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ENVIRONMENTAL POLLUTION: RESTRUCTURING THE REFRIGERATION INDUSTRY AS A WAY OUT

The threats posed to human health and the ecosystems due to the environmental pollution resulting from chlorofluorocarbons (CFC) commonly used as refrigerants in the refrigeration industry are presented. Global warming impacts of the refrigeration systems using CFCs are two-fold: direct global warming caused by any release of the refrigerant and indirect global warming resulting from the energy consumption of the system. The release of CFC refrigerants also damages the stratospheric ozone layer that protects the earth environments from the harmful effects of the sun's ultra-violet radiations.

Apart from international and local responses to significant reduction of CFCs emissions, retrofitting the existing refrigeration systems with substitute environmentally-friendly refrigerants and the development of refrigeration systems using new energy sources and refrigerants are considered complete solutions to these problems.

1. INTRODUCTION

Environmental pollution is the presence, in the earth, of substances in such quantities and of such lifetimes as to cause harm to living things, changes in climates, and damage to amenities or property values of people. The polluting substances may result from natural disasters such as earthquakes, accidental discharges such as oil spillage from crude oil exploitation, and deliberate human activities to improve living standards and quality of life. Gas flaring, a process of burning excess gas pumped out of an oil well during crude oil production, by-products of manufacturing processes, automotive exhaust gas emission etc are examples in the last category.

Many other environmental problems are a direct consequence of the second law of thermodynamics, which implies that waste production is inevitable. Human life is sustained by intake of suitable raw materials such as air and food which are converted to body building materials, thus producing polluting substances such as carbon dioxide, urea and faeces. The wastes must be discharged as soon as they accumulate or life ceases. Industry also uses raw materials, processes them to yield useful products, and

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is left with wastes which may exceed 50% of the raw materials used. The problem, therefore, is effective management of wastes to avoid pollution. Environmental pollution degrades not only the atmosphere, but also destroys the land, rivers and streams. Acid rains due to release of toxic fumes, dumping of toxic polychlorinated biphenyl (PCB) industrial wastes (e.g. the Koko, Nigeria incident), disposal of sludge from palm-oil processing etc., all contribute to depleting vegetation and ultimate land degradation. In the last few years, it has become common to observe that rivers and streams have either dried up or stopped flowing completely due to channeling of solid and liquid wastes into them. The Aba and Otamiri [1] and Nwaorie rivers [2], for example, have been found to contain chemical pollutants like Cd, NO_3, Mn, Pb in very high concentrations throughout the year. The Otamiri river, which is a source of water for inhabitants of Owerri and its environ, has values of pH ranging from 4.3 to 8, measured along its course! Thus farm lands and rivers or streams are turned into sterile environments which are unable to support vegetation or livestock and aquatic life or domestic water needs respectively for many years. Perhaps, most alarming is the global concern on environmental pollution from conventional energy development, emission from factories, vehicles etc and the continued use of long-lived industrial gases such as chlorofluorocarbons (CFC), which considerably increase the growth of greenhouse gases emission into the atmosphere and hence the threat of global climate change. In addition, these gases have been seriously implicated in the reduction of stratospheric ozone layer. This paper discusses the details of these problems with reference to the refrigeration industry. In particular, some suggestions are proffered to either help mitigate or adapt to changes resulting from environmental pollution from CFCs emission.

2. INDUSTRIAL APPLICATIONS OF CHLOROFLUOROCARBONS

Chlorofluorocarbons (CFCs) are refereed to as refrigerants in the refrigeration and air conditioning industry. They are vital constituents of the products in this industry. This is because they are the media through which the energy for cooling is transferred to the cooling chamber. Some common examples of CFCs are: trichloromonofluoromethane (CCl_3F) or R-11or dichlorodifloromethane (CCl_2F_2) or R-12 etc. Due to the unique properties of CFCs, they find wide applications in domestic and industrial refrigerators and air conditioning units. CFCs are also used:

- in the manufacture of polyurethane foams; also used as insulation materials in the industry as well as in the packaging industry, and for making all kinds of foamed plastic products such as cups and food containers,
- as fire extinguisher fluids,
- as solvents for cleaning components of computers, printed electronic circuits boards,
- as propellants in spray cans and in production of ink, paint etc.

The table illustrates CFCs consumption in these applications for some selected years in Nigeria. It is seen that the total consumption for 1992 increased by about 34% from 1989 level and decreased by about 7%, 10%, 18%, 13%, and 6% in 1993, 1994, 1995, 1996, and 1997, respectively, from 1992 level. The sharp increase in consumption corresponds to the beginning of unrestricted importation of outdated models of refrigeration and air conditioning equipment into Nigeria, mainly due to onset of the effects of decline in the nation's economy. The decreases can be attributed to partial implementation of the various local and international efforts to reduce the consumption. However, smuggling and illegal trade in these substances caused the slight decrease experienced in 1997. Overall R-12 is the most commonly used CFC in these industries.

Table

CFCs consumption in metric tones for selected years in Nigeria

CFC	1986	1989	1992	1993	1994	1995	1996	1997
R-11(refrigerant)	22.36	23.3	7.15	7.15	7.15	7.17	7.15	6.40
R-11(foam)	626.2	569.3	901.2	700.1	716.1	584.7	617.1	689
R-12	1070	686.4	799.2	874.3	810.1	788.6	851	889.8
R-114	–	–	1.3	9.36	9.36	12.48	15.6	12.4
R-115	–	–	1.76	1.35	1.27	0.88	0.78	1.3
R-502	2.34	1.8	3.29	6.44	6.16	4.99	4.99	5.6
Total	1721	1281	1714	1599	1550	1399	1497	1,605.00

3. DISCHARGE OF CFCs INTO THE ATMOSPHERE

In the refrigeration and air conditioning industry, the main activities through which CFCs may be released into the atmosphere can be categorized into:

1. *Deliberate venting*. This includes practices such as venting of surplus refrigerant from an overcharged system to atmosphere.

- Venting of refrigerant charge without recovery when decommissioning a refrigerating system.
- Release of refrigerant to atmosphere without using a suitable gas purge when removing non-condensables from a system.
- Adding of refrigerant to a leaking system before thorough examination to locate and remedy the leaks.

2. *Inadvertent losses*. They are as follows:

- Loss of refrigerant due to mechanical failure such as leaking seals, joints etc before the leak has been detected and properly repaired.
- Loss of refrigerant resulting from the proper operation of safety devices such as relief valves and bursting discs.

• Loss of refrigerant dissolved in the compressor lubricant in a system after correct refrigerant recovery.

• Loss of refrigerant from charging hoses during normal processes of operation.

• Loss of refrigerant when a system is purged through a proper operated non-condensable gas purger.

4. ENVIRONMENTAL IMPACTS OF CHLOROFLUOROCARBONS

4.1. GLOBAL WARMING

One of the six established green house gases (GHG) is hydrofluorocarbon refrigerant, which also belongs to the group of chlorofluorocarbons. The other GHGs are carbon dioxide, nitrous oxide, methane, perfluorocarbon, and sulphur hexafluoride. The impact of these gases, from various human activities, on the climate of the Earth has become a major focus of attention worldwide since the last decade. This is because their release into the atmosphere warms the surface of the Earth by retaining heat (infra-red radiation) that would otherwise escape from the lower atmosphere: thus rising the global temperature. The warming trend that has characterized recent decades is illustrated in figure 1 [3].

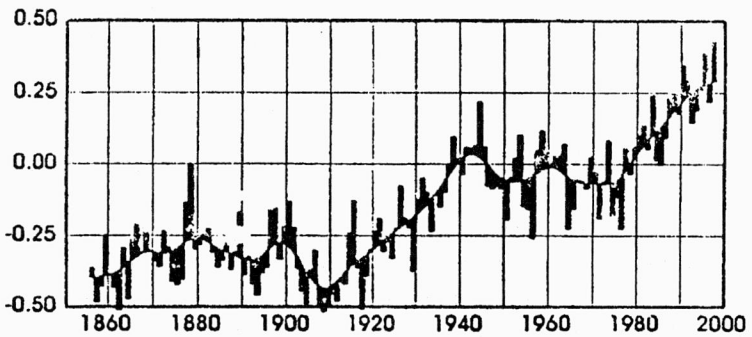

Fig. 1. Global surface air temperature, annual values as departures from the 1961–1990 mean and filtered curve

Because of this so-called greenhouse effect, the climate will become hotter, wetter, and cloudier. Changes in the climate involve not only the atmosphere, but also the world's oceans, ice masses, the global land surfaces and bio-mass. Figure 2 shows clearly the contributions of the GHGs to global warming by 1980 [4]. CFCs are seen to account for about 23% of the total contribution. The concentration of CFCs in the air has increased from zero in 1950 to about 0.4 and 0.2 million metric tones for R-12 and R-11, respectively, in 1990, a trend which is certainly significant and coincides with the development of refrigeration industry worldwide (see figure 3 [4]). Global

climate change is occurring now, will continue for the foreseeable future and is likely to intensify in many respects. Disposal of CFCs from old or abandoned units of refrigeration and air conditioning units remain a major problem in both industrial and developing nations. For Nigeria and other developing countries, where reliance on outdated models, imported as fairly used products, is very common, the situation is critical. We seem, therefore, to accept increasing emission of GHGs as a necessary evil if we are to raise our living standards. The continuing geometrically progressive decline in the national economy is not helping matters. These outdated technologies, in addition, consume more energy in service than needed. This is perhaps why a typical Chinese refrigerator uses 365 KWh of electricity per annum, whereas a similarly sized South Korean model uses 240 KWh, and Danish one needs less than 100 KWh [5].

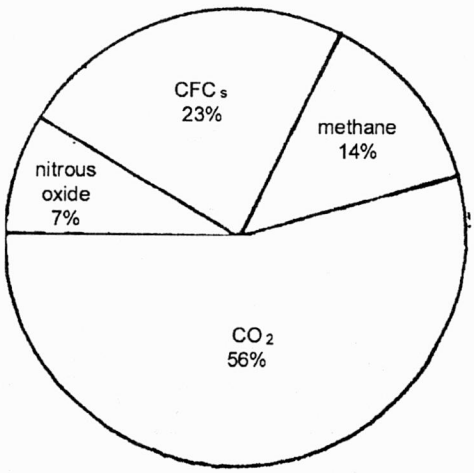

Fig. 2. Contribution of greenhouse gases to global warming (1980) [4]

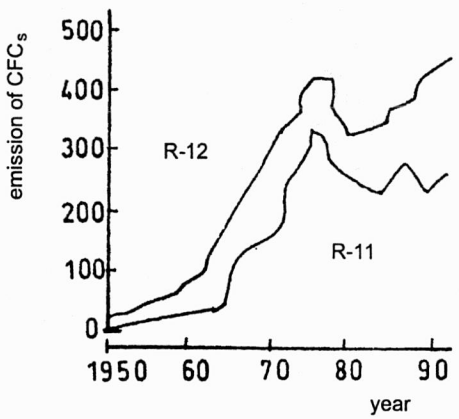

Fig. 3. Annual emission of CFCs (thousand tonnes)

It is important to note that the global warming impact of a refrigeration system involves:

- direct global warming caused by any release of the refrigerant gas,
- indirect global warming resulting from the energy consumption of the system.

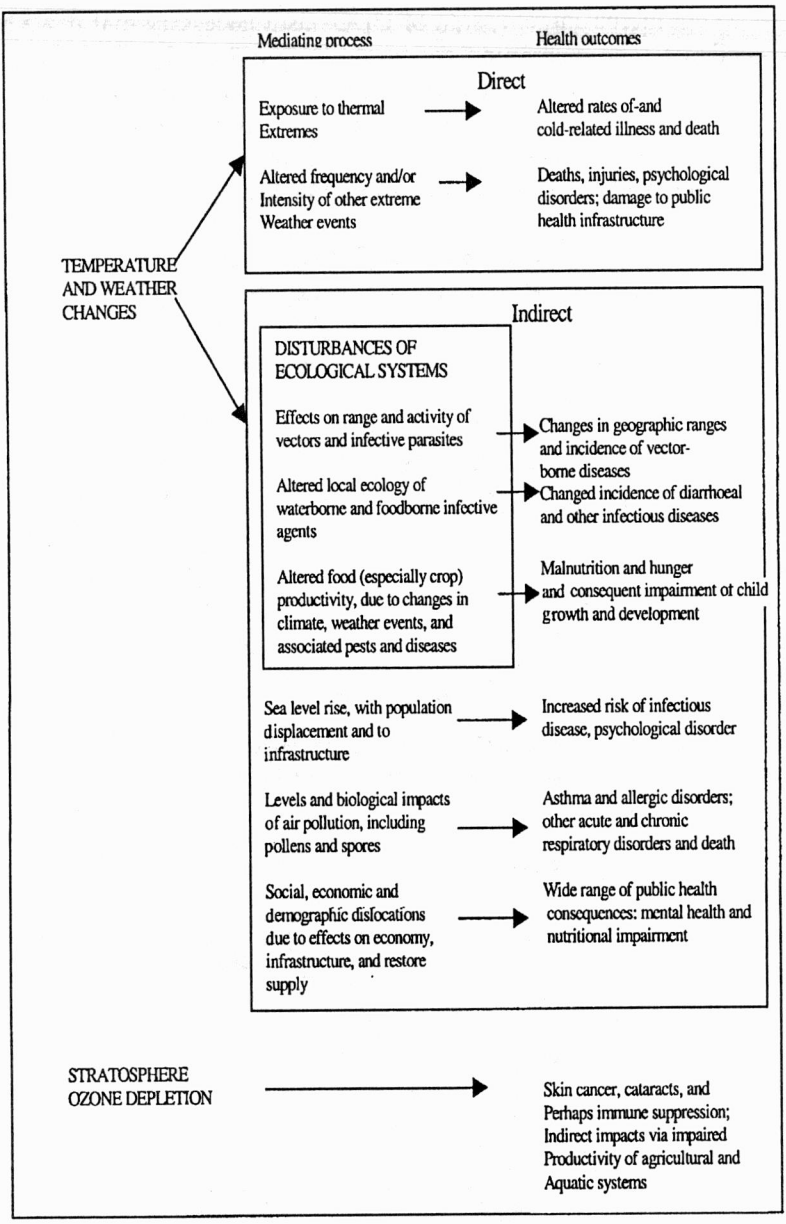

Fig. 4. Possible major types of impact of climate change and stratospheric ozone depletion on human health

Most energy in Nigeria is derived from the combustion of fossil fuels which result in the emission of carbon dioxide, principally GHG. Therefore, the energy efficiency of the operating system is considered a major factor in the overall global warming contribution of the refrigeration system.

The majority of Nigerian architects and civil engineers also rely heavily on air conditioning in commercial/public buildings instead of improved building designs including better windows and other natural ventilation techniques. Such designs which can significantly reduce cooling requirements (possibly CFC emission) and costs appear to be completely ignored.

4.2. STRATOSPHERIC OZONE DEPLETION

The primary concern for the continued application of CFC refrigerants in the refrigeration and air conditioning industry is their link to the cause of damage to the stratospheric ozone layer such as that found in Antarctica. Because of this effect, CFCs and other compounds containing man-made chlorine and bromine are referred to as ozone depleting substances (ODS). CFCs have long atmospheric life times of 4–80 years and are a long term source of chlorine in the atmosphere.

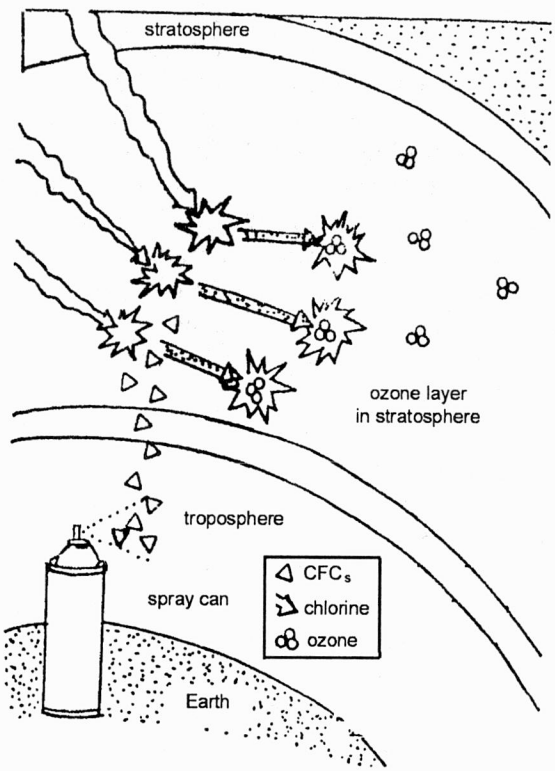

Fig. 5. Ozone layer depletion scheme

The theory of the so-called Antarctic ozone depletion centers around the diffusion of chemically stable CFCs to the stratosphere where, under the sun's irradiation, chlorine atoms are liberated to form chemical species such as HCl and $ClONO_2$. On the cloud particles, these chemical species undergo conversion to highly reactive forms. In sunlight, further chemical reactions then release reactive chlorine radicals to form chlorine monoxide at levels sufficient to destroy ozone at rates up to a few percent a day. Over the past 25 years the ozone layer has been depleted by some 3 to 7% [10].

The ozone layer performs the important role of absorbing significant quantity of the sun's ultra-violet radiation thereby protecting the earth environment from its harmful effects. These radiations are known to cause increased skin cancer, blindness (from cataracts and eye tumors), loss of food production, acid rain and change in overall global climate. They also affect the growth, composition and function of a wide variety of plant species. Figure 4 shows the summary of possible major types of impacts of climate change and stratospheric ozone depletion on human health [6], while figure 5 is an illustration of the concept of ozone layer depletion [10].

5. POSSIBLE SOLUTIONS

The above scenarios have necessitated the numerous international actions through the United Nations Framework Convention on Climate Change (UNFCCC) to foster, since 1980s, global co-operation for reduction of GHGs emission and the protection of the earth's stratospheric ozone layer. The Vienna Convention in 1985, Montreal Protocol in 1987, Kyoto Protocol in 1997 and Buenos Aires Conference of the parties in 1998 have led to important decisions aimed at implementing globally the ultimate goal of the Conventions and Protocols which is *...greenhouse gas concentrations stabilized at a level compatible with sustainable development, food production and the preservation of ecosystems* [7]. Nigeria is a signatory to agreements from these major international Conventions. In its efforts to implement the various decisions of the Conventions and Protocol in the country, the Federal government through Federal Environmental Protection Agency (FEPA) established the National Advisory Ozone Committee (NAOCOM) and the National Ozone Office (NOO) which coordinates [8]

- country wide programmes to phase-out ODS,
- CFCs phase-out strategy for refrigeration and air conditioning and other industries.

In addition, there are legislative measures in place to check unwholesome practices in trade in virgin CFCs and other ODS containing equipment. The trade in these substances have been banned in Europe since 1996, except for essential applications such as in asthma inhalers which must be through import license. Recycled and reclaimed CFCs can also be imported to Europe under license. Nigeria's FEPA established in January, 1998 a licensing system for ODS under its Hazardous Chemicals Tracking and Toxic Waste Dump Watch Programme in compliance with UNFCCC's decisions cited elsewhere in this work. The problem is that with 2010 phase out date for developing countries, CFCs shipments still enter European Union (EU) countries

for inward processing relief (IPR) whereby they are repackaged and exported to developing countries including Nigeria. This legal loophole is responsible for dealers in EU labeling virgin CFCs either as legal alternatives intended for packaging for export or under the guise of being recycled or reclaimed. These practices reinforce the common knowledge that developed countries are not only responsible for the bulk of GHGs and ODS emission, but have been the major contributors to the build-up of GHGs and ODS concentrations in the atmosphere since the industrial revolution. In Nigeria, inadequate implementation of legislation and confused bureaucracy that simultaneously regulate, license and control have combined to make trade in CFCs, especially in the outdated models of ODS containing equipment flourishing and an environmental concern. Absence of penalties for non-compliance with targets appears to be the most serious omission in the decisions so far to reduce ODS. The submission of the Brazilian government at Kyoto Conference for a fine, or penalty, equivalent to US $10/ton of carbon of emissions above the ceiling, to be channeled towards the automatic financing of a clean environment development fund, is one such enforcement mechanism.

The international and local responses to climate change so far discussed can conveniently be called mitigation responses. This is because they simply seek to reduce the building up of GHGs and ODS. There is, therefore, the need for every country to adopt long term solution measures aimed at charting sustainable development path to conserve the earth's atmosphere. For the refrigeration and air conditioning industry, the way out of this dilemma is to focus on restructuring in the form of:

1. Retrofitting existing systems with substitute environmentally-friendly refrigerants. New refrigerants have been identified as possible CFC replacement in many refrigeration and air conditioning applications. All ASHRAE 400 series refrigerants are in this category. Products such as FORANE FX10 (R-408A), FORANE FX56 (R-409A), FORANE FX70 (R-404A), FORANE 407C etc are now well established. In particular FORANE 134a is useful both as pure refrigerant in traditional R-12 applications and a component in alternative blends for R-22 and R-502. These alternative refrigerants contain hydrogen in their structure to form either hydrochlorofluorocarbon (HCFC) or hydrofluorocarbon (HFC). HCFCs contain chlorine but have short atmospheric life times and can easily be destroyed in the lower atmosphere. The HFCs such as R-134a and R-404A do not contain chlorine and have no known potential to deplete ozone layer.

2. *Development of refrigeration and air conditioning units using new energy sources and refrigerants.* In the long run, it will still be necessary to develop refrigeration and air conditioning units using new energy sources and refrigerants. Many developing countries have extensive, unexploited reserves of natural gas, which could replace fossil fuels use in homes, industry and power generation. And all have enormous potentials to rely on solar, wind, biomass or geothermal energy resources. Already, western countries are increasingly pursing these options. Indeed the past decade has seen significant technological improvements in tapping these resources to

power refrigeration units using non-polluting working refrigerants. The possible technologies in this group have been classified in [9] as shown in figure 6.

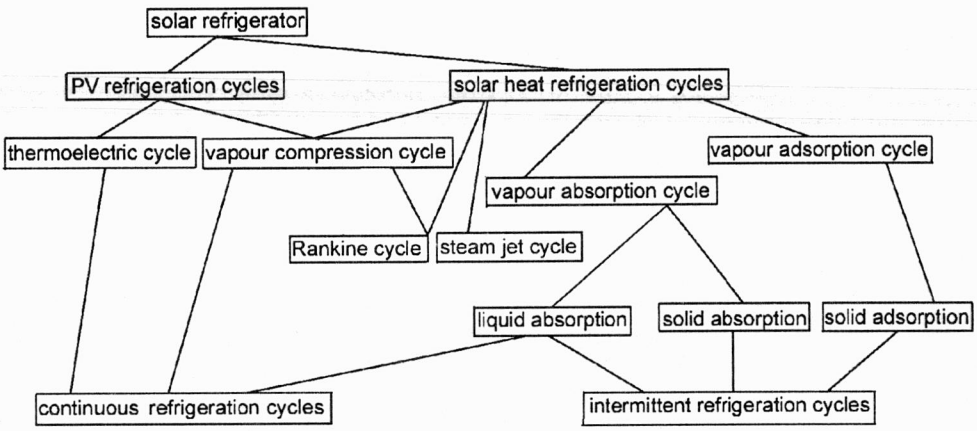

Fig. 6. Classification of solar refrigerators and refrigeration cycles

6. CONCLUSION

The speed of change of technology and patterns of living are quite rapid and produce unexpected results. For the entire world in recent times, the threat to human health and ecosystems due to these changes is alarming. This is why any delay in tackling the problems may likely lead mankind to the Biblical Armageddon.

Refrigerant losses can be significantly minimized by overall good house keeping and care in handling ODS containing units by users and maintenance technicians. In particular, education of the public through symposia, seminars, workshops etc on the dangers of CFCs to human health is important for general appreciation of the magnitude of this problem. Most importantly, use of newly identified refrigerants as alternatives to CFCs in retrofitting applications must be encouraged. Finally, a gradual shift of refrigeration systems design and manufacture to new energy sources (solar, wind, etc) powered options using non-polluting working substances would be rewarding on the long run.

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ZANIECZYSZCZENIE ŚRODOWISKA: RESTRUKTURYZACJA PRZEMYSŁU CHŁODNICZEGO JAKO WYJŚCIE

Pokazano, jakim zagrożeniem dla ludzkiego zdrowia i dla ekosystemów jest zanieczyszczenie środowiska związkami węgla z chlorem i fluorem, których używa się jako środka chłodniczego w lodówkach. Globalne ocieplenie, będące skutkiem wykorzystania powyższych związków w systemach chłodniczych, jest dwojakiego rodzaju: bezpośrednie globalne ocieplenie spowodowane uwolnieniem środka chłodniczego i pośrednie globalne ocieplenie będące wynikiem zużycia energii przez system. Uwolnienie czynników chłodniczych niszczy warstwę ozonową stratosfery, która chroni Ziemię przed szkodliwym promieniowaniem ultrafioletowym.

Oprócz międzynarodowych i lokalnych wysiłków, aby znacznie ograniczyć emisję związków węgla z chlorem i fluorem, rozważono całościowe rozwiązanie tego problemu, które polega na modyfikacji istniejących systemów chłodniczych, zastąpieniu używanych dotychczas środków chłodniczych środkami przyjaznymi dla środowiska i sprzyjającymi rozwojowi systemów chłodniczych korzystających z nowych źródeł energii i nowych środków chłodniczych.