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CHLOROFLUOROCARBON ENVIRONMENTAL
ISSUES RELATED TO CONSERVATION
ACQUISITION IN COMMERCIAL BUILDINGS

T. J. Marseille
M. C. Baechler

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Pacific Northwest Laboratory
Richland, Washington 99352

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SUMMARY

Recent scientific evidence strongly suggests that the release of large quantities of chlorofluorocarbon (CFC) gases into the atmosphere will result in environmentally harmful long-term effects. Because of those effects, a massive worldwide effort is currently under way to ban their use.

At request of the Bonneville Power Administration, the Pacific Northwest Laboratory conducted a literature search to identify the issues surrounding the CFC phaseout. The search was focused on how these issues impact the commercial building sector. Information was obtained that describes:

- how the release of CFCs into the atmosphere may affect the global environment
- legislative and regulatory programs initiated to restrict CFCs
- potential impacts the reduced CFC supply will have on commercial buildings
- the most promising CFC substitute technologies
- the potential costs of CFC restriction.

Chlorofluorocarbons pose a twofold environmental threat. First, in sufficient concentrations, CFCs could significantly deplete ozone in the stratosphere, allowing increasing amounts of ultraviolet (UV) rays to penetrate to the earth's surface. Second, CFCs are known "greenhouse gases," and, thus, will contribute to the expected man-induced global warming phenomena.

Concern over these environmental effects has led to international treaties such as the Montreal Protocol calling for the complete phaseout of CFCs. National and local legislative activity has also flourished, resulting in uncertainty about what the eventual regulations regarding CFCs and other ozone-depleting halocarbons will be and what alternative fluids will be allowed.

The primary uses for CFCs in commercial buildings include air conditioning, retail food refrigeration, and rigid foam insulation. Replacement of CFCs in these applications is expected to have both energy and cost ramifications. However, assuming a technologically conservative scenario for the

phaseout, the overall energy impact on the commercial building sector appears to be small, with energy penalties on the order of only 5 trillion Btu by 2000 and 42 trillion Btu by 2010 over predicted levels if no CFC ban occurs. Costs are more uncertain, being highly dependent on when non-CFC substitute fluids and equipment become commercially available, and at what price.

Capital obsolescence of existing equipment is an economic danger that will be magnified by more stringent phaseout timetables. However, a well organized and executed refrigerant reclaim and recycling program, along with improved practices designed to minimize leakage and service losses, should help extend CFC supplies to meet the decreasing demands over the coming years.

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1.0 INTRODUCTION

Recent scientific evidence has generated strong recognition of the environmentally harmful long-term effects caused by the release of large quantities of chlorofluorocarbon (CFC) gases into the atmosphere. As a result, a massive worldwide effort is currently under way to first restrict and then end CFC use. Research and development (R&D) is ongoing to find acceptable CFC replacements and alternative technologies. The success of these research and development programs, as well as the subsequent integration of their products into the commercial sector, are crucial if current and proposed timetables for the CFC phaseout are to be met and the costs to society minimized.

This report provides an overview of CFCs, the ways in which their release into the atmosphere may eventually affect our global environment, and some of the legislative and regulatory programs that have been initiated to restrict their use. Some of the potential impacts that the reduced CFC supply will have on the commercial building sector are then described, followed by a discussion of potential CFC substitutes and alternative technologies, and their incorporation into everyday use. Finally, the results of an Energy Information Administration (EIA) analysis assessing the potential costs of restricting CFC usage (EIA 1989) are summarized.

1.1 THE BONNEVILLE POWER ADMINISTRATION ENVIRONMENTAL ASSESSMENTS

Pacific Northwest Laboratory^(a) (PNL) prepared this review for the Bonneville Power Administration (Bonneville) to aid that agency in preparing environmental documents. Bonneville has taken a leading role among federal agencies in assessing the environmental impacts of its conservation acquisition programs. These efforts have included extensive research programs into residential ventilation and indoor pollution characterization and monitoring.

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

Bonneville has also prepared three environmental documents under the National Environmental Policy Act (NEPA) that focused on the environmental effects of conservation measures.

One of these documents, the 1982 *Environmental Assessment of Energy Conservation Opportunities in the Commercial-Sector Facilities in the Pacific Northwest*, supported conservation programs in existing buildings (Bonneville 1982). Bonneville is now planning the implementation of aggressive commercial conservation programs in both new and existing buildings. Because of changing information, and because of the change in scope of the anticipated programs, Bonneville is now reexamining the potential environmental effects of conservation activities in commercial buildings.

1.2 DEFINITION OF CHLOROFLUOROCARBONS

Chlorofluorocarbons are one member of the halocarbon family, chemically stable compounds derived from common hydrocarbons such as methane, ethane, and propane. The halocarbons also include hydrogenated chlorofluorocarbons (HCFCs) and hydrogenated fluorocarbons (HFCs). Of all the halocarbons, the most commonly used are CFCs. These include most of the best refrigerant fluids available today, as well as the foaming agents in low-density insulating materials that have greatly improved the energy efficiency of both buildings and appliances. For this reason, CFC use is widespread; worldwide annual production reached approximately 2 billion pounds in 1986 in First- and Third-World countries. Of that total, more than 700 million pounds was in the United States (Moore 1989).

1.3 THE CHLOROFLUOROCARBON THREAT TO THE OZONE LAYER AND GLOBAL WARMING

Chlorofluorocarbons have life expectancies on the order of 100 years. It is theorized that over time, individual CFC molecules that have been released on the earth's surface diffuse into the stratosphere, where they then will break down under ultraviolet (UV) bombardment from the sun. Once broken down, the halogen chlorine, found in all CFCs, disrupts normal stratospheric chemistry, causing ozone destruction. It has been estimated that every free atom of chlorine can participate in the destruction of 100,000 ozone molecules (DOE 1989). The environmental significance of this phenomenon lies in the fact

that the so-called "ozone layer" found in the stratosphere normally acts as a protective shield to the earth, effectively blocking harmful UV rays emitted from the sun from reaching the surface. The U.S. Environmental Protection Agency (EPA) has predicted that every 1% decrease in ozone will result in a 1% to 2% increase in melanoma skin cancer incidence (Baechler 1989). Other expected effects of ozone depletion include crop damage, increased incidence of cataracts, increased formation of tropospheric ozone (smog), and increased degradation of manmade materials such as polymers. The term *ozone depletion potential* (ODP) has been developed to provide a relative measure of the detrimental effect that different chemicals have on the ozone layer.

The second threat posed by the release of CFCs into the atmosphere relates to global warming, also known as the *greenhouse effect*. Concentrations of various gases found in the atmosphere, known collectively as the greenhouse gases, are increasing because of society's activities. Among these gases are CFCs and carbon dioxide (CO₂). Because of these larger concentrations, a larger portion of the long-wave radiation emitted from the earth's surface that previously escaped into space is absorbed by these gases, producing additional heat that warms the atmosphere. The term *global warming potential* (GWP) has been developed as a relative measure of the potential of various greenhouse gases to absorb long-wave radiation. The GWP of CFCs is as much as 10,000 times as large as that of CO₂, which is by far the most prevalent greenhouse gas. Thus, though much smaller concentrations of CFCs than CO₂ are present in the atmosphere, it is estimated that CFCs contribute approximately 10% to 15% to the greenhouse effect.^(a)

1.4 DIFFERENCES BETWEEN HALOCARBON REFRIGERANTS

In CFCs, all of the hydrogen atoms surrounding the carbon atoms in the original hydrocarbons are replaced by either fluorine or chlorine--two of the so-called halogen elements.

(a) Herbert T. Gilkey, Speaker, April 6, 1990, CFC Seminar for Inland Empire Chapter of American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. and Washington State Energy Office. Spokane, Washington.

Hydrogenated chlorofluorocarbons are similar to CFCs except that some of the original hydrogen atoms remain. These compounds generally contain less chlorine and break down sooner in the atmosphere than CFCs. Thus, HCFCs have lower ODPs, meaning that they have less of an impact on the ozone layer. Their shorter atmospheric lifetimes also result in lower GWPs, reducing global warming as well. Coupled with the fact that many HCFCs have thermodynamic and physical properties similar to those of CFCs, these lower ODPs and GWPs make HCFCs, at least in the near term, attractive potential candidates for replacing CFCs in many applications.

Hydrogenated fluorocarbons are fluorine compounds that are similar to HCFCs and CFCs except that they contain no chlorine. Consequently, they have ODPs of 0. They also have shorter atmospheric lifetimes than CFCs and, thus, lower GWPs. Conversion to these substances in applications that currently employ CFCs is thus environmentally highly desirable.

Halons, a similar group of compounds, differ from CFCs in that they include bromine, the heaviest halogen element. Bromine has been found to have a higher potential for ozone damage than chlorine; thus, halons are usually included in environmental discussions about CFCs for completeness. Halons are used primarily as a fire-extinguishing agent in total flooding systems for critical civilian electronics installations and military applications. Halon use in commercial buildings is limited, so halons will not be discussed further in this report.

2.0 LEGISLATIVE AND REGULATORY PROGRAMS RESTRICTING CHLOROFLUOROCARBON USE

In response to the recognized threat CFCs pose to the ozone layer, over 60 nations, including the United States and other major world economies that produce and use CFCs, participated in drafting an international treaty known as the Montreal Protocol.^(a) The treaty commits signatory nations to reduce the production of CFCs, halon gases, and two other ozone-depleting compounds that contain chlorine--carbon tetrachloride and methyl chloroform--by 50% by the year 1998. Currently, 56 nations have signed this protocol.

More recent scientific evidence has indicated an even higher ozone-depleting potential for chlorine and bromine compounds than originally suspected, prompting further international response. The ODPs, GWPs, and atmospheric life expectancies of each of the major halocarbons are summarized in Table 2.1. A March 1989 meeting of the European Economic Community (EEC) called for a complete CFC phaseout by 2000, and a phaseout of HCFCs by 2005. The contracting parties to the Montreal Protocol met in Helsinki, Finland, in May 1989 and approved a declaration that stated a similar intent to phase out all consumption of CFCs by the year 2000 (assuming that environmentally acceptable alternatives are available), and a more gradual phaseout of applications using the less damaging HCFCs (Lorenz and Goswami 1990). A meeting held in London in June 1990 resulted in the adoption of these more stringent proposals. The new schedule is shown in Table 2.2.

On July 1, 1989, EPA regulations designed to implement the first stage of the Montreal Protocol took effect. Different arms of the federal government are actively developing accelerated phaseout plans of their, independent of the June 1990 meeting of United Nations Environmental Program (UNEP). The EPA is currently drafting a Notice of Proposed Rulemaking (NOPR) for more stringent regulation of CFC production. Release of this NOPR was still pending at the time this document was prepared. An amendment to the Clean Air Act was approved by the U.S. Senate in March 1990 that provides for a phaseout

(a) Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environmental Program (UNEP), Final Act, September 1987.

TABLE 2.1. Potential Environmental Effects of Refrigerants

		<u>Atmospheric Lifetime</u>	<u>Ozone Depletion Potential</u>	<u>Global Warming Potential</u>
CFC	11	60	1.00	1.00
	12	120	0.93	3.20
	113	100	0.83	1.45
	114	240	0.71	4.95
	115	540	0.38	10.60
Blends	500 (73.8% of R-12: (26.2% of R-152a)			
	502 (51.2% of R-115: (48.2% of R-22)			
HCFC	22	18	0.05	0.40
	123	2	0.02	0.02
	124	8	0.02	0.11
	141b	8	0.09	0.10
	142b	22	0.05	0.40
HFC	125	30	0	0.63
	134a	18	0	0.31
	143a	47	0	0.80
	152a	2	0	0.04
R-717	(Ammonia)	< 2 weeks	0	No

Source: UNEP/WMO 1989, "Scientific Assessment of Stratospheric Ozone: 1989."

schedule that is even more aggressive than the schedule agreed upon at the June 1990 UNEP meeting. Included is a ban on HCFCs for use in new equipment by 2015, a 100% ban on HCFC production by 2030, and guidelines for government procurement policies on CFC equipment. The U.S. House of Representatives also approved a clean air act amendment with similar restrictions. The Omnibus Budget Reconciliation Act of 1989 included substantial tax burdens for chemicals covered by the Montreal Protocol to help discourage their future use, even though scarcity of these chemicals due to limited production will drive prices up because of market pressures. Finally, an amendment to the Federal Energy Management Act (S.324) requires CFC replacements to be used in the federal sector.

TABLE 2.2. Phaseout Schedules Agreed Upon at June 1990
UNEP Meeting in London

CFCs	Production phaseout by year 2000 if environmentally acceptable alternatives are available
HCFCs	New equipment phaseout by 2020-2040
	Existing equipment phaseout by 2035-2060
Halons	Phaseout by 2000, provided that safe substitutes are available
Carbon tetrachloride	Freeze with phaseout along with CFCs
Methyl chloroform	Cutback of 25-100% by year 2000

Along with these federal initiatives, 21 state governments including Oregon and Washington have also considered CFC legislation of their own (Lorenz and Goswami 1990). The banning of polystyrene foam food containers from Portland, Oregon, restaurants further demonstrates the growing regional interest in controlling CFCs.

In summary, it is uncertain what the exact phaseout schedule of ozone-depleting chemicals will be because consideration must be given to ongoing events and proposed regulations on international, national, state, and local levels. It now appears, though, that the most conservative schedule would be the one outlined in Table 2.2.

3.0 THE USE OF CHLOROFLUOROCARBON IN THE COMMERCIAL BUILDING SECTOR

In the United States, nearly 60% of all CFC usage is energy related (EIA 1989). Major applications include home refrigeration, retail food refrigeration, building and appliance insulation, commercial air conditioning, mobile air conditioning, and miscellaneous industrial applications. Total primary energy consumption for equipment containing CFCs was estimated to be 5.8 quadrillion Btu in 1986 (EIA 1989). However, the overall impact that CFCs have on energy consumption is considerably greater because of their widespread use as a foaming agent in insulation for buildings and appliances.

The EIA recently concluded a report in which the prospects and problems related to the reduction of CFC usage were considered for each major CFC application (EIA 1989). In this report EIA describes a "best judgment" scenario that is based on technical information then available (August 1989). In the scenario, conventional air-conditioning and refrigeration technology and foam insulation manufacturing concepts are assumed to be essentially unchanged but will use non-CFC replacements.

The EIA used this technologically conservative scenario because 1) the relative infancy of development efforts of the more innovative alternative technologies described in Section 3.4 makes large-scale commercialization in the 1990s unlikely, and 2) other commercially available alternatives will likely have only limited applications. Finally, because industry is reluctant to commit to major new equipment designs and tight timetables until it is clear what future regulations restricting their use will actually be, this conservative path has wide support.

The discussion that follows in Sections 3.1, 3.2, and 3.3 regarding commercial building applications of CFCs, the likely phaseout scenario, and associated technical issues, emphasizes the EIA report. However, it should be recognized that many uncertainties remain with respect to the timely and successful commercialization of the CFC substitutes identified in this scenario. In Section 3.4, alternative technologies are described that may provide long-term solutions if, for example, a complete ban on HCFCs does

follow the CFC phaseout. Energy conservation measures (ECMs) that may be impacted by the CFC phaseout are described in Section 3.5.

3.1 COMMERCIAL AIR CONDITIONING

Two general types of heating, ventilating, and air-conditioning (HVAC) systems are used to air condition most commercial buildings. Each is discussed in the following paragraphs.

3.1.1 System Descriptions

One type of HVAC system uses unitary packaged equipment. This type of equipment is typically used for smaller applications to directly cool air. Most of this type of equipment uses HCFC-22. The low ODP and GWP and good thermal physical properties make HCFC-22 an attractive alternative refrigerant for applications using CFCs. Thus, assuming that public sentiment does not result in a political push for an accelerated phaseout of HCFCs, the unitary equipment sector of the commercial HVAC market should be little affected in the near term. It may actually enjoy an increased market share in the short term because of owners' and engineers' concerns about the future cost and availability of equipment that uses CFCs.

The other type of HVAC system commonly found in commercial buildings uses a vapor compression cycle liquid chiller to cool water, which is then circulated to heat exchangers for cooling and dehumidifying air. Liquid chillers primarily use one of three compressor designs: centrifugal, reciprocating, and, to a lesser extent, screw. Chiller capacities range from 10 to 10,000 tons refrigeration; however, most are between 100 to 500 tons capacity and use centrifugal compressors. Life expectancies normally are 25 years for centrifugal and 20 years for reciprocating/screw compressor chillers.

Design optimization considerations have resulted in the use of CFC-11 and (to a lesser extent) CFC-12 for most centrifugal chiller applications, though machines using CFC-114, R-500 (an azeotrope [solution] of CFC-12 and HFC-152a), and HCFC-22 (over 1500 tons) are also manufactured in small quantities.

Reciprocating compressor liquid chillers are generally smaller than 100 tons and are increasingly being manufactured for use with HCFC-22, where in the past CFC-12 was used. Centrifugal chillers using HCFC-22 are also currently available from 1500 to 8000 tons.

3.1.2 Chlorofluorocarbon Reduction Strategies for Liquid Chillers

To avoid or mitigate the costs of converting to dramatically altered equipment designs, equipment manufacturers have pushed for the development of near drop-in substitutes. A near drop-in substitute is one that can directly replace existing refrigerants in current equipment designs with little impact on operating performance and with only minor, if any, modification required to the equipment. Three candidate refrigerants have been identified as the most promising substitutes for most applications: HFC-134a for CFC-12, and HCFC-123 for CFC-11, and a ternary blend of HCFC-22, HFC-152a, and HCFC-124 for CFC-12. Recent published research on refrigerants has focused primarily on these substitutes.

The refrigerant HCFC-123 is currently undergoing field testing in equipment that originally used CFC-11. HCFC-123 has an ODP of 0.02, only 2% that of CFC-11. This refrigerant is corrosive to gaskets and low-voltage motor windings,^(a) found in CFC-11 chillers. These problems are of sufficient severity that the field replacement of HCFC-123 in existing CFC-11 chillers is deemed economically impractical. These problems also have prompted development efforts to find new materials for these parts in future chillers.

Two of the major chiller manufacturers, Trane and York, have recently announced that HCFC-123 compatible chillers will soon be available for shipment. However, both long-term toxicity tests and construction of large-scale HCFC-123 production facilities are still underway, forestalling its large scale use in commercial products until at least 1993 (EIA 1989). Federal legislation limiting the acceptable concentration of HCFC-123 to 100 parts per million (ppm) in mechanical equipment rooms has been passed.

(a) In high-voltage motor applications (>600 V), the low-corona voltage limit of HCFC-123 makes it totally incompatible in motor-cooled chiller designs.

Recently, it was announced that HCFC-133a, the primary decomposition product of HCFC-123, is an animal carcinogen (*The Air Conditioning, Heating, and Refrigeration News* 1990). HCFC-133a has been found in small quantities under certain conditions in chiller and rigid foam applications. The regulatory impact this new finding may have on the introduction and use of HCFC-123 has not as yet been announced. Overall, it has been estimated that shifting from CFC-11 to HCFC-123 would increase new chiller installation costs by between 5% and 15%, with energy penalties of about 4% (Little 1989).

HCFC-123 also appears to be compatible with CFC-11 as a blend, and could thus help reduce future demand for CFC-11 in the existing installed liquid chiller stock. This demand is the result of service venting and leaks, and amounts on average to between 10 and 30 million pounds annually of the total installed chiller refrigerant charge of 97 million pounds nationally (EIA 1989).

The replacement of CFC-12 with HFC-134a poses similar problems. HFC-134a is chemically more reactive than CFC-12 and would require different desiccants, gaskets, and motor-insulating materials for hermetic motor-compressor designs or shaft seals for open drive machines. It also has a slightly lower theoretical cycle efficiency than CFC-12 and decreased capacity. Lubricity problems have also been encountered during drop-in tests using HFC-134a in automotive air conditioners (EIA 1989). These problems occurred because mineral oil, commonly used in CFC-12 applications, is nonmiscible with HC-134s. Extensive ongoing research into synthetic oils for HFC-134A applications has identified polyalkylene glycols and esters as likely candidate lubricants. With an appropriate oil, it is assumed that the overall negative impact on energy efficiency of using HCFC-134A will be between 4% and 8%. Toxicity testing of HCFC-134a is also still underway, and is expected to continue until 1992. As was the case with HCFC-123 use in CFC-11 chillers, the material incompatibilities make its use as a field drop-in to existing CFC-12 chillers unlikely.

The ternary blend of HCFC-22, HFC-152a, and HCFC-124 recently announced by DuPont appears to be a near drop-in substitute for CFC-12 (and possibly R-500) (Little 1989). It has an overall ODP of approximately 0.03 and a cycle

efficiency and capacity that are slightly improved when compared to CFC-12, provided that the chillers, evaporator, and condenser heat exchangers are enlarged to account for the ternary blend's poorer heat transfer performance (>10% decrease). However, concerns over 1) small composition shifts during operation in flooded evaporators, 2) lubricity issues, 3) flammability of HFC-152a, and 4) the uncertain toxicity characteristics of HCFC-124 make the ternary blend's earliest expected commercial availability date sometime after 1995.

Theoretically, another option would be to use HCFC-22 in all sizes of liquid chillers. However, major redesign and retooling of existing production facilities would be required to do this because HCFC-22

- has significantly higher working pressures and different operating characteristics than CFC-11 or CFC-12
- is nearly twice as expensive
- has a lower cycle efficiency.

Because of these concerns, HCFC-22 is not suitable as a drop-in substitute to help serve the existing chiller stock. Nonetheless, consideration is being given toward redesigning HCFC-22 compressors down from the current lower limit of 1500 tons to 200 tons. Because of its lower cycle efficiency, this would result in an energy penalty of up to 10% and a cost premium of 5% to 15% over existing chillers in the lower capacity ranges (Little 1989).

Another major industry push toward reducing CFC usage has been to change operational practices in order to extend future CFC supplies. This includes practices that minimize leakage and venting both in the field and during manufacturing, and making recycling and reclamation of CFCs a standard service practice in larger equipment (ASHRAE 1990). If successfully implemented, such a program could reduce the costs associated with the early capital obsolescence of chillers that use CFCs after new CFC production stops.

3.2 RETAIL FOOD REFRIGERATION

The use of CFCs in retail food stores generally falls into two categories: medium-temperature applications for cooling dairy, meat, and related

products; and low-temperature applications for frozen foods. These systems tend to be built up, in that installing contractors do most of the refrigerant piping, interconnecting the various systems components supplied by equipment vendors (i.e., compressor, condenser, evaporator). Because of their size and the amount of piping required, system refrigerant requirements are large, often as high as 40 to 60 lb/ton (Little 1989).

Currently, medium-temperature refrigeration systems are increasingly being designed and installed with HCFC-22, displacing earlier CFC-12 designs. This change is driven in part by lower capital costs and in part by recognition of the upcoming CFC phaseout. Energy consumption and other operating costs of HCFC-22 systems are about the same as those using CFC-12 in these applications. Thus, the industry planned near-term (2 to 4 years) conversion to only HCFC-22 new systems should proceed with little difficulty. Also, because the average useful life of retail refrigeration equipment is only 10 years (Little 1989), recycling of CFC-12 will limit capital obsolescence of existing CFC-12 based equipment, even if no true drop-in substitute is released commercially.

Most of the low-temperature equipment currently sold uses R-502, an azeotrope containing CFC-11 and HCFC-22. These systems are currently being redesigned to use HCFC-22 alone. Achieving similar (or improved) energy efficiency over an R-502 system, and limiting excessively high gas discharge temperatures, requires using a two-stage compression system with intercooling and interstage liquid subcooling. This type of system is well understood, but the additional hardware requirements are expected to raise capital costs on the order of 5% (EIA 1989). However, the estimated potential 20% to 30% efficiency improvement will help offset these higher costs.

3.3 ALTERNATIVE AIR-CONDITIONING/REFRIGERATION TECHNOLOGIES

Several technologies are being considered in addition to simply replacing CFCs with substitute HFC and HCFC refrigerants. These alternatives are considered longer-term solutions because of the time required for their development and subsequent commercialization.

Current absorption chillers operate at a much lower coefficients of performance (COP) than do electric-driven vapor compression cycle chillers, and thus use considerably more primary energy. In addition, they can cost twice as much as equivalent capacity vapor compression liquid chillers, and have difficulty producing water cooler than 42°F (Little 1989). Nonetheless, sales of absorption equipment have increased over the last few years, primarily as a means of reducing electrical demand charges. Advanced multi-effect absorption cycle concepts under development have the promise of raising COPs to levels comparable to those of vapor compression cycle chillers (Little 1989). Gas-fired absorption chillers are also beginning to make an impact in the United States, and it is possible that through the continued research push by the gas industry, improved designs will emerge that are competitive.

The use of ammonia in vapor compression cycle chillers is being seriously considered for commercial applications as an alternative to halocarbons. Currently used in some low-temperature refrigeration applications, ammonia has a theoretical cycle efficiency that is nearly the same as CFC-11 or CFC-12 at temperature ranges suitable for commercial air conditioning. Because ammonia's physical properties differ from the halocarbons, vastly different compressor and heat exchanger designs/materials would be required, thus slowing the time frame within which commercial liquid ammonia chillers could be introduced into the market. In addition, the high toxicity of ammonia has raised serious questions about its suitability for commercial applications when units are located indoors (Little 1989).

Another promising cooling system technology that has recently been receiving renewed interest is Stirling cycle-based air-conditioning and refrigeration equipment. Preliminary research indicates that Stirling cycle air-conditioning systems could have cycle efficiencies approaching those of vapor compression systems. However, there would probably be a significant cost premium for Stirling cycle equipment, because of the need for highly effective heat exchangers.

Desiccant-based air-conditioning systems also are being viewed as one alternative to CFC-using air-conditioning equipment. Desiccant systems are used to absorb moisture and the latent heat associated with the moisture from

a building's supply airstream. The very dry air created by the desiccant is then cooled sensibly before being injected into the building's conditioned spaces by a heat exchanger containing evaporatively cooled water. Improved desiccant materials and systems that would significantly lower costs are currently under development by the U.S. Department of Energy (DOE) and the Gas Research Institute (GRI). However, even with improved desiccant systems, this alternative is still limited to applications where ambient wet-bulb temperatures are always low enough to ensure the effective use of evaporative coolers.

3.4 CHLOROFLUOROCARBONS IN COMMERCIAL BUILDING INSULATION SYSTEMS

Rigid foam insulation containing CFCs has recently become popular in commercial building construction. These insulations are used primarily in masonry cavity walls, prefabricated panel walls, and low-slope roofs, and in the construction of the building HVAC and refrigeration systems. The primary types of rigid foam insulation used for these applications include extruded polystyrene, polyisocyanurates, and phenolics.

In rigid foam insulation, the blowing agent used in the foaming process becomes a captured gas within the cells of the product, contributing in part to the product's structural characteristics. Thus, release of the blowing agent gas into the atmosphere does not occur at the time of use, but gradually over a period of years. Because of the very low thermal conductivity of CFC-11 and CFC-12, CFC blowing agents exhibit superior insulating properties compared to other readily available blowing agents, and consequently are being widely used.

The effect of a CFC phaseout on the insulation industry is somewhat more straightforward than it is in commercial air conditioning in that there is no residual demand for CFCs after production of the insulation is completed, and recycling or reclamation of refrigerants from scrapped insulation is not deemed practical. The primary concern is finding a good alternative to CFCs for the rigid foam insulation that is produced in the future.

Recently, several alternative blowing agents have been identified that exhibit thermal properties nearly as good as those of CFC-11 and CFC-12, and meet the other physical requirements for a good blowing agent. These include

HCFC-123, HCFC-141b, and HFC-134a. When incorporated into foam insulation, the insulating capability is 90% to 95% as good as identical-thickness insulation made with CFCs (EIA 1989). Although the long-term toxicity tests of these chemicals will not be completed until around 1992 and large commercial quantities are not yet available, the expectation is that after 1993 CFCs will be phased out in favor of these new blowing agents (EIA 1989).

In the interim, some foam manufacturers have begun reducing CFCs in insulation by diluting them with carbon dioxide. Assuming that the amount of carbon dioxide is less than one-third of the mixture, most of the insulating capability is maintained (EIA 1989).

Oak Ridge National Laboratory (ORNL) (Fisher 1990) concluded an energy impacts study on CFCs that estimated the incremental increase in annual energy consumption that would result from decreases in the R-values of roofs and walls. The ORNL analysis included several broad assumptions to simplify characterization of the existing commercial building stock, its energy usage and space-conditioning loads, construction practices, and the current market penetration of rigid foam insulation. Oak Ridge found that use of rigid foam insulation with R-values 15% worse than those constructed using CFCs would have resulted in an incremental increase in energy consumption on the order of only 0.07 quadrillion Btu annually if applied to the entire existing commercial building stock. This negligible change is due in part to the fact that the large percentage of window area in walls (30%) used in the analysis minimizes the impact of changes in wall insulation R-values on total heat gains/losses.

The foregoing information suggests that the future increase in energy usage because of CFC substitute foaming agents in commercial building insulation is likely to be small. The higher production costs of these substitute chemicals compared to CFCs may result in lower market shares in the future for this type of product because of noncompetitiveness with alternative insulations that have lower R-values. If this happens, future energy usage could increase. Alternatively, a sacrifice in energy efficiency may not occur at all using the CFC substitute foaming agents if the thickness of the installed insulation were increased 0.1 inch for every 1-inch thickness, an adjustment

that would not pose a serious difficulty in most applications (EIA 1989). Finally, energy consumption might actually drop in the future if the market share of these products increases above current levels (65% of low slope roof construction, 40% of commercial building walls) (Fisher 1990) because even rigid foam insulation constructed using CFC substitutes appears to be considerably more effective as an insulator than alternative insulation designs.

3.5 POTENTIAL COMMERCIAL BUILDING ENERGY CONSERVATION MEASURES IMPACTED BY CHLOROFLUOROCARBON BAN

Because the use of CFCs is prevalent both in air-conditioning and refrigeration applications and in building insulating products, the impact of several ECMs on energy usage in the commercial building sector could be altered. For example, because of the CFC ban's potential negative impact on the future energy efficiency of air-conditioning equipment used, the cost payback incentive of some ECMs may be diminished. Of course, for most packaged unitary equipment, HCFC-22 is the predominant refrigerant, and is, at least for now, considered part of the short-term solution. Thus, for ECMs related to packaged equipment such as heat pumps, the CFC ban initially should be of small import. Of more concern are the impacts on those ECMs related to liquid chiller air-conditioning systems, because these use CFC-11 and CFC-12. These could include

- installation of high-efficiency chillers
- installation of efficient compressors
- installation of thermal storage.

In retail food refrigeration, for example, the ECM that may be impacted from the use of CFC substitutes would be the installation of efficient compressors.

Rigid foam insulating building materials could potentially increase in cost and/or decrease in insulation effectiveness. ECMs impacted by this would include insulating systems for walls, roofs, ceilings, floors, foundations, slab perimeters, and the replacement of existing doors with insulated doors.

In summary, ECMs that could be impacted by the CFC phaseout can be identified. However, uncertainty as to 1) what CFC phaseout schedule will finally be adopted, 2) what the final technical solutions will be, and 3) when these solutions will be commercially available make it difficult to quantify with confidence the effect of the CFC ban on specific ECMs in commercial buildings.

4.0 IMPACT OF RESTRICTING CHLOROFLUOROCARBONS

In response to a request by the U.S. Secretary of Energy, the EIA recently developed a capital vintaging computer model to estimate existing stocks, capital and operating (including energy) costs, energy use, and CFC consumption and emissions for CFC-using equipment and their non-CFC-using replacements (EIA 1989). Another economic analysis that also considers environmental impacts was conducted by the EPA in preparation for the June 1990 London meeting of the Montreal Protocol contracting parties. Because the EPA report was unavailable at the time this report was being prepared, the discussion that follows is limited to describing the EIA analysis and results.

4.1 ENERGY INFORMATION ADMINISTRATION ANALYSIS SCENARIOS

The EIA analysis considered three separate scenarios:

- **Scenario 1: no limitations on CFC use** - This case bounds the lowest cost, as no restriction on CFC usage is assumed.
- **Scenario 2: phaseout in new equipment** - This scenario assumes CFCs are gradually phased out in newly manufactured equipment over the 1990s. Sufficient supplies of CFCs to service this equipment are expected to be available until their normal retirement.
- **Scenario 3: no CFCs after 2000** - This scenario assumes that CFCs are simply unavailable after 2000, forcing the early retirement of CFC-using equipment as soon as additional CFCs are needed for servicing, and the immediate replacement by non-CFC equipment. This case bounds the maximum cost of capital obsolescence.

Three sensitivity analyses were also performed to bound potential costs. These are:

- **Sensitivity 1** - A conservation/recycling program is initiated, reducing production demand for new CFCs.
- **Sensitivity 2** - A 3-year delay in the phaseout of CFC-using equipment occurs because new equipment and non-CFC refrigerants are not commercially available soon enough.

- **Sensitivity 3** - A high cost case, where costs for non-CFC substitutes and equipment are assumed to be at the high end of DOE's technology assessments range (Little 1989), rather than the middle.

4.2 CHLOROFLUOROCARBON DEMAND

Demand for CFCs in the commercial air-conditioning sector assuming a phaseout in new equipment (Scenario 2) would only reduce to 76.8% of 1986 production levels, because its capital stock turns over slowly. Thus, though new equipment does not use CFCs, servicing requirements are still high. The EIA estimates demand could potentially be reduced by one fourth in 2000 if 40% of the refrigerant normally lost from equipment servicing and scrappage were recycled. By cannibalizing some pieces of equipment to keep others running additional CFC refrigerants could be made available. However, this early obsolescence increases economic costs.

Under Scenario 2, retail food refrigeration CFC demand drops to 15% of 1986 production levels and continues to decline to zero by 2006. In this case, recycling would also help ease demand, but it is not as important as with commercial water chillers because of a generally more rapid turnover in capital stock.

4.3 COST IMPACTS

The economic impacts of phasing out CFCs take two different forms: changing capital and operating costs of non-CFC-using equipment relative to CFC-using equipment and early capital obsolescence costs of equipment if CFCs become unavailable before normal retirement.

For the analysis, the assumed energy efficiency change for chillers that previously used CFC-11 is a 3% decrease, with an increase of 10% in capital costs. All other chillers are assumed to increase 5% in capital cost, but at no change in energy efficiency. Results of Scenario 1 indicate that the net present value of the increase in capital and operating (including energy) costs of chillers from 1989 to 2000 is only \$0.1 billion in 1988 dollars. Extended through 2015, the net increase is \$0.6 billion in 1988 dollars. Because the change in energy efficiency of future chillers is assumed to be

small, the sensitivity of this total to the price of energy is small. Assuming that the energy and capital costs are high (Sensitivity 3), these costs increase to \$0.5 billion through 2000 and \$2.8 billion through 2015 (in 1988 dollars).

Retail refrigeration capital and operating costs associated with replacing medium-temperature CFC-12 applications is projected to decrease by 3%, offsetting a 3% increase associated with replacing low-temperature R-502 applications. No net change in energy efficiency is forecast. Because of this, results indicate no appreciable change in the net present value of costs for retail food refrigeration.

As described earlier in Scenario 3, an upper bound on potential capital obsolescence costs was estimated by assuming that no CFCs are available after 2000, and that all remaining CFC-using equipment is scrapped and replaced as soon as additional CFCs are needed for servicing. This results in a sharp jump in costs right after 2000, with a total increase of approximately \$1.5 billion for commercial water chillers and \$0.12 billion for retail food refrigeration (1988 dollars). This cost could be reduced on the order of 25% through increased conservation and recycling efforts (Sensitivity 1). Reclamation of CFC refrigerant from scrapped equipment could further reduce capital obsolescence costs by 20% to 30%. On the other hand, the EIA assumes that replacement non-CFC equipment will be introduced within the next few years. A 3-year delay (Sensitivity 2) would raise the capital obsolescence for chillers to \$2.0 billion, and retail food refrigeration to \$0.5 billion (1988 dollars).

4.4 ENERGY IMPACTS

Under Scenario 2, increased energy usage due to the phaseout of CFCs is predicted to be modest. Assuming a gradual phaseout of CFCs, the increase in total annual energy consumption nationally for commercial liquid chillers is only 5 trillion Btu in 2000 and 42 trillion Btu in 2010. Retail food refrigeration is predicted to suffer no net increase in energy consumption.

5.0 CONCLUSIONS

Recent scientific evidence strongly suggests that release of large quantities of CFCs gases into the atmosphere will result in environmentally harmful long-term effects. Because of these effects, a massive worldwide effort is currently under way to ban their use.

The timing for the phaseout, and when suitable substitutes and equipment are made commercially available, is crucial if energy and economic costs are to be minimized. However, increasing concerns at global, national, and local levels have resulted in uncertainty about what the eventual regulations regarding ozone depleting halocarbons will be and what alternate technologies will be allowed. For example, while HCFC-22 and other partially hydrogenated hydrocarbons are widely viewed as important CFC substitutes by industry, they may also be banned in the long term, because they have nonzero ODPs thus requiring development of less familiar technologies and chemicals at greater expense.

Commercial building applications that are impacted by the CFC phaseout include air conditioning, retail food refrigeration, and rigid foam insulation, which all have an important link to building energy usage. However, assuming a technologically conservative scenario for the phaseout, the overall impact on national energy usage in commercial buildings appears to be small, i.e.:

- Liquid chiller energy increase of only 5 trillion Btu (0.19%) by 2000 and 42 trillion Btu (1.52%) by 2010 over predicted levels if no CFC ban occurs.
- No increase in energy usage in the retail food refrigeration industry.
- Negligible increase in building skin cooling/heating loads from the use of rigid foam insulation with CFC substitutes.

The capital and operating costs of the CFC ban also appear to be relatively small, but are highly dependent on when non-CFC substitute fluids and equipment becomes commercially available, and at what price. Capital obsolescence of equipment with residual CFC demands could raise these costs

considerably; however, a well organized and executed refrigerant reclaim and recycling industry, along with improved practices designed to minimize leakage during servicing and operation, would help minimize this problem.

6.0 REFERENCES

The Air Conditioning, Heating, and Refrigeration News. 1990. "Limit Exposure to HCFC-123 Byproduct, Allied-Signal Warns Refrigerant Users." May 21, 1990. Business News Publishing Co., Troy, Michigan.

ASHRAE. 1990. *Guideline for Reducing Emission of Fully Halogenated Chloro-Fluorocarbon (CFC) Refrigerants in Refrigeration and Air-Conditioning Equipment and Applications*. Guideline 3-1990. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

Baechler, M. C. 1989. *Summary of Commercial Conservation Programs Environmental Issues and Program Consistency*. PNL-6982, Pacific Northwest Laboratory, Richland, Washington.

Bonneville Power Administration. 1982. *Environmental Assessment of Energy Conservation Opportunities in the Commercial-Sector Facilities in the Pacific Northwest*. Portland, Oregon.

Department of Energy. 1989. "Report to the Secretary of Energy on Ozone-Depleting Substances--An Analysis of the Energy and Economic Effects of Phasing Out Certain Organic Chlorine and Bromine Products." U.S. Department of Energy, Washington, D. C.

Energy Information Administration. 1989. *Potential Costs of Restricting Chlorofluorocarbon Use*. SR/ESD/89-01, U.S. Department of Energy, Washington, D.C.

Fischer, S. K. 1990. "National Energy Impacts of CFC Alternatives in Heating, Air-Conditioning, and Refrigerating Equipment and Foam Insulation." *ASHRAE Transactions* 1990, 96 Pt. 1.

Author D. Little, Inc. 1990. "Impact of a CFC Ban on the Cost and Performance of Household Refrigerators, Centrifugal Chillers, and Commercial/Industrial Refrigeration Systems." Reference 53674-10, Technical Memorandum to U.S. Department of Energy, Washington, D.C.

Lorenz, M. R., and D. Goswami. 1990. "CFCs: The Designer's Dilemma." *Heating Piping Air Conditioning* 62:51-55.

Moore, T. 1989. "The Challenge of Doing Without CFCs." *EPRI Journal* 14:4-13.

Reitz, K. 1990. "CFCs for Water Chillers." *Heating Piping Air Conditioning* 62:57-61.

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