, however, there are few data for this compound, and the use is very small. The compound is not considered in this analysis.

[6] For this analysis, RIA estimates of historical (pre-1986) production of HCFC-22 were revised, resulting in slightly larger emissions of this compound following 1985.

[7] NOTE: The phaseout assumptions used in estimating total emissions for carbon tetrachloride and methyl chloroform have been developed for modelling purposes only and do not reflect policy statements.

EXHIBIT A-15

PROJECTED GLOBAL GROWTH RATES
FOR OTHER OZONE DEPLETING COMPOUNDS

	Projected Global Growth Rates			
	1986-1992	1992-2000	2000-2050	2050+
Halon 1211	9.77	4.80	2.93	0
Halon 1301	3.46	-2.20	3.16	0
HCFC-22	4.37	2.74	2.50	0
Methyl Chloroform	4.70	2.78	2.50	0
Carbon Tetrachloride	4.90	2.91	2.50	0

Source: U.S. EPA, Regulatory Impact Analysis: Protection of Stratospheric Ozone, August 1, 1988. Exhibits 4-6 and 4-7.

- RIA projections of Halon 1211 and Halon 1301 use and emissions were used to estimate emissions assuming there are no controls. For the phaseout estimates, the use of halons was assumed to be frozen at 1986 levels starting in 1992, as specified in the Montreal Protocol.

- Concentrations of other trace gases (CO_2, CH_4, and N_2O) were assumed to grow at the same rates as those presented in the RIA for both the no controls and phaseout estimates. These rates are presented in Exhibit A-16.

EXHIBIT A-16

GROWTH OF TRACE GAS CONCENTRATIONS OVER TIME

Year	CO_2 (ppm)	CH_4 (ppm)	N_2O (ppb)
1985	350.2	1.8	303.1
2000	366.0	2.0	312.3
2025	422.0	2.4	328.3
2050	508.0	2.9	345.1
2075	625.0	3.3	362.8
2100	772.0	3.7	381.4
2165	1,154.2	4.8	434.3

Source: U.S. EPA, Regulatory Impact Analysis: Protection of Stratospheric Ozone, August 1, 1988, page 4-24.

APPENDIX B

ENVIRONMENTAL ATTRIBUTES AND APPLICABILITY OF POTENTIAL SUBSTITUTES FOR CFCs

EXHIBIT B-1

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-22

Formula: $CHClF_2$

Molecular Weight: 86.47

Ozone Depletion Potential:

Equilibrium -- 0.05[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.053°C[b]

Atmospheric Lifetime: 20 years[c,d]

Flammability: No

Toxicity Status: TLV = 1000 ppm

Current Uses:

Refrigerant	- Residential air conditioning Retail food refrigeration Process refrigeration Cold storage warehouses Refrigerated transport Other end-uses (refrigerated appliances, etc.)
Aerosol Propellant	
Blowing Agent	- Extruded polystyrene foams

Potential Substitution:

Refrigerant	- Mobile air conditioners Residential refrigeration Chillers Retail food refrigeration Process refrigeration Cold storage warehouses Refrigerated transport Other end-uses
Blowing Agent	- Rigid non-polyurethane foam (insulation) Rigid non-polyurethane foam (packaging)

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-2

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-22

Formula: $CHCl_2CF_3$

Molecular Weight: 152.95

Ozone Depletion Potential:

Equilibrium -- 0.02[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.045°C[b]

Atmospheric Lifetime: 2 years[c,d]

Flammability: No

Toxicity Status: [TO BE COMPLETED]

Current Uses: None

Potential Substitution:

Refrigerant	- Chillers (CFC-11)
Blowing Agent	- Rigid polyurethane foam (refrigeration) Rigid polyurethane foam (insulation) Rigid polyurethane foam (packaging) Flexible foam
Solvent Cleaning	- Cold cleaning

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-3

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-124

Formula: $CHClFCF_3$

Molecular Weight: 136.49

Ozone Depletion Potential:

Equilibrium -- 0.02[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.053°C[b]

Atmospheric Lifetime: 8 years[c,d]

Flammability: No

Toxicity Status: [TO BE COMPLETED]

Current Uses: None

Potential Substitution:

Blowing Agent	- Rigid non-polyurethane foam (insulation) Rigid non-polyurethane foam (packaging)
Refrigeration	- Chillers Mobile air conditioners (as blend component with HCFC-22 and HFC-152a) Residential refrigeration (as blend component with HCFC-22 and HFC-152a)

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing components derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-4

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-141b

Formula: CH_3CCl_2F

Molecular Weight: 116.97

Ozone Depletion Potential:

Equilibrium -- 0.08[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.037°C[b]

Atmospheric Lifetime: 9 years[c,d]

Flammability: Yes

Toxicity Status: Incomplete [TO BE COMPLETED]

Current Uses: None

Potential Substitution:

Blowing Agent	- Rigid polyurethane foam (refrigeration) Rigid polyurethane foam (insulation) Rigid polyurethane foam (packaging) Flexible foam
Solvent Cleaning	- Cold cleaning Vapor degreasing
Aerosol Propellant	

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-5

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-142b

Formula: CH_3CClF_2

Molecular Weight: 100.51

Ozone Depletion Potential:

Equilibrium -- 0.06[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.050°C[b]

Atmospheric Lifetime: 25 years[c,d]

Flammability: Yes

Toxicity Status: TLV = 1000 ppm

Current Uses: None

Potential Substitution:

Blowing Agent	- Rigid non-polyurethane foam (insulation) Rigid non-polyurethane foam (packaging)
Aerosol Propellant	
Refrigerant	- (As blend component with HCFC-22 alone or HCFC-22 and HCFC-124)

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-6

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HFC-125

Formula: CHF_2CF_3

Molecular Weight: 101.03

Ozone Depletion Potential:

Equilibrium -- 0.0[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.08°C[b]

Atmospheric Lifetime: 37 years[c,d]

Flammability: No

Toxicity Status: [TO BE COMPLETED]

Current Uses: None

Potential Substitution: Refrigerant

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-7

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HFC-134a

Formula: CH_2FCF_3

Molecular Weight: 102.04

Ozone Depletion Potential:

Equilibrium -- 0.0[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.047°C[b]

Atmospheric Lifetime: 21 years[c,d]

Flammability: No

Toxicity Status: [TO BE COMPLETED]

Current Uses: None

Potential Substitution:

Refrigerant	- Mobile air conditioners Residential refrigerators and freezers Chillers (CFC-12,CFC-114, Reciprocating) Process refrigeration Cold storage warehouse Retail food refrigeration Refrigerated transport Other refrigeration end-uses
Blowing Agent	- Rigid non-polyurethane foam (insulation) Rigid non-polyurethane foam (packaging)
Sterilization	- (As a blend with ethylene oxide)
Aerosol Propellant	

[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-8

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HFC-143a

Formula: CH_3CF_3

Molecular Weight: 84.05

Ozone Depletion Potential:

Equilibrium -- 0.0[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.041°C[b]

Atmospheric Lifetime: 54.0 years[c,d]

Flammability: Yes

Toxicology: [TO BE COMPLETED]

Current Uses: None

Potential Substitution: Refrigerant

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

EXHIBIT B-9

ENVIRONMENTAL ATTRIBUTES OF POTENTIAL SUBSTITUTES: HCFC-152a

Formula: CH_3CHF_2

Molecular Weight: 66.06

Ozone Depletion Potential:

Equilibrium -- 0.0[a]

Greenhouse Characteristics:

Radiative forcing constant (°C per ppb concentration) -- 0.029°C[c,d]

Atmospheric Lifetime: 2 years[c,d]

Flammability: Yes

Toxicology: TLV = 1000 ppm

Current Uses:

Refrigerant - Chillers (as blend component with CFC-12)
Refrigerated transport (as blend component with CFC-12)

Potential Substitution:

Refrigerant - Residential refrigerators and freezers (as blend component with DME or HCFC-22 and HCFC-124)
Chillers (CFC-12, CFC-114, Reciprocating)
Refrigerated transport
Other refrigeration end-uses (as blend component with DME or HCFC-22 and HCFC-124)

Aerosol Propellant

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[a] Relative to CFC-11. Ozone depletion estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere.

[b] Radiative forcing constants derived from DuPont modeled warming estimates in D.A. Fisher et al., "Relative Effects on Global Warming of Halogenated Methanes and Ethanes of Social and Industrial Interest," Scientific Assessment of Stratospheric Ozone: 1989, AFEAs Report, September 1989.

[c] The lifetimes indicate how long the chlorine associated with the compound will remain in the atmosphere. The lifetimes are "e-folding" lifetimes, meaning that after the period of one lifetime has elapsed, the remaining level in the atmosphere is about 1/e or 37 percent of the original value.

[d] Lifetime estimates from Lawrence Livermore National Laboratory 1-D Model of the Troposphere and Stratosphere. The estimates used in this analysis have been updated from previous EPA analyses (personal communication with P. Connell).

APPENDIX C

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES IN VARIOUS END USE AREAS

EXHIBIT C-1

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- MOBILE AIR CONDITIONERS

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
DME/CFC-12	X			E	1.0	-3.0%?
CFC-500	X			N	1.0	0.0%
HCFC-22/HCFC-142b	X			N	1.0	
HCFC-22/HFC-152a/HCFC-124		X		E,N	1.07	-2.0%
HFC-134a		X		N	0.9	+3%
HCFC-22				N	1.0	+8.9%
Other Mixtures and Compounds[2]			X	N		

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] For example, if producible HFC-134a would appear to be a very good substitute; however, a variety of mixtures might also work.

EXHIBIT C-2

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- RESIDENTIAL REFRIGERATORS AND FREEZERS

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
DME/CFC-12	X			N	1.0	-3.0%
CFC-500	X			N	1.0	-5.0%
HCFC-22/HCFC-142b	X			E,N	1.0	
HCFC-22/HFC-152a/HCFC-124		X		E	1.0	-3.0%
HFC-134a		X		E	1.0	+3.0%
HCFC-22/HFC-152a	X		X	E,N	1.0	
DME/HFC-152a			X	N	1.0	-5.0%
HFC-134			X	E?	1.0	
Mixture with a temperature glide of 26°F (12 options)		X		N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-3

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- CHILLERS

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
HCFC-22	X			N	1.0	+4.0%
Ammonia	X			N	1.0	-10.0%
HCFC-123		X		N,E	1.0	+1.0%
HCFC-22/HCFC-152a	X			N	1.0	-20.0%
Other mixtures and compounds[2]			X	N		

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated improvements in energy efficiency might also work.

EXHIBIT C-4

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- CHILLERS

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
DME/CFC-12	X			N	1.0	-3.0%
HCFC-22	X			N	1.0	+4.0%
Ammonia	X			N	1.0	-10.0%
HCFC-22/HFC-152a/HCFC-124		X		N	1.0	-3.0%
HFC-134a		X		E,N	1.0	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Other mixtures and compounds[2]			X	N		

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated improvements in energy efficiency might also work.

EXHIBIT C-5

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- CHILLERS

Original CFC: CFC-114

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	+4.0%
Ammonia	X			N	1.0	-10.0%
HCFC-22/HFC-152a/HCFC-124		X		N	1.0	-3.0%
HCFC-124		X		N,E	1.0	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Other mixtures and compounds[2]			X	N		

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] Other mixtures with associated energy efficiency improvements might also work.

EXHIBIT C-6

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- PROCESS

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
DME/CFC-12	X			N	1.0	-3.0%
HCFC-22	X	X		N	1.0	+4.0%
HCFC-22/HFC-152a/HCFC-124		X		N,E	1.0	-3.0%
HFC-134a				E	1.0	+3.0%
HCFC-22/HCFC-142b	X			E?	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Ammonia	X			N	1.0	-10.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-7

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- PROCESS

Original CFC: CFC-115 (As component of CFC-502)

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			E	1.0	+4.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Ammonia	X			N	1.0	-10.0%
HFC-125		X		N,E	1.0	0.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-8

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- COLD STORAGE WAREHOUSE

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	-2.5%
HCFC-22/HFC-152a/HCFC-124		X		N,E	1.0	-3.0%
HFC-134a		X		E	1.0	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Ammonia	X			N	1.0	-10.0%
Other mixtures and compounds[2]			X	N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated improvements in energy efficiency might also work.

EXHIBIT C-9

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- COLD STORAGE WAREHOUSE

Original CFC: CFC-115 (As component of CFC-502)

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	-2.5%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
HFC-125		X		N,E	1.0	0.0%
Ammonia	X			N	1.0	-10.0%
Other mixtures and compounds[2]			X	N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated improvements in energy efficiency might also work.

EXHIBIT C-10

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- RETAIL FOOD STORAGE

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X	X		N	1.0	-3.1%
HCFC-22/HFC-152a/HCFC-124		X		N,E	1.0	-3.0%
HFC-134a				N	1.0	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Ammonia	X			N	1.0	-10.0%
Other mixtures and compounds[2]			X	N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated improvements in energy efficiency might also work.

EXHIBIT C-11

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- RETAIL FOOD STORAGE

Original CFC: CFC-115 (As component of CFC-502)

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	-3.1%
HCFC-22/HCFC-142b	X			E?	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Ammonia	X			N	1.0	-10.0%
Other mixtures and compounds[2]			X	N	1.0	
HFC-125		X		N,E	1.0	0.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated energy efficiency improvements might also work.

EXHIBIT C-12

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- REFRIGERATED TRANSPORT

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0?	0.0%
HCFC-22	X			N	1.0	
HCFC-22/HFC-152a/HCFC-124		X		N,E	1.07	-2.0%
HFC-134a		X		N,D	0.9	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
Other mixtures and compounds[2]			X	N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures with associated energy efficiency improvements might also work.

EXHIBIT C-13

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- REFRIGERATED TRANSPORT

Original CFC: CFC-115 (As component of CFC-502)

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	+4.3%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
HFC-125		X		N,E	1.0	0.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-14

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- OTHER END USES

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-500	X			N	1.0	0.0%
HCFC-22	X			N	1.0	+4.3%
HCFC-22/HFC-152a/HCFC-124		X		N,E	1.0	-3.0%
HFC-134a		X		N,D	1.0	+3.0%
HCFC-22/HCFC-142b	X			E	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-15

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

REFRIGERATION -- OTHER END USES

Original CFC: CFC-115 (As component of CFC-502)

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
HCFC-22	X			N	1.0	+4.3%
HCFC-22/HCFC-142b	X			E?	1.0	
HCFC-22/HFC-152a	X			E	1.0	-20.0%
HFC-152a	X			N	1.0	
HFC-125		X		N,E	1.0	0.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-16

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID POLYURETHANE (RESIDENTIAL REFRIGERATION)

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O	X			N	1.00	0.0% to +5.0%
Thick Fiberglass Batts	X			N	N/A	+20.0% to +30.0%
HCFC-123[2] (Same Thickness)		X		N	1.15[3]	0.0% to +7.0%
HCFC-123 (Increased Thickness)		X		N	1.21	0.0%
HCFC-141b[2] (Same Thickness)		X		N	0.85[3]	0.0% to +10.0%
HCFC-141b (Increased Thickness)		X		N	0.94	0.0%
Vacuum Panels Foamed with CO_2			X	N	N/A	-40.0% to -60.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] The lower values of the range of energy consumption changes for HCFC-123 and HCFC-141b assume that the foams have been optimized (e.g., by improving cell density, cell thickness, etc.) to provide the same energy efficiency.

[3] An additional substitute involves the manufacture of these foams using water to replace a portion of the HCFC as the blowing agent. It is estimated that water can be used to replace approximately 30% of the substitute HCFC without resulting in a reduction in the insulating capacity of the foam. Such a change in the formulation process reduces the replacement factor of the chemical substitute used.

EXHIBIT C-17

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID POLYURETHANE (OTHER REFRIGERATION APPLIANCES)

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O	X			N	1.00	0.0% to +5.0%
Thick Fiberglass Batts	X			N	N/A	+20.0% to +30.0%
HCFC-123[2] (Same Thickness)		X		N	1.15[3]	0.0% to +7.0%
HCFC-123 (Increased Thickness)		X		N	1.21	0.0%
HCFC-141b[2] (Same Thickness)		X		N	0.85[3]	0.0% to +10.0%
HCFC-141b (Increased Thickness)		X		N	0.94	0.0%
Vacuum Panels Foamed with CO_2			X	N	N/A	-40.0% to -60.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] The lower values of the range of energy consumption changes for HCFC-123 and HCFC-141b assume that the foams have been optimized (e.g., by improving cell density, cell thickness, etc.) to provide the same energy efficiency.

[3] An additional substitute involves the manufacture of these foams using water to replace a portion of the HCFC as the blowing agent. It is estimated that water can be used to replace approximately 30% of the substitute HCFC without resulting in a reduction in the insulating capacity of the foam. Such a change in the formulation process reduces the replacement factor of the chemical substitute used.

EXHIBIT C-18

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID POLYURETHANE (REFRIGERATED TRANSPORT)

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O	X			N	1.00	0.0% to +5.0%
Thick Fiberglass Batts	X			N	N/A	+20.0% to +30.0%
HCFC-123[2] (Same Thickness)		X		N	1.15[3]	0.0% to +7.0%
HCFC-123 (Increased Thickness)		X		N	1.21	0.0%
HCFC-141b[2] (Same Thickness)		X		N	0.85[3]	0.0% to +10.0%
HCFC-141b (Increased Thickness)		X		N	0.94	0.0%
Vacuum Panels Foamed with CO_2			X	N	N/A	-40.0% to -60.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] The lower values of the range of energy consumption changes for HCFC-123 and HCFC-141b assume that the foams have been optimized (e.g., by improving cell density, cell thickness, etc.) to provide the same energy efficiency.

[3] An additional substitute involves the manufacture of these foams using water to replace a portion of the HCFC as the blowing agent. It is estimated that water can be used to replace approximately 30% of the substitute HCFC without resulting in a reduction in the insulating capacity of the foam. Such a change in the formulation process reduces the replacement factor of the chemical substitute used.

EXHIBIT C-19

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID POLYURETHANE (STRUCTURE INSULATION)

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O (60%/40%)	X				N/A	0.0%
Thick Fiberglass Batts	X				N/A	0.0%
HCFC-123[2] (Same Thickness)		X		N	1.15[3]	0.0% to +7.0%
HCFC-123 (Increased Thickness)		X		N	1.21	0.0%
HCFC-141b[2] (Same Thickness)		X		N	0.85[3]	0.0% to +10.0%
HCFC-141b (Increased Thickness)		X		N	0.94	0.0%
Shards with Optimized Foam (HCFC-123) Cells			X	N	1.0	-1.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] The lower values of the range of energy consumption changes for HCFC-123 and HCFC-141b assume that the foams have been optimized (e.g., by improving cell density, cell thickness, etc.) to provide the same energy efficiency.

[3] An additional substitute involves the use of water to replace a portion of the HCFC substitute used as the blowing agent in the manufacture of the foam. It is estimated that water can be used to replace approximately 15% of the HCFC substitute without resulting in a reduction of the foam's insulating capacity. Such a change in the formulation process reduces the replacement factor of the chemical substitute used.

EXHIBIT C-20

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID POLYURETHANE (PACKAGING)

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O	X			N	1.00	N/A
H_2O Only (CO_2)	X			N	1.00	N/A
HCFC-123		X		N	1.15	N/A
HCFC-141b		X		N	0.85	N/A
EPS Beadboard				N	N/A	N/A
Other Packaging Materials				N	N/A	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-21

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAMS -- FLEXIBLE

Original CFC: CFC-11

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-11/H_2O	X			N	1.00	N/A
H_2O Only (CO_2)	X			N	1.00	N/A
HCFC-123		X		N	1.15	N/A
HCFC-141b		X		N	0.85	N/A
CO_2 Process/Header Foam	X			N	N/A	N/A
Engineered Plastic Cushioning	X			N	N/A	N/A
Latex Foams	X			N	N/A	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-22

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID NON-POLYURETHANE (INSULATION)

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
HCFC-22	X			N	1.00	
Thick Fiberglass Batts	X			N	N/A	+20.0% to +3.0%
HCFC-134a		X		N	0.80	+10.0%
HCFC-124				N	1.20	+%
HCFC-142b	X			N	1.00	+%
HCFC-22/HCFC-142b	X			N	1.00	0.0%
Shards with Optimized Foam (HFC-134a) Cells			X	N	1.00	-1.0%

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-23

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

FOAM -- RIGID NON-POLYURETHANE (PACKAGING)

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
HCFC-22 (All)	X			N	1.00	N/A
HCFC-142b (Polyethylene, Polypropylene, PVC)	X			N	0.80	N/A
HCFC-22/HCFC-142b (All)	X			N	1.00	N/A
Product Substitutes (All)	X			N	N/A	N/A
HCFC-124 (All)		X		N	1.00	N/A
HCFC-134a (Polystyrene Sheet)		X		N	0.84	N/A
HCFC-22/Hydrocarbon (Polystyrene)	X			N	0.75	N/A
CO_2 Auxiliary Blowing Agent (Polystyrene)	X			N	0.60	N/A
Hydrocarbon Blowing Agent (Polystyrene)	X			N	0.83	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-24

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

SOLVENT CLEANING -- COLD CLEANING

Original CFC: CFC-113

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-113 Azeotropes	X			E,N	1.00	N/A
Organic Solvents	X			E,N	1.00	N/A
Methyl Chloroform	X			E,N	1.00	N/A
Aqueous Cleaning/Terpenes	X			E,N	1.00	N/A
HCFC-123		X		E,N	1.00	N/A
HCFC-141b		X		E,N	1.00	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-25

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

SOLVENT CLEANING -- VAPOR DEGREASING

Original CFC: CFC-113

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
CFC-113 Azeotropes	X			E,N	1.00	N/A
Methyl Chloroform						
Open Top	X			E,N	2.40	N/A
Conveyorized	X			E,N	2.20	N/A
Aqueous Cleaning/Terpenes	X			E,N	1.00	-15.0%
HCFC-123		X		E,N	1.00	N/A
HCFC-141b		X		E,N	1.00	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

EXHIBIT C-26

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

STERILIZATION

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
90% CO_2/10% EO Blend	X			E,N	0.94	N/A
Nitrogen Purge, Ethylene Oxide	X			E,N	1.00	N/A
HFC-134a/EO Blend		X		E,N	1.00	N/A
HCFC-A[2]				E,N	1.00	N/A
HCFC-B[2]				E,N	1.00	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] Proprietary compounds/mixtures.

EXHIBIT C-27

APPLICABILITY OF POTENTIAL CHEMICAL SUBSTITUTES

AEROSOLS

Original CFC: CFC-12

Substitutes: Compound/Blend	Currently Available	Strong Candidate(s)	Additional Possibilities	Retrofitability[1]	Replacement Factor	Changes in Energy Consumption with Substitute
Hydrocarbons/Pumps/	X			N	1.00	N/A
HCFC-22	X	X		N	1.00	N/A
HCFC-123				N	1.00	N/A
HCFC-22/HCFC-142b	X			N	1.00	N/A
HCFC-22/HCFC-152a	X			N	1.00	N/A
HCFC-141b				N	1.00	N/A
HCFC-142b	X			N	1.00	N/A
HFC-134a				N	1.00	N/A
HFC-152a	X			N	1.00	N/A
Other mixtures and compounds[2]			X	N	1.00	N/A

[1] Retrofitability: D represents difficult retrofit, E represents easy retrofit, and N indicates that the compound/blend is applicable to new equipment.

[2] A variety of mixtures and other compounds might also work.

APPENDIX D

METHODS USED TO DEVELOP ESTIMATES OF EMISSIONS OF ENERGY-RELATED GREENHOUSE GASES AND CHANGES IN ENERGY COSTS ASSOCIATED WITH INCREMENTAL ENERGY CONSUMPTION FOR THE TRADE-OFF ANALYSIS AND SUBSTITUTION SCENARIOS

APPENDIX D

This appendix describes the approach used to estimate incremental emissions of energy-related greenhouse gases for the trade-off analysis in Chapter 3 and the four substitution scenarios in Chapter 4 of this report. Estimates are developed for four greenhouse gases (carbon dioxide, carbon monoxide, nitrogen oxides, and methane) and two other air pollutants (sulfur dioxide and particulate emissions). Emission estimates are developed for four regions: the United States, Western industrialized countries (WIC), centrally planned economies (CPEs) not including China, and the rest of the world (ROW). Estimates of the energy-related impacts associated with substitutes for CFCs are developed only for the period 1985 to 2075.

CFCs are used in energy consuming appliances such as refrigerators and air conditioners, and in the production of energy conservation materials such as foam insulation. Potential substitutes (HCFCs and HFCs, as well as alternative technologies) are not expected to have the same performance characteristics as CFCs and CFC-based technologies, and their use may change the energy efficiency of appliances and insulation materials. Reductions in energy efficiency could lead to increased energy use, higher levels of energy-related greenhouse gas emissions, and global warming. Improvements in energy efficiency could lead to opposite effects.

1. ESTIMATION APPROACH

The general approach used to estimate incremental energy use and energy-related greenhouse gas emissions was the same for the four substitution scenarios in Chapter 3 and the trade-off analysis in Chapter 4. This approach is summarized below:

(1) Total energy use in CFC-related end uses is estimated in British thermal units (Btu's) assuming no controls on CFC use;

(2) Total increases or decreases in energy use are estimated for each end use based on assessments of relative energy efficiencies of substitutes (i.e., replacement of CFCs with HCFCs or HFCs, or replacement of CFC-blown insulation with fiberglass or vacuum panel insulation);

(3) Total energy use in Btu's is distributed among the various sources of energy (i.e., electricity, motor gasoline, diesel fuel, natural gas, and home heating oil); and

(4) Emissions of greenhouse gases are estimated based on the emission factors associated with each of these energy sources in the four regions of the world.

1.1. Energy Use Assuming No Controls on CFC Use

The first step in the energy analysis was to forecast annual energy consumption in CFC-using end use areas assuming there are no controls on CFC use. Estimates were developed in Btu's for the period 1985 through 2075 for the end use areas evaluated in each of the four geographical regions defined for this report. To develop these forecasts, an analysis of U.S. energy use in the energy-related end use areas was performed. The results for the U.S. were then extrapolated to estimate worldwide energy consumption in the end uses evaluated. U.S. data were used because information on the capital stock and energy efficiency in non-U.S. economies is limited.

In Chapter 3, this energy analysis is limited to the end uses listed in Exhibit D-1 in this appendix, because some of the 20 CFC end-use areas considered in the substitution scenarios do not consume energy. The aerosols, cold cleaning, and flexible and packaging foam end uses are examples of the end uses that do not consume energy. The energy analysis for the substitution scenarios, therefore, is limited to end uses which consume energy (e.g., refrigeration and foam insulation end uses). In Chapter 4 the energy impacts are estimated for each of the following end uses: mobile air conditioning, residential refrigeration, rigid polyurethane foam (refrigeration), retail food storage, chillers, process refrigeration, and rigid polyurethane foam (insulation).

Baseline energy consumption for each end use was estimated by first grouping the end uses into three different categories. This included (1) refrigeration application end uses, (2) foam application end uses corresponding to the refrigeration end uses that use foam (i.e., rigid polyurethane foam refrigeration applications), and (3) rigid and non-rigid polyurethane foam insulation end uses. For the first end use category baseline energy for the U.S. was developed based on energy use estimates per unit of end use capital stock[1]. This per unit estimate was then multiplied by estimates of total capital stock in that end use in each of the years from 1985 to 2075 to derive a time series of baseline energy use in the U.S[2].

Baseline energy data for this end use category for the remaining three regions of the world was estimated by dividing the emissions of the CFCs used in each end use by the baseline energy to obtain a time series of energy-emission factors for the end use. This time series of energy emission factors

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[1] The derivation of the energy use for each end use area is documented in U.S. EPA, Documentation of Engineering and Cost Data used in the Vintaging Analysis, Draft Report, February 23, 1989 and Oak Ridge National Laboratory, Energy Impact of Chlorofluorocarbon Alternatives, June 2, 1988.

[2] Reliable information on projected stock data is available to year 2010 and is documented in U.S. EPA, Documentation of Engineering and Cost Data used in the Vintaging Analysis, Draft Report, February 23, 1989. To estimate baseline energy consumption to year 2075 the stock data was extrapolated using growth rates estimates for each end use.

EXHIBIT D-1

ENERGY CONSUMING END USES	
Mobile Air Conditioners	Refrigerated Transport
Residential Refrigeration	Rigid Polyurethane Foam (Residential Refrigeration)
Chiller	Rigid Polyurethane Foam (Other Refrigeration Appliances)
Process Refrigeration	Rigid Polyurethane Foam (Refrigerated Transport)
Cold Storage Warehouses	Rigid Polyurethane Foam (Structure Insulation)
Retail Food Storage	Rigid Non-Polyurethane Foam (Structure Insulation)
Other Refrigeration Appliances	Vapor Degreasing

was then multiplied by the CFC emission estimates for the end use in the three regions of the world to obtain the baseline energy[3].

Baseline energy estimates for the four regions of the world for the second category of end uses were estimated by assuming them to be similar to the first category (i.e., the amount of energy consumed by the residential refrigeration end use is the same as that consumed by rigid polyurethane foam refrigeration end use). This is based on the assumption that the foam used in refrigeration application end use is an integral part of the end use, and therefore, the energy consumption has to be considered as an overall estimate as opposed to separate estimates for foam and fluid[4].

The approach used to develop baseline energy consumption estimates for the rigid polyurethane foam and rigid non-polyurethane foam insulation end uses (third category) is different from that used above, because energy use in this end-use area is not related directly to capital stock. This alternative approach can be summarized as follows:

(1) Estimates of energy savings per metric ton of CFC foam insulation were derived from work performed by the Oak Ridge National Laboratories.[5] This estimate was based on the energy savings associated with CFC-blown rigid foams relative to a fiberglass insulation of the same thickness.

(2) Total energy savings associated with CFC insulation materials were then calculated by multiplying the estimates of energy savings per ton developed in step 1 by the

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[3] The assumption that the ratio of energy use per CFC emissions is constant throughout the world implies that the energy efficiency of refrigerators in the U.S., for example, is the same as the energy efficiency of refrigerators in Europe, China, and the U.S.S.R. This simplification is necessary because of the general lack of data on energy efficiency and stock of appliances throughout the world.

[4] The energy impacts associated with the use of substitutes for the refrigeration foam application end uses and their counterpart refrigeration application end uses are not additive. For example, in the case of the residential refrigeration and rigid polyurethane foam end uses, if the substitute used to replace CFC-12 working fluid results in a 10 percent increase in energy usage and the substitute used to replace the foam also results in a 10 percent increase in energy usage, the overall increase in energy consumption of the residential refrigeration unit is not necessarily 20 percent.

[5] Oak Ridge National Laboratories, op. cit., pp 56-71.

total stock of CFC foam insulation in 1985 as reported in the RIA.[6]

(3) Energy savings per unit of CFC emission were then calculated by dividing the total energy savings developed in step 2 by estimated CFC emissions from rigid foam insulation in 1985.

(4) The energy savings per unit of CFC emission factor was then multiplied by estimates of CFC emissions in the four regions of the world to obtain the baseline energy data for the rigid and non-rigid polyurethane foam insulation end uses.

1.2. Estimating Changes in Energy Use For the Trade-off Analysis and Substitution Scenarios

For the trade-off analysis in Chapter 4, estimates of the changes in CFC-related energy use were developed for each substitute evaluated in each of seven end use areas. The estimates for each substitute were developed for each end use based on assumptions about the percent change in energy use associated with the substitute. The assumptions about changes in energy use associated with each substitute are presented in Chapter 4 of this report. The energy estimates all are incremental to the baseline energy use estimated for the end use. Estimates of the energy implications for each substitute in each end use, therefore, are a function of:

(1) Baseline energy use in the end use area; and

(2) The estimated percentage change in global energy use associated with use of the substitute in the end use area.

Changes in CFC related energy use were estimated for each of the substitution scenarios in Chapter 3 based on assumptions about the percent change in energy use for each end-use category resulting from the substitution of HCFCs, HFCs or other substitutes for CFCs. For each scenario, estimates of the percentage changes in energy consumption by end-use category were obtained.[7] The assumptions used in this analysis to represent the percent change in energy use are presented in Chapter 3. The estimates of the energy impacts under each scenario are all measured as incremental to the baseline.

Estimates of total annual changes in energy use under each substitution scenario were estimated as a function of:

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[6] Radian Corporation, Regulatory Impact Analysis: Protection of Stratospheric Ozone, Vol. III, 1988, p. 3.1.1-A7.

[7] Estimates for percent energy change were based on information obtained from Oak Ridge National Laboratory, Energy-Use Impact of Chlorofluorocarbon Alternatives, June 2, 1988 and from discussions with industrial contacts.

(1) baseline global energy use in all end uses;

(2) the cumulative percent change in global energy use developed taking into account the energy use changes defined for each end use; and

(3) the portion of total CFC use in each end use estimated to be replaced by HCFC, HFC, and other substitutes that have implications for energy consumption.

2. FUEL SHARES FOR EACH END-USE CATEGORY

The aggregate estimates of incremental energy consumption by end-use area developed using the methods above are expressed in terms of Btu's. To estimate the emissions of greenhouse gases associated with changes in energy demand, the specific energy sources that will provide this incremental energy must be defined. Specific energy sources have different emissions of greenhouse gases; to develop accurate estimates of the indirect greenhouse effect under each scenario, therefore, it is important that energy demand be correctly categorized. For this analysis, energy demand is distributed among the following fuel types:

- Electricity;
- Motor gasoline;
- Diesel fuel;
- Natural gas; and
- Home heating oil.

In most of the end uses considered in this energy analysis, the incremental energy consumed under the substitution scenarios is expected to come from the same sources of energy used to fuel the end uses when CFCs are used. For example, additional energy required for mobile air conditioners is assumed to be supplied by diesel and gasoline in proportion to their use in current fleets of vehicles. This assumption is based on the premise that all vehicles will be retrofitted during servicing to eliminate CFC use.

In a few cases, however, there are data to support the assumption that the incremental amounts of energy expected to be used under the substitution scenarios could be provided from a different type of fuel than currently is used. In the insulation end uses, for example, changes in building insulation materials requirements are assumed not to affect the current stock of buildings because replacement would be too costly. Instead, alternative insulation is assumed to be used only in new buildings which could use fuel types different from those used currently in buildings. The following sections present the fuel share assumptions applied in this analysis for each of the four regions of the world.

2.1. Fuel Shares by End Use in the United States

Fuel shares for the U.S. are summarized in Exhibit D-2 for selected end-use categories. For example, one hundred percent of the energy consumption in

EXHIBIT D-2

FUEL SHARES FOR U.S. CFC-RELATED ENERGY CONSUMPTION -- 2000*

End-Use Category	Electricity**	Motor Gasoline	Diesel Oil	Natural Gas	Home Heating Oil**
Mobile Air Conditioners	-	96	4	-	-
Residential Refrigeration	100	-	-	-	-
Process Refrigeration	100	-	-	-	-
Cold Storage Warehouses	100	-	-	-	-
Chillers	100	-	-	-	-
Retail Food Storage	100	-	-	-	-
Other Refrigeration Appliances	100	-	-	-	-
Refrigerated Transport	-	16	84	-	-
Rigid Polyurethane Foam (Refrigeration)	100	-	-	-	-
(Other Appliances)	100	-	-	-	-
(Refrigerated Transport)	-	16	84	-	-
(Insulation)	46	-	-	32	22
Rigid Non-Polyurethane Foam (Insulation)	46	-	-	32	22

* CFC-related energy use is allocated year-by-year for each category to one of five types of fuels.

** Further differentiated by sector for costing purposes.

the chillers category is allocated to electricity, whereas energy consumption in the mobile air conditioners end use is allocated to both gasoline (96 percent) and diesel fuel oil (4 percent). Each of the end-use areas are described briefly below.

Automobile and Light-Duty Truck Air Conditioning (Mobile Air Conditioners)

Oil products are by far the primary fuel used by automobiles and light duty trucks, and it is generally viewed as unlikely that other fuels (such as electricity or natural gas) will significantly penetrate the transportation sector over the forecast period.

Because different emissions are associated with gasoline- and diesel-fueled vehicles, oil consumption is disaggregated into gasoline and diesel vehicle shares. Estimated fuel consumption shares for distillate and motor gasoline over the period 1990 to 2010 are based on forecasts by Saricks and Vyas (1986) of "vehicle miles traveled."[8]

Refrigerated Transport

Heavy duty trucks are responsible for most refrigerated transport in the United States. All heavy duty trucks currently consume oil and are expected to continue to do so throughout the forecast period. The percentage shares of gasoline and diesel-powered trucks are estimated based on the vehicle miles traveled forecast by Saricks and Vyas (1986).

Rigid Foam Insulation

Rigid foam insulation is installed in the walls and roofs of residential and commercial buildings. CFCs currently are used as a blowing agent in the production of this foam. Use of other materials for insulation, such as expanded polystyrene beadboard, may lead to an increase in energy use for space heating and cooling. As described earlier, because rigid foam insulating materials are contained within the walls of buildings, removing the CFCs from existing buildings would be difficult and expensive. The estimates of energy source shares for this end-use area, therefore, reflects only new (or "incremental") buildings in any particular year.

Information provided by the Gas Research Institute[9] is the principal source used to estimate fuel shares in this end-use area. The following

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[8] A compilation of Saricks and Vyas' vehicle miles traveled forecast was included in a technical memorandum from L.A. Mahoney and L.R. Chinkin of SAI to C.S. Burton of SAI regarding "projecting the effects of a new (0.4 gram/mile) NO_x standard upon on-road mobile NOx emissions for the 48 states," March 2, 1988.

[9] Gas Research Institute, Baseline Projection Data Book: 1988 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010, 1988.

assumptions were made to estimate the fuel shares for the residential and commercial sector's aggregate heating and cooling needs for new buildings:

- Efficiency - Heating new residential homes was assumed to require 50 percent less energy than heating the average existing home, although this may be conservative as some evidence indicates that the most efficient new homes are achieving a 70 percent reduction.[10] New home energy use for cooling was assumed to be the same in new and existing homes. New commercial buildings were assumed to be five percent more efficient in both cooling and heating than existing buildings.

- Saturation - 50 percent of new homes were assumed to be cooled, which is reflective of current U.S. trends. Ninety percent of new commercial square footage was assumed to be cooled, 25 percent of new commercial buildings were assumed to replace older cooled buildings. The remaining seventy-five percent of new cooled commercial buildings were assumed to replace non-cooled buildings.

- Fuel Types - All cooling was assumed to be powered by electricity. Heating was assumed to be provided by natural gas, home heating oil, and electricity.

Rigid Polyurethane Foam (Refrigeration)

Electricity is the sole energy source used for refrigeration. For this analysis, electricity use is assumed to be used solely among the residential sector.

Electricity-Only End-Use Categories

In a number of CFC end-use categories, electricity is the only fuel used. The electricity-only categories include:

- Cold Storage
- Retail Refrigeration
- Industrial Process Refrigeration and Air Conditioning
- Household Refrigerated Appliances
- Solvent Cleaning
- Sterilization

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[10] U.S. EPA, OPPE, Policy Options for Stabilizing Global Climate, Draft Executive Summary, page 62.

- Chillers[11]
- Other Refrigeration Appliances

2.2. Fuel Shares for Non-U.S. Regions

The following section documents the method used to estimate fuel shares for the non-U.S. regions. The discussion focuses on those instances in which foreign shares differ from those used for the U.S. are presented below. The fuel shares for the other three regions of the world are presented in Exhibit D-3.

Mobile Air Conditioners

Estimates of mobile air conditioner fuel shares for the WIC region are based on the split of diesel and gasoline fuel used for road transportation as reported by the International Energy Agency (IEA).[12] The IEA data show that the non-U.S. industrialized countries consume a considerably higher proportion of diesel fuel for road transport than is used in the U.S. This relationship also applies to the refrigerated transport sector.

The same fuel shares developed for mobile air conditioners and refrigerated transport in WICs are assumed to apply to the centrally planned economies and the rest of the world regions. This assumption is reasonable because these regions also use more diesel fuel than does the U.S.

Rigid Polyurethane and Non-Polyurethane Foam (Insulation)

The 1985 fuel shares for these end-use categories for the WIC region are based on data on residential and commercial fuel use as reported by the International Energy Agency.[13] WIC residential consumers currently use less natural gas than consumers in the U.S. The use of natural gas and electricity or residential heating and cooling in Europe, however, is expected to increase in the future. The fuel shares developed here reflect that assumption.

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[11] Chillers are used for cooling large offices and other commercial buildings, and in petroleum refineries in certain cryogenic processes associated with gas separation. It is assumed that chillers primarily consume electricity. Based on an estimate of the proportion of commercial buildings (such as office buildings) versus industrial installations (such as petroleum refineries), the fuel consumption shares in this category are assumed to be split between the commercial sector (99 percent) and the industrial sector (1 percent).

[12] International Energy Agency, Energy Statistics: 1985-1986, (1988).

[13] Ibid.

EXHIBIT D-3

FUEL SHARES FOR NON-US CFC-RELATED ENERGY CONSUMPTION -- 2000*

End-Use Category	Electricity**	Motor Gasoline	Diesel Oil	Natural Gas	Home Heating Oil**
Mobile Air Conditioners	-	80	20	-	-
Residential Refrigeration	100	-	-	-	-
Process Refrigeration	100	-	-	-	-
Cold Storage Warehouses	100	-	-	-	-
Chillers	100	-	-	-	-
Retail Food Storage	100	-	-	-	-
Other Refrigeration Appliances	100	-	-	-	-
Refrigerated Transport	-	16	84	-	-
Rigid Polyurethane Foam (Refrigeration)	100	-	-	-	-
(Other Appliances)	100	-	-	-	-
(Refrigerated Transport)	-	16	84	-	-
(Insulation) WIC/CPE	24	-	-	40	36
ROW	12	-	-	29	59
Rigid Non-Polyurethane Foam Insulation (WIC/CPE)	24	-	-	40	36
(ROW)	12	-	-	29	59

* CFC-related energy use is allocated year-by-year for each category to one of five types of fuels.

** Further differentiated by sector for costing purposes.

No data are available on the use of energy by fuel type for residential and commercial heating and cooling for the remaining two regions. For the ROW region, distillate fuel oil is assumed to account for a higher proportion of the fuel used for residential heating and cooling than in the WIC countries. The fuel shares for natural gas and electricity, however, are assumed to increase slightly over time at the expense of the distillate fuel oil share. The fuel shares for the CPE region reflect the assumption that the fuel shares for the U.S.S.R. are similar to those in western Europe.

3. EMISSIONS

This section describes the process used to estimate energy-related greenhouse gas emissions associated with the substitution of HCFCs, HFCs, or other substitutes for CFCs in the trade-off analysis and the substitution scenarios. These emission estimates are developed using changes in energy consumption by fuel type estimated above, and emission factors that represent the amount of emission per incremental unit of energy use.

Emission factors were developed to reflect the following:

- Types of Energy - Factors are developed for the seven types of energy used by CFC end-uses: electricity, motor gasoline, diesel, commercial use of natural gas and heating oil, and residential use of natural gas and heating oil.

- Types of Emission - For each of the seven fuel types, factors are developed for each of six types of emissions: carbon dioxide, carbon monoxide, nitrogen oxides, methane, sulfur dioxide, and total suspended particulates (TSP).

- Regions - Separate sets of factors were developed for the four geographical regions analyzed in this report.

- Time - Emission factors change over time through 2010 but remain constant at 2010 levels thereafter, reflecting the uncertainty and lack of attention focused on post-2010 forecasts. Greater attention is focused on pre-2010 trends because of the greater availability of relevant information and energy market perspectives. Further, post-2010 trends are more likely to be affected by new technologies and other developments that are especially difficult to predict.

The remainder of this subsection is divided into three parts. The first section discusses electricity emission factors. The second section describes motor gasoline and diesel emission factors for mobile sources. Finally, the third section discusses heating oil and natural gas factors for the commercial and residential sectors.

Electricity

Electricity is an important energy source for CFC-using appliances. Further, the electricity industry accounts for significant shares of total U.S. emissions of greenhouse gases and other pollutants associated with fossil fuel combustion.

The development of electricity emission factors involved three steps. The first was to determine the types or mix of powerplants that would supply the additional amount of power required due to CFC substitution. The second was to determine the emissions characteristics of the powerplants. The third step was to multiply the emission rate of a particular type of powerplant by its share in the generating mix, or, in other words, the fraction of electricity supplied by that type of powerplant to develop a weighted average emission rate (in units of pollution per unit of electricity delivered).

The mix of powerplants meeting future power demands can differ substantially from the current average mix. In the near team, power demand will be met by existing powerplants with excess capacity. Some types of powerplants, in particular nuclear and hydroelectric plants, are already fully utilized, and hence, future demand will be met by less utilized fossil-fueled powerplants. Thus, the future mix of plants supplying incremental amounts of energy above current forecast levels is assumed not to include nuclear and hydroelectric powerplants. Over time, excess existing capacity will become exhausted and new powerplants will be required. Again, the mix of new powerplants may differ substantially from the existing mix. For example, few nuclear powerplants are expected to be built in the U.S. over the next two decades, whereas nearly 20 percent of U.S. electricity currently is produced by nuclear plants.

3.1. U.S. Emission Rates

For the United States, powerplant mix assessments were made using a linear programming optimization approach to estimate existing powerplant utilization and forecast new powerplant construction. The model used contains detailed information about all major U.S. powerplants, fuel market conditions, and most key operating constraints. The assumptions about electricity sales growth rates, future oil and gas market conditions and other factors applied in this estimation process are documented elsewhere.[14] Using this model, power demand in 1990 is forecast to be met by existing coal, oil and natural gas burning powerplants (see Exhibit D-4). Coal powerplants account for 60 percent of energy production, natural gas powerplants represent 35 percent and oil powerplants represent 5 percent. In the longer term, power requirements are met by the construction of new powerplants and reduced reliance on coal (See Exhibit D-5).

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[14] The assumptions applied in this modeling exercise are detailed in ICF, CFC-Phase-Out Analysis: Energy Scenarios, February 1989.

EXHIBIT D-4

1990 ELECTRIC GENERATING MIXES
(%)

	U.S.	WIC	CPE	ROW
Coal	60	38	60	40
Oil	5	25	15	15
Natural Gas	35	37	25	45
Nuclear	-	-	-	-
Hydro Other	-	-	-	-
	100	100	100	100

Source: ICF forecasts for U.S.; non-U.S. forecast from DOE Energy Forecasts adjusted by ICF.

EXHIBIT D-5

2005 ELECTRIC GENERATING MIXES
(%)

	U.S.	WIC	CPE	ROW
Coal	47	54	55	18
Oil	15	-	-	5
Natural Gas	38	20	17	36
Nuclear	-	7	5	5
Hydro Other	-	19	23	39
	100	100	100	100

Source: ICF forecasts for U.S.; non-U.S. forecast from DOE Energy Forecasts adjusted by ICF.

Information on the emissions characteristics of U.S. powerplants were generated using the same model that projects powerplant utilization. That model simultaneously forecasts both the incremental fuel mix expected to be used in the future and the emission rates associated with that mix. The model forecasts emissions of: sulfur dioxides, nitrogen oxides and total suspended particulates. Emission factors for carbon dioxide, methane, and carbon monoxide were estimated separately for each fuel and weighted by the generating mix shares. For example, the carbon dioxide emission rate for coal was multiplied by the share of coal in the mix (See Exhibit D-6).

Emission rates for carbon dioxide were provided by Radian.[15] Carbon dioxide rates for coal-fired power plants are about forty percent higher than oil-fired plants and more than twice as high as natural gas based plants. Emission rates for carbon monoxide were also supplied by Radian, but are very low for all fuels.

Methane emission rates were developed for this study but are highly uncertain. Electricity production can cause methane emissions in three ways: (1) incomplete combustion of fossil fuels, (2) methane releases during the production and delivery of natural gas to utilities, and (3) methane emissions during coal mining when methane gases trapped in coal seams are released. Methane production during combustion is very small and is assumed here to be negligible. Natural gas related emissions were assumed to be zero because of the lack of data. Coal mining emissions were estimated based on a assumption that 300 cubic feet of methane is released per ton of coal mined.[16] This estimate is highly uncertain because it is based on data from only one type of mine (underground mines). Additional study of this issues is strongly recommended.

3.2. Non-U.S. Emissions

For the other regions of the world, generating mix estimates were based on forecasts developed by the Department of Energy[17] adjusted based on other data sources. These estimates were not based on detailed modeling because a modeling framework such as that used in developing U.S. estimates was not readily available. Hence, the non-U.S. mix estimates are more uncertain.

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[15] Radian Corporation, Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO_x, N_2O, CH_4, CO, and CO_2, Draft, December 1987.

[16] R.H. Grau III, Bureau of Mines, "An Overview of Methane Liberations from U.S. Coal Mines in the Last 15 Years", Third U.S. Mine ventilation symposium, October 12-14, 1987.

[17] DOE, International Energy Outlook 1987, 1988.

EXHIBIT D-6

1990 AVERAGE ELECTRIC EMISSION RATES
(lbs./MMBtu[a] output)

	U.S.	WIC	CPE	ROW
Carbon Dioxide	545	573	642	563
Carbon Monoxide	0.1	0.1	0.1	0.1
Nitrogen Oxide	1.6	0.9	2.0	1.7
Particulates	0.3	0.3	2.8	1.9
Sulfur Dioxide	2.5	1.3	3.0	6.3
Methane	0.8	0.7	1.1	0.8

a "MMBtu" represents million British thermal units.

Emission rate estimates for carbon dioxide, methane, and carbon monoxide were developed using the same sources used for the U.S. emissions estimates for these compounds. The emissions rates for nitrogen oxides, sulfur dioxide, and total suspended particulates were developed as follows:

- Nitrogen Oxides - Powerplant emissions of NO_x are generally controlled in Western Industrialized Countries, and in some cases, such as Japan and West Germany, the controls are tighter than in the United States. NO_x emission limits were estimated for key countries in WIC from several sources and an average rate weighted by each country's fuel use was then calculated. NO_x rates are assumed to be uncontrolled in CPE and ROW regions.[18]

- Sulfur Dioxides - Sulfur dioxide emissions are primarily a function of the sulfur content of fuels, and in some cases, the level of technological emission controls employed. Emission rates for SO_2 are based on estimates of the regional differences in the sulfur contents of fuels, and in the case of WIC, levels of control. Non-WIC rates are assumed to be uncontrolled.[19]

- TSP - In the U.S., particulate emissions from powerplants are very tightly controlled. WIC emission limits are assumed to be as tight as U.S. standards. In other regions, rates were assumed to be approximately equal to rates in the U.S. prior to the Clean Air Act. This estimate was based in part on estimates of uncontrolled emissions from EPA's AP-42 emission rate document.[20]

Mobile Sources

Mobile sources consume large amounts of oil products and are important sources of carbon monoxide, nitrogen oxide, and carbon dioxide emissions. Estimates of U.S. mobile source emission rates are from several sources. The NO_x forecasts developed by SAI, Inc. for EPA were used.[21] The principal carbon monoxide source was EPA's compilation of emission factors known as the

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[18] EPA, Briefing on International Comparison of Air Pollution Control by EPA's OPPE and Office of International Activities, August, 5 1988. IEA, Electricity in IEA Countries - Issues and Outlook, 1985.

[19] World Energy Conference, "1986 Survey of Energy Resources," 1987. CIA, "USSR Energy Atlas," 1985. Selected Issues of Coal Week International.

[20] EPA, EPA AP-42 Factors: Air Pollution Emission Factors Volume I: Stationary Point and Area Sources; October 1986.

[21] ICF, "NO_x Emission Estimates and Forecasts 1980-2010," Memorandum from B. Braine and L. Nixon to P. Stolpman, February 8, 1988.

AP-42 factors.[22] The on-going reductions in carbon monoxide and nitrogen oxide emissions in the U.S. due to implementation of existing regulations were factored into the development of these estimates.

Carbon dioxide emission rates increase as carbon monoxide is controlled and converted to carbon dioxide. Thus, the overall amount of carbon emissions is constant. Carbon dioxide rates are based on Radian's estimates adjusted so the level of carbon emissions, as represented by the sum of carbon dioxide and carbon monoxide, is constant.

Sulfur dioxide estimates are based on sulfur content assumptions for diesel and gasoline. The sulfur content of gasoline is very low and assumed here to be zero, whereas the sulfur content of diesel fuel was assumed to be 0.25 percent.

TSP estimates were made without differentiating between diesel and gasoline. This may overestimate gasoline emissions and underestimate diesel emissions, but the size of any resulting error should be small because overall mobile source TSP emission levels are low. Estimates were based on EPA's National Air Pollutant Emission Estimates.

Radian estimates were used for methane emissions associated with combustion which Radian estimates to be very low.[23]

NO_x and CO emission rate estimates for Western Industrialized Countries were developed by comparing control levels in key countries and calculating a weighted average based on fuel use. The source of data used to assess the control levels in European and other large countries is the same as for the electricity sector. Emissions in other regions were assumed to be uncontrolled (See Figure D-1).

Commercial and Residential

Commercial and residential oil and gas emission rates are from Radian and are assumed to be constant worldwide. The principal exception relates to sulfur dioxide emission rates for non-U.S. regions, which are assumed to be higher for oil than in the U.S. reflecting less stringent environmental restrictions in these regions, and hence, higher sulfur contents in heating oils.

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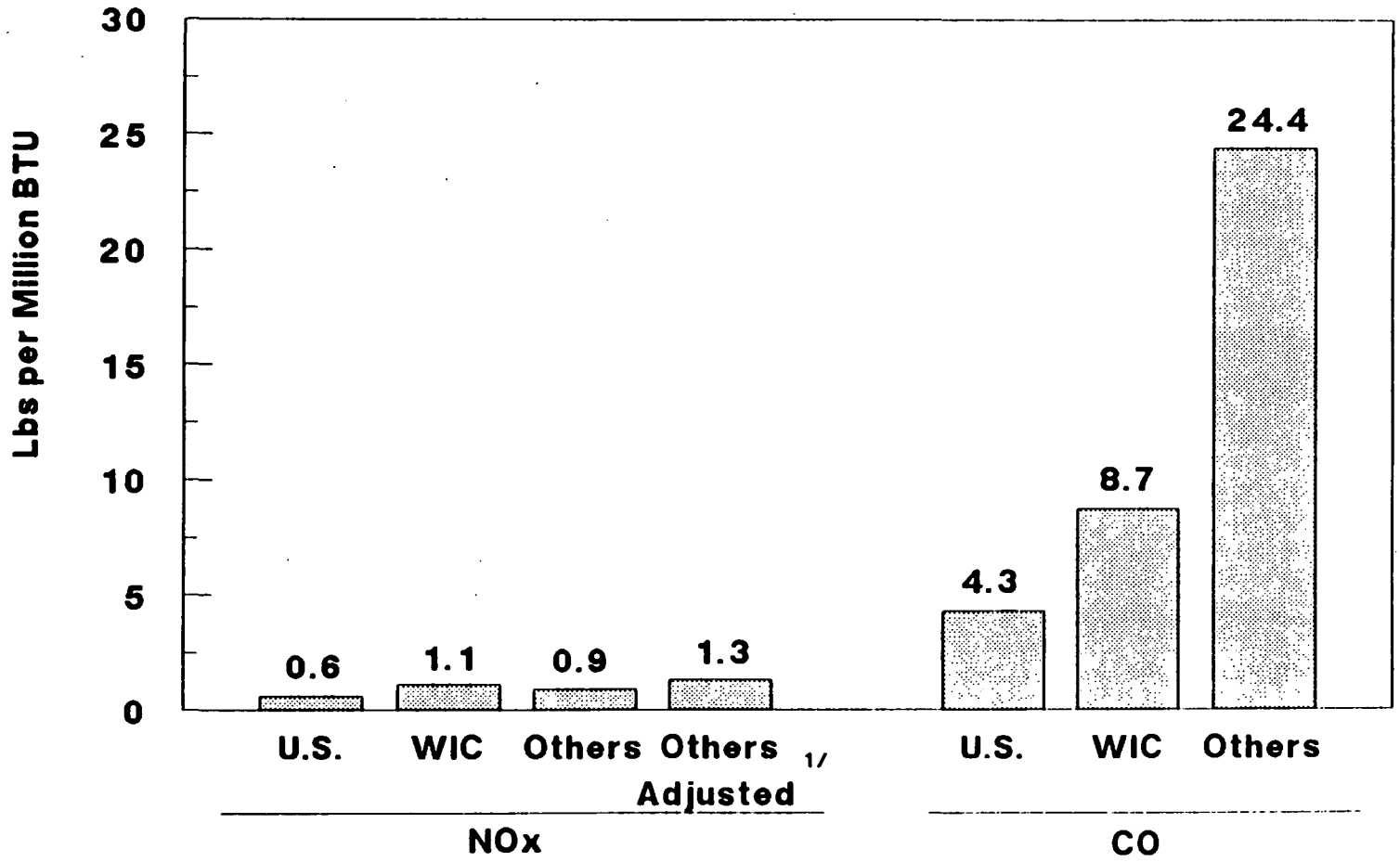
[22] EPA, AP-42 Factors: Air Pollution Emission Factors Volume II: Mobile Sources, September 1985.

[23] Radian, op cit.

Figure D-1

Average Gasoline Vehicle Emission Rates - 2000



1/ Most NOx emissions standards are expressed in grams/mile driven. Vehicles in Other Countries (CPEs, ROW) generate more NOx per mile than WIC vehicles, but because their fuel milage is low, they generate less on a per gallon and per Btu basis. The adjusted rate assumes Other Countries have the same average fuel efficiency as WIC vehicles. A similar adjustment would increase the CO rate to 35.

4. METHODS USED TO ESTIMATE ENERGY COSTS FOR THE SUBSTITUTION SCENARIOS IN CHAPTER 3

The cost to the United States of increased energy use associated with HCFC substitution was calculated for each substitution scenario in Chapter 3by multiplying the change in energy use by projected energy prices. Energy price projections were developed as part of an integrated U.S. energy market assessment. Because oil prices are determined in an international market, additional but less detailed analysis was also conducted on the international supply and demand for crude oil. Within the context of this integrated energy market analysis, the approach used to estimate prices for each fuel type can be summarized as follows:

- Electricity - Prices were estimated based on adjusted projections from the Energy Information Administration.
- Natural gas - Prices were estimated based on the supply and demand analysis of the U.S. natural gas market.
- Residential heating oil, motor gasoline, and diesel fuel - Prices were projected as a function of the estimated crude oil prices and the long-run refinery costs of production.

Exhibit D-7 demonstrates that the energy price estimates developed for this analysis are in the middle of the range of recent energy price projections made by private sector firms as well as other federal agencies.

International Energy Costs: Developing precise estimates of energy costs for the other regions included in this analysis is difficult because the regions are large and include nations with very diverse energy resources and demand structures. In addition, end-use energy prices in other regions may be poor indicators of actual real resource costs. For example, gasoline prices in many European countries include a large tax component.[24] In addition, many developing countries subsidize energy consumption by setting price levels below the real cost of supply.

For this analysis, U.S. energy prices projections were also used as a proxy for energy costs in other regions (for additional details see Attachment A-1). U.S. oil prices are reasonable estimates of oil costs in other regions because they are determined in the international oil market. Oil price differences among regions primarily reflect transportation cost differentials. Other fuel prices are linked to the international oil price because suppliers of the other fuels such as coal and natural gas must compete with oil products

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[24] Taxes are typically excluded from any measure of the real resource cost of energy consumption because they represent transfers from the consumers to the government and not actual costs incurred by society related to energy use. On the other hand, some analysts may claim that these energy taxes should be included because they represent the real cost of energy to society in terms of increased energy vulnerability and environmental costs.

EXHIBIT D-7

OVERVIEW OF ENERGY PRICE FORECASTS

	Range of Estimates	Price Estimates Used in this Analysis
2000 World Oil Prices (1988 $/billion barrels)	$17-$42 (ICF-EIA High Oil)	$29
2000 Natural Gas Wellhead Price ($/MMBtu)	$2.60-$5.70 (AGA-DOE NEPP)	$ 3.40
2000 Average Electricity Price (¢/kilowatt hour)	$0.056-$0.08 (DRI-EPA/WRI)	$ 0.067

Sources:

AGA - American Gas Association, TERA Analysis 88-1, January 15, 1988, Table 1, p. iii.

DOE NEPP - U.S. DOE, Natural Energy Policy Plan, Long Range Energy Projections to 2010, DOE/PE-0082, July 1988, High U.S. and World Economic Growth Scenario, Table 4-6, p. 4-14.

DRI - Data Resources, Inc., Energy Review (Lexington, MA, Winter 1987-88), as referenced in EIA's 1987 Annual Energy Outlook, DOE/EIA-0383 (87).

EPA/WRI - U.S. Environmental Protection Agency/World Resources Institute "Rapidly Changing World, No Policy" scenario developed for forthcoming report to Congress on stabilizing greenhouse warming.

EIA - U.S. DOE's Energy Information Administration, 1987 Annual Energy Outlook, Appendix C: High World Oil Price/Low Growth Case Forecasts.

for the key industrial and electric utility segments of the energy market. Consequently, where they are determined by free market competition, long-run energy prices in other regions tend to change over time in line with U.S. energy prices.

ATTACHMENT D-1

WORLD ENERGY COSTS

World Prices (1985$/mmBtu) 1/

Year	Electricity 2/ Res	Electricity 2/ Commer	Electricity 2/ Indus	Natural Gas 3/ Res	Natural Gas 3/ Commer	Oil 4/ Gasoline	Oil 4/ Heating Oil Residential	Oil 4/ Heating Oil Commercial	Oil 4/ Diesel
1985	22.61	21.67	14.97	5.88	5.28	8.94	7.99	6.04	6.94
1986	20.97	20.19	13.84	5.50	4.80	6.65	6.47	4.03	5.63
1987	20.41	19.19	12.90	5.08	4.37	6.80	6.01	4.23	5.90
1988	20.41	19.30	12.88	5.22	4.52	6.88	5.68	4.06	6.19
1989	20.41	19.42	12.87	5.31	4.60	6.97	5.36	3.91	6.50
1990	20.41	19.53	12.85	5.49	4.78	7.06	5.07	3.75	6.82
1991	20.39	19.47	12.81	5.58	4.87	7.34	5.30	3.98	7.06
1992	20.36	19.42	12.77	5.75	5.05	7.63	5.55	4.23	7.31
1993	20.33	19.36	12.73	5.89	5.19	7.93	5.81	4.48	7.57
1994	20.31	19.30	12.69	6.04	5.33	8.24	6.08	4.76	7.84
1995	20.28	19.24	12.65	6.20	5.49	8.57	6.36	5.05	8.12
1996	20.44	19.39	12.80	6.29	5.58	8.71	6.49	5.17	8.25
1997	20.60	19.55	12.95	6.38	5.67	8.86	6.61	5.30	8.37
1998	20.77	19.71	13.10	6.48	5.77	9.01	6.74	5.43	8.50
1999	20.93	19.87	13.25	6.58	5.87	9.17	6.87	5.56	8.64
2000	21.10	20.03	13.41	6.68	5.98	9.32	7.01	5.69	8.77
2001	21.27	20.19	13.57	6.74	6.03	9.38	7.06	5.74	8.82
2002	21.44	20.35	13.73	6.80	6.10	9.44	7.10	5.79	8.87
2003	21.61	20.51	13.89	6.86	6.15	9.49	7.15	5.84	8.91
2004	21.78	20.68	14.06	6.93	6.22	9.55	7.20	5.89	8.96
2005	21.95	20.84	14.22	6.99	6.28	9.61	7.25	5.94	9.01
2006	22.13	21.01	14.39	7.05	6.35	9.66	7.30	5.98	9.06
2007	22.30	21.18	14.56	7.13	6.42	9.72	7.35	6.03	9.11
2008	22.48	21.35	14.73	7.20	6.49	9.78	7.40	6.08	9.16
2009	22.66	21.52	14.91	7.26	6.56	9.83	7.44	6.13	9.21
2010	22.84	21.69	15.08	7.34	6.63	9.89	7.49	6.18	9.26

1/ World prices are assumed to be the same as U.S. prices.
Prices were converted from 1988 dollars to 1985 dollars assuming a deflator of .9113.
Historical values used for 1985-1987. 1985 data from EIA Annual Energy Outlook 1987 and was escalated from 1987$ to 1988$ using the EIA Implicit GNP Price Deflator of 2.8% found in the 1989 report. 1986 and 1987 numbers come directly from the 1989 report.

2/ 1988-2010 electricity prices based on ICF forecasts of U.S. average electricity prices.

3/ 1988-2010 natural gas prices estimated from wellhead forecasts in ICF's Energy Service '88B.

4/ 1988-2010 oil prices estimated from world crude prices forecast by ICF using the following:

Price formulas:
- Gasoline ($/Bbl) = 1.087*Crude ($/Bbl) + 22.22
- Diesel ($/Bbl) = 1.038*Crude ($/Bbl) + 25.95
- Residential Heating Oil ($/Bbl) = 1.033*Crude ($/Bbl) + 14.84
- Commercial Heating Oil ($/Bbl) = 1.033*Crude ($/Bbl) + 6.44

Heat Contents:
- Crude - 5.736 mmBtu/bbl
- Gasoline - 5.253 mmBtu/bbl
- Diesel - 5.825 mmBtu/bbl
- Heating Oil - 5.825 mmBtu/bbl

Source: DOE/EIA Monthly Energy Review, 5/86.

APPENDIX E

DETAILED RESULTS FOR THE SUBSTITUTION SCENARIOS

AGGREGATE SCENARIOS (ALL END USES)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.029	0.056	0.020	0.024
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11						
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				35.500	48.700	9.200	17.400
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				8.700	1.800	14.100	11.700
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	20.800	42.700	10.600	13.700
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.217	0.575	1.466	0.241	0.328
Maximum Increase Relative to 1985	ppb	50.939	1.295	1.367	1.509	1.313	1.332
Year of Maximum Increase		2165	2010	2015	2020	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	21.130	-23.258	28.158	-62.040
Global		0.000	0.000	74.590	-151.110	129.154	-444.896
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	5.690	-20.286	8.458	-72.321
Global		0.000	0.000	-9.050	-101.141	22.323	-378.039
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.247	0.334	0.205	0.167
Indirect (Energy Emissions)		4.323	4.323	4.335	4.280	4.352	4.203
Total		7.011	4.684	4.847	4.878	4.821	4.635
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			12.5	34.4	2.3	5.4
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.358	1.249	0.024	0.111
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				21.130	-23.258	28.158	-62.040
Global				74.590	-151.110	129.154	-444.896
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				5.690	-20.286	8.458	-72.321
Global				-9.050	-101.141	22.323	-378.039
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.151	0.237	0.109	0.071
Indirect (Energy Emissions)				0.012	-0.043	0.029	-0.120
Total				0.163	0.194	0.138	-0.049

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Mobile Air Conditioners

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			80.0%	80.0%	80.0%	80.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.000	0.035	0.000	0.029
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.000	0.022	0.000	0.008
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.000	1.500	0.000	0.600
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				1.600	0.400	1.600	1.200
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.300	9.000	8.300	8.600
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.119	0.146	0.119	0.125
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.161	1.164	1.161	1.162
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.909	-0.669	0.909	-1.604
Global		0.000	0.000	1.630	-1.206	1.630	-2.885
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.473	-0.842	0.473	-1.547
Global		0.000	0.000	0.691	-1.293	0.691	-2.352
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.109	0.105	0.109	0.103
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.322
Total		7.011	4.674	4.687	4.682	4.687	4.680
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.0	0.7	0.0	0.3
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.000	0.027	0.000	0.006
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.909	-0.669	0.909	-1.604
Global				1.630	-1.206	1.630	-2.885
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.473	-0.842	0.473	-1.547
Global				0.691	-1.293	0.691	-2.352
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.013	0.008	0.013	0.007
Indirect (Energy Emissions)				0.000	-0.000	0.000	-0.000
Total				0.013	0.008	0.013	0.006

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Residential Refrigeration

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			100.0%	100.0%	92.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.050	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.028	0.038	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.800	0.700	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.200	0.200	0.900	1.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.700	8.800	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.131	0.135	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.158	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-1.620	-9.247	1.012	-3.780
Global		0.000	0.000	-22.542	-119.702	11.528	-52.597
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-5.213	-10.301	-3.008	-12.163
Global		0.000	0.000	-32.866	-65.473	-18.787	-76.688
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.100	0.102	0.102	0.097
Indirect (Energy Emissions)		4.323	4.323	4.317	4.289	4.326	4.309
Total		7.011	4.674	4.672	4.646	4.684	4.661
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.4	0.5	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.012	0.016	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-1.620	-9.247	1.012	-3.780
Global				-22.542	-119.702	11.528	-52.597
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-5.213	-10.301	-3.008	-12.163
Global				-32.866	-65.473	-18.787	-76.688
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.004	0.005	0.006	0.001
Indirect (Energy Emissions)				-0.006	-0.034	0.004	-0.014
Total				-0.002	-0.029	0.010	-0.013

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Chillers (centrifugal and reciprocating)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			60.0%	60.0%	47.0%	60.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.050	0.020	0.029
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.008	0.030	0.006	0.006
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				2.200	3.400	1.800	0.900
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				1.100	0.000	0.900	1.600
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.900	10.500	8.800	8.600
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.125	0.202	0.124	0.127
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.162	1.159	1.159
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.373	0.970	0.345	-3.086
Global		0.000	0.000	4.357	8.474	3.674	-25.266
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.710	1.405	0.658	-2.225
Global		0.000	0.000	5.731	9.128	4.884	-11.405
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.106	0.121	0.104	0.105
Indirect (Energy Emissions)		4.323	4.323	4.324	4.325	4.324	4.316
Total		7.011	4.674	4.685	4.701	4.683	4.676
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.6	2.2	0.5	0.3
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.006	0.083	0.005	0.008
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.373	0.970	0.345	-3.086
Global				4.357	8.474	3.674	-25.266
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.710	1.405	0.658	-2.225
Global				5.731	9.128	4.884	-11.405
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.009	0.025	0.008	0.009
Indirect (Energy Emissions)				0.001	0.002	0.001	-0.007
Total				0.011	0.027	0.008	0.002

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Process Refrigeration

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			84.0%	84.0%	50.0%	84.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.050	0.000	0.035
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.024	0.042	0.000	0.024
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				1.100	1.400	0.000	1.100
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.300	0.000	0.800	0.300
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.800	9.200	8.300	8.800
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.139	0.156	0.119	0.139
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.161	1.162	1.159	1.161
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-0.064	0.072	0.031	-0.064
Global		0.000	0.000	-0.224	0.229	0.097	-0.224
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-0.121	-0.010	-0.017	-0.121
Global		0.000	0.000	-0.352	-0.044	-0.056	-0.352
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.102	0.107	0.103	0.102
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.680	4.685	4.681	4.680
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.5	0.9	0.0	0.5
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.020	0.037	0.000	0.020
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-0.064	0.072	0.031	-0.064
Global				-0.224	0.229	0.097	-0.224
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-0.121	-0.010	-0.017	-0.121
Global				-0.352	-0.044	-0.056	-0.352
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.006	0.011	0.006	0.006
Indirect (Energy Emissions)				-0.000	0.000	0.000	-0.000
Total				0.006	0.011	0.006	0.006

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Cold Storage Warehouses

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			81.0%	81.0%	50.0%	81.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.050	0.000	0.029
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.019	0.041	0.000	0.008
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.900	1.300	0.000	0.300
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.400	0.000	0.800	0.600
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.700	9.200	8.300	8.400
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.134	0.151	0.119	0.122
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.160	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-0.043	-0.556	0.025	-3.029
Global		0.000	0.000	-0.238	-1.048	0.137	-5.667
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-0.048	-0.444	0.010	-2.002
Global		0.000	0.000	-0.219	-0.843	0.033	-3.582
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.103	0.106	0.103	0.100
Indirect (Energy Emissions)		4.323	4.323	4.323	4.322	4.323	4.321
Total		7.011	4.674	4.681	4.684	4.681	4.676
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.4	0.9	0.0	0.1
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.015	0.032	0.000	0.003
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-0.043	-0.556	0.025	-3.029
Global				-0.238	-1.048	0.137	-5.667
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-0.048	-0.444	0.010	-2.002
Global				-0.219	-0.843	0.033	-3.582
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.007	0.010	0.006	0.003
Indirect (Energy Emissions)				-0.000	-0.000	0.000	-0.002
Total				0.007	0.009	0.006	0.002

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Retail Food Storage

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			75.0%	75.0%	62.0%	75.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.050	0.000	0.029
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.010	0.038	0.000	0.008
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.700	1.700	0.000	0.400
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				1.100	0.000	1.400	0.700
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.600	9.400	8.300	8.500
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.131	0.163	0.119	0.123
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.162	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-0.035	-0.095	0.027	-0.399
Global		0.000	0.000	-0.138	-0.210	0.108	-0.880
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-0.087	-0.163	0.043	-0.587
Global		0.000	0.000	-0.285	-0.384	0.131	-1.294
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.110	0.110	0.110	0.100
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.322
Total		7.011	4.674	4.688	4.687	4.688	4.678
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.3	1.1	0.0	0.2
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.012	0.044	0.000	0.004
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-0.035	-0.095	0.027	-0.399
Global				-0.138	-0.210	0.108	-0.880
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-0.087	-0.163	0.043	-0.587
Global				-0.285	-0.384	0.131	-1.294
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.014	0.013	0.014	0.004
Indirect (Energy Emissions)				0.000	-0.000	0.000	-0.000
Total				0.014	0.013	0.014	0.004

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Other Refrigeration Appliances

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			95.0%	95.0%	90.0%	95.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.050	0.000	0.035
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.026	0.048	0.000	0.026
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.100	0.200	0.000	0.100
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.200	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.400	8.400	8.300	8.400
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.122	0.123	0.119	0.122
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.158	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-0.930	1.215	0.764	-0.930
Global		0.000	0.000	-7.380	8.672	5.401	-7.380
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-1.657	-0.255	-0.524	-1.657
Global		0.000	0.000	-9.371	-1.907	-3.271	-9.371
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.097	0.098	0.098	0.097
Indirect (Energy Emissions)		4.323	4.323	4.321	4.325	4.324	4.321
Total		7.011	4.674	4.673	4.678	4.677	4.675
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.1	0.1	0.0	0.1
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.003	0.004	0.000	0.003
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-0.930	1.215	0.764	-0.930
Global				-7.380	8.672	5.401	-7.380
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-1.657	-0.255	-0.524	-1.657
Global				-9.371	-1.907	-3.271	-9.371
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.001	0.001	0.001	0.001
Indirect (Energy Emissions)				-0.002	0.002	0.002	-0.002
Total				-0.001	0.004	0.003	-0.001

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Refrigerated Transport

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			95.0%	95.0%	90.0%	95.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.035	0.035	0.000	0.029
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.027	0.027	0.000	0.010
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				1.000	1.000	0.000	0.400
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.300	0.300	1.000	0.800
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.800	8.800	8.300	8.500
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.135	0.136	0.119	0.123
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.159	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-0.129	-0.107	0.156	-0.305
Global		0.000	0.000	-4.230	-3.998	5.421	-10.202
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-0.161	-0.149	-0.007	-0.254
Global		0.000	0.000	-2.597	-2.543	0.463	-4.449
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.102	0.102	0.104	0.101
Indirect (Energy Emissions)		4.323	4.323	4.322	4.322	4.324	4.320
Total		7.011	4.674	4.678	4.678	4.683	4.676
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.5	0.5	0.0	0.2
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.016	0.017	0.000	0.004
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-0.129	-0.107	0.156	-0.305
Global				-4.230	-3.998	5.421	-10.202
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-0.161	-0.149	-0.007	-0.254
Global				-2.597	-2.543	0.463	-4.449
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.005	0.005	0.007	0.004
Indirect (Energy Emissions)				-0.001	-0.001	0.001	-0.002
Total				0.004	0.004	0.009	0.002

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (refrigeration)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential - CFC-11	Percent			100.0%	100.0%	80.0%	100.0%
- CFC-12	Percent			100.0%	100.0%	0.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.080	0.020	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.020	0.080	0.016	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				2.000	1.700	1.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.800	10.000	8.600	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.124	0.176	0.122	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.164	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	2.400	0.000	1.920	-11.980
Global		0.000	0.000	26.784	0.000	21.427	-133.840
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	4.231	0.000	3.385	-20.770
Global		0.000	0.000	22.299	0.000	17.839	-109.818
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.098	0.100	0.097	0.096
Indirect (Energy Emissions)		4.323	4.323	4.330	4.323	4.329	4.285
Total		7.011	4.674	4.683	4.678	4.581	4.637
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.5	1.7	0.3	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.005	0.057	0.003	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				2.400	0.000	1.920	-11.980
Global				26.784	0.000	21.427	-133.840
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				4.231	0.000	3.385	-20.770
Global				22.299	0.000	17.839	-109.818
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.001	0.003	0.001	0.000
Indirect (Energy Emissions)				0.007	0.000	0.006	-0.037
Total				0.008	0.003	0.006	-0.037

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam
(other refrigeration appliances)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential - CFC-11	Percent			95.0%	95.0%	65.0%	95.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.080	0.020	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.019	0.076	0.013	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.100	0.100	0.100	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.400	8.400	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.119	0.122	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.158	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	1.453	0.000	0.994	-7.264
Global		0.000	0.000	8.702	0.000	5.954	-43.495
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	1.004	0.000	0.687	-4.969
Global		0.000	0.000	4.155	0.000	2.843	-20.441
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.097	0.097	0.097	0.096
Indirect (Energy Emissions)		4.323	4.323	4.325	4.323	4.324	4.310
Total		7.011	4.674	4.677	4.675	4.676	4.662
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.1	0.1	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.000	0.003	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				1.453	0.000	0.994	-7.264
Global				8.702	0.000	5.954	-43.495
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				1.004	0.000	0.687	-4.969
Global				4.155	0.000	2.843	-20.441
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.000	0.000	0.000	0.000
Indirect (Energy Emissions)				0.002	0.000	0.002	-0.012
Total				0.003	0.000	0.002	-0.012

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (refrigerated transport)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential - CFC-11	Percent			95.0%	95.0%	65.0%	95.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.080	0.020	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.019	0.076	0.013	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.300	0.300	0.100	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.400	8.600	8.400	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.120	0.129	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.159	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.318	0.000	0.218	-1.589
Global		0.000	0.000	8.126	0.000	5.560	-40.617
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.169	0.000	0.116	-0.830
Global		0.000	0.000	2.080	0.000	1.423	-10.306
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.097	0.097	0.097	0.096
Indirect (Energy Emissions)		4.323	4.323	4.325	4.323	4.324	4.313
Total		7.011	4.674	4.676	4.675	4.676	4.665
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.1	0.3	0.1	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.001	0.010	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.318	0.000	0.218	-1.589
Global				8.126	0.000	5.560	-40.617
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.169	0.000	0.116	-0.[illegible]
Global				2.080	0.000	1.423	-10.306
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.000	0.001	0.000	0.000
Indirect (Energy Emissions)				0.002	0.000	0.001	-0.009
Total				0.002	0.001	0.001	-0.009

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (insulation)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential - CFC-11	Percent			60.0%	60.0%	40.0%	60.0%
- CFC-12	Percent			60.0%	60.0%	0.0%	60.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.029	0.069	0.020	0.020
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.017	0.041	0.008	0.012
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				7.200	6.300	2.800	6.600
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	11.000	13.900	9.000	10.000
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.183	0.309	0.127	0.136
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.162	1.173	1.159	1.161
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	10.588	0.000	7.059	-1.059
Global		0.000	0.000	32.575	0.000	21.717	-3.258
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	6.105	0.000	4.070	-0.614
Global		0.000	0.000	14.782	0.000	9.854	-1.486
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.114	0.120	0.098	0.100
Indirect (Energy Emissions)		4.323	4.323	4.327	4.323	4.326	4.322
Total		7.011	4.674	4.696	4.698	4.679	4.677
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			2.7	5.6	0.7	1.7
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.064	0.190	0.008	0.017
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				10.588	0.000	7.059	-1.059
Global				32.575	0.000	21.717	-3.258
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				6.105	0.000	4.070	-0.614
Global				14.782	0.000	9.854	-1.486
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.018	0.024	0.002	0.003
Indirect (Energy Emissions)				0.004	0.000	0.003	-0.000
Total				0.022	0.024	0.004	0.003

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (packaging)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			20.0%	20.0%	0.0%	20.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.028	0.070	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.006	0.014	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.300	0.200	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.400	8.500	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.122	0.126	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.159	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.097	0.097	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.675	4.675	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.1	0.2	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.003	0.007	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.001	0.001	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.001	0.001	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Flexible Foams

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			20.0%	20.0%	0.0%	20.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.080	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.004	0.016	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.800	0.600	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.500	8.900	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.121	0.140	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.164	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.097	0.098	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.675	4.676	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.2	0.6	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.002	0.021	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.000	0.001	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.000	0.001	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Non-Polyurethane Foam (insulation)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			40.0%	40.0%	40.0%	40.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.055	0.055	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.022	0.022	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.400	0.400	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.200	0.400
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.500	8.500	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.129	0.129	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.158	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.432	-0.058
Global		0.000	0.000	0.000	0.000	2.352	-0.314
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.319	-0.043
Global		0.000	0.000	0.000	0.000	1.482	-0.198
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.099	0.099	0.098	0.099
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.677	4.677	4.676	4.677
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.2	0.2	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.010	0.010	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.432	-0.058
Global				0.000	0.000	2.352	-0.314
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.319	-0.043
Global				0.000	0.000	1.482	-0.198
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.002	0.002	0.002	0.003
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.002	0.002	0.002	0.003

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Non-Polyurethane Foam (packaging)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			30.0%	30.0%	0.0%	30.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.050	0.050	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.015	0.015	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.600	0.600	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.700	8.700	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.135	0.135	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.161	1.161	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.101	0.101	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.679	4.679	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.4	0.4	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.016	0.016	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.005	0.005	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.005	0.005	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Solvent Cleaning - Cold Cleaning

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			67.0%	43.0%	31.0%	67.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.000	0.058	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.000	0.025	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.000	0.700	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.300	8.900	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.119	0.137	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.160	1.161	1.159	1.160
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.096	0.098	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.674	4.675	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.0	0.6	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.000	0.018	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.000	0.001	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.000	0.001	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Solvent Cleaning - Vapor Degreasing

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			67.0%	43.0%	31.0%	67.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.000	0.058	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.000	0.025	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.000	6.500	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.300	13.100	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.119	0.273	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.172	1.191	1.164	1.172
Year of Maximum Increase		2165	2010	2010	2015	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.796	0.000	0.368	0.796
Global		0.000	0.000	2.564	0.000	1.186	2.564
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.760	0.000	0.351	0.760
Global		0.000	0.000	2.396	0.000	1.108	2.396
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.096	0.106	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.675	4.684	4.675	4.675
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.0	4.8	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.000	0.154	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.796	0.000	0.368	0.796
Global				2.564	0.000	1.186	2.564
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.760	0.000	0.351	0.760
Global				2.396	0.000	1.108	2.396
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.000	0.010	0.000	0.000
Indirect (Energy Emissions)				0.001	0.000	0.000	0.001
Total				0.001	0.010	0.000	0.001

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Sterilization (hospital)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			72.0%	72.0%	72.0%	72.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.050	0.050	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.036	0.036	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.200	0.200	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.500	8.500	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.125	0.125	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.160	1.160	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.098	0.098	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.676	4.676	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.2	0.2	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.006	0.006	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.002	0.002	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.002	0.002	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Aerosols

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes Scenario 1	Scenario 2	Scenario 3	Scenario 4
Substitute Market Potential	Percent			25.0%	25.0%	25.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.050	0.000	0.000
Average Ozone-Depleting Potential of All Substitutes	Relative to CFC-11			0.005	0.013	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				3.100	3.100	0.000	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	9.100	10.300	8.300	8.300
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.145	0.201	0.119	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.164	1.171	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	0.000	0.000	0.000	0.000
Global		0.000	0.000	0.000	0.000	0.000	0.000
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.103	0.121	0.096	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.681	4.699	4.674	4.674
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.8	2.0	0.0	0.0
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.026	0.082	0.000	0.000
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				0.000	0.000	0.000	0.000
Global				0.000	0.000	0.000	0.000
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.006	0.024	0.000	0.000
Indirect (Energy Emissions)				0.000	0.000	0.000	0.000
Total				0.006	0.024	0.000	0.000

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

APPENDIX F

DETAILED RESULTS FOR THE TRADE-OFF ANALYSIS

END USE: Mobile Air Conditioners

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3	Option 4
Substitute Market Potential	Percent			100.0%	100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.050	0.035	0.000	0.029
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				2.300	1.900	0.000	0.800
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.500	2.000	1.500
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	9.700	9.200	8.300	8.600
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.180	0.153	0.119	0.127
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.170	1.166	1.158	1.160
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	3.728	-0.838	1.257	-2.094
Global		0.000	0.000	6.722	-1.511	2.266	-3.776
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	4.745	-1.066	1.599	-2.666
Global		0.000	0.000	7.278	-1.636	2.453	-4.089
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.114	0.107	0.112	0.105
Indirect (Energy Emissions)		4.323	4.323	4.324	4.323	4.323	4.322
Total		7.011	4.674	4.693	4.684	4.690	4.682
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			1.4	0.9	0.0	0.3
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.061	0.034	0.000	0.008
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				3.728	-0.838	1.257	-2.094
Global				6.722	-1.511	2.266	-3.776
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				4.745	-1.066	1.599	-2.666
Global				7.278	-1.636	2.453	-4.089
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.018	0.010	0.016	0.008
Indirect (Energy Emissions)				0.001	-0.000	0.000	-0.001
Total				0.019	0.010	0.016	0.008

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Residential Refrigeration

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3	Option 4
Substitute Market Potential	Percent			100.0%	100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.050	0.035	0.000	0.029
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.700	0.800	0.000	0.300
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.200	0.200	1.000	0.600
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.800	8.700	8.300	8.400
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.135	0.131	0.119	0.122
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.158	1.158	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-10.834	-1.625	1.625	-10.834
Global		0.000	0.000	-150.397	-22.559	22.559	-150.397
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-35.468	-5.320	5.320	-35.468
Global		0.000	0.000	-221.588	-33.238	33.238	-221.588
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.102	0.100	0.103	0.100
Indirect (Energy Emissions)		4.323	4.323	4.282	4.317	4.329	4.282
Total		7.011	4.674	4.639	4.672	4.687	4.637
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.5	0.4	0.0	0.1
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.016	0.012	0.000	0.003
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-10.834	-1.625	1.625	-10.834
Global				-150.397	-22.559	22.559	-150.397
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-35.468	-5.320	5.320	-35.468
Global				-221.588	-33.238	33.238	-221.[illegible]
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.005	0.004	0.007	0.003
Indirect (Energy Emissions)				-0.040	-0.006	0.006	-0.040
Total				-0.035	-0.002	0.013	-0.037

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Chillers (centrifugal and reciprocating)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3	Option 4
Substitute Market Potential	Percent			100.0%	100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.029	0.050	0.020	0.024
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				1.500	5.600	3.700	5.200
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				2.700	0.000	1.900	0.400
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.900	11.900	9.300	9.900
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.132	0.258	0.129	0.154
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.160	1.169	1.160	1.163
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	-5.693	1.656	0.733	-0.225
Global		0.000	0.000	-50.329	14.641	7.817	-4.653
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	-10.097	2.937	1.401	-0.598
Global		0.000	0.000	-64.873	18.872	10.392	-6.630
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.111	0.138	0.112	0.106
Indirect (Energy Emissions)		4.323	4.323	4.310	4.326	4.325	4.322
Total		7.011	4.674	4.676	4.720	4.692	4.683
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			0.6	3.6	1.0	1.6
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.013	0.139	0.010	0.035
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				-5.693	1.656	0.733	-0.225
Global				-50.329	14.641	7.817	-4.653
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				-10.097	2.937	1.401	-0.598
Global				-64.873	18.872	10.392	-6.630
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.014	0.042	0.016	0.010
Indirect (Energy Emissions)				-0.013	0.004	0.002	-0.001
Total				0.002	0.046	0.018	0.009

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Process Refrigeration

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3
Substitute Market Potential	Percent			100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.050	0.050	0.035
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.300	1.600	1.300
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.300
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.500	9.400	8.900
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.128	0.163	0.142
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.164	1.161
Year of Maximum Increase		2165	2010	2010	2010	2010
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States		0.000	0.000	-0.183	0.102	-0.076
Global		0.000	0.000	-0.641	0.356	-0.267
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States		0.000	0.000	-0.353	0.196	-0.147
Global		0.000	0.000	-1.020	0.567	-0.425
Equilibrium Global Warming	Degrees C in 2075					
Direct (HCFCs/HFCs)		0.142	0.096	0.099	0.109	0.103
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.323
Total		7.011	4.674	4.677	4.687	4.681
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs						
Weighted HCFC Emissions Increase	Times 1986 Value			0.2	1.1	0.6
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075			0.009	0.044	0.023
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States				-0.183	0.102	-0.076
Global				-0.641	0.356	-0.267
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States				-0.353	0.196	-0.147
Global				-1.020	0.567	-0.425
Equilibrium Global Warming (2)	Degrees C in 2075					
Direct (HCFCs/HFCs)				0.003	0.013	0.007
Indirect (Energy Emissions)				-0.000	0.000	-0.000
Total				0.003	0.013	0.007

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Retail Food Storage

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3
Substitute Market Potential	Percent			100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.029	0.050	0.035
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				0.500	2.300	0.900
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				1.000	0.000	1.400
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.500	9.800	8.700
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.124	0.178	0.134
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.158	1.163	1.160
Year of Maximum Increase		2165	2010	2010	2010	2010
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States		0.000	0.000	-0.541	-0.127	-0.046
Global		0.000	0.000	-1.200	-0.281	-0.184
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States		0.000	0.000	-0.965	-0.226	-0.118
Global		0.000	0.000	-2.230	-0.522	-0.386
Equilibrium Global Warming	Degrees C in 2075					
Direct (HCFCs/HFCs)		0.142	0.096	0.102	0.114	0.115
Indirect (Energy Emissions)		4.323	4.323	4.322	4.323	4.323
Total		7.011	4.674	4.679	4.692	4.693
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs						
Weighted HCFC Emissions Increase	Times 1986 Value			0.2	1.5	0.4
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075			0.005	0.059	0.015
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States				-0.541	-0.127	-0.046
Global				-1.200	-0.281	-0.184
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States				-0.965	-0.226	-0.118
Global				-2.230	-0.522	-0.386
Equilibrium Global Warming (2)	Degrees C in 2075					
Direct (HCFCs/HFCs)				0.005	0.018	0.019
Indirect (Energy Emissions)				-0.000	-0.000	-0.000
Total				0.005	0.018	0.019

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (refrigeration)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3	Option 4
Substitute Market Potential - CFC-11	Percent			100.0%	100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.080	0.080	0.080	0.020
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				1.500	1.500	1.700	2.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	9.800	9.800	10.000	8.800
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.170	0.170	0.176	0.124
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.163	1.163	1.164	1.159
Year of Maximum Increase		2165	2010	2010	2010	2010	2010
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	2.402	0.000	0.000	2.402
Global		0.000	0.000	26.794	0.000	0.000	26.794
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	4.284	0.000	0.000	4.284
Global		0.000	0.000	22.507	0.000	0.000	22.507
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.099	0.099	0.100	0.098
Indirect (Energy Emissions)		4.323	4.323	4.330	4.323	4.323	4.330
Total		7.011	4.674	4.685	4.677	4.678	4.683
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			1.5	1.5	1.7	0.5
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.051	0.051	0.057	0.005
Energy Impacts (3)							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				2.402	0.000	0.000	2.402
Global				26.794	0.000	0.000	26.794
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				4.284	0.000	0.000	4.284
Global				22.507	0.000	0.000	22.507
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.003	0.003	0.003	0.001
Indirect (Energy Emissions)				0.007	0.000	0.000	0.007
Total				0.011	0.003	0.004	0.009

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

(3) The energy impacts associated with the use of substitutes for rigid polyurethane foam (refrigeration) and residential refrigeration are not additive.

END USE: Rigid Polyurethane Foam (refrigeration)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 5	Option 6	Option 7
Substitute Market Potential - CFC-11	Percent			100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.020	0.020	0.000
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				2.000	2.100	0.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	8.800	8.900	8.300
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.124	0.125	0.119
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.159	1.159	1.158
Year of Maximum Increase		2165	2010	2010	2010	2010
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States		0.000	0.000	0.000	0.000	-12.012
Global		0.000	0.000	0.000	0.000	-133.970
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States		0.000	0.000	0.000	0.000	-21.420
Global		0.000	0.000	0.000	0.000	-112.533
Equilibrium Global Warming	Degrees C in 2075					
Direct (HCFCs/HFCs)		0.142	0.096	0.098	0.098	0.096
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.285
Total		7.011	4.674	4.675	4.675	4.637
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs						
Weighted HCFC Emissions Increase	Times 1986 Value			0.5	0.6	0.0
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075			0.005	0.006	0.000
Energy Impacts (3)						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States				0.000	0.000	-12.012
Global				0.000	0.000	-133.970
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States				0.000	0.000	-21.420
Global				0.000	0.000	-112.533
Equilibrium Global Warming (2)	Degrees C in 2075					
Direct (HCFCs/HFCs)				0.001	0.001	0.000
Indirect (Energy Emissions)				0.000	0.000	-0.037
Total				0.001	0.001	-0.037

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

(3) The energy impacts associated with the use of substitutes for rigid polyurethane foam (refrigeration) and residential refrigeration are not additive.

END USE: Rigid Polyurethane Foam (insulation)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 1	Option 2	Option 3	Option 4
Substitute Market Potential - CFC-11	Percent			100.0%	100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.029	0.029	0.029	0.069
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				12.100	12.100	12.500	9.900
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	12.800	12.800	12.900	16.900
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.225	0.225	0.226	0.413
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.166	1.166	1.166	1.185
Year of Maximum Increase		2165	2010	2010	2010	2010	2015
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States		0.000	0.000	17.652	0.000	0.000	17.652
Global		0.000	0.000	54.306	0.000	0.000	54.306
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States		0.000	0.000	10.230	0.000	0.000	10.230
Global		0.000	0.000	24.766	0.000	0.000	24.766
Equilibrium Global Warming	Degrees C in 2075						
Direct (HCFCs/HFCs)		0.142	0.096	0.126	0.126	0.127	0.134
Indirect (Energy Emissions)		4.323	4.323	4.330	4.323	4.323	4.330
Total		7.011	4.674	4.711	4.704	4.704	4.719
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs							
Weighted HCFC Emissions Increase	Times 1986 Value			4.5	4.5	4.6	8.6
Global Clx Concentrations							
Increase Relative to 1985	ppb in 2075			0.106	0.106	0.107	0.294
Energy Impacts							
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)						
United States				17.652	0.000	0.000	17.652
Global				54.306	0.000	0.000	54.306
Cumulative Energy Cost 1989-2010	Billions of 1985 US $						
United States				10.230	0.000	0.000	10.230
Global				24.766	0.000	0.000	24.766
Equilibrium Global Warming (2)	Degrees C in 2075						
Direct (HCFCs/HFCs)				0.030	0.030	0.030	0.038
Indirect (Energy Emissions)				0.007	0.000	0.000	0.007
Total				0.037	0.030	0.030	0.045

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

END USE: Rigid Polyurethane Foam (insulation)

	Units	No Controls	CFC Phase-Out	CFC Phase-Out with HCFC/HFC Substitutes: Option 5	Option 6	Option 7
Substitute Market Potential - CFC-11	Percent			100.0%	100.0%	100.0%
Average Ozone-Depleting Potential of HCFC Substitutes	Relative to CFC-11			0.069	0.069	0.020
Percent of Fully-Halogenated Compounds Replaced by HCFC Substitutes (1)				9.900	10.500	11.000
Percent of Fully-Halogenated Compounds Replaced by only HFC Substitutes				0.000	0.000	0.000
Weighted HCFC Emissions Increase	Times 1986 Value	8.300	8.300	16.900	17.600	11.100
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075	26.703	0.119	0.413	0.435	0.148
Maximum Increase Relative to 1985	ppb	50.939	1.158	1.185	1.188	1.162
Year of Maximum Increase		2165	2010	2015	2015	2010
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States		0.000	0.000	0.000	0.000	-1.960
Global		0.000	0.000	0.000	0.000	-7.962
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States		0.000	0.000	0.000	0.000	-1.136
Global		0.000	0.000	0.000	0.000	-3.315
Equilibrium Global Warming	Degrees C in 2075					
Direct (HCFCs/HFCs)		0.142	0.096	0.134	0.136	0.102
Indirect (Energy Emissions)		4.323	4.323	4.323	4.323	4.322
Total		7.011	4.674	4.712	4.714	4.679
INCREMENTAL CONTRIBUTION OF HCFCs/HFCs						
Weighted HCFC Emissions Increase	Times 1986 Value			8.6	9.3	2.8
Global Clx Concentrations						
Increase Relative to 1985	ppb in 2075			0.294	0.316	0.029
Energy Impacts						
Cumulative Energy Impact 1989-2075	Quadrillion Btus (Quads)					
United States				0.000	0.000	-1.960
Global				0.000	0.000	-7.962
Cumulative Energy Cost 1989-2010	Billions of 1985 US $					
United States				0.000	0.000	-1.136
Global				0.000	0.000	-3.315
Equilibrium Global Warming (2)	Degrees C in 2075					
Direct (HCFCs/HFCs)				0.038	0.039	0.006
Indirect (Energy Emissions)				0.000	0.000	-0.001
Total				0.038	0.039	0.005

Footnotes:

(1) These are estimated by calculating the emissions of the HCFC substitutes as a percentage of the baseline CFCs emissions. They are therefore influenced by the replacement factor of the substitutes.

(2) These results compare to a 5.65 degree C equilibrium temperature increase for the rapidly changing world scenario of EPA's draft report on the Policy Options for Stabilizing Global Climate.

APPENDIX G

SENSITIVITY ANALYSIS OF HCFC LIFETIMES

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SENSITIVITY ANALYSIS OF HCFC LIFETIMES

Projections of the atmospheric concentration of HCFCs and HFCs (and therefore stratospheric chlorine and equilibrium global warming) depend on estimates of atmospheric lifetimes. The lifetimes characterize the decay of the atmospheric burden of these compounds due to various removal processes, particularly via reaction with tropospheric OH.

The HCFC and HFC lifetimes used in this report are derived from the LLNL 1-D model as reported in Fisher et al., 1989.

Although the fact that HCFCs and HFCs have shorter lifetimes than CFCs is well-established, uncertainties remain in estimates of HCFC and HFC lifetimes. For example, Prather (1989) has presented new lifetime estimates for these compounds that are generally lower than the LLNL 1-D lifetimes used for the calculations in this report.

To show the sensitivity of stratospheric chlorine and global warming estimates to assumptions about HCFC and HFC lifetimes, this Appendix presents an analysis of these factors for alternative lifetimes. The following sensitivity runs are presented:

- Base Lifetimes (LLNl 1-D Model);
- Base Lifetimes increased by 25 percent;
- Base Lifetimes decreased by 25 percent;
- Prather's (1989) Scaled Lifetimes.

Estimates of HCFC and HFC emissions from the "Prudent Use" substitution scenario presented in Chapter 3 are used for each sensitivity run. The only difference among the runs is the atmospheric lifetimes of the HCFCs and HFCs.

Exhibit G-1 presents the atmospheric lifetimes assumed for HCFCs and HFCs in each run.

Equilibrium global warming estimates as of 2075 for each of these sensitivity runs are shown in Exhibit G-2.[1] Exhibit G-3 presents the estimated contribution of HCFC and HFC substitutes to global warming over time for the alternative lifetime values. When lifetimes are increased from the base values (i.e., slower decay), greater global warming occurs as atmospheric

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[1] The warming values shown are the contribution of HCFCs and HFCs to equilibrium warming, including indirect impacts associated with changes in energy-related trace gas emissions.

EXHIBIT G-1

ATMOSPHERIC LIFETIMES FOR HCFCs AND HFCs USED IN SENSITIVITY ANALYSIS

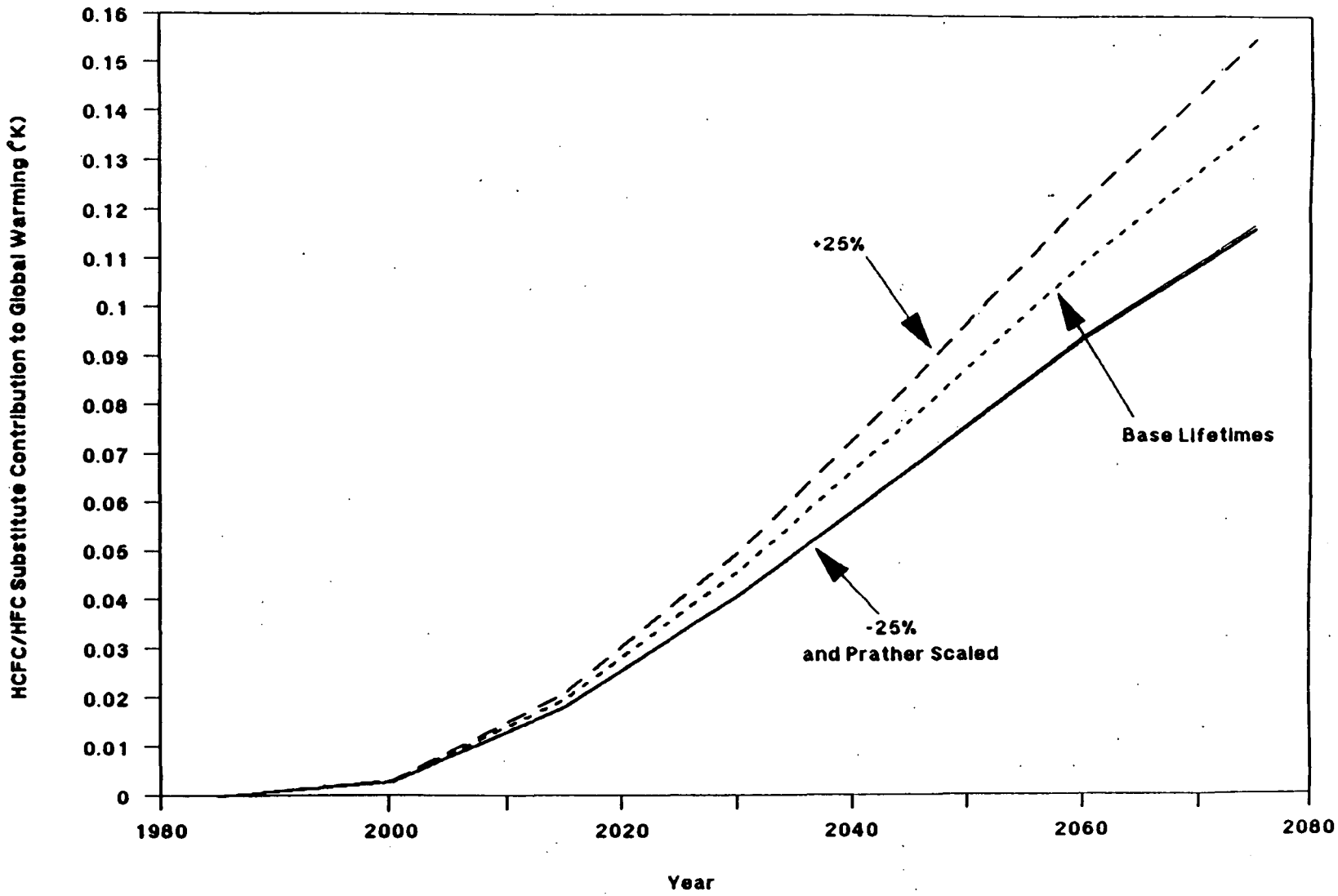
Compound	Base (LINL) Lifetimes	Base +25%	Base -25%	Prather Scaled
HCFC-22	20	15	25	15.3
HCFC-123	1.9	1.4	2.4	1.59
HFC-134a	21	16	26	15.5
HCFC-141b	8.9	6.7	11.1	7.8
HCFC-124	8.4	6.3	10.5	6.6
HFC-152a	2.1	1.6	2.6	1.68
HFC-125	37	28	46	28.1
HCFC-142b	25	19	31	19.1

EXHIBIT G-2

SENSITIVITY OF EQUILIBRIUM WARMING AS OF 2075 TO HCFC/HFC LIFETIMES

Sensitivity Run	Contribution of HCFC/HFC Substitutes to Global Warming (degrees C)
1. Base Lifetimes	0.138
2. Base Lifetimes + 25%	0.155
3. Base Lifetimes - 25%	0.117
4. Prather Scaled Lifetimes	0.116

EXHIBIT G-3 Global Warming: HCFC/HFC Lifetime Sensitivity



concentrations of the HCFCs and HFCs increase above base run levels. For a 25 percent increase in lifetimes, the HCFC and HFC contribution to global warming increases by about 12 percent. Total equilibrium global warming increases by less than 1 percent.

As the data in Exhibit G-2 indicate, the difference between the warming contribution for the Prather scaled and the BAse -25 percent runs is very small. The time series of global warming contribution for these two runs are nearly coincident in Exhibit G-3.

Clx contributions from HCFC and HFC substitutes are presented for the sensitivity runs in Exhibit G-4.[2] As with the global warming runs, the effect of greater lifetimes (e.g., +25 percent) is to increase the atmospheric concentration of the HCFC's, which leads to greater stratospheric concentrations of chlorine. A 25 percent increase in lifetimes is calculated to yield a 63 percent increase in the HCFC/HFC contribution to Clx in 2075.

The time series of HCFC/HFC contribution to Clx is shown in Exhibit G-5. The rapid initial growth in Clx contributions shows after 2005, reflecting decreases in use of several HCFCs (22, 141b, and 124).

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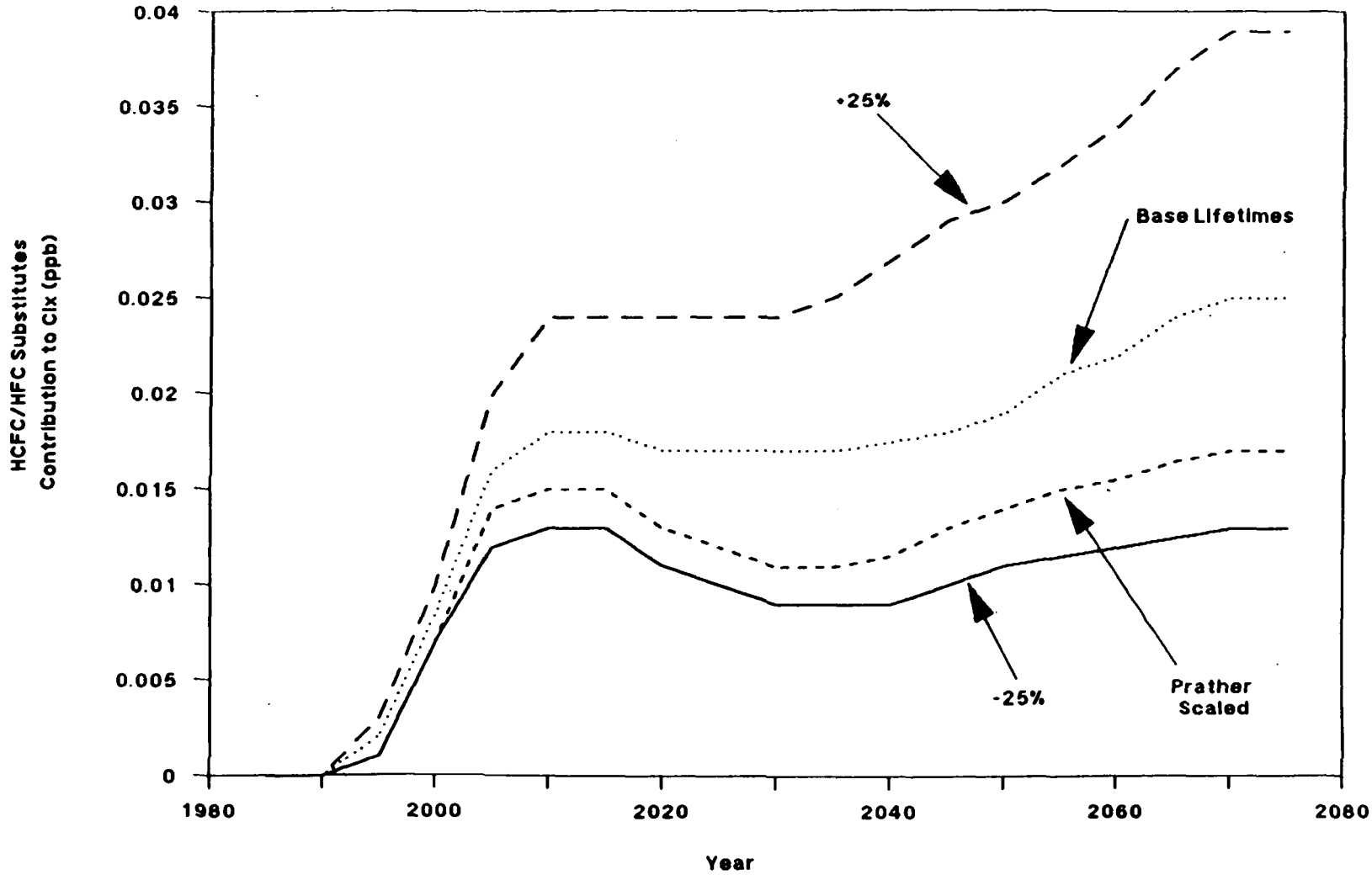
[2] Note that HFCs have no chlorine and therefore have zero contribution to Clx levels.

EXHIBIT G-4

SENSITIVITY OF CLX IN 2075 TO HCFC/HFC LIFETIMES

Sensitivity Run	Contribution of HCFC/HFC Substitutes to Global Warming (degrees C)
1. Base Lifetimes	0.024
2. Base Lifetimes + 25%	0.039
3. Base Lifetimes - 25%	0.013
4. Prather Scaled Lifetimes	0.017

EXHIBIT G-5 Sensitivity of Clx to HCFC/HFC Lifetimes



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APPENDIX H

ANALYSIS OF RECYCLING IN CURRENT USES OF HCFC-22

APPENDIX H

ANALYSIS OF RECYCLING IN CURRENT USES OF HCFC-22

One HCFC compound, HCFC-22, is currently used in refrigeration and air conditioning applications (i.e., not as a substitute for CFCs). Emissions of HCFC-22 from these current uses may contribute to stratospheric chlorine and global warming. This Appendix presents the results of an analysis of the changes in stratospheric chlorine and global warming that may be expected if HCFC-22 is recycled in current applications.

1.1 APPROACH

The impacts of recycling in current uses of HCFC-22 on stratospheric chlorine and global warming were estimated by undertaking the following steps:

- identifying current applications of HCFC-22;
- allocating HCFC-22 use quantities to these applications over time;
- estimating for each application the reduction in HCFC-22 emissions that may be achieved through recycling; and
- calculating stratospheric chlorine concentrations and global warming after this recycling is put in place.

Exhibit H-1 shows the current applications of HCFC-22 where fugitive emissions occur[1] and the portion of HCFC-22 consumption accounted for by each.

HCFC-22 consumption in current uses was allocated to these applications over time. HCFC-22 emissions were then estimated by applying release tables for each application that indicate the fraction of use that is emitted each year following the initial year of use. (The release tables used for each application are presented in Appendix A[2].) This calculation resulted in estimates of HCFC-22 emissions in the absence of recycling.

Recycling is estimated to reduce HCFC-22 emissions by varying amounts in each application due to differences in equipment physical location, charge size, and service practices. For example, emissions from room, unitary, and packaged terminal air conditioning units would be reduced by 29 percent, whereas emissions from cold storage warehouses would be reduced by 41 percent.

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[1] HCFC-22 is also used as a chemical precursor for polymer manufacturing. This use is not considered here because little or no emissions are estimated to occur from this application.

[2] Because no release table is available for air conditioning applications, the release table for chillers is used.

EXHIBIT H-1

CURRENT USES OF HCFC-22

Application	Share of HCFC-22 Fugitive Use [a]	Reduction from Recycling
Air Conditioning [b]	49.1	29.0
Chillers	18.8	32.0
Retail Food	10.6	39.0
Cold Storage Warehouses	20.9	41.0
Refrigerated Transportation	0.12	N/A
Industrial Process Refrigeration [c]	0.40	N/A
Household Ice Machines	0.08	N/A

Notes:

N/A: Not available.

[a] Fugitive uses include air conditioning and refrigeration and exclude the HCFC-22 used as polymer precursor.

[b] Includes room, unitary, and packaged terminal air conditioning.

[c] Indications are that HCFC-22 is used in larger quantities in industrial process refrigeration; however, no data is available to account for such use.

Source: Worldwide Use and Emissions of Chlorodifluoromethane (HCFC-22), EPA Draft Paper, August 9, 1989.

Exhibit H-1 shows the emission reductions used in this analysis. Applying these emission reduction estimates to each application results in a new pattern of total HCFC-22 emissions over time with recycling.

Stratospheric chlorine concentrations and global warming were estimated for HCFC-22 emissions both with and without recycling in current uses. The difference between these estimates represents the reduction in stratospheric chlorine and global warming that may be achieved through recycling.

2.1 RESULTS

Recycling HCFC-22 in current uses is estimated to reduce equilibrium warming by 0.0274 degrees C as of 2075. This reduction is 0.5 percent of the equilibrium temperature increase estimated in U.S. EPA's draft report to Congress, Policy Options for Stabilizing Global Climate.

Recycling of HCFC-22 also is estimated to reduce stratospheric chlorine concentrations by 0.090 parts per billion as of 2075. Comparing this reduction to the analyses presented in Chapter 4 reveals that, with few exceptions, the impact of HCFC-22 recycling on stratospheric chlorine levels is at least as large as the selection of HCFC/HFC replacements for CFCs in specific end uses.

APPENDIX I

DESCRIPTION OF THE CONCENTRATIONS MODEL

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This appendix presents the concentrations model used to evaluate the potential increases in stratospheric inorganic chlorine levels, Clx. The method is taken from Connell and is based on a simplified representation of the exponential decay of abundances of each compound.[1] The rate of decay is defined by an estimate of each compound's lifetime.

Of note is that the method recognizes that each of the compounds has slightly different "efficiencies" with which its chlorine can perturb stratospheric ozone. The greater a compound's efficiency, the larger the impact its chlorine will have on stratospheric ozone. For example, HCFC-22 dissociates (and consequently injects its chlorine) at a different altitude than does CFC-11. Therefore, its chlorine is less efficient at depleting stratospheric ozone. The estimates of chlorine abundances produced by this method adjust for these relative efficiencies so that the total change in chlorine abundances summed across the compounds is a consistent measure of the potential impact on stratospheric ozone.

The estimates of changes in Clx from 1985 levels are driven by the following data:

- Emissions: the emissions for the scenarios No Controls and phaseout scenarios are presented in Appendix A.

- Lifetimes: the "e-folding" lifetimes of each of the compounds. These lifetimes (taken from Connell 1986) were evaluated from a series of 1-D model runs with total column ozone depletions of around 10 percent (Connell 1986, p. 5). Lower levels of depletion would result in higher estimates of the lifetimes, and consequently higher estimates of Clx.

- Conversion Factors: the factors that convert emissions (in millions of kilograms) into abundances of Clx. These conversion factors reflect the number of chlorine atoms per molecule, the molecular weight of the molecule, the relative efficiency of the compound's chlorine at depleting ozone, and a factor combining the column number density of the atmosphere, the surface area of the earth, and Avogadro's number (see Connell 1986, p. 5). The values used to compute the conversion factors are shown in Exhibit I-1. As shown in the exhibit, the relative efficiencies for the compounds vary from 0.187 for CFC-115 to 1.185 for methyl chloroform.

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[1] P.S. Connell, A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere, Lawrence Livermore National Laboratory, Livermore, California (1986).

- Mixing Time: the time constant for mixing a surface-released tracer completely in the atmosphere and stratosphere is estimated at 3.5 years.

- Clx from Historical Emissions: the algorithm estimates changes in Clx from levels in 1985. The contribution of historical emissions to these changes was estimated by Connell (1986) and is presented in Exhibit I-2. As shown in the exhibit, the contributions is initially positive, reflecting the mixing in of emissions prior to 1985. Over the long term the contribution becomes negative, reflecting the decay of the atmospheric abundance associated with emissions prior to 1985.

Given these values, the contribution of each compound to changes in Clx in year t relative to 1985 levels is computed as:

$$Clx(t,j) = CF(j) * \sum_{i=1}^{t} emissions(j) * e^{-(t-i)/L(j)} * (1-e^{(t-i)/MT})$$

where:

Clx(t,j) = the change in Clx in year t (relative to 1985) associated with emissions of compound j;

CF(j) = conversion factor for compound j;

L(j) = atmospheric lifetime of compound j;

MT = mixing time.

To compute the total change in Clx in year t, the contributions from each of the compunds is summed, and added to the change in Clx associated with pre-1985 emissions.

This general method is also used for computing halon abundances. However, the halon abundances are of the entire molecules, and are not adjusted for the number of bromine and/or chlorine atoms, or their relative efficiencies at perturbing stratospheric ozone. Also, the contributions of historical halon emissions to future changes in abundances from 1985 are assumed to be zero.

EXHIBIT I-1

CONVERSION FACTOR COMPUTATION DATA

Compound	#Cl/Molecule[a]	Molecular Weight	Relative Efficiency	Conversion Factor[b]
CFC-11	3	137.4	1.09	1.304×10^{-4}
CFC-12	2	120.9	0.75	0.679×10^{-4}
CFC-22	1	86.5	0.428	0.271×10^{-4}
CFC-113	3	187.4	1.017	0.891×10^{-4}
CFC-114	2	170.9	0.594	0.381×10^{-4}
CFC-115	1	154.5	0.187	0.066×10^{-4}
CCl4	4	153.8	1.103	1.571×10^{-4}
CH3CCl3	3	133.4	1.185	1.459×10^{-4}

[a] #Cl/Molecule = number of chlorine atoms per molecule.

[b] For each compound, the conversion factor is computed as: 5.477×10^{-3} * (#Cl/Molecule) / Molecular Weight * Relative Efficiency.

Sources: Adapted from P.S. Connell, A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere, Lawrence Livermore National Laboratory, Livermore, California (1986). Compound lifetimes and ozone depletion estimates used here are from Fisher, D.A., Hales, C.H., Filkin, D.L., Ko, M.K.W., Sze, N.D., Connell, P.S., Wuebbles, D.J., Isaksen, I.S.A., Stordal, F., "Relative Effects on Stratospheric Ozone of Halogenated Methanes and Ethanes of Social and Industrial Interest," in AFEAS Report, 1989. (unpublished).

EXHIBIT I-2

CONTRIBUTION OF PRE-1985 EMISSIONS TO POST-1985 CHANGES IN Clx

Change in Clx Year	ppbv
1985	0.000
1990	0.045
1995	-0.079
2000	-0.206
2005	-0.316
2015	-0.495
2020	-0.571
2025	-0.641
2030	-0.706
2035	-0.767
2040	-0.823
2045	-0.876
2050	-0.926
2055	-0.973
2060	-1.017
2065	-1.059
2070	-1.098
2075	-1.135

Source: Connell 1986.