



The State of Stratospheric Ozone Depletion

September 2003



I. Executive Summary

Ozone, composed of three molecules of oxygen bonded together, forms a protective barrier in the Earth's upper atmosphere. The greatest concentration of ozone molecules, about 90 percent of all found on the planet, is found about 15 miles (25 km) above the Earth's surface in the stratosphere. This concentration is what scientists refer to as the *ozone layer*. Ozone shields the Earth from harmful ultraviolet (UV) radiation that damages all living things on the planet.

Over 30 years ago, scientists began noticing a decrease in the concentration of ozone in the Earth's stratosphere. They noticed new health and ecological problems and pinpointed ozone-destroying substances, created and released by natural, and overwhelmingly, human, processes as causing the thinning of Earth's protective ozone layer. Through years of study, scientists are beginning to understand the processes contributing to breakdown of stratospheric ozone, especially over the polar regions. They have worked with governments and industries in the U.S. and around the world to institute measures to address those factors and find substitutes for the chemicals causing the problem.

While important strides have been made through the cooperative efforts of the scientific community, governments and industry, much remains to be done before stratospheric ozone depletion ceases to be a serious environmental problem. Continued perseverance and dedication to finding and developing the best solutions to this phenomenon is necessary to enable the full recovery of this critical atmospheric resource.

The world has come far, but not far enough, on solutions to stratospheric ozone depletion. The increase in our knowledge of the dangers of ozone depletion, particularly the public health and environmental effects, has convinced the international community, both politically and practically, that cooperative and immediate action is necessary to halt further destruction of the protective ozone layer. Landmark international accords showcase the world's acknowledgement of the need for global cooperation to address ozone depletion, but we are in no position to cease work on this issue. Steps have been taken and progress made, but a formidable challenge remains – to cease production and consumption of manmade compounds that are primarily responsible for the destruction of the ozone layer. Further, more stringent action is needed by the collective global community to ensure all nations stop the use and production of these harmful substances in advance of, or at a minimum in accordance with, current timetables.

Kofi Annan, United Nations Secretary General, summed up the situation facing the world today in his International Day for the Preservation of the Ozone Layer address in September 2002:

“Life started to develop significantly on our planet only after the ozone layer was in place in the stratosphere to filter out harmful levels of sunlight. The battle to repair this life-sustaining system is far from over.

The scientific assessment carried out this year concluded that although some ozone-depleting agents in the atmosphere are declining slowly from the peak that occurred in 1992-1994, others are still on the increase. Scientists predict that the

ozone layer will remain particularly vulnerable during the next decade or so, even if all countries comply with the measures put in place by the Montreal Protocol to control and phase-out ozone-depleting substances. Failure to comply with the Protocol would delay and could even prevent the ozone layer's future recovery."

The effects of stratospheric ozone depletion are still being observed and felt worldwide.

In the early 1970s, scientist began to notice that stratospheric ozone levels were decreasing, and in 1985 the first hole in the ozone layer was documented over Antarctica. Since then, scientists have been paying close attention to ozone levels all over the world, especially over the Antarctic, and have begun to pay more attention to Arctic regions as well.

With the thinning of the ozone layer, increased UV-B radiation reaches the Earth's surface. Research has determined that increased exposure to UV-B rays detrimentally affect humans and the environment, linking such exposure to increased incidence of skin cancer, eye damage, and immune system problems. Plants, marine ecosystems, and biogeochemical cycles also are negatively impacted by the additional UV-B radiation that reaches the Earth as the result of lower stratospheric ozone concentrations. The effects of reduced stratospheric ozone are being felt all over the planet; in places like Punta Arenas, Chile, where residents have to take adaptive measures to protect themselves from the increased radiation that hits the Earth during the Antarctic Spring.

New factors and synergistic effects that influence ozone depletion are being discovered.

Since research into stratospheric ozone depletion commenced in the early 1970s, scientists have identified the process and chemicals that cause the destruction of ozone in the upper atmosphere. The culprit chemicals, most notable being chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), are collectively referred to as ozone depleting substances (ODS). These substances have largely been developed by people to serve industrial purposes and provide consumers with products and services that improve their lifestyles. Use of these products and services often result in the release of ODS, which are difficult to break down in the atmosphere. Eventually, they make it into the stratosphere, where they are broken down by intense solar radiation. They become destructive once reduced to their composite atoms - chlorine, a component of CFCs and HCFCs, and bromine, present in methyl bromine, are the atoms that destroy ozone molecules. One chlorine atom released by an ODS molecule has the potential to destroy over 100,000 ozone molecules.

Meteorological processes trap ODS over polar regions in the winter, causing the greatest impact in the extreme southern and northern hemispheres. Once sunlight returns, these large concentrations of ODS break down and the atoms destroy many ozone molecules. This process creates "holes" in the ozone layer and is the reason that the Antarctic ozone hole occurs annually in September and October - the end of winter in the southern hemisphere.

In the past few years, the size of the southern ozone hole has reached record proportions. Increasingly, ozone depletion problems in the Arctic are being observed as well. Recent research has also pointed to the potential interactive effects between the phenomenon of ozone depletion and that of global warming, requiring further study.

Government and business cooperation on ozone solutions provide a successful model.

As evidence of the seriousness of stratospheric ozone depletion grew, the international community joined together to phase-out the use of ODS. The United Nations Environment Programme brought the international community together through a series of meetings to negotiate specific goals and actions all nations would take to cease the production of ODS and phase-out their use. Out of these meetings came the 1985 Vienna Convention for the Protection of the Ozone Layer (the Vienna Convention), the first-ever agreement between nations to, in principle, address environmental problems before the concrete scientific evidence was found or the effects of stratospheric ozone were felt. In the Vienna Convention, no mention was made of specific steps to be taken; rather, the Convention encouraged, research, international cooperation, and sharing of information.

Two years later, in 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer ("Montreal Protocol") expanded upon the Vienna Convention to set control measures on ODS, but intentionally left room for adjustment as scientific evidence mounted. Four Amendments have since refined the Montreal Protocol, accelerating the phase-out schedules for some of the most damaging ODS.

The United States (U.S.), on the federal and state level, has enacted a variety of measures to address stratospheric ozone depletion and respond to the limits set by the Montreal Protocol and its Amendments. After the U.S. ratified the Montreal Protocol, Congress amended the Clean Air Act in 1990, which became the main federal mechanism to address the problem of ozone depletion. In Chapter Six of Title VI, the Clean Air Act classifies ODS and strictly regulates their use and phase-out through a variety of monitoring, reporting, labeling, recycling, maintenance, and research regulations, all overseen by the U.S. Environmental Protection Agency (U.S. EPA). The Clean Air Act also gives the U.S. EPA the ability to issue allowances to control the amounts of ODS manufactured in accordance with phase-out schedules, prevent illegal entrance of ODS into the U.S., and provide information on alternatives to use in place of ODS. While the Montreal Protocol establishes use deadlines, countries, including the U.S., may accelerate those deadlines as the European Union has done.

The federal government has enacted other measures to further mitigate ozone destruction. Industry partnership programs, developed by the U.S. EPA, have been instrumental in providing information, incentives, and a collaborative atmosphere for the business community to join forces in the reduction and elimination of ozone-depleting substances.

Individual states in the U.S. have developed a variety of innovative approaches to educate the public, and in some cases, to go above and beyond federal and international requirements to reduce ODS emissions. Several states have taken independent action and instituted legislation and policy, undertaken research studies, enacted local ordinances, increased enforcement, revised regulations, implemented new programs, created public awareness campaigns, and created green tax credits and other financial incentives to ensure that their residents and businesses are safer and healthier than required by the federal and international governments. States have often been visionaries with their ozone-saving strategies, employing and creating new solutions before the federal government. On many occasions, successful state legislation and regulation was later

adopted by the federal government. Above all, states stress the need of individuals to make conscious choices on the local level in order to heal the ozone layer.

As evidence of the effects of ozone depletion grew and public sentiment for action mounted, industry responded to the phase-out of ODS with ingenuity and entrepreneurial innovation. In response to limits on the use of and total elimination of substances such as chlorofluorocarbons, methyl bromide, and halons, companies and manufacturers quickly and efficiently developed functional alternatives to ODS. Thus far, the refrigerant, solvent, blowing agent, and metered-dose inhaler applications have been generally addressed through the development of replacement compounds. Moderate success has been made in finding replacements for halons used in fire suppression. More progress is needed to find replacements for methyl bromide as a soil fumigant, which is proving to be most challenging to replace.

Governments and businesses must build on past success to enhance future progress. Improvements have been made to reduce the impact of human-made ozone depleting substances, but much more remains to be done before the public can rest easy about the state of the ozone layer and the amount of UV radiation the Earth receives. Creative policies and incentive programs by the government have successfully spurred industrial innovation to develop replacements for ODS and new systems. Such programs should be expanded to encourage development of alternatives to methyl bromide and halons, and to identify mechanisms to accelerate the transition to non-ozone depleting products in all applications. The market for non-ozone depleting products, particularly in air conditioning and refrigeration, is robust, competitive and growing.

Raising the public awareness about ozone depletion and the steps they can take to help the cause is the next step to ensuring the public's health and safety and the preservation of the Earth's critical ecosystems. The federal government, states, and non-profit organizations must continue and expand efforts to explain the problem of stratospheric ozone depletion to all generations, including its public health impacts and environmental risks. Most importantly, the public needs to be more effectively engaged to prevent further stratospheric ozone depletion through making informed purchases and continuing to motivate governments and industry to eliminate production and use of all ozone-depleting substances.

II. Introduction

The world has come far, but not far enough, on solutions to stratospheric ozone depletion. Reports about the state of the “ozone hole” point to the great success the global community has had in addressing the serious issue of stratospheric ozone depletion; however, it is still too early to declare victory. Stratospheric ozone depletion is still a very pervasive problem which has begun to show effects over the Arctic as well as in the southern hemisphere, and which still has significant implications for our public health and the environment. Governments, the scientific community and businesses must continue to cooperate to motivate, develop, and adopt policy and technological solutions to fully restore the health of the ozone layer.

The effects of stratospheric ozone depletion are still being observed and felt worldwide. Every year in September and October news about the ozone hole appears in newspapers, magazines and journal articles around the globe. Most people recognize it as the large dark spot that appears in satellite photographs over the Antarctic from August to November or December. In October of 2002 the news focused on the surprising phenomenon that the ozone hole, smaller than that of the previous two years, had split into two parts and perhaps begun to break down earlier than usual. While its smaller size and earlier disappearance may indicate that the condition of the ozone layer is improving, it is much too early to tell.¹

Only two years ago the world experienced its largest ever ozone hole, stretching out to a size nearly three times that of the U.S. That year it extended out beyond its usual boundaries to reach over the southernmost parts of Chile, exposing the city of Punta Arenas to very high levels of ultra violet (UV) radiation.² In the spring, the citizens of Punta Arenas now have a “solar stoplight” to warn them about the severity of UV exposure they will be subject to on any given day and provide them with advice as to how to limit their exposure.³ Chile as well as Australia and New Zealand have documented a rise in the rate of cases of skin cancer, believed to result from the thinning of the ozone layer.⁴ Other problems are expected in Australia and New Zealand, since thinning ozone is likely to affect their agriculture, fishing and tourism industries.⁵ Substantial ozone losses have recently been detected above the Northern Hemisphere as well. While these losses are not as extreme as those found in the southern hemisphere are, Canadian scientists have noticed preliminary impacts.

Continuous monitoring of the ozone layer over the country since 1998 has led scientists with the United Arab Emirates Meteorological Department to the conclusion that ozone depletion has raised the level of ultraviolet rays, especially during the months of July and August, thus increasing health hazards for humans and plants all over the world. Department Director, Ali Abdulla Al Gifri cautioned that the effects of UV radiation are now more insidious and detrimental to the eye and vision than previously suspected.⁶

The presence of long-lived ozone depleting substances, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and other chemicals, in the upper atmosphere and their ability to destroy ozone faster than it can be formed is not the only factor in thinning the ozone layer.

Government and business cooperation on ozone solutions provides a successful model.

As consensus began to be reached on the ozone depletion issue, governments and corporations mobilized to develop policies to phase-out ozone depleting substances and employ technological innovation to develop substitutes and processes to replace or reduce their usage. The Montreal Protocol, now signed by 175 nations, provided a framework and timetable for phasing out CFCs, HCFCs, halons, and other ozone-destroying chemicals with consideration for economic impacts and the needs of developing countries. Additional agreements have resulted in policies and timeframes for dealing with the many issues that have arisen subsequent to the development of the initial treaty. As corporate leaders learned more about the scientific evidence pointing to the need for mitigating ozone depletion, they worked internally and through their supply and distribution chains to find and develop solutions and to commercialize new technologies that would eliminate the need for ozone depleting substances.

In the U.S., the incentives and tools that the government brought to the table, along with corporate drive for cost-effective alternatives helped the U.S. meet the international deadline for phasing out production of CFCs for domestic use on January 1, 1996. Due to incentives and innovation, the U.S. has accomplished the phase-out earlier and at less cost than originally estimated.⁷ The European Union (EU) accelerated its phase-out schedule for HCFCs and implemented several use restriction on HCFCs, including HCFC-22 and HCFC-123, starting in 2001. The final phase-out date for HCFCs in the EU is 2015, which will drive U.S. companies to move early to identify and change over to acceptable substitutes.⁸

United Nations Secretary General Kofi Annan emphasized the need for continued vigilance and aggressive efforts to combat ozone depletion in his address on International Day for the Preservation of the Ozone Layer in September 2002:

“Life started to develop significantly on our planet only after the ozone layer was in place in the stratosphere to filter out harmful levels of sunlight. The battle to repair this life-sustaining system is far from over.

The scientific assessment carried out this year concluded that although some ozone-depleting agents in the atmosphere are declining slowly from the peak that occurred in 1992-1994, others are still on the increase. Scientists predict that the ozone layer will remain particularly vulnerable during the next decade or so, even if all countries comply with the measures put in place by the Montreal Protocol to control and phase-out ozone-depleting substances. Failure to comply with the Protocol would delay and could even prevent the ozone layer’s future recovery.”⁹

Governments and businesses must build on past success to enhance future progress. It is therefore imperative that further progress be made through the combined efforts of U.S. industry, federal and state governments, and the public. Through partnerships and innovation it is possible to continue to mitigate the factors that contribute to ozone depletion, including making further and faster reductions in emissions of ozone-depleting substances.

This paper explores the state of the stratospheric ozone depletion issue, from the beginning of its recognition in the 1970s to current findings and observations about whether the

ozone layer is on the road to recovery. It examines the role stratospheric ozone plays in the health of the planet, and looks at the scope of the problem and actions taken by the international community to reduce ozone loss. The paper then reviews the U.S. response to ozone depletion from the federal and state government perspectives, and looks at the leadership role U.S. industry played in developing new substances and processes. Finally, the report goes one step further to outline recommendations for motivating public action to continue to mitigate ozone loss.

III. The Importance of Stratospheric Ozone

Within the past 30 years, stratospheric ozone loss has come to the forefront of a global list of environmental concerns. The function of stratospheric ozone -- its origins and importance to life on Earth -- set the stage for understanding how the depletion of this protective layer threatens our planet and our public health.

a. Stratospheric Ozone – What It Is And What It Does

Stratospheric ozone is a layer of ozone-rich air that acts as the Earth's sunscreen, providing a filter to help protect all life forms from the sun's damaging ultraviolet (UV) rays. The stratosphere is the upper layer of the atmosphere, between 6-30 miles (10-50 km) above the ground. While ozone can be found throughout the entire atmosphere, the greatest concentration of it occurs at an altitude of about 15 miles (25km). This is what scientists refer to as the "ozone layer," and it accounts for 90 percent of the planet's ozone.

Ozone also occurs in small amounts at ground level in the layer of the Earth's atmosphere that surrounds us, called the troposphere. This ozone is produced at ground level through a reaction between sunlight and volatile organic compounds (VOCs) and nitrogen oxides (NOx), many of which are produced by human actions. Tropospheric ozone is a major component of urban smog –and is considered a serious air pollutant.

Even though both types of ozone are exactly the same molecule, their presence in different parts of the atmosphere has very different consequences. Stratospheric ozone helps block harmful solar radiation –which is very important because all life on Earth has developed in the presence of this filtered solar radiation. Tropospheric ozone, in contrast, is harmful to breathe, and although it will absorb some incoming solar radiation, it cannot make up for stratospheric ozone loss. It also contributes to the degradation of buildings, bridges and most man-made structures.

Stratospheric ozone is created when solar rays strike molecules of oxygen (O₂) and cause the two oxygen atoms to split apart. When one of these freed atoms bumps into another O₂ molecule, it joins up, forming ozone (O₃). Ozone also naturally breaks down in the stratosphere by exposure to sunlight and by chemical reactions with various compounds containing nitrogen, hydrogen and chlorine. These chemicals all occur naturally in the atmosphere in very small amounts. Most incoming UV radiation is absorbed by ozone and prevented from reaching the Earth's surface. Without the shielding effect of ozone, it is likely life on Earth would not have evolved the way that it has.¹⁰

The amount of ozone above a location on the Earth varies naturally depending on latitude, season, weather systems and other daily meteorological conditions. Under normal circumstances, the ozone layer is thickest over the poles and thinnest around the equator. The ozone layer over North America is normally thicker in winter and early spring; it can vary naturally by about 25 percent between January and July. Weather conditions can also cause considerable daily variations.

If there were no man-made ozone depleting substances in the atmosphere there would be an overall balance between the amount of ozone being produced and the amount of ozone being destroyed. Consequently, the total concentration of ozone in the stratosphere would remain relatively constant over a period of time. That balance, however, has been altered and we are beginning to understand how the state of the ozone layer plays a key role in the health of our planet and our own lives.¹¹

b. Depletion Effects on Public Health and Environment

The Earth's ozone layer protects all life from the sun's harmful radiation, but human activities have damaged this UV shield. Without it, life on Earth as we know it would not have developed. A diminished ozone layer allows more radiation to reach the Earth's surface. Overexposure to UV rays can lead to skin cancer, cataracts, and weakened immune systems in humans. Increased UV can also lead to reduced crop yields, disruptions in terrestrial ecosystems and interruptions in the marine food chain. UV also has other harmful effects, such as causing cancers and cataracts in domestic animals, and causing widely used materials such as wood, wool, and polymers to degrade much more quickly.¹²

UV radiation falls into segments in the electromagnetic spectrum with wavelengths shorter than visible light. The sun produces UV radiation, which is commonly split into three bands: UV-A, UV-B, and UV-C. UV-A is not absorbed by ozone and is just shorter than visible violet light. UV-B is mostly absorbed by ozone, although some reaches the Earth. UV-C has a shorter wavelength than UV-A and UV-B and is entirely absorbed by ozone and normal oxygen (O₂) in the upper atmosphere. (The National Aeronautics and Space Administration (NASA) provides more information on their web site: www.nasa.gov.)

The greatest threats to human health come from UV-B. UV-B is particularly effective at damaging DNA. The ozone layer protects the Earth against most UV-B coming from the sun. It is always important to protect oneself against UV-B, even in the absence of ozone depletion, by wearing hats, sunglasses, and sunscreen. However, these precautions become more important as ozone depletion worsens. For example, a recent study released by the Archives of Dermatology and the Journal of the American Medical Association suggests that cancer-causing UV rays can actually penetrate clothing. The study, based on Swedish research, examined more than 51,000 Swedish people diagnosed with squamous cell cancer for almost four decades (from approximately 1961-1998). The study found that skin cancer among men rose from 5.75 to 14.88 cases per 100,000 in sun-exposed areas of the body, and from 0.46 to 3.60 cases per 100,000 in clothing-covered areas. In women, cancer rates rose from 1.36 to 9.50 cases per 100,000 in sun-exposed areas, and from 0.08 to 1.26 cases per 100,000 in clothing covered areas.¹³ While there are several

factors included in possible causes for the increase, continued depletion of the ozone layer is among them.

The relationship between ozone depletion and UV-B radiation is one of great importance because decreases in ozone levels will lead to higher levels of UV-B reaching the Earth's surface. Studies have shown that in the Antarctic, the amount of UV-B measured at the surface can double during the annual ozone hole. Other studies have confirmed the relationship between reduced ozone and increased UV-B levels in Canada, Chile, and parts of the U.S. during the past several years.¹⁴

According to clinical and epidemiological studies by the American Cancer Society (www.cancer.org), increased exposure to UV-B radiation can be associated with the following conditions in humans:

- Melanoma – the most serious form of skin cancer that begins in the cells that produce skin coloring (melanocytes). It is the fastest growing form of cancer in the U.S.
- Non-melanoma skin cancer - a form that develops from skin cells other than melanocytes and is highly curable if detected and treated early.
- Cataracts – a loss of transparency in the lens of the eye that clouds vision. Other types of eye damage include macular degeneration, pterygium (tissue growth that blocks vision) and skin cancer around the eyes.
- Immune suppression – hindrance of the body's immune system and the skin's natural defenses, including impaired response to immunizations, increased sensitivity to sunlight, and reactions to certain medications.¹⁵

Residents in Punta Arenas, Chile have been reluctantly learning how to adapt to increased UV-B exposure, by covering their skin in the spring when the ozone layer in the southern hemisphere is at its thinnest. Chilean health officials have also noticed an increase of 105 percent in the incidence of melanoma in the capital city of Santiago, in the central part of the country.¹⁶

According to the U.S. Environmental Protection Agency (U.S. EPA, or “the Agency”), increased levels of UV-B radiation reaching the Earth have serious environmental impacts. A thinning ozone layer can adversely affect physiological and developmental processes of plants, orientation and mobility of phyto-plankton and other organisms necessary to support marine ecosystems, and Earth's biogeochemical cycles in the following ways:

- Plants -Indirect changes caused by UV-B (such as changes in plant form, how nutrients are distributed within the plant, timing of developmental phases and secondary metabolism) may be equally, or sometimes more, damaging than UV-B's direct effects. These indirect changes can have important implications for plant competitive balance, herbivory, plant diseases, and biogeochemical cycles.
- Marine Ecosystems - Phytoplankton form the basis of aquatic food chains. Exposure to solar UV-B radiation can affect both orientation mechanisms and motility in phytoplankton, resulting in increased death rates for these organisms. Scientists have

demonstrated a direct reduction in phytoplankton production due to ozone depletion-related increases in UV-B.

Solar UV-B radiation has been found to cause damage to early developmental stages of fish, shrimp, crab, amphibians and other animals. The most extreme effects are lowered reproductive rate and impaired larval development. Even at current levels, solar UV-B radiation is a limiting factor, and small increases in UV-B exposure could result in significant reduction in the size of the population of animals that eat these smaller creatures. According to a recent report from researchers at the U.S. Geological Survey and the U.S. EPA, increases in UV-B are causing a decline in frog populations worldwide.¹⁷

In addition, researchers have found that the intensifying UV-B radiation is blinding barnacle larvae and threatening their survival. As the tiny crustacean larvae swim towards the ocean's surface using light receptors in their eyes, they encounter rising levels of UV-B radiation causing damage to retinal cells. The sightless larvae not only stop foraging for food, but also in the study they were unable to latch onto the surface of a glass beaker or settle, which means in the ocean they would not be able to mature into adults.¹⁸

According to another study conducted by researchers from New Zealand's Otago University and the University of New Hampshire, the increased UV radiation levels have also reduced the survival rate of newly hatched sea urchin eggs by up to 40 percent. The study, conducted in Antarctica during the summer of 2002, indicated that increased levels of UV radiation resulting from the annual ozone hole, which forms over the region, were able to penetrate more than 2.5 meters into sea ice.¹⁹

- Biogeochemical Cycles - Increases in solar UV radiation could affect terrestrial and aquatic biogeochemical cycles thus altering both sources and sinks of greenhouse and chemically important trace gases such as carbon dioxide (CO₂), carbon monoxide (CO), carbonyl sulfide (COS) and possibly other gases, including ozone. These potential changes would contribute to biosphere-atmosphere feedbacks that support the atmospheric buildup of these gases.²⁰

IV. The Cause of Stratospheric Ozone Depletion

Stratospheric ozone depletion is the result of a complex set of circumstances and chemistry. It is caused by the release of stable organic compounds containing chlorine and/or bromine. The most common of these compounds are referred to as chlorofluorocarbons, or CFC's, and hydrochlorofluorocarbons, or HCFCs. Collectively these compounds are referred to as ozone depleting substances, or ODS. The CFCs and HCFCs have found many uses in aerosols, foams, refrigeration, air conditioners, solvents, fire extinguishers and other products and processes. These ODS remain in the atmosphere upwards of 50 to 1500 years; their emissions reach the stratosphere and cause ozone depletion.

The phenomenon of ozone depletion has been dramatically confirmed through the appearance of an ozone "hole" over Antarctica that has occurred annually during the Antarctic Spring since the early 1980s. Rather than being a literal hole through the layer, the ozone hole is a large area of the stratosphere with extremely low amounts of ozone. Ozone levels have fallen by over 60 percent during the worst years.²¹ The phenomenon of stratospheric ozone depletion involves the exacerbation of a natural process, the presence of chemical substances with ozone-destroying affinity, and the contribution of other atmospheric factors.

a. The Process

In the early 1970s, researchers began to investigate the effects of various chemicals on the ozone layer, particularly CFCs, which contain chlorine. CFCs are extremely stable and do not dissolve in rain. Thus, there are no natural processes that remove CFCs from the lower atmosphere. The ozone depletion process begins when CFCs, HCFCs and other ODS are emitted into the atmosphere where winds continually mix the troposphere and lower stratosphere and evenly distribute the gases. Measurements of ODS in the stratosphere are made using satellites, aircraft, and weather balloons.²²

ODS are carried further into the stratosphere over time (as long as 2-5 years). Many of these compounds are very stable - so much so that only exposure to strong UV radiation breaks them down. This break down process occurs in the stratosphere and when it happens, the CFC or HCFC molecule releases atomic chlorine. One chlorine atom is capable of destroying over 100,000 ozone molecules. Bromine compounds in the atmosphere break down similarly to chlorine compounds and are produced from methyl bromides used as soil fumigants, and from halons used in fire suppressants. Although chlorine is more abundant than bromine as a pollutant, bromine remains disproportionately responsible for ozone depletion because it is more reactive than chlorine. The net result is that these ODS destroy ozone faster than it is naturally created.²³

A closer look at the process shows that for five or six months every year, each of the Earth's polar regions remains in extreme-cold winter darkness. During polar winters icy polar stratosphere clouds (PSCs) made of ice, nitric acid and sulphuric acid form some 6-10 miles (10 to 15 km) high at temperatures near minus 120 Fahrenheit (minus 85 degrees Celsius). These PSCs last for only several weeks and generate 200-mph polar vortex winds which trap ODS above the poles for weeks. This process lays much of the foundation for ozone depletion when the sun returns.²⁴

When sunlight returns, the breakdown of these ODS (fixed above the poles as a result of the polar vortex winds) accelerates due to the increase in UV radiation which thereby causes a large decrease in the ozone concentration over the polar regions. UV radiation breaks down ODS to yield chlorine, bromine, or other chemical radicals. These chemical radicals then quickly combine with organic compounds to form such things as hydrogen bromide (HBr), hypobromous acid (HOBr), and hydrogen chloride (HCl), which are photo-chemically stable precursors to ozone-depleting compounds. For example, when HCl joins with chlorine nitrates contained in PSCs it makes nitric acid and ozone-damaging chlorine. Chlorine from CFCs and HCFCs accounts for 70 percent of ozone depletion. Another 25 percent is caused by bromine, and other compounds cause about five percent.²⁵

While Antarctica has experienced significant ozone depletion since the early 1980s, concerns with ozone depletion are not isolated to a single polar region. The Arctic region has begun to display extensive ozone losses with potential for more frequent and severe depletion episodes over the next 10-20 years.²⁶ Even in the Arctic where the temperatures are far more variable, the formation of PSCs can lead to a series of chemical reactions that can destroy ozone. Currently the effects are not as severe for the Arctic region as they are for Antarctica. This is due in part to the higher level of ozone the Arctic region has to start with as well as the fact that the more variable atmospheric circulation of the Northern Hemisphere often makes the Arctic stratosphere too warm for PSC formation.²⁷ However, with unusually cold winters in recent years the ozone loss has proven to be more severe than anticipated with losses of up to 50 percent at some altitudes,²⁸ and maximum total column ozone losses due to halogens reaching 30 percent during the last decade winters.²⁹ Although seasonal ozone loss is more severe in the Antarctic, the ozone loss in the Arctic is likely to increase if the Arctic air mass continues to become colder and more humid.³⁰

b. The Substances

The substances that cause ozone depletion comprise chemicals that can be broken down by UV radiation, releasing chlorine or bromine atoms. The chlorine and bromine atoms released then attack and destroy ozone molecules. While a few hundred chemical reactions are involved in ozone depletion, not all of them are equally as destructive. The substances involved in these chemical reactions have been evaluated and assigned a designation indicating their potential to contribute to ozone loss, which has also been used to assess what type of regulatory action may need to be taken for a substance.

Each of these substances has an Ozone Depletion Potential (ODP), which is the number that refers to the amount of ozone depletion a substance can cause. The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11. Thus, the ODP of CFC-11 is defined to be 1.0. Other CFCs and HCFCs have ODPs that range from 0.01 to 1.0. The halons have ODPs ranging above 10. Carbon tetrachloride has an ODP of 1.2, and methyl chloroform's ODP is 0.11.³¹

The U.S. EPA categorizes them into two classes of substances in relation to the severity of their ODPs:

- Class I Substances comprise the group of chemicals with an ozone-depletion potential of 0.2 or higher. Class I substances include carbon tetrachloride, CFCs, halons, hydrobromofluorocarbons (HBFC), methyl bromide, and methyl chloroform. There are many more listed on U.S. EPA's website: <http://www.epa.gov/ozone/ods.html>
- Class II Substances are those chemicals with an ozone-depletion potential of less than 0.2. Currently, all of the hydrochlorofluorocarbons (HCFC) are class II substances. There are nearly 30 Class II substances listed on the U.S. EPA's website. A list of Class II substances including their ODPs and GWPs is available at <http://www.epa.gov/ozone/geninfo/gwps.html>.

Class I Substances

Chlorofluorocarbon (CFC) - There are several different kinds of CFCs that have various uses. For example, CFC-11 is a liquid used as a refrigerant in sealed systems such as building chillers. CFC-12 is a gas often used in car air conditioner systems, which happen to be inherently leaky. It is also used in tightly sealed systems, e.g. household refrigerators and reciprocating chillers. CFC- 113 is used as a refrigerant, as a cleaner for high-quality electronics assemblies, and as an industrial solvent. In addition, CFCs are used to make a variety of foam products, including, polyurethane foam, phenolic foam, extruded polystyrene foam, and polyolefins.³²

Carbon Tetrachloride (CCl₄) - This compound was used widely in the production of refrigerator coolants and propellants for aerosol cans until it was phased out. It was also used by the military to clean electronic components for avionics, radar, and communication systems, and in various industries as a degreasing and cleaning agent, as a fire retardant, and as a laundry spot remover.

Halons - Halons are used mainly as fire extinguishing agents by the military and industry.

Hydrobromofluorocarbon (HBFC) – This compound is used mainly in fire suppression.

Methyl Bromide (CH₃Br) – Methyl bromide is a highly potent fumigant used to control insects, nematodes, weeds, and pathogens in more than 100 crops, in forest and ornamental nurseries, and in wood products. Its primary uses are for soil fumigation, post-harvest protection, and quarantine treatments.

Methyl Chloroform (CH₃CCl₃) – This compound is used as a solvent and degreasing agent in industry. It is also used as an ingredient in consumer products such as household cleaners, paints, glues, aerosol sprays, and formerly as a food and grain fumigant. The Montreal Protocol and its amendments control the phase-out of methyl chloroform production and use.

Class II Substances

Hydrochlorofluorocarbon (HCFC) – This is one class of chemicals used to replace CFCs. HCFCs are used primarily as refrigerants and foam blowing agents to produce polyurethane, phenolic and polystyrene insulation products, and certain polyolefin packaging and polyurethane integral skin for automotive applications.

A listing of Class I and selected Class II ODS by group classification and including their ozone depletion and global warming potentials as assigned by the U.S. EPA are included in Table 1 below:

Table 1. Ozone-Depleting Substances

Class I Substances		
Chemical Name	ODP	GWP
Group I (from section 602 of the CAA)		
CFC-11 (CCl ₃ F)	1	4000
CFC-12 (CCl ₂ F ₂)	1	8500
CFC-113 (C ₂ F ₃ Cl ₃)	0.8	5000
CFC-114 (C ₂ F ₄ Cl ₂)	1	9300
CFC-115 (C ₂ F ₅ Cl)	0.6	9300
Group II (from section 602 of the CAA)		
Halon 1211 (CF ₂ ClBr)	3.0	1300
Halon 1301 (CF ₃ Br)	10	5600
Halon 2402 (C ₂ F ₄ Br ₂)	6	
Group III (from section 602 of the CAA)		
CFC-13 (CF ₃ Cl)	1	11700
Other CFCs (111, 112, 211, 212, 213, 214, 215, 216, 217)	1	Not listed
Group IV (from section 602 of the CAA)		
CCl ₄	1.1	1400
Group V (from section 602 of the CAA)		
Methyl Chloroform (C ₂ H ₃ Cl ₃)	0.1	110
Group VI (from Accelerated Phase-out Final Rule)		
Methyl Bromide (CH ₃ Br)	0.6	5
Group VII (from Accelerated Phase-out Final Rule)		
CH ₂ Br ₂	1	Not listed
HBFC-12B1 (CHF ₂ Br)	0.74	Not listed
CH ₂ FBr	0.73	Not listed
Selected Class II Substances (HCFCs)		
Chemical Name	ODP	GWP
HCFC-21 (CH ₂ Cl ₂)	0.04	210
HCFC-22 (CH ₂ ClF)	0.055	1700
HCFC-123 (C ₂ H ₃ Cl ₂ F)	0.02	93
HCFC-124 (C ₂ H ₂ Cl ₂ F ₂)	0.022	480
HCFC-141b (C ₂ H ₃ ClF ₂)	0.11	630
HCFC-142b (C ₂ H ₂ ClF ₃)	0.065	2000
HCFC-225ca (C ₃ H ₂ ClF ₅)	0.025	180
HCFC-225cb (C ₃ HClF ₅)	0.033	620

Sources: <http://www.epa.gov/ozone/ods.html>
<http://www.epa.gov/ozone/ods2.html>

c. Other Factors

Although CFCs and other ODS are widely thought of as being solely responsible for the depletion of the stratospheric ozone layer, there is some evidence suggesting that volcanoes and other natural events, in addition to other human related factors, also play a role in accelerated ozone depletion.

Volcanic eruptions

Volcanic eruptions are one of the few natural events that can have a diminishing effect on the ozone layer. Most volcanic eruptions are too weak to reach the stratosphere. Thus, any hydrogen chloride (HCl) emitted during smaller eruptions remains in the lower atmosphere and is easily dissolved in water and washes out (in steam from volcanic plumes and in rain) before it can reach the ozone layer. The HCl and ice particles containing sulfuric acid from large eruptions, however, may contribute to short-term ozone loss when they interact with chlorine compounds (resulting from the breakup of CFCs) in the stratosphere and serve to convert them into more active ozone depleting forms.

In contrast to most volcanic emissions, ODS are more prevalent, are not broken down in the lower atmosphere, and do not dissolve in water. The chlorine in these human-made molecules readily reaches the stratosphere through atmospheric mixing; data show that the increase in chlorine found in the stratosphere since 1985 correlates with the amount released from CFCs and other ODS given off by human activities.³³

Aircraft emissions

Aircraft-emitted nitrogen oxide (NO_x) also affects ozone chemistry. Subsonic aircraft fly in the upper troposphere and lower stratosphere at altitudes of about 5 to 9 miles (10 to 15 km), whereas supersonic aircraft cruise several miles higher, at about 10 to 12 miles (17 to 20 km) in the stratosphere. At higher altitudes, increases in NO_x lead to decreases in the stratospheric ozone layer, due to the catalytic effect NO_x has on ozone destruction, accelerating the reactions between ozone and ODS. The impacts of NO_x vary from regional effects in scale (pollution in the troposphere) to global effects in scale (ozone depletion in the stratosphere). There are ongoing balloon studies being performed by NOAA to determine the concentrations of water vapor, NO_x, methane, and other aircraft emissions that interact with ozone chemistry.³⁴

Space shuttle and other high altitude flights have also been examined for effects on ozone depletion. In the early 1970s, it was suggested that chlorine from solid rocket boosters might have a significant effect on the ozone layer. A study by Cicerone and Steadman in 1974 found the resulting contribution of chlorine to be relatively small, as have many studies since then. Recent studies on the issue estimate that the shuttle program has some influence on stratospheric chlorine levels. Each shuttle launch produces about 200 tons of HCl, most of that released in the troposphere.³⁵

Greenhouse gases and global warming

A recent NASA study has shown that while CFC concentrations will decrease over the next 20 years, the levels of CO₂, methane, and other greenhouse gases will continue to rise. Such increases in greenhouse gas levels could have consequences on stratospheric ozone, possibly lowering stratospheric temperatures that would in turn disrupt polar air masses and accelerate ozone loss to polar regions. More specifically, methane, like CFCs, has a long tropospheric lifetime and is capable of penetrating into the stratosphere, where it interacts with ozone and eventually produces water vapor. Since tropospheric methane has increased by nearly 100 percent in the past century, there has been a corresponding increase in stratospheric water vapor, which may contribute to intensification of PSC in the polar regions.³⁶

Most ODS also have the potential to contribute to global warming, including all CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide and all HCFCs. The global warming potentials (GWP) for each compound are different, depending on its formulation. Many of the GWPs for ODS are significantly higher than that of some common greenhouse gases; however, the total effect any of these compounds is likely to have in regard to global warming should consider additional factors, including assumptions about system usage, leakage, end-of-life disposal and indirect impacts on energy use due to the efficiency properties of the substance, where applicable.³⁷

Decreases of about 70 percent of the “business as usual” use of CFCs for refrigeration and air conditioning applications were primarily achieved through reductions in initial charge and servicing of those systems and by tightening up system operations. The CFC phase-out, in combination with the phase-out of halons, produced a reduction of about 94 percent in the contribution of fluorocarbon gases to global warming. Primary drivers for this level of reductions included the increased price of refrigerants, awareness of ozone depletion and climate change issues, and regulations, such as the “no venting” rules in the U.S. These drivers will continue to reduce fluorocarbon emissions from previous “business as usual” estimates, particularly for HCFCs, as the phase-down of production for these compounds proceeds. This should help to further reduce the contribution of fluorocarbon emissions to global warming.³⁸

V. The Scope of the Problem

Stratospheric ozone depletion is one of the first truly global environmental issues faced and dealt with collectively by the world community. Since any emissions of ODS anywhere in the world contribute to thinning of the ozone layer, all nations producing and using these chemicals had to be engaged in finding solutions to the problem. Even though ozone depletion seems to concentrate mostly around the polar regions, the impacts are far reaching in terms of the human health and environmental impacts.

The scope of the ozone depletion problem is incredibly broad. It spans over geographical, generational and cultural boundaries. The thinning of the ozone layer affects human health, the environment and the economy. It requires multiple players on many fronts –

government, industry, and the scientific community – to join together to develop the policies and technologies necessary for its solution.

a. Early Evidence – The Ozone “Hole” and Other Effects

The first observation of a hole in the ozone occurred over the Antarctic in 1985; however, scientists discovered data pointing to its existence as early as the 1970s. Multi-agency scientific expeditions throughout the mid-to-late 1980s provided data that helped link the destruction of the ozone layer to chlorine from CFC decomposition. These excursions also revealed variations in the size and depth of the loss over the years.

Scientific reviews of data gathered over a 20-year period showed decreases in ozone concentrations of up to five percent, depending on latitude, occurring over both the northern and southern temperate zones, in addition to the hole over the Antarctic. The rate of decline in ozone levels was approximately 25 percent per year from 1980 – 1992, according to satellite data. In the late 1980s, scientists began to focus studies on the Arctic stratosphere, to determine if ozone loss was occurring there as well. Although inconclusive, findings in the early-to-mid 1990s showed some slight depletion in the Arctic and pointed to changes in the stratosphere in the North that were analogous to changes in the Antarctic. Using monitoring stations in the northern hemisphere, the World Meteorological Organization (WMO) reported that depletions were occurring over Siberia and the below average ozone levels were evident as far south as Spain.³⁹ More recent observations by Environment Canada have shown depletion of up to 50 percent in the Arctic stratosphere.⁴⁰

Along with the observations about ozone loss, scientists also observed and quantified significant increases in ultraviolet radiation at the ground level in Antarctica. In 1996 scientists presented the results of a review of 14 years of Total Ozone Mapping Spectrometer (TOMS) data confirming that in areas with declining levels of stratospheric ozone, surface UV-B levels increase.⁴¹ Plankton studies in the waters off of the coast of Antarctica revealed that increased UV-B penetration decreases photosynthesis up to four percent per day. The overall effect shown was small, however, due to the short duration of the ozone hole.⁴²

Other studies published in the early 1990s showed the effects of higher UV-B radiation on ecosystems. One study in British Columbia found that UV-B radiation killed insect larvae that feed on algae, resulting in unsuppressed algal growth.⁴³

b. Recent Findings, Observations and Current Trends

In October 2002, much of the news about the ozone hole focused on the surprising phenomenon that it was not only smaller than it had been in the previous two years, but that it also had split into two parts and perhaps begun to break down earlier than usual. While its smaller size and earlier disappearance may indicate that the condition of the ozone layer is improving, it is much too early to tell.⁴⁴

According to the most recent United Nations Environment Programme/World Meteorological Organization (UNEP/WMO) scientific assessment report released in August

2002, current observations suggest that ozone recovery has not yet begun. Ozone depletion occurring during the Antarctic spring remains very large. During this time daily local total column values are measuring 60-70 percent less than pre-ozone hole conditions, reflecting a near complete ozone loss in the 12-20 km range. The ozone hole has continued to increase in size over the last decade, though not as rapidly as it did during the 1980s. Its area varies from one year to another, and there has been an increase in recent years in the area enclosed by the 220 DU contour (which measures the severity of the ozone hole), making it difficult to determine whether the ozone hole has maximized. The WMO panel's findings also show the hole persisting into early summer in recent years, thus increasing its impact on ultraviolet radiation. UV irradiance calculations and other measurements confirm that UV radiation increases are the result of decreases in ozone column amounts.⁴⁵

Only two years ago the world experienced its largest ever ozone hole, stretching out to a size nearly three times that of the U.S. That year it extended out beyond its usual boundaries to reach over the southernmost parts of Chile, exposing the city of Punta Arenas to very high levels of ultra violet radiation.⁴⁶ The citizens of Punta Arenas offer an example of what life is like under the ozone hole. They are taking serious precautions, including the use of a "solar stoplight" warning system to tell them what the level of danger is regarding UV exposure on a daily basis in the spring, and the development of a far-reaching governmental education and prevention campaign.⁴⁷ Chile as well as Australia and New Zealand have documented a rise in the rate of cases of skin cancer, believed to result from the thinning of the ozone layer.⁴⁸

Other problems are expected in Australia and New Zealand, since thinning ozone is likely to affect their agriculture, fishing and tourism industries.⁴⁹ Substantial ozone losses have recently been detected above the Northern Hemisphere as well. While these losses are not as extreme as those found in the Southern Hemisphere, in December 2000, the American Geophysical Union presented a study showing that nearly 70 percent of the Arctic ozone layer had been lost that winter.⁵⁰

c. Outlook for the Future

In August 2002, the UNEP/WMO Scientific Assessment Panel reported that chemistry-climate models predict that springtime Antarctic ozone levels will be increasing by 2010. This prediction is based on projected decreases of halogens in the stratosphere. The report further predicts that total ozone column amounts in the Antarctic are expected to return to pre-1980 levels by the middle of this century, and forecasts that the ozone hole will disappear at about this same time. These scenarios are predicated on a continued adherence to the fully amended and adjusted Montreal Protocol.

Nevertheless, even though stratospheric ozone levels may begin to increase over the next ten years, the Scientific Assessment Panel further indicates that during this same time, the ozone layer will remain particularly vulnerable, even with full compliance with the Montreal Protocol. Because atmospheric concentrations of ODS are expected to be near their highest levels in the next several years, the human-induced effects of those emissions will be at or near their largest. Due to the variability of ozone, it will be difficult to detect the onset of the long-term recovery of the ozone layer.⁵¹

VI. Taking Action and Making Progress

With the depletion of the ozone hole and the potential for further extensive damage, the global community came together to craft a policy solution. The United Nations Environment Programme convened international negotiations to protect the ozone layer. This series of meetings to study and develop solutions to the ozone problem resulted in overcoming major obstacles and developing concrete goals and actions for phasing out ODS. In addition, the policy developments that occurred as a result of the Montreal Protocol blazed a path for technology improvements to develop ozone-friendly chemical substitutes and processes.

a. The Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer (“Montreal Protocol” or “the Protocol”) was created under the Convention for the Protection of the Ozone Layer. The Convention was developed as a framework for the international community to cooperate on research, monitoring, and the exchange of information on stratospheric ozone depletion and to develop control measures as needed according to an outlined set of procedures. The U.S. Senate expressed support for the Convention in 1986 and then signed on to the Protocol on September 16, 1987.

The Protocol is an agreement reached initially by 47 countries, outlining control measures for ODS. Included within the Protocol is a cap on consumption of specific CFCs (11, 12, 113, 114 and 115) at 1986 levels within a year after its effective date, and a subsequent reduction in consumption by 20 percent over 3 years and by an additional 30 percent by 1999. The Protocol also capped consumption of halons 1211, 1301, and 2402, but did not specify further reductions of them.

On January 1, 1989 the Protocol became effective, having been ratified by 29 countries representing 82 percent of the world's consumption (required to have at least 11 nations representing at least 2/3 consumption). As of December 2002 a total of 184 countries have ratified the 1987 Protocol.

b. Policy Progress in the 1990s

The Parties to the Montreal Protocol continued to meet and work on solutions to ozone depletion throughout the 1990s. Each subsequent meeting resulted in new agreements or accords that amended the original treaty. These agreements promulgated new scientific findings about the process and outcomes of ozone depletion, added new ODS to the phase-out timeline, and established and/or further limited the production and consumption of ODS by accelerating schedules and setting new limits, as appropriate. While there were a number of additional amendments to the Montreal Protocol, the London Amendments and the Copenhagen Accord resulted in significant changes that have been ratified by a large number of parties, including the U.S.

The London Amendments

Resulting from work that began in Finland in 1989, the Parties reached an agreement that established the London Accord in 1990. It was designed to accelerate the phase-out of ozone-depleting substances and make other substantive changes and additions to the 1987 Protocol goals. The Accord required further reductions from 1986 levels for CFCs, halons and some new chemicals, the reduction of CFCs by 20 percent by 1993, 50 percent by 1997 and 100 percent by 2000; the reduction of halons 50 percent by 1995 and 100 percent by 2000; the reduction of Carbon Tetrachloride by 85 percent by 1995 and 100 percent by 2000; and the reduction of Methyl Chloroform by 30 percent by 1995, 70 percent by 2000 and 100 percent by 2005. The London Accord called for a grace period of 10 years for less developed nations to complete these phase-outs. The elimination of HCFCs was called for no later than 2040, and earlier than 2020 if possible.

To address issues on the need for technology and funds to be provided to less developed nations, the London Accord created an international fund for this purpose. It provided for \$160 million in the fund over the period 1991-1993, and was to be administered by a 14-nation board. The U.S. holds a permanent seat on the board and contributes 25 percent to the fund. Approximately 30 other nations also contribute. The U.S. Senate ratified these Protocol amendments in 1991. As of May 2000, 139 countries had ratified the London Amendments.

The Copenhagen Accord

Prompted by the results of a scientific review conducted in 1991 and 1992, the Parties agreed to an additional acceleration of the phase-out of ODS in November 1992 with the adoption of the Copenhagen Accord. This Accord accelerated the phase-out of CFCs, methyl chloroform and carbon tetrachloride to the end of 1995, with an interim goal of 75 percent reduction by 1994. The Accord called for the complete phase-out of halons by the end of 1994 and set a phase-out schedule for HCFCs. The phase-out schedule for HCFCs included a cap in 1996 at an amount equal to 3.1 percent of the total ozone depleting potential of CFCs plus the total for HCFCs consumed in 1989 and a reduction from the capped amount to 65 percent in 2004, 35 percent in 2010, 10 percent in 2015, 0.5 percent in 2020 and 0 in 2030. The U.S. ratified the Copenhagen Amendments on February 3, 1994. The formula was since changed in 1995, lowering the factor from 3.1 percent to 2.8 percent. In addition, it was stipulated that from 2020 to 2030, HCFCs could only be used to service existing equipment. (See the Handbook for the International Treaties for the Protection of the Ozone Layer, 5th edition, which can be downloaded from www.unep.org/ozone/Handbook2000.shtml)

The policy changes instituted through these agreements are responsible for the significant reductions in emissions of ODS to the atmosphere that have been achieved so far. An overview of the consumption freeze and phase-out schedules for Class I and II ODS are outlined in Table 2 at the end of this section.

c. The Role of Technology

The Montreal Protocol and its subsequent agreements set targets and timetables for freezing the consumption and production of ODS; they did not prescribe particular substances or alternatives. In implementing these targets and timetables, the U.S. did not employ traditional “command and control” approaches, relying instead on a combined strategy of regulatory and market-based policies that allowed for flexibility and innovation on the part of industry. Cooperation between government and industry and entrepreneurial approaches to developing and finding substitutes created opportunities for new technologies with lower or zero ozone-depleting properties to be developed and “pulled” into the marketplace in less time than it would normally take.⁵²

Firms that took early and aggressive action to develop new technologies and get them into the marketplace as substitutes found a competitive advantage in doing so, due in large part to the policies implemented by the federal government. The competitive nature of corporations took over, and more companies became engaged in efforts to produce better and cheaper substitutes and alternatives. As future targets and timetables come into view, technology developments and improvements will continue to have a prominent role in repairing and protecting the ozone layer.

Table 2. Phase-out Schedule for Ozone Depleting Substances

Substance	Developing Countries		Developed Countries		European Union (if different from Montreal Protocol)		United States (if different from Montreal Protocol)	
	Consumption Freeze	Phase-out	Consumption Freeze	Phase-out	Consumption Freeze	Phase-out	Consumption Freeze	Phase-out ⁽¹⁾
Bromochloro-methane	N/A	January 1, 1996	N/A	January 1, 1996	No change	No change	No change	No change
Carbon Tetrachloride	85% reduction January 1, 2005 (1998-2000 average levels)	January 1, 2010	85% reduction January 1, 1995 (1989 levels)	January 1, 1996	No change	No change; no exemptions (used for making CFCs)	50% reduction 1994	No change; no exemptions (used for making CFCs)
CFCs (11, 12, 113, 114, 115)	July 1, 1999 (1995-1997 average level)	January 1, 2010	July 1, 1989 (1986 average level)	January 1, 1996	No change	No change; exemptions include medical devices (5322 tons used in 1998)	No change	No change; exemptions include medical devices (2426 tons used in 1998)
Other CFCs (13, 111, 112, 211, 212, 213, 214, 215, 216, 217)	20% reduction January 1, 2003 (1998-2000 average levels)	January 1, 2010	20% reduction January 1, 1993 (1989 levels)	January 1, 1996	No change	No change; no exemptions	No change	No change; no exemptions
Halons (1211, 1301, 2402)	January 1, 2002 (1995-1997 average level)	January 1, 2010	N/A	January 1, 1994	No change	New halons banned as of 1994; recycled banned as of 2003 ; limited exemptions for certain sectors		No change; limited exemptions for certain sectors
HBFCs	N/A	January 1, 1996	N/A	January 1, 1996	No change	No change	No change	No change
HCFCs	January 1, 2016 (2015 levels)	January 1, 2040	January 1, 1996 (1989 level + 2.8% of 1989 CFCs levels)	January 1, 2030	2.0% factor in formula. 65% reduction January 1, 2008	By application ⁽²⁾ ; exemptions include precision cleaning for aerospace and aeronautic electrical components, until 2008, and as halon replacement. HCFC consumption phase-out started in 2001 and is complete in 2010.	No change	By compound ⁽³⁾ ; limited use of 141b in space and military uses; critical uses for other HCFCs not yet identified; exemptions will not exceed cap
Methyl Bromide	January 1, 2002 (1995-1998 average levels)	January 1, 2015	January 1, 1995 (1991 levels)	January 1, 2005	No change	Phase-out January 1, 2005, or earlier, except for quarantined and preshipment applications (Over 20% of current use; use for these applications is frozen at 1996-1998 average levels)	25% reduction 1999	No change; exemptions for quarantined and preshipment applications; other critical uses addressed on a case-by-case basis
Methyl Chloroform	January 1, 2003 (1998-2000 average levels)	January 1, 2015	January 1, 1993	January 1, 1996	Same	No change; exemptions for aircraft and aerospace	50% reduction 1994	No change; exemptions for aircraft and aerospace

(1) The U.S. EPA allocates "essential use" exemptions on a case-by-case basis each year. There is a fixed total of allowances corresponding to the Montreal Protocol cap.

(2) No new HVAC/R equipment using HCFCs after 2004; no new HCFC refrigerants after 2010; no recycled HCFC refrigerant after 2015; no HCFC solvents after 2001; no new HCFC foam-blowing agents after 2003.

(3) No new HCFC-141b after 2003; no new equipment using HCFC-22 or HCFC-142b after 2010; no new HCFC-22 or HCFC-141b after 2020; no new equipment using other HCFCs after 2020; no new HCFCs after 2030.

VII. The U.S. Response: Federal Programs and Partnerships

After the U.S. ratified the Montreal Protocol, the federal government developed a two-pronged approach to help to mitigate depletion of the stratospheric ozone layer. The first phase of this response began with a reevaluation of the Clean Air Act (CAA or “the Act”) and the development of Chapter Six of Title VI, Stratospheric Ozone Protection. With the newly amended Act as a foundation, the federal government initiated a series of partnership programs, education and outreach efforts, and coordinated strategies with other federal statutes. The specific regulations developed and promulgated by the U.S. EPA to implement Title VI are available on the Agency’s website, at www.epa.gov/air/caa/title6.html.

The Clean Air Act Amendments of 1990 established mechanisms for classifying, monitoring, and eliminating the substances that cause ozone depletion. Additional policies and programs developed by the federal government provided information and education on impacts and alternatives, and incentives/motivators for changing behavior regarding the use of these substances. Another environmental statute, the Toxic Substances Control Act, also has applicability in the context of regulating substances that may affect ozone depletion.

a. The Clean Air Act – Federal Response To Ozone Depletion

Prompted by evidence of the verifiable negative impacts of ozone depletion and increased public concerns, federal action became an inevitable next step for the U.S. Policymakers began to indirectly protect the Earth’s surface and human health by directly mandating the protection of the ozone layer. While the Montreal Protocol initially froze the production of chlorofluorocarbons and halons at 1986 levels with a schedule for future phase-out, the U.S. had to assess its own statutory framework and modify the section of the Clean Air Act that addressed ozone protection to more adequately address the problem of ozone depletion. Ultimately, Congress repealed Part B of Title I of the Act, replacing it with Title VI, “Stratospheric Ozone Protection.”⁵³

Title VI of the CAA establishes the types of substances that are regulated to protect against ozone loss, sets out monitoring and reporting requirements, and outlines phase-out schedules for these substances. It also establishes a system of tradable production and consumption credits, and outlines requirements for a comprehensive program to limit emissions of ODS during their use and disposal. The Act also includes provisions regarding the servicing of motor vehicle air conditioners and regulations governing nonessential products that contained chlorofluorocarbons.

To provide clear information about product content to the public as well as opportunities for interested parties to move toward non-ozone destroying alternatives, the Act also specifies labeling requirements and the identification of safe alternatives to ODS. Several subsections within Title VI also address the relationship of the CAA to other law, including the Montreal Protocol, describing the importance of transferability among all affected parties. The Title VI provisions also calls for a series of reports on methane, and requires that the U.S. EPA assign a global warming potential value to all ODS.

Classification of ozone depleting substances

Under Title VI, Congress outlines a categorization of ozone-depleting chemicals into Class I and II substances, and requires that the U.S. EPA update and revise the list to add any substances found to present a hazard to the ozone layer. Updates are done at least every three years for both Class I and Class II substances. The Act also allows for any person to petition the Agency to add a substance to the list. Class I was initially divided into five subgroups: chlorofluorocarbons, or CFCs, (Groups I and III); halons (Group II); carbon tetrachloride (Group IV); and, methyl chloride (Group V). Two additional subgroups, methyl bromide (Group VI) and the HBFCs (Group VII), were added within the accelerated phase-out final rule in December 1993.⁵⁴ Consistent with the Montreal Protocol, the CAA requires that the U.S. EPA assign ozone-depletion potentials, to all listed substances at publication. A list of twenty numerically assigned Class I substances was published by the Agency on January 29, 1991. Currently there are 55 substances included within the seven Class I groups. Class II includes 34 substances, all of which are HCFCs.⁵⁵ A complete list of Class I and Class II substances is available on the U.S. EPA website, at www.epa.gov/docs/ods.html.

Monitoring and reporting

The CAA includes very prescriptive monitoring and reporting requirements for all listed substances, which were defined in a set of regulations issued by the U.S. EPA on July 30, 1992. Producers, importers or exporters of listed substances must submit reports to the Agency on an annual basis. A prerequisite to these annual reports is a “baseline report” that must be filed along with the first annual report of all Class I substances. This baseline report must provide a detailed explanation of the quantity of a particular substance that is produced by the filing party during the defined baseline year. The U.S. EPA uses this information to prepare reports to Congress every three years regarding the production, use, and consumption of all listed substances. In addition to the three- year report, the Agency must also submit a report to Congress on the environmental and economic impacts of stratospheric ozone depletion every six years. As of the 1997 report to Congress, data showed a dramatic decrease in the production, use and consumption of ozone-depleting substances as a result of accelerated phase-out. A separate report, published by the United Nations Environment Programme and the Technology Assessment Panel in late 1998, addressed the environmental and economic impacts of ozone-depleting substances. The U.S. EPA is currently developing the next reports addressing the production, use and consumption, as well as the environmental and economic impacts, of ODS, to be released in early 2003.

There are additional provisions affecting the NASA and NOAA, requiring them to submit a report on the current average tropospheric concentration of chlorine and bromine and on the level of atmospheric ozone depletion at least every three years to Congress. The Act also requires the monitoring of technological progress in developing alternative systems or products necessary to operate appliances without the use of Class II substances (HCFCs). The U.S. EPA must inform Congress by January 1, 2015 if progress is insufficient to allow for production of such equipment without the use of Class II substances.

Phase-out of Class I and Class II substances

The CAA outlines the timeframes for ceasing production and consumption of ozone-depleting substances, without mandatory specific substitutes or technologies. It lays out a process for considering accelerations to that schedule, and provides a flexible mechanism in the form of allowance trading to assist the regulated community in meeting the schedule. While the Act originally established a phase-out date of January 1, 2000 for Class I substances, this was accelerated to January 1, 1996 based on the release of new information by NASA in February and April 1992.⁵⁶ President Bush announced the acceleration of the phase-out on February 11, 1992.⁵⁷ EPA issued the final rule for the accelerated schedule in December 1993.⁵⁸ The new information pointed toward the possibility that an ozone hole similar to the one that has been seen periodically at the South Pole may have also appeared over the Northern Hemisphere. Other phase-out schedules have also been accelerated through a series of amendments.⁵⁹

Timeframes and Exceptions

As stipulated in the accelerated schedule within the CAA, the requirements for the phase-out of Class I substances determine that the production of all Class I substances will be unlawful after December 31, 1995 with the exception of methyl chloroform, which will be unlawful to produce after January 1, 2002. Methyl bromide was added as a Class I substance in 1993, but was subject to a later phase-out schedule.

There are a few exceptions to the regulated phase-out of Class I substances. The U.S. EPA authorizes these exceptions, after public comment, only in the cases where no safe and effective substitute is available, including:

- methyl chloroform for essential uses (such as nondestructive testing for metal fatigue and corrosion in aircraft engines);
- medical devices; and,
- halon-1211, halon-1301, and halon-2402 for aviation safety.

Additional exceptions allow for the Agency to permit limited production and export of Class I substances to developing countries that are parties to and governed by Article 5 of the Montreal Protocol. The protection of national security may also allow the President of the U.S. to authorize the production and use of CFC-114, halon-1211, halon-1301, and halon-2402. Final exceptions related to the Class I phase-out are related to fire suppression and explosion prevention. The production of limited quantities of halon-1211, halon-1301, and halon-2402 were permitted for the period beginning after December 31, 1999 through December 31, 2003 for fire suppression and explosion prevention in association with domestic production of crude oil and natural gas energy supplies on the North Slope of Alaska. Prior to authorization, consultation must be made with the U.S. Fire Administration and any exception must also provide for an opportunity for public comment.

The following table represents the U.S. schedule for phasing out its use of Class II substances, HCFCs, in accordance with the terms of the Protocol. The Agency intends to meet

the limits set under the Protocol by accelerating the phase-out of HCFC-141b, HCFC-142b and HCFC-22.⁶⁰

Comparison of the Montreal Protocol and United States Phaseout Schedules			
Montreal Protocol		United States	
Year to be Implemented	Percent Reduction in Consumption, Using the Cap as a Baseline	Year to be Implemented	Implementation of HCFC Phaseout through Clean Air Act Regulations
2004	35.0	2003	No production and no importing of HCFC-141b
2010	65.0	2010	No production and no importing of HCFC-142b and HCFC-22, except for use in equipment manufactured before 1/1/2010 (so no production or importing for NEW equipment that uses these refrigerants)
2015	90.0	2015	No production and no importing of any HCFCs, except for use as refrigerants in equipment manufactured before 1/1/2020
2020	99.5	2020	No production and no importing of HCFC-142b and HCFC-22
2030	100.0	2030	No production and no importing of any HCFCs

Excluding the defined exceptions for Class II phase-out, the Act prescribes an absolute stop on all production by January 1, 2030. Exceptions to this rule may be reached after consultation with the Food and Drug Administration and after the opportunity for public comment is provided for with regards to medical devices. The U.S. EPA may also authorize production for export of Class II substances for developing countries that are parties to the Montreal Protocol, but only after notice and opportunity for public comment.

Acceleration

The Act allows for the phase-out of the production and consumption of Class I and II substances to be accelerated by the U.S. EPA if a demonstration is made that human health and the environment are being threatened. The Agency must consider two things when determining the necessity of acceleration:

1. the assessments of current scientific information regarding harmful effects on the stratospheric ozone layer associated with a Class I or Class II substance; and
2. whether suitable substitutes are available to make acceleration practical in light of factors such as technological achievability and safety.

The CAA provides that any person may present a petition to U.S. EPA requesting the promulgation of a regulation requiring an accelerated schedule. Every petition must be acted on within 180 days of receipt. The Agency issued a final rulemaking to amend and accelerate the phase-out of ODS (specifically all CFCs and certain HCFCs) on December 10, 1993 in response to petitions from environmental and industry groups. The rulemaking also added methyl bromide as a Class I ODS.⁶¹

Allowance Trading

To assist in the phasing out of certain ozone-depleting substances, the CAA provides the U.S. EPA with the ability to issue allowances to control the manufacture of chemicals designated for phase-out. Allowances based on the production and consumption limits on ODS may be issued to companies that produce or use it. Allowances of one substance may be traded for another on an ozone-depletion weighted basis. The trading of production and consumption allowances must be done for substances in the same group within the Class I list. Effective January 21, 2003, the U.S. EPA established an allowance system to control the U.S. consumption and production of Class II substances, known as HCFCs. The action includes consumption and production allowances in the HCFC system. According to the Agency's policy, both types of allowances are necessary based on the existing consumption cap and the production cap that will become effective in 2004.⁶² Companies can also sell unused allowances to companies still making the chemicals or can use the allowances, within certain limits, to make a different, less ozone-destroying chemical on the phase-out list.⁶³

An exemption from the allowance requirements for the production of ODS is permitted if such production is inadvertent or coincidental during a manufacturing process. In addition, as part of the final phase-out rule, the CAA amendments permit production of controlled substances for transformation or destruction outside of the production and consumption allowance requirements. This is only permitted if the destruction is achieved by one of the processes approved by the Parties to the Montreal Protocol. Finally, no allowances are needed when producing or importing controlled substances used for feedstock purposes.⁶⁴

Recycling, maintenance, and servicing requirements

In addition to phasing-out certain ODS, the Act includes a set of guidelines developed into the National Recycling and Emission Reduction Program to limit emissions of ODS during their use and disposal. The program requires that the lowest achievable level for the use and emission of Class I and II substances be met and that the recapturing and recycling of such substances be maximized to the greatest level. As of July 1, 1992, it became unlawful to knowingly release or dispose of a Class I or II substance into the environment while maintaining, servicing or disposing of an appliance or industrial process refrigeration unit. All other substances not previously covered in the standards were to be addressed by November 15, 1994.

On January 1, 1992, the U.S. EPA implemented regulations requiring the use of approved recycling equipment in the repair and service of motor vehicle air conditioners. Following this, on November 15, 1992, the Agency implemented regulations requiring any service on motor vehicle air conditioners to certify with the agency that they had:

- acquired, and are properly using, approved refrigerant recycling equipment and that each individual authorized to perform such service is properly trained and certified; or
- serviced fewer than 100 motor vehicle air conditioners in 1991. Certification in accordance with subparagraph (1) is required as of January 1, 1993.

The regulation of equipment that recovers and recycles CFC-12 was implemented on July 12, 1992. At the same time a separate proposal for “recovery only” equipment became effective.⁶⁵

Nonessential products

The U.S. EPA promulgated regulations in 1993 that prevent the entrance of nonessential products that release Class I substances into the environment and into the stream of interstate commerce. Nonessential products are determined with regards to their purpose and intended use, health, safety and other relevant factors, and the technological availability of substitutes. In January 1994, it became unlawful to introduce aerosol products or pressurized dispensers containing Class II substances and plastic foam products containing or manufactured with a Class II substance into interstate commerce. However, a range of product categories are exempted. Closed cell rigid polyurethane foam, for example, is exempted and can be manufactured for interstate commerce with any blowing agents that can be used in new products. However, as of January 2003, HCFC-141b is now prohibited for use in new products and can no longer be used in this foam type (or any other).⁶⁶

Labeling

There are numerous labeling requirements described within the Act for products that are both manufactured with or that contain Class I substances. Within the Act, there is a clear distinction between containers “made from” and those “containing” Class I substances. For example, “a product containing, such as an adhesive, must be labeled as ‘containing.’ When that product is applied by a subsequent manufacturer in affixing a cushion to a seat, the seat must be labeled as a ‘product manufactured with’ because the CFCs have been released.”

Any container enclosing for storage or transport a Class I substance must be clearly labeled as such before it may enter into interstate commerce. Products may be exempt only if the manufacturer is able to show, *within 24 hours*, upon request, that its products were made before that date. As of May 15, 1993, products containing Class I substances must be labeled unless that the U.S. EPA determines that substitutes do not exist. Products containing Class II substances will be subject to similar requirements no later than January 2015, provided that the Administrator makes a determination that substitutes are available for these products. These labeling requirements will go into effect for all products manufactured with a Class I or II substances as of January 1, 2015. Petition options similar to those for the phasing-out of Class I

and II substances also exist for labeling. The Agency must respond to all petitions within 180 days of receipt. Explanations for the denial of any petitions must be published.⁶⁷

Alternatives for Class I and II substances

Under the Act, the U.S. EPA must also communicate with the public and interested federal agencies concerning the transition from Class I and II substances to non-ozone destroying alternatives. Such communication may include recommending research for programs and looking into federal procurement practices that may offer advice for moving forward with the use of safer alternatives. This provided the catalyst for development of the Significant New Alternatives Policy (SNAP) program, which is discussed later in this paper. A petition may be made to the Agency to add or remove a substance on either the prohibited substitutes list or the safe alternatives list. The petition must be acted upon within ninety days of receipt.

Construct with the Montreal Protocol

Title VI of the CAA is designed to implement the provisions set forth in the Montreal Protocol. Where conflict may arise between the two, the more stringent provisions will govern. The U.S. EPA may also issue regulations, after notice to Congress, regulating any substance, practice or activity that has the potential to negatively impact the stratosphere and is not limited to only those ODS that are known about today. The Act also provides for the transfer of production allowances to another party of the Montreal Protocol if specified revisions to production limits are met by the U.S. The CAA also provides for the President of the U.S. to authorize international cooperation that fosters cooperative research to compliment ongoing studies to safeguard the stratosphere.

b. Additional Federal Actions

There are a number of federal actions, beyond the provisions outlined in the CAA, that have been designed to help further mitigate the depletion of the Earth's stratospheric ozone layer or are relevant to the regulation of ODS. For example, additional policies and programs to enhance efforts to identify and use substitutes have been initiated, including industry partnerships, incentives and education programs and awards/recognition. Furthermore, regulated entities must also be mindful of provisions of the Toxic Substances Control Act (TSCA) that apply to ODS.

Industry Partnership Programs

As concern for the stratospheric ozone layer continued to rise, the U.S. EPA developed a number of industry partnership programs to provide information, incentives and a means for the business community to work together to develop solutions to reduce and ultimately eliminate ozone-depleting substances.

Industry Cooperative for Ozone Layer Protection (ICOLP)

The Industry Cooperative for Ozone Layer Protection (ICOLP), initiated by the U.S. EPA, was one of a variety of cooperative arrangements that formed to facilitate technology transfer rather than competition in the search for CFC solvent alternatives. The ICOLP was developed under the umbrella of the Montreal Protocol when several large corporations with major electronics interests joined forces. ICOLP was created to help industries eliminate ODS in their manufacturing processes through an information-exchange of individual industry discoveries and procedures.⁶⁸

Incentives and Education

Incentives and education have been vital to motivating actions that will help protect the stratosphere. The federal government developed and implemented several policies and programs to provide an opportunity to move beyond simply meeting regulation standards toward offering alternative products and educational tools that provide a beneficial outcome for all affected parties. These include a chlorofluorocarbon tax, the Significant New Alternatives Policy (SNAP) program, and the Stratospheric Ozone Protection Awards.

Chlorofluorocarbon (CFC) Tax

As part of the final budget reconciliation package for FY 1990, Congress included an excise tax on CFCs. The CFC tax was implemented at a rate of \$1.37 per pound, rising to \$2.65 in 1993 and 1994, with an increase of 45 cents per pound per year thereafter. The excise tax was substantially increased in the Energy Policy Act of 1992 of the 102nd Congress to \$5.35 per pound. With the \$0.45 increase per year, the tax in 2002 reached \$8.50 per pound. Three types of events trigger the incidence of the tax. One is the sale or use of the compounds by a manufacturer, producer or importer. Another is the sale or use of imported products by an importer, when a taxed compound is used in the manufacture or production of that imported product. The third event is the holding of any stocks of taxed compounds owned by any person other than the manufacturer, producer or importer on January 1, 1990 for future sale or use in further manufacture. There are some exemptions to the tax, however, for recycled chemicals, exports, and chemicals used as feedstock or in rigid foam insulation manufacturing.⁶⁹

The CFC tax, in combination with the allowance trading program, reduced CFC consumption 35 percent below the allowable limit in the first four years that both policy tools were in force.⁷⁰

Significant New Alternatives Policy (SNAP)

To implement the safe alternatives provision of the CAA, the U.S. EPA established the Significant New Alternatives Policy (SNAP) program. It was established through a final rule published on March 18, 1994. In addition to introducing the SNAP program, the rule defines how substitutes for ozone depleting chemicals will be evaluated and regulated.

SNAP is a mechanism to provide education and information to the general public and the regulated community by providing both acceptable and unacceptable lists of substitutes for ozone-depleting substances. The program requires anyone who produces a substitute to provide the Agency with health and safety studies and notify them prior to the substitute's introduction into interstate commerce. The Agency performs a review of all submissions and once completed, the substance is added to either the list of acceptable substitutes or the list of unacceptable substitutes.

The goal of the SNAP program is to evaluate alternatives to ODS in order to determine their acceptability for use across various industry sectors. These sectors include refrigeration and air conditioning, solvents, foam blowing, fire suppression and explosion protection, sterilants, aerosols, adhesives, coatings, and inks, and tobacco expansion. In one of its recent actions the U.S. EPA published an Advance Notice of Proposed Rulemaking (ANPRM) on February 18, 1999 to provide information regarding uncertainties surrounding policy decisions regarding the ozone-depletion potential and human toxicological risks of n-propyl bromide, nPB.⁷¹ The Agency will use this information to help determine whether nPB will be listed as acceptable or unacceptable for the various submitted end-uses under SNAP.⁷²

Stratospheric Ozone Protection Awards

The U.S. EPA sponsors and hosts an annual Stratospheric Ozone Protection Awards program to provide public recognition and outreach as an incentive to motivate individuals and organizations to take action toward preserving the Earth's protective stratospheric ozone layer through leadership and innovation. The Agency has presented this award to over 420 individuals and organizations from 37 countries since 1990. The countries recognized to date include Australia, Belgium, Brazil, Canada, Chile, China, Dominica Republic, France, Germany, Hungary, India, Ireland, Japan, Kenya, Malaysia, Malta, Mexico, the Netherlands, Norway, Poland, Singapore, Spain, Sweden, Switzerland, Taiwan, Thailand, the United Kingdom, the U.S., and Venezuela. The awards are unique in that recipients are nominated by their peers to be recognized for outstanding accomplishments in protecting the Earth's ozone layer. Past winners review the nominees and the Agency determines the final award recipients.⁷³ Recently the Agency combined the Stratospheric Ozone Awards with the Climate Protection Awards as part of its Earth Technologies Forum, which takes place annually in March.

SunWise School Program

In addition to SNAP, the U.S. EPA developed a number of education and outreach programs that promote protection of the stratosphere. One such program is the SunWise School Program. The SunWise School Program was designed to help educate children on the dangers associated with UV radiation. The program teach children the effects UV radiation impact human health and the environment, with a particular focus on protecting against UV-A and UV-B, which penetrate the Earth's stratospheric ozone layer.⁷⁴

c. Other Applicable Statutes - *Toxic Substances and Control Act (TSCA)*

The Toxic Substances and Control Act (TSCA) is the primary federal statute of its kind designed to regulate the use of certain chemicals and substances, including asbestos, PCBs, radon and lead. Under TSCA, the U.S. EPA is authorized to secure information on all new and existing chemical substances and to control any of these substances determined to cause an unreasonable risk to public health or the environment. To assist in the prevention of continued depletion of the stratospheric ozone layer, TSCA gives the Agency responsibility for ensuring that the federal facilities held responsible under TSCA comply with regulations governing the proper handling, use, storage and disposal of certain substances and that the facilities maintain accurate records.⁷⁵

Working with the General Services Administration (GSA) and the Secretary of Defense, the Agency has adopted regulations that require all federal agencies to conform their procurement regulations to the policies of the Act and maximize the substitution of alternatives for Class I and II substances. All new chemicals submitted for review under the SNAP program must also be submitted to EPA under the Pre-manufacture Notice (PMN) program under the Toxic Substances Control Act (TSCA).

In the past, U.S. EPA was only authorized to control toxic substances only after damage occurred; the Agency was not required to screen toxic substances before they entered the marketplace. With the development of TSCA, it became a requirement that the health and environmental effects of all new chemicals be reviewed before they are manufactured for commercial purposes.

VIII. U.S. Response: State and Local Actions and Policies

a. The Role of States and Localities

Stratospheric ozone depletion is largely a global issue. In the U.S., state and local governments are not directly delegated with the responsibility for carrying out these provisions of the CAA. Nevertheless, there are several ways in which individually, or collectively, states and localities can assist the federal government's efforts toward slowing the rate, and reducing the contributory sources of ozone depletion. These include instituting and implementing public awareness programs, funding research projects, generating legislation and policy aimed at establishing or facilitating standards and codes, assisting with compliance and enforcement actions, and creating incentives and benefits programs to support industry compliance.

b. Initiatives and Partnerships

By 1992, more than 35 states and localities had considered or enacted policies for controlling ODS use and emissions. Several states have ongoing initiatives aimed at reducing ozone layer impacts caused by ODS. In several of these initiatives and programs, states and localities have partnered with corporations, non-governmental organizations and international

institutions to pursue viable solutions to the problems posed by ozone loss. A state-by-state overview of some of these initiatives and programs follows.

California

Policy

The California Environmental Protection Agency (Cal/EPA) specifically mentions stratospheric ozone in its 2000 Strategic Plan, which lays out the Agency's vision and mission, and guides its future policy-making. The Plan states that reducing ozone depleting gases is a priority for sustaining and improving ecosystems and preserving natural and cultural resources.

Research

In 1992, the California Air Resources Board (CARB), a subdivision of Cal/EPA, released its *"Study of Emissions and Control of Stratospheric Ozone-Depleting Compounds in California."* CARB sponsored this research to provide them with a comprehensive compilation of data and analyses to help them understand and assess the full range of issues regarding emissions of ODS and options for their control in California. The report estimates that on an ozone-depleting potential weighted basis, emissions of ODS from California sources in 1990 were nearly 77 million pounds, roughly 13 percent of the total for the U.S. About 70 percent of these estimated emissions were from motor vehicle air conditioning systems, solvent cleaning processes, and foams. The study estimates that in 2005, after implementation of the requirements of the CAA, emissions from California would be projected to significantly decrease, ranging from 16.5 to 19 million pounds, and accounting for about 16 percent of the projected national total that year. The study projects foams would then account for over 70 percent of these emissions. The three percent increase in the proportion of national emissions for California from 1990 to 2005 assumes that the state's population and employment will grow more rapidly than the nation's. This study also identified several control measures for reducing ODS use and emissions over the next 10 to 15 years, including introduction of new low-ODS-containing products and processes, use of chemical substitutes, and recycling.⁷⁶

Local Ordinances

The city of Santa Monica, California adopted an ordinance in 1990 to prohibit the sale, distribution, or manufacture of products containing ODS. The ordinance was further amended in 1992 to prohibit the use of ozone-depleting materials in construction. While Santa Monica supported all international, national and state bans on CFC use, the city decided to take early action on its own to reduce CFC and halon use in order to promote the long term health, safety, and welfare of the general public and the environment. The ordinance did not restrict the use of ODS used as coolants or fire suppressers, since there were no economically viable substitutes at the time, but instead required these substances to be recycled in the course of repair or maintenance activities on equipment that used them, including refrigerators, air conditioning systems and fire extinguishers. Exemptions were also provided for health care facilities, research projects examining the effects of ozone depletion on the environment, and businesses

that could substantiate that no feasible alternatives were available. This ordinance has largely been superseded by subsequent Air Quality Management District regulations.⁷⁷

Legislation

In 1991, the California legislature issued Assembly & Senate Legislative Findings and Declarations 44470, which declared that the ozone shield above California had been depleted about three percent over the last 20 years. In its declaration, the legislature further stated its intent to protect the health and safety of all Californians by taking necessary steps to further decrease and halt the destruction of the ozone layer by CFCs and halons. As such the California legislature subsequently took actions to phase-out of the use of CFC-based refrigerants in mobile air-conditioning systems by banning the sale of any new automobile, truck, or other motor vehicle in California that utilized CFC-based refrigerants.^{78,79}

Regulations and Funding Initiatives

The state of California recently released a report that showed overall pesticide use throughout the state, and particularly the use of the ODS methyl bromide, dropped to a new low in 2001. The report attributed the reduction in pesticide use to dry weather, a tight economy and strict environmental controls, and indicated that agricultural pesticide use dropped from 172 million pounds in 2000 to 137 million pounds in 2001. The California Department of Pesticide Reduction (DPR) stated that the use of methyl bromide compounds alone dropped by about four million pounds last year, attributed to the adoption of state regulations limiting its use. Methyl bromide use will be banned entirely in 2005.⁸⁰ In addition to the methyl bromide regulations, Cal/EPA instated a grants program offering \$750,000 in grants for projects aimed at developing reduced-risk methods of controlling pests, including projects focused on alternatives for methyl bromide.⁸¹

Enforcement

The Los Angeles Federal Environmental Task Force, which includes the U.S. Customs Service and U.S. Environmental Protection Agency, participated in a joint investigation concerning a CFC smuggling operation. The owner and operator of a California import business that sells and distributes refrigerants to automotive parts stores and repair shops pleaded guilty in U.S. District Court for the Central District of California in Los Angeles to conspiracy to smuggle 1,200 30-pound cylinders of the restricted refrigerant CFC-12 into the U.S. in violation of the CAA.⁸²

Colorado

Regulations and Programs

Colorado's Chlorofluorocarbon Program was authorized by the state legislature in 1992, and established via the Air Quality Control Commission's Regulation 15. Its mission is to reduce emissions of CFCs and HCFCs through an inspection and compliance program that is fee-supported. The program regulates all air conditioning and refrigeration sources throughout the

state, and is administered by the Colorado Department of Public Health and Environment (CDPHE).

The provisions of the Air Quality Control Commission's rules dealing with motor vehicle air conditioner (MVAC) service regulations are somewhat stricter than the federal standards. MVAC service facility owners or operators are required to perform mandatory leak checks of air conditioning systems prior to the addition of ozone depleting compound refrigerants. They must also maintain service and leak check records for at least one year and make these records available for inspection. Owners or operators that use recovery-only methods are required to maintain documentation of the handling and disposition of all ozone-depleting compounds removed from vehicles. Salvage facility owners or operators that recycle or recover ozone-depleting substances are also required to maintain documentation of all compounds removed from vehicles.

Through twelve local agency health departments, the Chlorofluorocarbon Program performs approximately 2,200 inspections of automotive and stationary sources each year. Businesses that perform air conditioning/refrigeration service, owners of such systems rated at 100 compressor horsepower or greater, and businesses that own refrigeration equipment used in food sales must register with the program.⁸³

Maine

Research

A decade-long study in Toronto, Canada revealed that UV-B radiation reaching the Earth's surface during the winter months increased five percent per year. Although initially discovered at the poles, a thinning of the ozone layer has been documented at mid-latitudes by the stratospheric ozone monitoring station located in Caribou, Maine, which has been in operation since 1962. The Caribou station recorded deficits of up to 18 percent over Maine in January 1993, and unusually low values were also recorded during that summer. From 1979 to 1996, the station recorded an overall decrease in ozone of nearly four percent.⁸⁴

Minnesota

Policy

In accordance with provisions under Minnesota Statute 116D.10, passed in 2002, the governors must transmit to the energy, environment and natural resources committees of the legislature a concise, comprehensive written report on the energy and environmental strategy of the state, including a discussion on stratospheric ozone depletion, among other issues. This report is used to assist the legislature in allocating funds to support all of the policies, plans, and programs of the state related to energy and the environment. In addition, the report must include a concise description and assessment of all efforts by the state to effectively integrate its energy and environmental strategy with the national environmental education strategy of the federal government, including objectives, priorities, timing, funding details, and expected results of all

domestic and international education efforts supported by the U.S. to improve both public participation and awareness of the need for environmental protection.

New Hampshire

Public Awareness Programs

The New Hampshire Department of Environmental Services (NH DES) designed a set of public awareness programs to encourage state residents to help protect the ozone layer by making sure they are aware of the procedures that should be followed during air conditioner service and repair. These programs alert consumers to make sure that technicians working on their car air conditioner, home air conditioner, or refrigerator recover the refrigerant; are certified and use certified recovery equipment; that car and home air conditioner units and refrigerator are free from leaks; that leaky air conditioning units are repaired before refilling them; and that refrigeration or air conditioning equipment are disposed of properly. In addition, NH DES reminds residents to protect themselves against intense sunburn by wearing UV screening sunglasses, hats, and sunscreen.

New York

Green Tax Credits

In May 2000, New York became the first state to offer an incentive package to developers who build environmentally sound commercial and apartment buildings. This innovative tax law -- or "green building tax credit" -- is aimed at encouraging the housing materials and construction industries to adopt green practices on a large scale by providing tax credits to building owners and tenants who invest in increased energy efficiency, recycled and recyclable materials and improved indoor air quality. The credit allows builders who meet energy goals and use environmentally preferable materials to claim up to \$3.75 per square foot for interior work and \$7.50 per square foot for exterior work against their state tax bill. To qualify for the credit, a licensed architect or engineer must certify a building, and must meet specific requirements for energy use, materials selection, indoor air quality, waste disposal and water use. Ten percent of the cost of ozone-friendly air-conditioning equipment, 30 percent of the installed cost of fuel cells and 100 percent of the cost of built-in photovoltaics (PV) solar panels may also be recouped through the credit.⁸⁵

Green Purchasing Program

The New York State Energy Research and Development Authority (NYSERDA) recently announced it has joined with the New York Public Service Commission, the New York Power Authority and the Long Island Power Authority to launch the annual "Keep Cool Campaign," an effort to reward New York residents for trading in old, inefficient, working room air conditioners and replacing them with new, CFC-free, energy-efficient Energy Star models. Under the program, consumers who upgrade to Energy Star units receive a \$75 check from the State. So far, NYSERDA estimates approximately 160,000 (as of 9/2002 - per NYSERDA website) New

Yorkers have participated in the program. The Keep Cool program is designed to help consumers reduce their energy costs and to ease the strain on the state's energy resources.

Funding Initiatives

The New York Department of Environmental Conservation (DEC) has provided more than \$500,000 in grants to local governments, schools and not-for-profit organizations for projects that promote alternatives to pesticides. The purpose of the grants is to promote non-toxic pest control methods to reduce the amount of pesticides used in the state. The grant program demonstrates New York's commitment to encouraging non-toxic alternatives to pesticides to prevent pest infestations and protect the public from unnecessary exposure to chemicals. Funds are also included to provide municipalities with training in non-toxic pest control methods and for basic building repairs designed to prevent pest infestations. Most grant recipients are expected to conduct training projects focusing on non-toxic pest management and alternatives to current pesticides, such as the ozone depleting substance methyl bromide.⁸⁶

Public Awareness Programs

As early as 1976, two years before federal action, New York State warned aerosol spray-can users of the potential danger of CFC discharges to the air. By 1989, New York and other eastern states were curbing CFC production and use and developing more efficient fuels, actions that were later championed by federal agencies. New York State continues to press for controls on air pollution through its active participation in a number of regional and national organizations. New York DEC's current public awareness programs encourage residents to help protect the ozone layer by making sure that a trained specialist removes the refrigerant before discarding refrigerators, air conditioners, and cars with air conditioners; that people check with local recycling or solid waste department for assistance before discarding refrigerators or air conditioning units.

Vermont

Publications

Vermont's Department of Environmental Conservation (VTDEC) has several resources available to residents concerned about ozone loss. One is an informational guide on the impacts of ozone depletion and actions to prevent it entitled, "How to Reduce Emissions of Ozone Depleting Chemicals." They also offer a 3-panel consumer guide on auto air conditioners and the ozone layer, a document developed by Vermont's Air Pollution Control Division (APCD) entitled "Stratospheric Ozone; its Condition and Cause of Depletion," and a 3-panel brochure by APCD covering Vermont laws on ozone-depleting chemicals.

Legislation

Vermont has included provisions in its state statutes relating to the control and elimination of ODS. The statutes referred to include limitations on facilities that repair and sell automobiles from selling or repairing vehicles with CFC containing air-conditioning systems

unless certified to do so in a safe and contained non-emitting way; limitations on the sale and recovery of ODS in noncommercial or non-industrial usages; and regulations on the usage of ODS in industry and as part of the manufacturing process.⁸⁷

c. Opportunities for Additional Actions

While the problem of stratospheric ozone depletion largely requires international solutions, what many of the above states candidly communicate to the public is that local lifestyle changes are required in order to heal the protective stratospheric ozone shield. This is a message that needs continued conveyance across the U.S. and around the world. This will mean continuing to discover and make changes in the materials used in consumer products, finding appropriate ways to handle and dispose of the chemicals industry produces; developing new engineering designs for more efficient cooling systems and changing individual lifestyles to become more aware and active in motivating and facilitating the changes that are necessary. An ozone-healthy world will require these changes on both an individual, societal and global level.

IX. The U.S. Response: Leadership from Industry

In response to the Montreal Protocol, U.S. industries reacted quickly to develop functional alternatives to CFCs, methyl bromide, and halons for nearly all of the applications that formerly relied upon these ODS. A number of companies demonstrated ingenuity and awareness in developing effective substitutes. The chemicals industry developed new refrigerants, solvents, and blowing agents. Manufacturing industries introduced new processes that reduced the need for ozone-depleting chemicals, as well as new systems that could use the replacement compounds. Some of these new processes and refrigerants allowed greater energy efficiency than the old CFC compounds, which are saving companies money and reducing greenhouse gas emissions as a co-benefit. The U.S. EPA has recognized many of these companies for their efforts.⁸⁸ As technology progresses, industry and government continue to identify, manufacture, and evaluate ODS replacements.

As industry has made progress on several fronts, the refrigerant, solvent, blowing agent, and metered-dose inhaler applications have been generally addressed. Replacement compounds have been developed, particularly the hydrofluorocarbon HFC-134a,[†] which has found a wide range of uses. All HFCs, including HFC-134a, have an ODP of 0.⁸⁹ Moderate success has been made in finding replacements for halons used in fire suppression. More progress is needed to find replacements for methyl bromide in the agricultural chemicals sector. In this case, the soil fumigant application, its major use, has proved the most challenging to replace.

The U.S. industry responded to the problem of stratospheric ozone depletion by making major changes to input and processes in certain sectors of industrial applications that used ODS because these chemicals originally provided better performing and safer products. The

[†] When used as refrigerants, HFCs, HCFCs, CFCs, and other compounds can also be identified with the generic prefix “R.” The numeric designation does not change in either case. In this report, the specific chemical prefixes are used where possible, and the “R” prefix is used for some mixtures and for substances such as ammonia or carbon dioxide.

transition to new chemicals and products has been facilitated by policies and actions by other key stakeholders, such as the U.S. Department of Defense (U.S. DoD), that have motivated companies to find and develop substitutes. As firms continue to look for and develop solutions that meet the requirements of the Montreal Protocol and its subsequent agreements, a number of overlapping issues, challenges, and solutions have arising between stratospheric ozone protection and climate change action that companies must consider. In addition, it will be helpful to note what may be on the horizon regarding the future of the stratospheric ozone depletion issue with regard to industry.

a. Alternative Substances, Products and Technologies

Many major U.S. chemical and industrial product companies have demonstrated leadership in achieving the goals of the Montreal Protocol. Among those major chemical manufacturers, DuPont, Dow, Honeywell, and Atofina have led the way in formulating and manufacturing alternatives to ODS and developing products that use substitutes.

DuPont Corporation has pioneered the development of non-ozone-depleting replacements for CFCs and HCFCs. DuPont developed and patented HFC-134a, and operates the world's largest HFC production facility in Corpus Christi, Texas. HFC-134a has proven to be the most widely used replacement for CFCs. Since 1995, all new automotive air conditioners have used HFC-134a.⁹⁰ It is also used in large-capacity chillers, and as a propellant in inhalers, and has seen some use as a foam blowing agent. HFC-134a has been a readily available replacement for CFCs in a number of applications for several years, with increasing efficiency as systems and processes are adapted to the properties of this compound. DuPont markets HFC-134a under several trade names for different applications. The product is sold under the names Suva 134a as a refrigerant, Formacel Z-4 as a foam expansion agent, and Dymel 134a as an aerosol propellant.⁹¹ DuPont markets HFC-152a under the name Formacel Z-2 for use as a foam expansion agent, and under the name Dymel 152a for use as an aerosol propellant.⁹² Although some researchers had considered using HFC-152a for refrigerators, DuPont believed that HFC-134a was better suited to this application, as HFC-152a is flammable.⁹³ DuPont also manufactures HFC and PFC solvents under the Zyrone brand name and HFC and HCFC fire suppressants under DuPont's FE brand name. The latter are replacements for halon 1301 and include HFC-227ea, HFC-125, HFC-236fa, HFC-23, and HCFC-124.⁹⁴

Dow has been instrumental in developing alternatives to methyl bromide and using substitutes in manufacturing foam products. Dow AgroChemicals has developed new uses for sulfur hexafluoride for the food processing, grain milling and stored commodity industries; the U.S. EPA is currently reviewing these uses. Dow Chemical Company produces its Ethafoam products with a blowing agent that is a blend of isobutane and HFC-152a.⁹⁵

Honeywell International, Inc., formed by the merger of Honeywell and Allied Signal, was one of the largest producers of CFCs. It has developed non-CFC alternatives, such as HFC-245fa, for use as a blowing agent in foam products and potential use as a substitute for HCFC-123 in chillers.⁹⁶ Honeywell markets some HFC and HCFC foam blowing agents under the Genetron brand name, and HFC-245fa under the brand name Enovate 3000. As the result of its acquisition

of Allied Signal, Honeywell holds the patent on HFC-410A, projected by some sources to be the dominant substitute for HCFC-22.

Atofina (formerly Elf Atochem) has been researching non-ODP alternatives since 1993. Atofina is the leading producer of HCFC-141b, sold under the trade name Forane® 141b.⁹⁷ Atofina produces a wide range of refrigerants and blowing agents under the Forane® name, including HFC-134a and HFC-365mfc; the latter has applications as a solvent and blowing agent. Atofina has also introduced FX 90, a blend of HFCs and methyl ether that it markets as a “drop-in” replacement for HCFC-22. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) designation of R-419A for this compound is under review.[†] ASHRAE designation will be crucial for Atofina to reach the community of HVAC/R professionals and market FX 90 as a refrigerant.

Refrigerants

About 37 percent of all CFCs produced or consumed in the U.S. when the Montreal Protocol was signed were used for refrigeration applications, including automotive air conditioners (20 percent of all CFCs) and stationary air conditioners and refrigerators (17 percent of all CFCs).⁹⁸ The primary component of refrigerants at that time was CFC-11 or CFC-12, both of which have a high ODP.

Some replacement chemicals can be used in existing equipment or applications with minimal changes, such as replacing a compressor lubricant with one compatible with the new refrigerant. Other replacement products require extensive modification or replacement of existing systems – for example, some new refrigerants require the system to operate at a considerably higher pressure than before. As all replacements require at least some modification of existing systems, some manufacturers claim that there is no “true” drop-in replacement for any refrigerant.

Chemical companies and manufacturers of cooling equipment and refrigerators have significant successes to point to in the development of replacements and substitutes for ODS, the formulation of processes that use refrigerants more efficiently, and the development of more energy efficient technologies, which also have the co-benefit of reducing greenhouse gas emissions.

Air conditioning and Refrigeration

The market for non-ozone depleting air conditioning and refrigeration products is robust, competitive and growing. Air conditioners use a variety of technologies, including screw, reciprocating, direct-expansion, and centrifugal chillers. Absorption chillers and geothermal heat pumps are also effective space cooling technologies. Most cooling technologies require refrigerants to transfer heat to or from a space, with the exception of certain types of air conditioning methods, such as evaporative cooling. Industry has developed a number of CFC

[†] The process laid out in ASHRAE Standard 34 assigns each compound a safety classification for both flammability and toxicity, as well as a unique reference number. Standard 34 lists the basic properties of all designated refrigerants, and other ASHRAE documents provide more detailed information.

replacement refrigerants for use in chiller and air conditioner applications that have lower or zero ozone depleting potential.

The most common refrigerant in use today is HCFC-22, which is a Class II substance and will eventually be phased out. New air conditioning and refrigeration systems using HCFC-22 can be manufactured in the U.S. until 2010, and HCFC-22 can be produced for use in existing systems in the U.S. until 2020. After that time, existing systems will be serviced with reclaimed or recycled HCFC-22; there is currently no requirement to phase-out the use of reclaimed HCFC-22.⁹⁹ Other CFC and HCFCs replacement refrigerants include the HFC blend HFC-410A, HFC-134a, HFC-152a, propane and other hydrocarbons, and ammonia. These alternatives are commonly used today ahead of the HCFC phase-out requirements. HCFC-123, used for commercial chillers, will be phased out in the U.S. in 2020. A non-ozone depleting alternative, HFC-245fa, may emerge as a substitute for HCFC-123.

The European Union (EU) has accelerated its phase-out of HCFCs, including HCFC-22 and HCFC-123. Manufacture of HCFC systems will cease in 2004, and manufacture and importation of HCFCs will cease in 2010. The final phase-out date for HCFCs in the EU is 2015. As of that date, reclaimed HCFCs may no longer be used to recharge existing systems.¹⁰⁰ The accelerated phase-out date in the EU will drive U.S. companies to make changes in their product lines even earlier than what is required to meet the U.S. time line.

According to the U.S. DOE, the two most common refrigerant/absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water, neither of which contributes to ozone depletion.¹⁰¹ Absorption chillers are usually gas-fired but can run on waste heat or even solar heat in many cases. They are also less efficient than mechanical chillers, but if waste heat is available, or if the electricity for the mechanical chiller is expensive or results in high levels of emissions, then the absorption chiller may be preferable.

Geothermal heat pumps (GHP) are an energy-efficient way of heating and cooling a space and typically use HCFC-22 as a refrigerant. The heat pumps circulate a working fluid (water, glycol, salt, or alcohols) through pipes in the ground, transferring thermal energy to heat or cool as needed. The refrigerant is used in a separate loop, transferring heat to or from the working fluid through a heat exchanger. Alliant Energy, a Midwestern energy services provider that offers incentives to customers for GHP installations, notes that there is no current “drop-in” substitute for HCFC-22. The company predicts that long-term substitutes will probably be blends of various HFC refrigerants.¹⁰²

Carrier Corporation manufactures air conditioning equipment for residential, commercial, and industrial applications, as well as refrigeration equipment for commercial, industrial, and transport applications. Carrier introduced an HFC blend under the name “Puron” in 1998 to be used as a substitute for HCFC-22. Developed in cooperation with Allied Signal, Puron is a 50-50 mix of HFC-32 and HFC-125, designated as HFC-410A, and with an ODP of 0.¹⁰³ HFC-410A is a high-pressure refrigerant, with pressures 50 percent higher than those for HCFC-22 at a given temperature. It therefore requires new systems with more powerful compressors, and is not a “drop-in” replacement for HCFC-22. HFC-410A is, however, more efficient than HCFC-22, nonflammable, and generally nontoxic.

According to an article in the *Supply House Times*, “in some markets, as many as 70 percent of retrofit customers are opting for the alternate refrigerant (HFC-410A), according to the manufacturer, and sales are quickly rising toward the 100,000-per-year mark.”¹⁰⁴ HFC-410A cannot be used in systems designed for HCFC-22, so the retrofits alluded to must actually be system replacements. Several sources project HFC-410A will become the dominant refrigerant for many applications where HCFC-22 systems are now used. HFC-410A is marketed by Dupont as Suva 410A, by Honeywell as AZ-20, and by Atofina as FORANE 410A. Carrier also uses HFC-134a as a replacement for R-12 (CFC-12) in existing systems, as well as in some centrifugal chillers and reciprocating chillers. HFC-134a is widely used in automotive air conditioners, but is less efficient than HCFC-22.

York International manufactures HVAC equipment for the residential, commercial, and industrial markets, and refrigeration equipment for commercial, industrial, and marine applications. York also markets products under the Luxaire and Coleman brand names. York is currently looking at four leading candidates to replace HCFC-22: HFC-407C, HFC-404a, HFC-134a, and HFC-410A.¹⁰⁵ York has devoted much of its manufacturing and marketing efforts on direct-expansion chillers using HFC-407C. York manufactures air-cooled chillers using this refrigerant in sizes from 10 to 400 tons. York recognizes that each refrigerant has merits for certain applications.¹⁰⁶ For example, HFC-134a is the only HFC suitable for centrifugal chillers, so York manufactures a line of HFC-134a chillers ranging from 350 to 5500 tons. Since HFC-407C is a blend of compounds, it undergoes a process known as “temperature glide” in which different compounds evaporate and condense at different temperatures during the refrigeration cycle. Although this effect is sometimes seen as a negative, York sees it as an opportunity to increase the efficiency of the system and is designing systems to take advantage of this property. Once systems are designed to take advantage of the properties of HFC-407C, the improved energy efficiency will provide a significant co-benefit for this ODS-free product.

The Trane Company, which manufactures HVAC equipment for residential, commercial, and industrial applications, has also examined the potential for replacement refrigerants to HCFC-22 in its manufactured product lines.¹⁰⁷ Trane projects that HFC-134a, HFC-407C, HFC-410A, other HFC blends, or R-717 (ammonia) will replace HCFC-22 in coming years. The company expects that HFC-134a will remain in use, and will dominate in the limited market for very large capacity products, such as chillers exceeding 4300 tons of capacity. The company also observes that HFC-134a can provide higher efficiencies than HCFC-22, and that all three of these refrigerants show significantly higher efficiencies than the CFC-11 and CFC-12 models of 20 years ago. Trane also uses HCFC-123 for low pressure chiller applications.¹⁰⁸

McQuay provides a range of large-capacity air conditioning products for commercial buildings, including a variety of compressor chillers, water-source heat pumps, and evaporative cooled chillers. McQuay uses HFC-134a in its Genesys air-cooled screw-compressor chillers and WPV centrifugal chillers, and uses HFC-410A for its Efinity water-source heat pump.

Lennox manufactures air conditioners and heat pumps, focusing on residential applications. Lennox uses HFC-410A for its higher-performance product lines, and it uses HCFC-22 in its economy line of systems.

Rheem manufactures air conditioning systems for the residential and small commercial markets (up to 20 tons) under the brand names Rheem and RUUD. Rheem emphasizes the proven reliability of HCFC-22.¹⁰⁹ Rheem also offers a line of air conditioners bearing the ProOzone seal; these models contain HFC-410A.¹¹⁰

Conair supplies chillers and other equipment to the plastics industry. It uses HCFC-22 in some of its systems,¹¹¹ although in 2001 it introduced a system for the European market that uses HFC-407C.¹¹²

Goodman Manufacturing produces air conditioners under the Janitrol, Goodman, GMC, and Amana brand names, primarily for the residential and small commercial market. Goodman is the second-largest manufacturer of central residential air conditioners, behind United Technologies (which owns Carrier) and ahead of American Standard (which owns Trane). Goodman's new Ultron product line for the Amana brand uses HFC-410A;¹¹³ other product lines use HCFC-22.

Copeland Corporation manufactures reciprocating, screw, and scroll compressors for residential and commercial air conditioner systems and for commercial refrigeration. Six years ago, Copeland switched to HFC-410A, and recently achieved a milestone with the production of its 500,000th scroll compressor using HFC-410A. Copeland notes "R-410A (HFC-410A) products are now available through all major air conditioning equipment manufacturers, including Carrier, Trane, Lennox, Amana, Rheem and York."¹¹⁴

Refrigerators

Refrigerators, obviously, require a refrigerant of some type to cool the interior volume. Industrial and commercial refrigerators, requiring large capacity and in some cases lower temperatures, are often manufactured by the same companies that manufacture air conditioners and chillers.

During the 1940s, electric refrigerators using CFCs became the dominant technology. There are many reasons for this, including the safety advantages of CFCs, the increased availability of electricity in the post-war period, and the investment in electric refrigerators by major electric appliance manufacturers (including such electric power industry giants as GE and Westinghouse).

Household refrigerators can use similar refrigerants to air conditioners, though the demands are somewhat different, and companies specializing in consumer appliances generally manufacture these products. Most U.S. manufacturers use HFC-134a in new refrigerators,¹¹⁵ including Maytag,¹¹⁶ Whirlpool,¹¹⁷ Electrolux/Frigidaire,¹¹⁸ GE Appliances,¹¹⁹ W.C. Wood,¹²⁰ and Viking.¹²¹

Large refrigerating systems, used for supermarkets display cases or industrial refrigerators, have different operating characteristics than household refrigerators. Supermarkets have phased out CFCs and now rely on HFC alternatives such as HFC-404a and HFC-507.¹²² These are also used in large industrial refrigerators.¹²³ For very low temperature applications,

HFC-508A is a suitable replacement for CFC-503¹²⁴. York, Carrier, and a number of smaller companies manufacture these systems.¹²⁵

Hydrocarbon Refrigerators

The use of hydrocarbons for refrigeration is not a recent innovation. Hydrocarbons were used as refrigerants in the early 1920s and 30s, but were replaced by CFCs in the 1940s. Recently, due to concerns that HFCs have global warming impacts, some manufacturers have reintroduced hydrocarbon refrigerants.ⁱ For most applications, hydrocarbons useable as refrigerants include propane (ASHRAE designation R290) and isobutane (R600a).

The advantages to hydrocarbon refrigerants include zero ODP, minimal direct GWP (about 11), and higher energy efficiency, which reduces greenhouse gas emissions from power plants (thus lower indirect GWP). The primary disadvantage is the flammability of the refrigerant.

Hydrocarbons have captured a significant portion of the non-U.S. refrigerant market for domestic refrigeration in Europe. Developed in 1992, the Greenfreeze technology uses a mix of propane and isobutane. This technology spread rapidly, and as of 1996, 35 percent of Western European refrigerators and 100 percent of German units used hydrocarbon refrigerants. All major European appliance manufacturers sell some refrigerators using this technology. The European “eco-label” criteria for refrigerators (Commission Decision 96/703/EC) requires the use of refrigerants and foaming agents that have GWP of less than 15 over a 100-year lifetime. In practice, this means that hydrocarbons must be used as refrigerants and foaming agents for “eco-label” products.

Concerns about safety have been the major reason why hydrocarbon refrigerants have not become widespread in the U.S. Leakage control measures, similar to those developed for CFC and HCFC refrigerators to address ozone depletion, can be employed with hydrocarbon refrigerators to prevent the development of hazardous conditions. Hydrocarbon refrigerants also require expensive safety measures in the refrigerator manufacturing process.¹²⁶

The term “propane refrigerator” may appear to refer to hydrocarbon refrigeration; however, it refers to a different technology altogether. Propane refrigerators employ an absorption-cooling process, with ammonia as the refrigerant and a propane flame as the heat source. These are often used in recreational vehicles (RVs) and off-grid homes. Refrigerators powered by propane or natural gas have been in use since the 1920’s. According to the Illinois Propane Gas Association, seven small companies currently manufacture propane-fired refrigerators.

New processes

A number of companies provide services in refrigerant recovery, reclamation, and recycling. Chiller manufacturers such as Carrier, McQuay, Trane, and York all manufacture

ⁱ Global warming potential is a measure of a compound’s impact as a greenhouse gas. This value is expressed in terms of its impact on a per-molecule basis relative to CO₂, which has a GWP of 1.

recycling/recovery equipment, as do a wide range of other companies.¹²⁷ Since recovered HCFCs can be used in extant systems even after new HCFCs can no longer be manufactured, a business opportunity exists. Numerous techniques and technologies have been developed to recover refrigerants. The U.S. EPA has developed certification requirements for technicians performing “maintenance, service, repair, or disposal that could be reasonably expected to release refrigerants into the atmosphere.” These requirements include best practices for refrigerant recovery, reclamation, and recycling.

Refrigerant recovery systems have been designed to capture the refrigerant in an existing unit so that it can be replaced with a more ozone-friendly alternative. These systems include the “Ozone Saver Bag” developed by Whirlpool for use in servicing household refrigerators.¹²⁸ In addition, many companies developed methods for recovering refrigerant in air conditioning systems. Companies have also developed a range of monitoring systems to detect refrigerant leakage. These systems reduce emissions, improve system performance, and alert technicians to needed maintenance. For example, Carrier’s “Containment Plus” system minimizes refrigerant loss from chillers. Through design improvements, including the replacement of gaskets and pipe joints with O-rings and O-ring joints, Carrier was able to reduce annual refrigerant loss to 0.1 percent of the total charge.¹²⁹

Solvents/Cleaning Agents

Many electronics companies used CFC-based solvents to remove residue from soldering. Solvents accounted for 21 percent of CFC use in 1987,¹³⁰ particularly CFC-113.¹³¹ As these substances were phased out, numerous solutions were identified to address this need. Different solutions were developed for the wide range of manufacturing processes that previously used CFC-based solvents, including no-clean processes, aqueous cleaning solutions and other types of substances. Some HCFC compounds have been used as solvents with the phase-out of CFCs. HCFC-141b was the most popular HCFC cleaning agent,¹³² but can no longer be manufactured or imported into the U.S. as of January 2003. The EU has prohibited the use of HCFCs as solvents, except for use in the aerospace industry. In this sector, HCFCs may be used as solvents until 2009.

No-clean processes

One of the most important advances to reduce the use of CFC-based solvents was the development of “no-clean” manufacturing processes – improved techniques that do not deposit wasteful amounts of solder or other residues. Special “no-clean” solders have been developed for use in the electronics industry, including the aircraft electronics sector. Process improvements have been developed for many other manufacturing sectors to reduce the need for cleaning specific components. For example, a manufactured steel component of a consumer product may have to undergo a degreasing process to remove the cooling oils used. Alternative cooling processes (air-based rather than oil-based) could eliminate the need for degreasing; alternatively, replacing a component with a different material may prove to be a suitable solution. For example, a steel component may require cleaning and painting after being molded, but a plastic component could incorporate the color in the molding process and avoid the need for cleaning.¹³³ Manufacturers have saved money by adopting no-clean methods that avoid the use of solvents.

Aqueous cleaning solutions

For other processes, including aircraft electronics, computer parts, metal finishing, numerous substitute solvents were developed by industry.¹³⁴ The metal finishing industry employs aqueous solutions to clean products ranging from baseball bats¹³⁵ to precision components. Aqueous cleaning solutions include either pure water or water with a dissolved cleaning agent such as a surfactant, acid, alkaline, or salt. There are many aqueous cleaning agents available on the market today that have no ODP, with more under development. Use of these agents creates effluent discharge, which can be hazardous in some cases.

Other solvents

Other cleaning processes involve alcohols, perfluoropolyether, perfluorocarbons (PFCs), hydrocarbons (such as terpene), or supercritical carbon dioxide. These chemicals are used to clean a wide variety of manufactured products; applications for supercritical carbon dioxide alone are as diverse as welding torches, automotive parts, and ballpoint pen components.¹³⁶ One cleaning agent developed by Hughes Aircraft is based on citric acid.¹³⁷ PFCs have high global warming potentials, but the U.S. EPA identifies them as acceptable in certain situations.¹³⁸ Carbon dioxide is a weak solvent that requires high pressure to be effective, but it is suitable for some work on microelectronics because in its supercritical phase it can penetrate very small physical features.¹³⁹ The selection of a particular solvent or process depends on a number of factors, such as the material to be cleaned and the residue to be removed. Local environmental constraints can impact this decision, as use of liquid solvents produces waste streams. Cost is a factor, as is the work environment; in some factories, it may be easier to make the necessary improvements to work safely with a toxic solvent.

Foam Blowing Agents

In 1987 when the Montreal Protocol was signed, the use of CFCs as a blowing agent for various foam products, such as Styrofoam, constituted 32 percent of total CFC usage.¹⁴⁰ Most familiar to the average consumer were the foam products used in packaging. There was also a large market for foam products used as an insulating building material, insulation for refrigerators, and other insulating applications. The function of a blowing agent is to create foam bubbles in a liquid – this liquid then solidifies into the final product, with the blowing agent in some cases remaining inside the bubbles to provide insulation. A number of substitutes have been developed for CFCs in foam blowing applications, both for building products and for packaging products.

Foam for building

Foam insulation products are often more expensive than other types of insulating materials, but due to their very high R-values they are often used in buildings or products where space limitations are significant. For example, refrigerator insulation has typically been foam, allowing manufacturers to maximize interior space. Major types of foams include polystyrene, polyurethane, and polyisocyanurate. Previously, CFC gases were used to inflate the foam. The “second-generation” replacements were HCFCs, especially HCFC-141b. New replacements

include HFCs and hydrocarbons such as pentane. Honeywell manufactures both HCFCs and HFCs for foam-blowing agents,¹⁴¹ and now markets HFC-245fa as a blowing agent for thermal insulation foams under the brand name Enovate 3000. Sources indicate that pentane-blown foam is no more flammable than HCFC-blown foam, even though the cells of the foam may still contain pentane.¹⁴² Research has continued on alternative blowing agents, and some of the newer compounds have been found to have comparable cost, durability, and insulation performance to CFC-blown foam.

In November 2002, the Polyisocyanurate Insulation Manufacturers Association (PIMA) announced that its members had transitioned to non-ozone-depleting substitutes;¹⁴³ the substitutes include pentane and HFC-245fa.¹⁴⁴ Members of this association include Atlas Roofing, Firestone Building Products, Johns Manville, and others.

Alternatives to foam insulation include a wide range of other insulation materials, such as fiberglass and cellulose. Improved building and product design can also lessen the need for insulation.

Foam for packaging

Polystyrene foam products are now manufactured primarily using two types of blowing agents: pentane and carbon dioxide. CFCs were previously used in some of these products, but have not been used since 1990.

To consumers, one of the most well known actions taken by a major corporation was the phase-out of Styrofoam packaging by McDonald's. McDonald's was the largest user of polystyrene foam packaging for fast food, but has since replaced its foam clamshell packaging for sandwiches with paperboard boxes. Although there were polystyrene foam products not produced with CFCs, Styrofoam had acquired a negative image in the mind of many consumers. The fact that Styrofoam is non-biodegradable also contributed to this decision.

Halons

Halons are bromine-containing fluorocarbons often used as firefighting agents. Halon 1301 was most commonly used in industrial applications, and halon 1211 was commonly used in portable fire extinguishers. Both have the capability to extinguish fires effectively without damaging nearby materials. There are two alternatives that are considered capable of replacing halon 1301; these are IG-541, better known as INERGEN, and HFC-227, commonly called FM-200. INERGEN is a mixture of 52 percent nitrogen 40 percent argon, and eight percent carbon dioxide. Release of INERGEN effectively lowers the oxygen level of the room to a point where most combustibles will not burn, yet humans can still function. The reformulated version INERGEN (LPI) is marketed as a "drop-in" replacement for halon 1301, capable of working with existing pipework rather than requiring a complete overhaul.¹⁴⁵

Branches of the U.S. military have begun removing halon systems and replacing them with alternatives. HFC compounds are commonly used. Other fire-suppression compounds include water, CO₂, foams, dry chemicals, surfactant blends, and certain HCFC blends.

Compounds have been developed that are as safe as halons and have no ozone-depleting potential, but these compounds are generally less effective than halons (requiring greater volume of agent to be effective) and more expensive.¹⁴⁶ Similar to the replacements for methyl bromide, replacements for halon 1301 are likely to vary based on the application. INERGEN appears to be a suitable substitute for many applications.

Methyl bromide

Methyl bromide is used as a pesticide; 85 percent of this usage is as a soil fumigant. Other uses are for application to agricultural products (“commodity use”) or for building fumigation (“structural use”). Methyl bromide is scheduled for phaseout under the Montreal Protocol in 2005 for developed countries and 2015 for developing countries. The U.S. EPA notes that three companies manufacture the vast majority of this chemical; two in Arkansas and one in Israel. Production and importation of methyl bromide will be banned in the U.S. and EU by 2005, with exceptions for certain specific uses. In 1998, the U.N. Methyl Bromide Technical Options Committee concluded there are existing alternatives for more than 95 percent of current methyl bromide uses. Many organizations and companies dispute this assertion, claiming that the replacements are both more expensive and less effective than methyl bromide.

The U.S. EPA has completed case studies on the effectiveness of 30 alternatives, compiled from 1995 through 1997.¹⁴⁷ These range from substitute chemicals to alternative agricultural processes. Non-chemical alternatives include crop rotation, soil solarization (placing a transparent tarp over the soil and heating it through the greenhouse effect), heat treatment, pre-plant flooding, irradiation, and hydroponics. Research is underway on the use of diatomaceous Earth – a naturally occurring soil made from the fossilized skeletons of microscopic aquatic plants – as a means to control certain types of flour beetles, among the food industry’s most difficult pests.¹⁴⁸ Many organic growers produce strawberries without methyl bromide or other chemical pesticides. Yields per acre tend to be lower for organic strawberries, but organic mulch from various sources has been proven to be effective at controlling pests and increasing yields. The cultivation of resistant strains of crops – including genetic modification as an option (which may be controversial in itself) – may decrease the need for pesticides in general and methyl bromide in particular.

On February 7, 2003, the U.S. submitted a nomination for methyl bromide critical use exemptions to the Ozone Secretariat of the United Nations under the terms of the Montreal Protocol. The two-year exemption request would begin in 2005 and is based on an extensive and rigorous technical review process, jointly undertaken by the U.S. EPA and the U.S. Department of Agriculture. The U.S. request is to be able to use 39 percent of the U.S. baseline consumption of methyl bromide in 2005 and the decrease to 37 percent in 2006. This will allow time to register additional alternatives for use. The Parties to the Montreal Protocol are scheduled to meet in November 2003 to review recommendations and authorize the continued production and import of methyl bromide after 2005 to meet authorized critical needs. The U.S. EPA will conduct a rulemaking process and propose to exempt specific amounts of methyl bromide for identified critical based on the decision of the Ozone Secretariat of the United Nations.¹⁴⁹ Applications for exemptions must consider the full range of alternatives available and demonstrate that there are no suitable alternatives for a specific application. Alternatives are

continually reviewed at an annual international research conference, and by the Department of Agriculture's Agricultural Research Service (ARS). The most recent ARS newsletter on methyl bromide alternatives contained a summary of the current status of alternatives.¹⁵⁰

There are several alternative chemical fumigants that are likely replacements, such as sulfuryl fluoride for structural use, metam sodium for field use, and carbonyl sulfide for commodity use. Research continues on new alternatives. To date, no single replacement has been identified for all the previous uses of methyl bromide. Research also continues on biological control and host-plant resistance, which may be more effective in the future. A combination of chemical and non-chemical approaches is the most likely replacement for methyl bromide.

Metered-dose inhalers

Inhalers previously used 5,000 tons of CFCs per year, which was 0.5 percent of worldwide CFC consumption in 1987.¹⁵¹ Most replacement propellants are HFCs; when used in inhalers, HFCs are often referred to by the alternate name of hydrofluoroalkanes or HFAs. The Food and Drug Administration approved 3M Pharmaceuticals' Proventil HFA (albuterol sulfate) inhaler in August 1996.¹⁵² Glaxo and 3M are both major manufacturers of MDIs, and both now produce HFA-propelled inhalers. The specific HFAs used include HFA-134a (the same compound as HFC-134a) and HFA-227. There is also another propellant called GR 106642X, but information on this is limited (it may be a brand name for one of the HFAs or a different substance).

b. Other Developments

The U.S. military and those of other NATO countries are widely seen as leaders in providing a market for non-ODS alternatives. This is in large part due to the fact that the previous military procurement rules explicitly required contractors to use CFC-based solvents for cleaning electronic parts, and military systems used large amounts of halon for fire suppression. The U.S. military has been active in replacing halon systems, fostering the development of manufacturing processes that avoid use of solvents, and employing alternative refrigerants.¹⁵³

The largest consumer of halons, the U.S. DoD, devised plans for reducing CFC and halon use by 1989, just two years after ratification of the Montreal Protocol. The military then went further, providing the leadership necessary within the Montreal Protocol process to move halons from its initial position of least controlled substance to the first to be phased out of production, as of January 1, 1994. The U.S. DoD also had a hand in getting "no clean" technology established. Through a joint working group with U.S. EPA, the two agencies revised military specifications that were originally technology-based to a new set of performance-based standards in record time, thus removing a significant roadblock to progress on reducing CFCs.¹⁵⁴

c. Crossover Opportunities/Issues Among Ozone Depletion and Global Warming

Faced with a pressing environmental challenge, governments of the world agreed upon a treaty that would compel them and their industries to act. Industry responded with innovative

solutions, governments assessed, catalogued, and approved these solutions, and the problem was addressed with considerably lower costs than initial estimates. In many cases, companies found ways to improve their manufacturing processes and realize cost savings. In others, they contributed to basic research that laid the groundwork for future innovations. Companies that acted rapidly and embraced the challenge found themselves in a superior position as industry evolved. Companies and organizations that had the greatest legacy of ODS production and use – such as DuPont and the U.S. DoD – also were key players in the development and penetration of non-ODS substitutes.

Issue 1: ODS substitutes have direct global warming potential (GWP).

Most refrigerants in use today are themselves greenhouse gases, which contribute to climate change. Many countries are seeking to limit emissions of these gases. The GWP of most HFCs is considerably less than that of CFC-11 (5,000) and CFC-12 (8,500) but higher than that of CO₂ (1), methane (21) and nitrous oxide (310). The widely used refrigerant HFC-134a has a GWP of 1,300, and some PFCs, used as solvents, have a GWP of over 10,000. The aggregate mass of HFC compounds is small enough that HFCs are currently only minor contributors to climate change, but greater market penetration of HFC compounds in developed and developing countries as substitutes for HCFCs is likely to increase their overall global warming impact. However projections by A.D. Little indicate that HFCs will represent 1.8 percent of global greenhouse gas emission in 2030.

Use of HFCs is projected to grow, but some forecasts indicate that emissions will not, due to reduced leakage and increased reclamation at end of system lifetime. Improved processes and technologies, meant to prevent release of ODS refrigerants, will also be effective in reducing direct GWP of HFC refrigerants. It is difficult to see how similar emission reductions might be accomplished in non-refrigeration applications such as foam-blowing agents or aerosols. Industry can provide greater assurance that emissions of ODS substitutes will be minimized by continuing to use and improve upon the technologies and processes that control system leakages of refrigerants. It will also be beneficial in the long term for industries to focus on finding and using alternatives with low GWP in applications where such system emissions control is not feasible.

Issue 2: ODS substitutes can reduce indirect GWP.

The generation of electricity to power refrigerators and air conditioners produces carbon dioxide, a greenhouse gas. Although energy efficiency is heavily dependent upon system design and maintenance, some refrigerants allow for systems with higher energy efficiency, thus requiring less electricity and producing fewer carbon dioxide emissions.

The search for CFC replacements has stimulated innovation in the HVAC/R sector, leading to technologies with higher energy efficiencies as a side benefit. Also, the turnover of capital stock necessitated by CFC phase-out led to many customers buying newer and more efficient models. Some compounds may have higher direct GWP, but also allow increased energy efficiency, thus creating a net greenhouse gas benefit. Use of these compounds can be especially advantageous if engineering improvements reduce leakage rates and bring direct GWP

to a lower level. The Total Equivalent Warming Impact (TEWI) assesses the direct and indirect GWP of refrigerants, based on assumptions about the electricity source, system usage, leakage, and end-of-life disposal. Industry should continue to develop energy-efficient applications for HFCs and other zero-ODP substances. They should also consider the indirect GWP of a substitute when selecting a substitute for a particular application.

Issue 3: Ozone depletion and global warming may be interconnected, but more study is needed.

There can be scientific, technical and financial links between ozone depletion and global warming. Preliminary evidence indicates that the causes and impacts of global warming and ozone depletion may have synergistic effects. These interactions are complex and not fully understood. Models of climate change generally predict that increases in CO₂ emissions will result in stratospheric cooling.¹⁵⁵ A study by NASA's Ames Research Center in 2000 suggested that this cooling in turn contributes to ozone destruction by extending the lifetime of polar stratospheric clouds, which accelerates the destruction of ozone by chlorine and bromine compounds.¹⁵⁶ Another study by NASA's Goddard Institute for Space Studies in 2001 suggested that global warming may lead to increased cloud formation by increasing water vapor levels in the stratosphere.¹⁵⁷ A theory presented in 2002 by researchers from the National Oceanic and Atmospheric Administration (NOAA) and Colorado State University suggested that stratospheric ozone depletion has caused localized cooling in the interior of Antarctica.¹⁵⁸ Global warming models generally predict that there will be more warming at the poles than elsewhere, yet the interior of Antarctica has shown a slight cooling trend over recent years. If this discrepancy has been caused by a localized cooling effect resulting from stratospheric ozone depletion, then greater Antarctic warming would be anticipated as stratospheric ozone recovers.

In the 2002 *Scientific Assessment of Ozone Depletion*, UNEP and WMO projected that stratospheric cooling (due to increasing CO₂ concentrations) would increase ozone concentrations in the upper stratosphere. UNEP and WMO were uncertain about the effects of this cooling on ozone in the lower stratosphere, and thus its effects on total column ozone. Transport effects between ozone in the upper and lower column could have either a negative or a positive effect on stratospheric ozone. UNEP and WMO also note that decreases in stratospheric ozone concentrations have offset a fraction of the greenhouse effect caused by increases in greenhouse gases. Recovery of the ozone layer would therefore have a warming effect.¹⁵⁹

While there is no "silver bullet" solution that addresses all of these issues, it would be prudent for government and industry to cooperate toward developing and implementing "win-win" solutions that address ozone depletion without exacerbating the problem of global warming as an initial strategy. Encouraging the coordination of investment for ozone protection and global warming mitigation would potentially be highly cost-effective, resulting in multiple and overlapping ozone and climate benefits. Governments could also craft and implement environmental performance standards, whether voluntary or mandatory, that would spur the development of products that maximize ozone protection and minimize global warming impacts.¹⁶⁰

d. Looking to the Future: What's on the Horizon

Substitutes developed to address stratospheric ozone depletion can have an impact on global climate change. HFCs and PFCs are widely used as a replacement for CFCs and HCFCs. HFC compounds often have high global warming potentials, although these global warming potentials are far less than those of CFC-11 and CFC-12.¹⁶¹ Total global warming emissions from HFCs, PFCs, and SF₆ constitute about 2 percent of U.S. anthropogenic greenhouse gas emissions; of this, 0.8 percent is attributable to the use of HFCs suitable as a replacement for CFCs. The impact of HFCs is projected to increase to 2.3 percent of anthropogenic U.S. emissions by 2030.¹⁶² This does not account for the indirect impacts of using more or less efficient refrigerants, which is significant.

As an indicator of a substitute's potential for contributing to global warming, Total Equivalent Warming Impact (TEWI) is emerging as a more useful indicator than GWP in examining the global warming implications of a refrigerant. The TEWI metric assesses the direct and indirect global warming impact of a given compound; the direct impact is the GWP of the refrigerant itself, and the indirect impact (for refrigerants) is based on the CO₂ emissions from the electricity used for the HVAC system. Refrigerants with a higher efficiency can produce the same amount of cooling with less electricity input. Thus, because 98-99 percent of the greenhouse gas emissions impact attributable to a refrigerant is based on the amount of power required to cool a space with that refrigerant, the global warming impact of the refrigerant itself is not as significant as its efficiency. TEWI accounts for the fact that newer systems have reduced refrigerant leakage. It is an application-specific metric, since the actual warming impact a given refrigerator depends not only on the type and amount of refrigerant, but on its temperature setting, outside temperature, patterns of use, insulation, and design. TEWI can also be used for assessing the impact of blowing agents, where a given compound may have a high direct GWP but also provide superior insulation value and thus have a moderate TEWI rating. In partnership with the U.S. DOE, the Alternative Fluorocarbon Environmental Acceptability Study (AFEAS) evaluated the TEWI rating for many CFC and replacement products.¹⁶³

Many of the innovations that accompanied the shift to non-ozone depleting substances can also be useful in mitigating the effect of global warming. For example, the absorption chiller, an HVAC system that does not utilize a CFC refrigerant, can be adapted to run off of waste heat or solar heat, thus reducing electricity demand. And, in many cases, the lack of CFC replacement refrigerant spurred facilities to install new HFC units. These newer systems tend to be more efficient due to a multitude of engineering improvements, reducing electricity use and greenhouse gas emissions and saving businesses money. The U.S. EPA notes:

“Building owners can typically pay back the investment cost of replacing an old CFC chiller in five years or less in virtually all locations that cool for more than three months a year. In fact, replacement chillers can pay for themselves in as little as two or three years, with a typical return on investment of 20 percent to 35 percent.”¹⁶⁴

Research continues in assessing the best substitutes to CFCs and HCFCs. The chemical and refrigeration industries will continue work on assessing the characteristics of new HFC

blends and other compounds, and developing new refrigeration and HVAC systems to optimize the performance of these new refrigerants. Total Equivalent Warming Impact (TEWI) will be an important tool for policymakers to use assessing the global warming impact of various refrigerants. Improvements in HVAC efficiency, which can be enhanced by particular refrigerants, will enable greenhouse gas reductions. One manufacturer, Carrier, announced in March 2002 that it achieved world-class chiller efficiency using a non-ozone depleting refrigerant, HFC-134a, marking an important technology breakthrough for HFC chiller efficiency. Another, York, notes that its HFC-407C chillers are the most efficient chillers available.

As HCFCs are phased out, the most likely replacement refrigerants will be HFC-407C, HFC-404a, HFC-507A, HFC-134a, HFC-152a, and HFC-410A. Different refrigerants will be preferred in different applications. As we have seen, HFC-134a is particularly versatile, being effective as a foam blowing agent and inhaler propellant, and is likely to be a widely used refrigerant as well. Manufacturers employing hydrocarbon refrigerants will work to demonstrate the safe manufacture, transport, use, and disposal of their systems; other manufacturers will not employ hydrocarbons unless the technology proves its safety record and demonstrates clear advantages. Manufacturers will optimize their system designs for their chosen refrigerants, which will increase efficiency but will turn away from standardization and interchangeability of parts. In foam blowing, a variety of blowing agents will continue to be used, depending on the desired characteristics of the final product as well as the local environmental constraints. For example, hydrocarbon blowing agents may be subject to stricter control in areas that have ground-level ozone problems. Current replacements for CFCs in metered-dose inhalers appear to be completely satisfactory.

Research on halon replacements will continue, as the industrial sector and the military sector look for safe and effective fire-suppression agents for a variety of applications. The military involvement in this area will continue to be substantial. Replacements to methyl bromide are perhaps the largest area of uncertainty. There currently is no one-size-fits-all replacement, and in fact there are some applications for which it is claimed there is no effective replacement at all. The search for non-ODS alternatives will be one aspect of a larger dialogue affecting the pesticide industry, including concerns about the impact of pesticides on laborer health and the development of genetically modified organisms.

X. The U.S. Response: Recommendations for Motivating Public Action

a. What the Public Can Do

While the solutions to ozone depletion are largely being dealt with on the international level and through cooperative efforts between governments and industries, the public has an important role to play in affecting how quickly products and services that rely on the best substitutes penetrate into the market. To continue to make progress and repair the ozone layer, consumers must keep abreast of the latest developments on this issue and how they are being incorporated into the products and services they use and access.

As product formulations change and become available in new products or for retrofit, consumers can have a significant impact by purchasing non-ODS products and services that have the least capacity to contribute to ozone depletion. While no universal label or indicator system has been developed to inform consumers of their best choices in this regard, there is a substantial amount of currently available information on the relative impacts of various substitutes and the products and applications they are used in from the U.S. EPA, manufacturers and service providers.

The public should also keep up to date about the latest developments regarding the ozone hole through major publications and news outlets, particularly on how areas in the world that are most exposed, like Punta Arenas, are having to adapt and cope with the impacts. Views and concerns about these developments, the importance of this issue, and the need for the U.S. to continue to lead in making technological advancements that help to protect and repair the ozone layer should be regularly communicated to local, state and federal government leaders. Furthermore, since ozone depletion is a problem that spans multiple generations, it is important to educate children about the ozone layer, its importance to their health and well being, and what is being done to help to remedy the situation.

b. Raising and Maintaining Public Awareness

Creating and maintaining a vitally aware public on any issue, including stratospheric ozone, falls mainly on the shoulders of the government, non-profit communities, and the media. While all of these entities develop and deliver information about stratospheric ozone, there are a number of possibilities for expanding and deepening the current state of public awareness on this issue, including:

- The federal government should continue to maintain and expand public sources of information in ways that make it easier for the public to recognize what they can and should do to help mitigate ozone depletion.
- More state governments could create exchange outlets that link to federal and international resources to make information more readily available to their communities.
- Federal and state governments, many environmental groups, and the media have exhibits and events to raise environmental awareness on Earth Day, whose timing does not coincide with the annual appearance of the ozone hole. Holding exhibits and events specifically related to the issue of stratospheric ozone during the fall season when the effects of ozone depletion are evident and in the news, will help to reinforce the public awareness of this serious issue.
- Federal and state governments and environmental groups should create distinct and separate messages on ozone depletion and the importance of the ozone layer, in addition to the combined messages on stratospheric ozone and climate change that have more recently been created and disseminated. This is necessary because the recent emphasis on climate change and its impacts, combined with fewer

individualized messages about stratospheric ozone and the impacts of its depletion, may cause the public to surmise that the latter problem is resolved. It is important that the public understand that these are two different environmental problems that affect our atmosphere and our planet in different but inter-related ways, and that diligence and technological innovation are still necessary now and well into the future to achieve our goals of repairing and maintaining a healthy ozone layer to protect them.

- The federal government and private sector should consider creating a visible and universally recognizable labeling approach and advertising campaign (e.g., the U.S. EPA's Energy Star label for energy efficient products) that will help consumers and businesses understand more easily recognize what they need to look for when purchasing products or services, and that will keep the ozone depletion issue out in front over a longer horizon than the annual ozone hole event time frame.

c. Motivating Beneficial Choices

As the public continues to become more informed and aware, it is critical that policies and programs are created or expanded to help motivate the choices and actions of consumers and industry alike. Again, the federal and state governments play a critical role here, working with industry and the public to formulate and implement such programs and policies. Certainly there are additional and more aggressive policy actions that the federal government can initiate to catalyze change and improve the condition of the ozone layer, including:

- Tax incentives, at the federal or state level, to encourage the use of non-ozone depleting products.
- The U.S. EPA should re-institute or revitalize the Industry Cooperative for Ozone Layer Protection, or another group like it, to continue to advance technology and policy innovation.
- The federal government could expand the scope of economic instruments, such as the tradable consumption permit system for CFCs and halons, and the CFC tax, to help achieve environmental goals with respect to other ODS with flexibility and at less cost.
- The federal government could create new programs modeled after the U.S. EPA's "Golden Carrot" approach on super-efficient refrigerators to tap into industry's innovative and competitive spirit to create new products and processes that will help to meet future phase-out goals, and to focus on "win-win" solutions to the overlap between ozone depletion and climate change.

State and local governments, while not directly delegated the responsibility for ozone depletion mitigation, can also take additional actions to motivate change at the community level, including:

- State and local governments should leverage the examples of policy, regulatory and economic incentive/initiative programs developed at the state and local level to facilitate greater adherence to freeze and phase-out schedules and to promote faster changeover to substitutes and alternatives.
- Significant achievements in the market penetration of alternatives can be achieved through the revamping of government procurement policies. This has been shown in the U.S. Department of Defense's progress in changing over from CFC-based refrigerants and solvents, and replacement of halon systems for fire suppression. State and local government purchasing power is significant, and could be targeted toward the best products and services from an ozone depletion mitigation standpoint. Many state and local governments are taking such action on the climate change front, promoting the purchase of energy efficiency products and services that will reduce greenhouse gas emissions. More specific and easily accessible information about choices affecting ozone depletion would need to be developed to facilitate such action.

XI. Conclusion

While the international community has devised policies and measures through the Montreal Protocol to address the serious environmental and human health impacts of stratospheric ozone depletion, much remains to be done before full recovery of the ozone layer can be realized.

The market for non-ozone depleting products is robust, competitive and growing, providing consumers with many alternatives to ozone depleting products well ahead of required phase-out dates.

Government and industry have worked well to chart a path for ozone layer recovery. Additional steps, including the accelerated phase-out of ozone depleting products, increased public awareness for ozone protection and consumer incentives for non-ozone depleting alternatives are all timely for consideration.

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- ⁹⁴ DuPont web site at <http://www.dupont.com/fire/products/>.
- ⁹⁵ Information from THARCO company web site at www.tharco.com/packinginfo/environmental/cfcs.html. THARCO is a supplier of shipping materials, including foam packing material.
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