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THE IMPACT OF THE CFC PHASE-OUT ON PG&E, ITS CUSTOMERS, AND ENERGY USE

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DISCLAIMER

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THE IMPACT OF THE CFC PHASE-OUT ON PG&E, ITS CUSTOMERS, AND ENERGY USE

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SUMMARY

Chlorofluorocarbons (CFCs) have recently been identified as responsible for the destruction of the earth's ozone layer. The ozone layer shields all living things from injurious ultraviolet light. The United States and other countries have agreed to cut their CFC use by 50% in the next decade. Since CFCs are used in activities as diverse as refrigerants, solvents, and foaming agents, this phase-out will have wide-ranging impacts on the economy. Some aspects of the phase-out will have little or no impact on PG&E. These include auto air conditioning, solvents, and aerosol sprays. These may have indirect effects because alternatives and better containment will be more or less energy-consuming.

In other cases, CFC applications have energy linkages. These linkages occur principally through their use as refrigerants and foaming agents for insulation. Residential refrigerators, commercial building chillers, and commercial refrigeration systems will be the most disrupted by the CFC phase-out and this could have an impact on the demand for electricity and gas because they are major users of CFCs. Curiously, most of the measures to reduce CFC use in chillers will result in lower electricity use and an improved load shape. The continued improvement in efficiency of residential refrigerators is threatened by the loss of the traditional refrigerant and the best available insulation materials (which use CFCs as a blowing agent). Finally, rigid insulation, which is a popular residential and commercial building material, will be much more expensive and possibly in short supply. These shortages may lead to increased electricity and gas use for space conditioning.

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Section 1

INTRODUCTION AND BACKGROUND

In September 1988, twenty-four countries signed the Montreal Protocols on Chlorofluorocarbons (CFCs). These protocols obligated the United States to reduce its use of CFCs by 50% before 1998. A cutback of this size will have enormous ramifications in a wide range of industries and applications. The purpose of this report, however, is to investigate the impact of the CFC restrictions on Pacific Gas and Electric Company, its customers, and future demand for energy.

WHAT ARE CFCs AND HOW ARE THEY USED?

Chlorofluorocarbons are a class of chemical compounds containing carbon and halogens (that is, chlorine, fluorine, bromine or iodine).[1] The most common CFCs are listed in Table 1. It is for these reasons that substitutes are difficult to develop; many compounds can achieve similar performance in a few of these aspects, but fail in the others.

Table 1. Common chlorofluorocarbons and halons.*

Common Name	Chemical Formula	Applications
R-11, CFC-11	CCl_3F	foaming agent in rigid insulation, refrigerant in chillers, solvent
R-12, CFC-12	CCl_2F_2	refrigerant in refrigerators, aerosol, mobile air conditioners, food freezant for shrimp, fruit, and vegetables
R-22, HCFC-22	$CHClF_2$	refrigerant in air conditioners, heat pumps
R-113, CFC-113	CCl_2FCClF_2	solvent, degreaser, dry cleaning
R-115, CFC-115	$CClF_2CF_3$	refrigerant
R-502, HCFC-502	HCFC-22/CFC-115 (49%/51%)	(azeotrope) refrigerant in supermarket refrigeration systems
Halon 1211, CFC-1211	CF_2BrCl	fire extinguishing
Halon 1301, CFC-1301	CF_3Br	fire extinguishing

* Adapted from Cogan (1988) and *ASHRAE Fundamentals* (1985).

CFCs serve many purposes, including the working fluid in refrigeration systems, a blowing agent in foam plastics, a solvent, and a fire extinguishing agent. A list of the 10

[1] A fully-halogenated CFC contains only carbon and halogens while a partially-halogenated CFC also contains hydrogen atoms. Recently scientists have sought to separate the less-potent partly-halogenated CFCs from the fully-halogenated CFCs. To this end they have created the term HCFC for a partly-halogenated CFC, that is, one with hydrogen atoms. In other words, the acronym, HCFC, means a "hydrogenated CFC."

largest uses of CFCs is given in Table 2. With the exception of global environmental consequences, CFCs are nearly ideal chemicals: they perform their desired functions very efficiently, are non-toxic, relatively non-flammable, relatively inert, and cheap to manufacture.

Table 2. The ten largest uses of CFCs in the United States.*

Application	1986 Consumption (millions of pounds/yr)	Primary CFCs Used
1. Air conditioning (motor vehicles)	120	CFC-12
2. Refrigeration (retail food)	95	CFC-11, CFC 502
3. Critical cleaning (electronics)	75	CFC-113
4. Open top vapor degreasing (metals, plastics, etc.)	61	CFC-113
5. Rigid insulation (roofing and sheathing)	55	CFC-11
6. Rigid insulation (pour-in-place foams)	44	CFC-11
7. Air conditioning (centrifugal chillers)	40	CFC-11, CFC-500
8. Sterilants (medical instruments)	22	CFC-12
9. Foam padding (flexible slabstock)	21	CFC-11
10. Aerosol sprays (essential uses)	21	CFC-11, CFC-12

* Adapted from Cogan (1988).

HISTORY OF THE OZONE PROBLEM

It had been long recognized that the stratospheric ozone layer (that is, the ozone located 10 - 50 kilometers above the earth's surface) protects life from the sun's damaging ultraviolet (UV) light. UV rays can break apart important biological molecules, including DNA, but can also contribute to increased melanoma, skin cancers, and damage to the immune system. Thus, the ozone layer plays a key role in protecting all living things.

The first stage of the ozone problem occurred in the mid-1970s. Laboratory studies showed that chlorine atoms could destroy ozone under certain conditions. This research (which was originally prompted by fears of atmospheric damage caused by the supersonic transport) found that chlorine atoms act as catalysts, such that each chlorine atom can destroy up to 100,000 ozone molecules. Furthermore, degrading CFCs are potentially a major source of the chlorine atoms.

The ability of CFCs to destroy ozone can be measured in the laboratory. The "ozone depletion factors" are measured on a relative scale; the destructive potential of CFC-11 is defined as one. The lifetimes of CFCs can also be measured in the laboratory, but not with great accuracy. Table 3 lists the ozone depletion factor and lifetime for each of the major CFCs.

Table 3. Lifetimes and ozone depletion factors of CFCs.

Compound	Ozone Depletion Factor*	Lifetime* (years)
CFC-11	1.0	75
CFC-12	1.0	111
CFC-113	0.8	90
CFC-114	1.0	185
CFC-115	0.6	380
Halon-1211	3.0	25
Halon-1301	10	110
HCFC-22	0.05	20

* Taken from EPA, 1987.

The CFC molecules are so inert that they do not readily degrade in the troposphere (from the Earth's surface to about 10 kilometers). The CFC molecules migrate into the stratosphere and degrade in proximity to ozone molecules. Unfortunately, most of the reactions were studied in test chambers, so the linkage between CFCs and ozone destruction was suggestive rather than conclusive.

Nevertheless, the results were strong enough to justify cutbacks in CFC use (Stolarski, 1988). The United States and many European countries banned the use of CFCs as a spray propellant in 1978. (At the time, about half of the CFC production was for spray propellants.) Cutbacks in other uses were proposed but were blocked by industry and the uncertainty that the problem was real. For example, it appeared that NO_x molecules could combine with the chlorine atoms and immobilize the reactive sites.

As a result of the laboratory studies, researchers began to measure stratospheric ozone concentrations. They focused on the polar regions because the ozone concentrations are much lower than those at the equator. The seasonal variation in ozone concentrations was also greater at the poles, peaking in summer and falling significantly in the winter. In 1985, British scientists found a significant drop in ozone concentrations above Antarctica. They found that ozone concentrations fell by over 40% between 1975 and 1984. Further research through 1988 (Stolarski, 1988) found even greater ozone reductions and more convincing links to CFCs. In 1988, Kerr (1988) reported similar evidence of ozone layer destruction and clear linkages to CFCs at the north pole. Kerr also found the first evidence of ozone-destroying chlorine atoms in the arctic. The identification of an antarctic (and possibly an arctic) "ozone hole" re-ignited concern over CFCs and prompted discussions of another CFC cutback, culminating in the Montreal Protocols.

IMPLEMENTING THE MONTREAL PROTOCOLS

The Montreal Protocols obligated the United States to reduce its CFC use by 50% in the next decade. The Environmental Protection Agency (EPA) has proposed regulations in order to implement the Protocols (Environmental Protection Agency, July 30, 1988). The EPA plans to spread the cutbacks in CFC production according to the market share of the present manufacturers. The precise marketing scheme has not been established, although the EPA prefers periodic auctions of CFCs to ensure that the users obtaining the highest value from the CFCs will be able to obtain supplies. There is strong pressure to reserve a fraction of the supplies for sensitive uses, but no decisions have been made. The EPA plans to capture any windfall profits through a special tax on manufacturers.

Recent events appear to have overtaken the EPA plans. First, even more recent research suggests that the ozone layer is deteriorating even faster than believed just two years ago. Scientists have called for a more rapid phase-out of CFCs than agreed upon in the Montreal Protocols. Second, the major CFC manufacturers have announced plans to cease CFC production entirely as soon as practical. The exact dates are not yet known, but the termination might well be before 1998. These two factors, indications that the ozone depletion is greater than earlier believed, and a premature termination of CFC production, suggest that a 50% cutback will occur much earlier than 1998.

This rapid phase-out of CFC production places the manufacturers of equipment using CFCs in an extremely uncomfortable position. Some replacements for CFCs have been developed, but none have been fully tested for toxicity and other biological hazards. The manufacturers of the CFC substitutes have joined together to complete the toxicity tests as soon as possible, but few potential users are willing to commit themselves until the tests are completed. Many compounds are so new that physical and thermodynamic properties have not been fully compiled. (The thermodynamic properties are essential for the development of compressors and refrigeration systems that can fully exploit the new refrigerants.) New compressors and refrigeration systems require at least five years to perfect and incorporate into mass production.. New lubricants which are compatible with the substitutes also need to be developed. Indeed, lubricants have proven to be a major problem for the most promising "drop-in" substitute, HCFC-134a.

Similar dilemmas exist for producers of CFC-based foam products and factories using CFCs in the production processes. Even if acceptable substitutes are found, there will be a multi-year delay before sufficient production capacity is available.

The Montreal Protocols originally excluded HCFC-22 because of its low ozone depletion factor and relatively short lifetime. HCFC-22 has only five percent of the ozone depletion potency of CFC-11 and stays in the atmosphere about one-third as long. As the perceived severity of the ozone problem increases, however, some researchers have also called for controls on HCFC-22. It is possible that the Montreal Protocols will be amended to include an HCFC-22 phase-out, too.[2]

Current users of CFCs fear that their equipment will be rendered obsolete if such a rapid cutback occurs. The problem is particularly acute in air conditioning systems in buildings and autos. Again, even if "drop-in" substitutes are found, there will be insufficient production capacity for many years.

The next ten years will certainly be challenging as the suppliers, manufacturers of CFC-reliant products, and users of CFCs struggle to adapt.

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[2] The Montreal Protocols do not distinguish between CFC production and CFC emissions. In the long run (i.e., many decades) essentially all production is emitted; however, the short run emission rate depends on the use. CFCs used in mobile air conditioning will enter the atmosphere within a few years of production. CFCs used in foams will be released much more slowly, sometimes as little as one percent per year.

Section 2

CUSTOMER IMPACTS OF CFC RESTRICTIONS

The CFC restrictions will affect nearly all PG&E customers to some degree, from the types of cups available in the supermarket to the increased cost of buying a new refrigerator. Owing to its unique position in the community, PG&E will be one of the first entities to learn of problems experienced by households, firms, and industries caused by the restrictions. In other cases, PG&E's own activities will involve CFCs. For these reasons, PG&E desires to fully understand the CFC impacts of its policies, programs, and procedures as well as to be generally aware of CFC issues. This section deals with the major technologies affected by the CFC restrictions. Current PG&E programs will be discussed in several cases to demonstrate the linkages between program design and CFC use.

MOBILE AIR CONDITIONING

Air conditioners in cars are the largest user of CFCs. They will be under the greatest pressure to reduce CFC use, along with refrigeration systems in trucks. The greatest near-term savings will be achieved through improved maintenance procedures because almost three-quarters of mobile CFC sales is to make up for leaks or loss of original coolant. There is already pressure on motor vehicle manufacturers to design sturdier air conditioning systems so that fewer leaks occur in the first place. Over the long term, manufacturers are exploring mobile air conditioning systems based on alternative refrigerants.

The EPA has not yet announced a policy to reduce CFC use in mobile air conditioning. It is considering establishing a network of certified mobile air conditioning maintenance stations (similar to California's smog check stations). These stations would have special equipment to reclaim CFC-12 with mechanics trained to avoid needless CFC leaks.

RESIDENTIAL REFRIGERATORS

The CFC restrictions appear to have the greatest immediate impact on residential refrigerators. Since the technologies themselves are being intensively researched and government policies have not yet been fixed, one can only speculate on the outcome. Refrigerators use CFCs in two critical areas: as a refrigerant and as a foaming agent in the insulation. Each area has its own unique obstacles to CFC-free operation.

The manufacturers have used CFC-12 (often called by DuPont's trade name "freon") as the refrigerant for decades and gradually perfected an extremely reliable refrigeration system often capable of operating continuously for twenty years. Each component, including the compressor, condenser, evaporator, and controls, has been optimized for CFC-12. The EPA regulations do not require the refrigerator manufacturers to cut back on CFC-12 use, but the higher refrigerant prices and the suppliers' decisions to terminate production by suppliers may force them to abandon CFCs in the next decade. Thus, the potential loss of CFC-12 has stimulated the manufacturers to search for alternative technologies that do not rely on CFCs which can be incorporated quickly and economically.

In the last decade, refrigerator manufacturers have gradually shifted from fiberglass insulation to foam insulation. CFC-based foam insulation is superior to fiberglass in two major aspects. First, the foam can be injected rapidly and uniformly, which permits more efficient mass production. Second, the insulation has a lower thermal conductivity per unit thickness. The CFC gas itself has a lower thermal conductivity than alternative gases. This permits greater insulation in the existing walls. Alternatively, one can obtain greater interior volume without sacrificing insulation. (The latter option was, until recently, the most frequent choice of manufacturers.)

CFC-11 has been used almost exclusively as the foaming agent in refrigerators. In addition to its non-toxic features, the gas itself has superior thermal properties. The bubbles of CFC-11 have extremely low thermal conductance relative to alternative gases. CFC-11 also appears to promote more uniform filling of the wall cavity than other foaming agents. Alternative foaming agents are available, but they will require thicker walls in order to achieve comparable levels of thermal resistance in addition to revised manufacturing procedures.

The National Appliance Energy Conservation Act of 1987 (NAECA) further limits the options available to the refrigerator manufacturers. NAECA requires substantial energy efficiency improvements in refrigerators by 1993. Most of the manufacturers had planned to achieve these efficiency improvements by increasing the wall insulation and further refinements of the compressor system. The wall improvements relied on increased use of CFCs. With this option eliminated, refrigerator manufacturers have turned to unconventional alternatives, some of which are virtually unproven. In walls, for example, vacuum insulation panels, aerogel insulation, and drastically thicker walls filled with different foams are being investigated. The refrigerator manufacturers are extremely concerned because eliminating CFCs will be a major technological challenge in itself, but to make the conversion while dramatically cutting energy use will be, according to the manufacturers, unacceptably expensive to consumers. Reliability is another factor. The manufacturers claim that they will not be able to adequately field-test these technologies prior to the 1993 starting date for the new standards.

Re-tooling a refrigerator assembly line is expensive, so manufacturers prefer to make all the changes at once, generally at the end of a model cycle (which occurs about once every eight to ten years). Yet the modifications needed to phase-out CFCs and increase energy efficiency may force the manufacturers to re-tool several times in the next decade. In a very short time -- in less than one model cycle -- the manufacturers must develop, test, and begin manufacturing refrigerators with a new refrigerant (and possibly a new compressor system), new insulation, while reducing overall energy use. As a result, the manufacturers are seeking to postpone the implementation of the energy efficiency standards. As of September 1988, no decision had been reached either with the federal government or with the state of California (which has its own efficiency standards).

Some experts believe that a low-CFC, or even a CFC-free, refrigerator could be produced relatively cheaply and with existing technology (Potter et al., 1988). There are certainly many technical options available to reduce energy use in refrigerators (Turiel et al.). Unfortunately, these designs have not yet been translated into prototypes, so there is no simple way to settle the dispute.

The refrigerator manufacturers fear that CFCs will become very expensive, or even unavailable, before reliable substitutes are developed. If the manufacturers' fears are realized, the price of refrigerators will rise sharply. Operating performance and reliability may decline. If this occurs, PG&E can expect more high-bill complaints (due to malfunctioning refrigeration systems) and general refrigerator-related inquiries. On the other hand, relatively simple modifications may greatly reduce the CFC content of refrigerators while maintaining high energy efficiency.

DISPOSAL OF REFRIGERATORS

In principle, transportation and disposal of a refrigerator requires special permits and procedures. The "Resource Conservation and Recovery Act" specifically identifies CFC-11 and CFC-12 as priority pollutants. Under this regulation, any emission greater than 1 kg must be reported and controlled to a non-hazardous condition (O'Meara, 1988). The typical current refrigerator contains about half a pound of refrigerant (CFC-12) and 2.5 pounds of foaming agent (CFC-11), so the disposal should be regulated. To our knowledge, no controls have yet been implemented, so refrigerators are still dumped into landfills without any special controls.

There is no simple procedure to remove the CFCs from residential refrigerators (Radian Corporation, 1987a). However, a simple modification in construction -- the insertion of a service valve -- would permit easy recovery of the refrigerant. Radian Corporation (1987a) estimated that it would cost only five dollars per unit to recover the refrigerant. This estimate did not include the cost of a central reclamation facility, so the true cost would probably be higher. The greater part of the CFCs in refrigerators, that trapped in the foam, is thought to be impractical to either reclaim or destroy. Federal policies towards these long-term emission sources have not yet been developed. State policies are likewise in flux.

It is not clear how federal or state regulations will affect large-scale disposal of appliances with CFCs. PG&E should monitor developments because its refrigerator buyback programs cause the disposal of many refrigerators.

INSULATION FOR BUILDINGS

Rigid polyurethane and polystyrene foam boards are commonly used as building insulation. These foams are generally produced by the volatilization of either CFC-11 or CFC-12 when added to a liquid plastic. The foam is sometimes poured as a liquid into enclosed spaces and allowed to harden. In this way, it can easily fill wall cavities of walk-in refrigeration facilities.

In California, rigid foam board has become a key element in meeting the Title 24 residential insulation requirements and generally improving insulation in commercial buildings. It is commonly used to provide roofing or sheathing insulation and has superior insulation properties to fiberglass and foam products using other gases. Rigid foam board is a standard insulation product for industrial applications, too.

Alternatives to CFC-based rigid foams exist, but builders and engineers have become so accustomed to using the CFC foams that it will be difficult for them to switch. The cathedral ceiling in California houses, for example, is largely possible due to CFC-based foams. Rigid foam board under the shingles provides sufficient insulation to meet Title 24 standards without causing design problems. Some alternatives to CFC-based foam are more expensive or most have inferior performance characteristics. They generally have lower thermal resistances, so thicker layers will be required to achieve the desired R-value.

The market for rigid foam insulation will become tighter and prices will climb sharply in the next few years. After that, however, builders will have shifted to other products and manufacturers will be introducing new rigid foams based on CFC-free foaming agents.

Already, manufacturers have developed prototype rigid foams using HCFC-123 and HCFC-141b with properties similar to foams based on CFC-11 and CFC-12, but large-scale production is not expected for at least five years (Environmental Protection Agency, 1988).

CHILLERS IN COMMERCIAL BUILDINGS AND EQUIPMENT FACILITIES

Commercial chillers rely on CFC-11, CFC-12 and, to a lesser extent, CFC-114 and CFC-500. (Residential and small commercial packaged air conditioning units use the unregulated CFC-22.) No simple replacement for the CFCs presently exists. In the short term, the principal strategies will be to improve maintenance procedures and initiate CFC reclamation at smaller facilities. The CFCs are either cleaned at the site and re-inserted after completion of maintenance or transported to a central reprocessing facility. Principal contaminants include water and oil (because of whose presence the CFC may to be considered a hazardous waste), dirt, waxes, acids, and metal particles (ASHRAE, 1986).

Most large air conditioning units are equipped with receiver and isolation valves. The receiver outlet valve is closed, and the system compressor is used to pump the refrigeration into a receiver, and then the receiver inlet valve is closed. If the compressor is broken, or the system lacks a receiver or isolation valves, the external receiver is cooled to collect the refrigerant. Newer recovery units contain their own compressors to speed transfer. Recovery efficiency is said to be 95%.

The rule of thumb has been that it is cost-effective to recycle if the cost of recycling is less than half the cost of new refrigerant. Until recently, CFC recovery was not considered economical for units with less than 100 pounds of CFC-11, CFC-12, or CFC-502. However, higher CFC prices, new recovery equipment, and greater environmental concern will lower the break-even size. Several recovery units have been developed for air conditioning units with less than thirty pounds of refrigerant (Robinair, 1988).

One obstacle to greater reclamation is the lack of standards for recycled refrigerant. For the moment, users generally recharge their units with the refrigerant that was removed earlier. Firms with many chillers sometimes establish a central reprocessing and storage facility. ASHRAE and ARI are working rapidly to develop standards for reprocessed refrigerants (Air Conditioning, Heating & Refrigeration News, July 4, 1988). The standards will include a standard testing procedure and maximum allowable levels of contaminants. At the same time, ASHRAE is revising its recommended procedures for servicing air conditioners so as to reduce emissions. When these standards are completed, one can expect a significant market in reprocessed refrigerants. The EPA is considering mandatory refrigerant recovery if insufficient voluntary recovery is undertaken (Environmental Protection Agency, July 30, 1988).

New buildings have several options to reduce or even eliminate CFC dependence. Nearly all options also save peak power.

- Large buildings (greater than 100 tons cooling capacity) can shift to gas-fired absorption cooling systems. These systems generally use lithium bromide (which is not a CFC) as the working fluid. Such systems also reduce the building's electrical peak caused by cooling, so they provide an additional benefit. The minimum economical size for gas-fired chillers will drop as CFC-based chillers become more expensive and supplies of refrigerant become less reliable (Broderick et al., 1988; Hopkins, 1988).

- Smaller buildings can install multi-stage cooling systems. Numerous studies in California have shown that the primary stage(s) of indirect and direct evaporative coolers can provide a major fraction of the cooling requirements (Usibelli et al., 1985). The multi-stage system permits substantial down-sizing of the conventional chiller (the final stage). This option also greatly reduces energy use and peak power demands.
- Smaller buildings can install chillers based on CFC-22. The range of units will increase significantly in the next few years as manufacturers expand the economical operating range of these units.
- Downsize required chiller capacity through stringent reductions in cooling loads. Significant investments in energy efficiency (lights, equipment, solar control, etc.) can reduce cooling loads (Usibelli et al., 1985). This, in turn, will permit a smaller chiller (or fewer chillers) and less CFC use. This strategy may have an immediate payback in new buildings because the increased efficiency investment may be offset by the reduced chiller investment. This strategy will also reduce energy and peak power demands. Older buildings might also be able to implement a load reduction/chiller capacity reduction strategy.
- Thermal storage. A cool-storage system permits a much smaller chiller, hence less CFCs. Energy use may increase (due to storage losses) but peak power demands will decrease. The savings depend very much on the buildings involved and the system configuration (Piette, 1988). Older buildings might supply the chiller capacity for a thermal storage system in a new building, hence eliminating the need for any additional chiller and CFC use.

Commercial refrigeration systems are often tested for leaks with CFCs. Alternatives are generally available, but maintenance procedures need to be revised to incorporate these techniques. This can occur relatively quickly.

SUPERMARKET REFRIGERATION SYSTEMS

In the last decade, the major supermarket chains have drastically reduced their use of CFC-12. Five years ago, about 60% of Safeway's refrigeration systems operated with CFC-12; now less than 2% use CFC-12 (Personal communication with Rich Oas, Safeway, Inc.) The remaining R-12 is used only in older, small refrigeration systems. The solution, unfortunately, is not free of problems. The supermarkets have switched to HCFC-502, which is a mixture (or azeotrope) of HCFC-22 and CFC-115. The ozone depletion factor of this mixture is about one-third that of CFC-12. Thus, HCFC-502 will be a temporary solution, perhaps until a drop-in substitute is developed. This may in fact be HCFC-134a.

SOLVENTS

CFCs are used in a wide variety of cleaning applications because they have superior wetting, penetration, and degreasing qualities. At the same time, most CFCs are relatively non-toxic and non-flammable. CFC-113 has become particularly popular in electronics fabrication. Defluxing printed circuit boards, for example, uses 70% of the CFC-113 manufactured in the U.S. (Cogan, 1988).

Electronics manufacturers already recycle a significant fraction of their CFCs. In the case of defluxing printed circuit boards, about one third of the CFC-113 is already recycled (Cogan, 1988). However, there remains considerable potential for further solvent recovery. Simple measures, such as better covers and splash shields, can greatly reduce solvent loss. It is expected that the rapid increase in solvent prices will induce the electronics manufacturers to institute more efficient reclamation processes. They will, in addition, begin trying other solvents not based on CFCs. A substitute for CFC-113, Bioact EC-7, has been developed to remove solder flux and other residue deposited on printed circuit boards (Appliance Engineer, 1988). The terpene-based solvent uses citrus fruit rinds and wastes from paper mills as the principal raw materials.

FOOD PROCESSING

Many food processing plants use CFC-12 to freeze fish, shrimp, fruit, and vegetables. The fraction of CFC-12 used as a "freezant" is very small nationwide, but the local impact of the phase-out will be disproportionately severe because California is the largest producer of vegetables and fruits. This application is not discussed in the technical literature so alternatives are not known. However, if food processing is similar to other industries that use CFCs as a operating medium (in contrast to a raw material such as in foam plastic), considerable conservation potential probably exists through simple modifications in the production process.

FIRE EXTINGUISHERS

The brominated CFCs, or halons, are used to extinguish fires. Only a tiny amount of halons are produced relative to CFC-11 or 12, but their capability to destroy ozone is about three to ten times larger. They also have long residence times. Thus, the halon's higher potency to some extent negates the smaller amounts being used. In addition, halon consumption is still rapidly growing.

Most large computer centers, document rooms, libraries, etc. use halon 1301 automatic fire extinguishing systems. When a fire is sensed, the computer center is "flooded" with the halon. The gas suffocates the fire. Halon is a superior fire extinguishing compound because it is non-toxic and leaves no residue. Once the fire is over, the halon can be easily vented to the atmosphere. Halon 1211 is used in fire extinguishers where human exposure is likely (such as in airplanes). An increasing number of commercial and residential portable extinguishers use halon 1211.

No satisfactory substitutes for halons have been proposed. For the moment, revised operating procedures will be the principal means of reducing CFC releases. For example, it will no longer be required to fully discharge the system during the initial tests. There will also be new procedures to avoid false alarms. Since less than five percent of the halon production is actually used to extinguish fires (Cogan, 1988), the savings from revised operating procedures will be very large. The use of halon 1211 in portable fire extinguishers, however, will soon be phased out because acceptable alternatives are already available.

Section 3

LOAD IMPLICATIONS OF CFC RESTRICTIONS

A significant fraction of PG&E's electricity and gas sales are influenced by CFCs. For example, commercial building chillers and residential refrigerators -- both major electrical loads -- rely on CFCs. Therefore it is worthwhile exploring the potential impact of the CFC restrictions on system energy demand. These explorations can only be speculative given the uncertainty in the regulations; moreover, most changes will occur only gradually as equipment turns over. Nevertheless, the impacts should not be ignored. New programs need to be considered now so as to mitigate any possible future deterioration in loads. In addition, PG&E must be prepared for the dislocations created by an accelerated CFC phase-out, which is becoming increasingly likely.

ELECTRICAL LOAD IMPACTs

The three largest electrical end uses affected by the CFCs are:

- residential refrigerators,
- commercial chillers, and
- commercial refrigeration systems.

Other industrial end uses may be affected and special industries, such as food processing, may have very special CFC requirements.

RESIDENTIAL REFRIGERATORS

Residential refrigerators represent over 20% of PG&E's residential electrical demand (Brodsky et al., 1986). The CFC phase-out will affect existing refrigerators through maintenance and repairs. Loss of refrigerant (CFC-12) is an occasional repair problem but repair technicians often discharge the refrigerant for other breakdowns. There should be no energy implications if CFC-12 merely increases in price. (A 10-fold price increase in CFC-12 corresponds to only ten minutes of a typical repair visit.) However, if the original CFC-12 cannot be obtained, then a drop-in substitute must be used. Even if a substitute is developed (and several are being tested) there is no assurance that it will have precisely the same performance as CFC-12. Limited measurements suggest that replacement of CFC-12 with HCFC-134a will increase a present refrigerator's electricity use by five to ten percent (Cogan, 1988). The aggregate impact will depend on the frequency of repairs (which is very low) and the performance penalty. When further measured data are available, PG&E might consider incorporating the gradual performance degradation of existing refrigerators into its electric load forecasts.

The energy use of *new* refrigerators is expected to decline about 30% between 1987 and 1992 as a result of the California and federal appliance efficiency standards. This trend is already being incorporated into PG&E forecasts. The energy use of new refrigerators will be doubly affected by the CFC phaseout by the loss of the most attractive insulation and refrigerant. If a limited phaseout occurs, then refrigerator manufacturers could simply pay more for the CFC-11 and CFC-12.[3]

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[3] Refrigerator manufacturers estimate that higher CFC prices would raise the construction cost about $30 and that CFC alternatives would raise the retail price by about $100. However, they fear

The refrigerator manufacturers are pressuring the state and federal governments to postpone implementation of the 1992 standards. They argue that a delay would give them time to retool at the same time for the CFC phase-out and the efficiency standards, thus saving hundreds of millions of dollars. The outcome of the intense lobbying is impossible to predict, but a postponement or cancellation of the standards must be quickly incorporated into PG&E's load forecast. If the standards are cancelled, aggregate refrigerator electricity use will fall by only about half as much as current forecasts.

ENERGY USE OF CHILLERS IN COMMERCIAL BUILDINGS

Owners of commercial buildings will encounter significantly higher repair and maintenance costs for their CFC-based chillers. In addition, revised maintenance and repair procedures may add new restrictions on operation. Curiously, the CFC phaseout will probably reduce aggregate chiller electricity use and peak demand. Many of the measures to reduce CFC use in chillers coincide with existing load management strategies. These include thermal storage, load reduction, evaporative cooling, and gas-fired absorption cooling. (See Customer Impacts section for an explanation.) It appears that the CFC phase-out will stimulate load management in commercial buildings.

COMMERCIAL REFRIGERATION SYSTEMS

This end use includes refrigeration systems in grocery stores, warehouses, agriculture, and restaurants. The impact on this end use has not yet been determined. Many of the applications are unique, and the ability to reduce CFC use needs to be determined on an individual basis.

Food processing plants may be a uniquely large CFC user in PG&E's service area because no other utility has so large an agricultural industry. These plants use the CFCs to freeze vegetables, fruit, and fish. Unfortunately, alternatives to CFCs have not been discussed in the technical literature. There is some reason to believe that the alternatives may be more energy intensive than CFCs. PG&E may want to monitor developments in this industry with particular care.

NATURAL GAS IMPACTS

CFC-based rigid foam is a popular building product. It is widely used to achieve the insulation levels needed to comply with California's building energy standards, Title 24. The CFC-based foam is in part responsible for the continuing decline in residential gas use because it allows the builder considerable architectural flexibility while still meeting the required insulation levels. Cathedral ceilings, for example, are much easier to build with foam insulation. The CFC phaseout will greatly increase the price of CFC-based rigid foam and could possibly lead to shortages. Indeed, the greater demand for CFCs as refrigerants may close out entirely the rigid foam market. None of the replacements (fiberglass, polystyrene bead-board, etc.) have comparable thermal or performance characteristics and most require more space or more complex installation. As a result, builders may be expected to take shortcuts by either substituting inferior insulation (in R-value or quality) or simply omitting foam insulation. In both cases, energy performance for new buildings could deteriorate and lead to increased heating and cooling

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that manufacturers of mobile air conditioners will outbid them and that no CFCs will be available for refrigerators (Whirlpool Corporation, 1988). These claims appear to be more an attempt to justify a special CFC allocation for refrigerator manufacturers and pressure to relax the efficiency standards than realistic estimates of costs.

demands. PG&E and the California Energy Commission may want to monitor compliance should foam shortages develop and evidence of builder fraud appear.

The likelihood of a CFC phase-out will persuade some commercial building owners to switch to gas-fired cooling systems. A large shift could create an increased summer demand for natural gas.

CUSTOMERS GAINED OR LOST BY THE CFC RESTRICTIONS

The production of CFCs is a multi-billion dollar industry, but its phase-out will probably cause few local industrial dislocations. Few or no CFCs are produced in the PG&E service area, so the production phase-out should not affect PG&E. Likewise, it appears that none of the major CFC substitutes will be produced in PG&E's service area. However, there may be new facilities for CFC reprocessing. (Some facilities already exist in Southern California.) These are not expected to be major energy users.

The production of substitutes for some speciality CFCs may begin in Northern California. In particular, non-CFC based solvents to service the electronics industry might originate locally.

Many firms will modify their manufacturing processes in response to higher CFC prices or to the phase-out. These include furniture manufacturers (due to the foam), electronics, and food processing. It is unlikely, however, that these modifications will greatly affect their energy use.

Section 4

IMPACT OF CFC RESTRICTIONS ON PG&E'S INTERNAL OPERATIONS

Only a few of PG&E's operations rely on CFCs, so the overall direct impact on internal operations will be small. Nevertheless, the restrictions will continue to be a continuing source of minor inconveniences for the utility. Some of the problem areas are discussed below.

AUTOMOBILE AND TRUCK AIR CONDITIONERS

PG&E's largest use of CFCs is probably in its motor vehicle fleet. Virtually all air conditioners in cars and trucks rely on CFC-12. (About 25% of total U.S. CFC use goes to mobile air conditioning units.) The total reliance on CFC-12 creates two major technical problems: to develop new air conditioning systems that do not rely on CFCs and to develop a drop-in replacement to replace CFCs in existing units. No simple alternatives have been identified, although HCFC-134a appears to be the best candidate for a drop-in replacement.

A related problem arises in reclaiming refrigerant already being used in air conditioning systems. Reclamation is most likely to occur during repairs. Since relatively small amounts of refrigerant are used in the mobile air conditioners, most repairs begin by completely discharging the refrigerant into the atmosphere. To reduce these discharges, the EPA is considering establishing special air conditioning service stations equipped with CFC recycling equipment. These units, which cost about $3000 each, would be able to reclaim much of the refrigerant, which could be used to recharge the original unit or to collect the CFC for centralized cleaning.

PG&E has several thousand cars and trucks, most of which are air conditioned. Any restrictions on air conditioner repair and maintenance will raise cost of repairs and reduce PG&E's ability to repair its own vehicles. In the near future, air conditioning repair will probably need to be performed with revised procedures so as to minimize atmospheric discharge. The EPA has not yet decided if special garages should be created for air conditioning maintenance and repairs. In any event, maintenance costs could easily double in the next decade.

CHILLERS IN PG&E's BUILDINGS AND FACILITIES

The CFC restrictions will affect nearly every PG&E office and facility because virtually all have some air conditioning. In the short term, the principal strategies will be to improve maintenance procedures and initiate CFC reclamation at smaller units. PG&E can implement a variety of measures to simplify reclamation. These consist of installing appropriate service valves to permit more convenient refrigerant recovery and purchase of mobile recovery stations. In addition, maintenance procedures must be revised to include refrigerant recovery. Given that the EPA predicts a five-fold increase in refrigerant prices before 1991 (from $0.45 to $2.40 per pound), recovery in all but the smallest units will probably become economical in the next three years (Air Conditioning, Heating and Refrigeration News, 1988).

PG&E might also consider centralizing refrigerant recovery and reprocessing. With planning, it might be able to cut new refrigerant purchases by over 80%. Standards for reclaimed refrigerant are being developed by ASHRAE. Once these standards are established, PG&E might consider offering the reclamation service (recovery and the sale of reprocessed CFCs to its commercial and industrial customers).

At the same time, PG&E should ensure that as many new chiller systems as possible use non-CFC refrigerants (such as HCFC-22). This policy may be difficult to implement because alternatives for some capacities are not yet widely available. When CFC-based chillers are the only alternative, measures should be considered to reduce the unit's capacity (hence the amount of refrigerant). These measures include reducing building cooling loads through efficient lighting, solar control, and possibly thermal storage. In some cases, a multi-stage cooling system (with an evaporative cooler as the primary stage) can further cut the cooling load for the refrigerant-based stage. In large buildings, gas-fired absorption chillers should be considered. The working fluid in these units is generally lithium bromide, which is not a CFC. These chillers provide an additional benefit: they do not contribute to the summer peak.

FIRE EXTINGUISHERS

The brominated CFCs, or halons, are used to extinguish fires in locations where exposure to humans is possible or any residue may affect the performance of the equipment. (The principal halons are halon 1301 and 1211.) PG&E has many computer centers, equipment rooms, and document storage facilities equipped with halon fire extinguishing systems. The major response to the CFC phase-out will be to drastically improve testing and maintenance procedures for the fire extinguishing systems. The revised procedures are now being developed but they are not expected to affect the reliability or operations of PG&E facilities in any major way.

TRANSPORTATION OF CFCs

Many federal regulations treat CFCs as if they were toxic wastes. The Resource Conservation and Recovery Act of 1984 specifically identifies CFC-11 and CFC-12 as priority pollutants (O' Meara 1988). Under this regulation, any emission greater than 1 kilogram must be reported and controlled to a non-hazardous condition. Furthermore, the EPA administrator has stated that no disposal into a landfill will be allowed when the waste contains greater than 1,000 ppm of halogenated components. In fact, clean CFCs (or even those with traces of oil) are less toxic than hundreds of chemicals presently being transported without any restrictions. Indeed, the CFC dilemma is principally related to finding replacements with the unusually low toxicity of CFCs.

Classification of CFCs as toxic wastes is causing extraordinary problems for numerous suppliers and users of CFCs and has deterred many firms from recycling CFCs. Part of the problem is due to strict interpretation of the RCRA by individual states (ASHRAE Journal, August 1988). There are also so many contradictory interpretations of the regulations that few firms are willing to risk large-scale recycling.

The legal uncertainties associated with transport of used CFCs has probably encouraged the development of on-site recovery systems. These portable recovery systems are generally not as effective as the centralized cleaning and recovery plants.

OTHER USES OF CFCs

PG&E uses CFCs in a variety of minor applications, including as solvents and as a foaming agent in insulation materials. Conversion to alternatives do not present unusual or insurmountable obstacles. However, PG&E staff should begin planning immediately for this conversion because availability of traditional materials may quickly diminish and prices will increase.

Section 5

FREQUENTLY ASKED QUESTIONS ABOUT CFCs

PG&E's customer representatives will no doubt receive numerous inquires regarding CFCs. While it is impossible to fully anticipate them, here are some obvious questions and answers.

WHICH APPLIANCES AND MATERIALS IN MY HOME HAVE CFCs?

The refrigerator has the most CFCs. Residential air conditoners and heat pumps use a hydrogenated CFC, called HCFC-22, as a refrigerant. This chemical has about 1/20 of the ozone-depleting power of the standard CFCs and is not covered in the Montreal Protocols (so no immediate shortages are foreseen). The fire extinguisher might also have CFCs. New homes probably have considerably more CFCs in the rigid board insulation used on the walls and ceilings. (Post-1978 homes with cathedral ceilings almost certainly have CFC-based insulation.) Some foam in furniture cushions might also contain CFCs.

ARE CFCs DANGEROUS?

For the most part they are extremely safe to touch, breathe, or allow near a flame. This is one reason CFC substitutes are so difficult to develop: CFCs were nearly ideal to begin with.

What happened to CFCs in Aerosol Cans?

In a sense, the United States has already reduced its CFC use 50% once. In the early about half of the CFCs were consumed as aerosol propellents. After CFCs were demonstrated to destroy ozone, this application was virtually prohibited. However, growth in other applications quickly offset any reductions. CFCs are used as propellents in only a few exotic applications. However, other countries, including Japan and Mexico, still use CFCs as propellents.

CAN CFCs BE DESTROYED?

Once produced, CFCs cannot be easily converted into a non-hazardous state. The characteristic which makes CFCs so attractive as a refrigerant and a chemical, that is, their inertness, mean that their destruction is particularly difficult. No industries presently destroy CFCs, although incineration technologies exist that should be able to destroy 95% of the CFCs (Radian, 1987b). EPA studies have so far only considered incineration facilities in plants that use large amounts of CFCs in their manufacturing processes (such as plastic foam producers). The incinerators would operate on exhaust air from the plant. No cost or efficiency projections for incinerators for central collection facilities have been made. A second CFC destruction process, carbon adsorption, also holds promise but the technology has not been fully developed (Radian Corporation, 1987b). A variant on the carbon adsorption technique also permits CFC recovery.

DO CFCs LEAK OUT OF MATERIALS AND REFRIGERATION SYSTEMS?

Yes, CFCs gradually leak from materials, but at a very low rate. For example, the expected rate of CFC-11 release from rigid foam board is less than 1% per year (Radian Corporation, 1987b). Thus, about 80% of the original CFC will be present in the foam after twenty years. Most of the CFC losses in refrigeration systems occur during servicing. Even then, it may be as little as 10%.

HOW MUCH CFCs ARE USED FOR PACKAGING FAST FOOD?

Until recently, foam packages accounted for about 3% of all CFC use in the United States. This is falling rapidly because manufacturers of fast-food foam containers have agreed to stop using CFCs by the end of 1988 (Air Conditioning, Heating & Refrigeration News, 1988). New disposable foam containers are being made with polystyrene with a process that does not need CFCs.

IF A HOLE IN THE OZONE LAYER IS BAD, WHY IS OZONE CONSIDERED PART OF SMOG IN CITIES?

The ozone in the atmosphere above cities is unfortunately in the wrong place to offset that being destroyed by the CFCs. The urban ozone problem consists of ozone in the atmosphere directly above cities (up to about 2 kilometers). CFCs destroy the "stratospheric" ozone, that is, a layer of he atmosphere about 25 kilometers above the earth. There is essentially no transport of atmospheric ozone to the stratosphere. Moreover, the "ozone hole" is located over the south pole, far from any cities.

WOULD THE OZONE PROBLEM DISAPPEAR IF WE STOPPED CFC PRODUCTION TODAY?

Some CFCs are discharged into the atmosphere soon after production. For example, CFCs in solvents and aerosol propellants enter the atmosphere in less than a year. CFC-12 in mobile air conditioners probably have a slightly longer residence time (on the order of a couple of years). There is a large reservoir of CFCs already in refrigerators and materials. CFCs in refrigerators and chillers will not be discharged for several years while the CFCs in foaming agents escape into the atmosphere very slowly, less than 1% per year. So CFC emissions would continue for many years after the cessation of CFC production.

Section 6

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