

**Sustainability in Stratospheric Ozone Protection:
A Global and Intergenerational Mentality in Engineering Solutions**

by

Patrick C. Chen

The University of Texas at Austin

The Department of Chemical Engineering

Submitted for

The 2008 Braden Engineering-Communication Contest

**Sustainability in Stratospheric Ozone Protection:
A Global and Intergenerational Mentality in Engineering Solutions**

Global human population growth has led to an increasing demand for technological products such as cooling systems and automobiles. However, rapid technological growth is almost always accompanied by environmental alterations that may one day permanently exhaust Earth's natural resources. While local treatments, such as waste disposal in a chemical plant, are essential in environmental protection, the less emphasized long-term global measures are equally important in enhancing the sustainability of human activities. In the context of this article, sustainability is defined as mankind's ability to indefinitely utilize Earth's natural resources by minimizing adverse alterations in the environment's natural cycles.

Ozone depletion, a significant worldwide concern, is a prime example of an environmental issue handled with global visions. Ozone (O₃), molecules composed of three oxygen atoms, benefits humans by forming a protective gaseous layer in a region 10-30 miles above ground-level called the stratosphere (EPA, 2007c). In the stratosphere, energy from solar ultra-violet (UV) radiation initiates a series of reactions in which ozone is continuously forming and decomposing. Under natural conditions, the rates of ozone formation and decomposition are roughly equal, forming a uniformly thick gaseous layer that prevents harmful solar UV radiation from penetrating to the Earth's surface (Rowland, 2001).

The ozone layer effectively filters the harmful ultraviolet-B (UV-B) component of solar radiation that can damage humans, animals, and plants (EPA, 2007b). Excessive exposure of UV-B radiation to organic life could degrade the DNA structure in all living cells (Lidgate, 1994).

Important consequences on humans include eye damage, sun burn, and skin cancer, as shown in Table 1 (Norval, 2007).

Table 1. Harmful effects of excessive UV radiation exposure in humans (Modified, Norval, 2007)

Tissue	Biological Response	Effects
Eye	Cataract	Severely impaired vision, blindness
	Pterygium	Severely impaired vision, blindness
Skin	Sunburn	Redness, blistering, peeling, freckling
	Tanning	Age spots, non-melanoma skin cancer
	Melanoma	Death, genetic mutations
	Non-melanoma skin cancer	Death, genetic mutations
	Reactivation of latent herpes simplex virus	Death, genital and oral blistering

In 1974, two chemists, Rowland and Molina, discovered that industrially emitted chlorofluorocarbons (CFCs) damage the protective ozone layer (Rowland, 2001). CFCs, a class of chemicals first commercialized in the 1930s by the chemical company DuPont as Freon, were the dominant industrial compounds of choice in refrigeration and air conditioning systems, foam blowing agents, cleaning solvents, and aerosols. Not only could CFCs serve a wide range of industrial functions, the compound's nontoxic, nonflammable, odorless, and chemically inert nature made them an excellent choice in home applications (Rotman, 2007). However, CFCs met the safety criteria so well that the fate of the molecules emitted into the atmosphere was utterly neglected for several decades (McCulloch, 1999).

Rowland and Molina found that chemically stable CFCs eventually find their way to a region above the stratosphere, where they absorb sunlight to form chlorine radicals. The chlorine radicals, which are highly reactive chemical species, attack the O₃ molecules of the stratospheric ozone layer.

The net effect is that the rate of O₃ depletion in the ozone layer largely exceeds the rate of O₃ regeneration, forming regions of thinner ozone layer (Rowland, 2006).

In 1985, the discovery of the Antarctic ozone hole by the British Antarctic Survey (BAS) confirmed Molina and Rowland's proposal (Rowland, 2001). This discovery prompted major countries to address the issue of ozone depletion, in which the most successful global regulatory event to date is the Montreal Protocol. In 1987, the Montreal Protocol was established by major countries of the world, including the United States. The protocol lists ozone depleting substances (ODSs) scheduled for phase-out, and aims to

“protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it with the ultimate objective of their elimination... [while] taking into account technical and economic considerations and bearing in mind the developmental needs of developing countries.” (UNEP, 2000)

The current most widely used replacements for CFCs are hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), which have much lower ozone-depleting potentials. HCFCs and HFCs, though still damaging to the ozone layer, serve the purpose of ensuring a smoother transition to the eventual phase-out of all ODSs (Tsai, 2005). By 2003, implementation of the Montreal Protocol reduced ODS consumption by more than 99% in industrialized countries and over 50% in developing countries (Luken, 2006). By 2165, proper execution of the protocol will have prevented “an estimated 6.3 million U.S. lives that would have otherwise been lost to skin cancer” (EPA, 2007a). Executed with the support of the United Nations Environmental Programme (UNEP), the Montreal Protocol has become one of the most successful global regulatory accords.

Increased global awareness of ozone depletion resulted in a worldwide preventative movement, setting the stage for people capable of actuating the Montreal Protocol's ideology—

engineers. Engineers play a significant role in designing energy-driven processes that convert raw materials into useful products. While society enjoys these products, their accompanying environmental effects have become an obligatory component of engineering considerations. Because “the engineer understands the problem and possible solutions far better than the layman,” engineers bear the responsibility to “minimize the damage caused by man’s activities” (Lidgate, 1994). This requires implementation of environmental protective measures “from the extraction of raw material to the ultimate disposal of the product” (Lidgate, 1994). In the case of ozone depletion, this meant that engineers needed to fundamentally change processes involving CFCs to effectively carry out ODS phase-out. However, with CFC consumption exceeding 2.2 billion pounds in 1988, ODS phase-out was a hefty task (NASA, 2001). Differing in properties between CFCs and their replacements required changing equipment that has been used for decades. Worldwide costs to completely execute the Montreal Protocol are estimated at over \$256 billion (Megie, 2006). This illustrates perhaps the biggest hurdle in enhancing sustainability—increased cost. Development and incorporation of environmental decisions into engineering designs almost always results in higher costs, which detracts from production and financial goals. An engineer is often responsible for a difficult task—finding the optimal balance between growth and sustainability.

The Montreal Protocol has been effective in reducing ODS consumption; however, significant changes in the stratospheric chlorine content will not be observed until several decades later. For CFCs to reach the stratosphere requires an average latency period of ten years, which is why the stratospheric chlorine content peaked at around 2000—even though CFC production was essentially stopped by 1997 (Megie, 2006). The long-term nature of Montreal Protocol’s provisions made ozone protection far-fetched compared to other environmental issues at the time.

After all, short-term waste treatments are generally considered the preferred solution at the local or plant level (Mihelcic, 2003). This highlights another obstacle in achieving sustainable goals—our society’s instinctive tendency to search for short-term solutions. Protecting the environment for future generations requires a balance between short-term treatments and long-term solutions.

Mankind’s tendency to address environmentally harmful effects rather than the causes can be illustrated by several proposals that attempted to “fix” the ozone layer. Most of these proposals are either economically unrealistic, or pose bigger issues than the original problem. One of the more viable proposals suggested dumping ethane and propane into the stratosphere to react away CFC chlorine radicals. Dumping large amounts of ethane and propane into the stratosphere would contribute to other serious climate problems such as global warming. Another proposal suggested destroying stratospheric CFCs with laser beams. With current laser technologies, zapping stratospheric CFCs would cost over \$10 billion per year. These quick-fix proposals only temporarily suppress, but do not eliminate the problems associated with ozone depletion (Davies, 1993). Enhancing sustainability requires the incorporation of preventive measures into engineering solutions, as opposed to corrective strategies after harmful effects have surfaced. (Libra, 2007)

While the future state of the stratospheric ozone layer looks promising, a return to its pre-industrial state will take centuries. (Megie, 2006) Complete ODS phase-out will allow humans to enjoy technology such as air conditioning without worrying that one day the will ozone deplete to a state that may completely unbalance Earth’s climate. The significance of the ozone depletion issue lies in the recognition that the international and intergenerational equity engineers used in ozone protection can be applied to the many other serious environmental problems shown in Table 2 (Lidgate, 1994).

Table 2. Thirteen key global environmental problems. (Modified, Lidgate, 1994)

Thirteen key environmental problems	
Greenhouse effect	Noise
Water quality	Volatile organic compounds and smells
Waste management	Persistent organics
Acid rain	Contaminated land
Heavy metals	Major spills and incidents
Stratospheric ozone depletion	Releases from biotechnology
Air quality	

How can energy industries improve the efficiency of energy extraction from raw materials to in turn limit fossil fuel wastes? What can be done to the continuously increasing industrial, radioactive, and other wastes produced by human activities? Can humans find ways to make raw materials for technological products unlimitedly reusable? These are all questions that are highly unlikely to be adequately answered in the near future with short-term solutions. From the success of ozone protection, elimination of problem sources from engineering solutions should serve as a lesson that can be applied to other environmental issues. Until humans can enjoy the benefits of technology without causing detriment to the environment, the possibility that pollutants will one day exceed the Earth's natural cleansing capacity will continue to remain a serious concern.

Word Count: 1,373

References

- Davies, O. (1993, June). Air Repair. *Omni*, 15(8). Retrieved January 21, 2008, from EBSCOhost database: <http://web.ebscohost.com.ezproxy.lib.utexas.edu/ehost/detail?vid=16&hid=101&sid=ff1f95f7-6f0e-40fa-a674-9f20010d104b%40sessionmgr107>
- Environmental Protection Agency (EPA). (2007, April 25). *Achievements in stratospheric ozone protection progress report*. Retrieved January 21, 2008, from http://www.epa.gov/Ozone/pdf/file/spd-annual-report_final_lowres_4-25-07.pdf
- Environmental Protection Agency (EPA). (2007, June 11). *The plain english guide to the Clean Air Act*. Retrieved January 21, 2008, from <http://www.epa.gov/oar/caa/peg/index.html>
- Environmental Protection Agency (EPA). (2007, October 5). *The science of ozone layer depletion*. Retrieved January 2, 2008, from <http://www.epa.gov/Ozone/science/index.html>
- Libra, J. A. (2007, October). Environmental process engineering: building capacity for sustainability. *Journal of Professional Issues in Engineering Education & Practice*, 133(4), 308-319. Retrieved January 2, 2008, from EBSCOhost database: <http://scitation.aip.org.ezproxy.lib.utexas.edu/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JPEPE3000133000004000308000001&idtype=cvips&prog=normal>
- Lidgate, D. (1994, February). A green world-the role of the engineer. *Engineering Science and Education Journal*, 3(1), 8-14. Retrieved December 26, 2007, from IEEE database: <http://ieeexplore.ieee.org.ezproxy.lib.utexas.edu/iel1/2222/6749/00273004.pdf?tp=&isnumber=&arnumber=273004>
- Luken, R., & Grof, T. (2006, February 15). The Montreal Protocol's multilateral fund and sustainable development. *Ecological Economics*, 56(2), 241-255. Retrieved January 21, 2008, from Science Direct database: http://www.sciencedirect.com.ezproxy.lib.utexas.edu/science?_ob=ArticleURL&_udi=B6VDY-4FXNRJ4-1&_user=108429&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000059713&_version=1&_urlVersion=0&_userid=108429&md5=8d51c0aba6018ac9792c60c629887d3a

- McCulloch, A. (1999, December). CFC and halon replacements in the environment. *Journal of Fluorine Chemistry*, 100(1-2), 163-173. Retrieved January 21, 2008, from Science Direct database: http://www.sciencedirect.com.ezproxy.lib.utexas.edu/science?_ob=ArticleURL&_udi=B6TGD-3Y3PSMB-M&_user=108429&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000059713&_version=1&_urlVersion=0&_userid=108429&md5=41aa8e3a0a181d692f8ba9a13d170f29
- Megie, G. (2006). From stratospheric ozone to climate change: historical perspective on precaution and scientific responsibility. *Science and Engineering Ethics*, 12(4), 596-606. Retrieved January 11, 2008, from EBSCOhost database: <http://web.ebscohost.com.ezproxy.lib.utexas.edu/ehost/pdf?vid=5&hid=102&sid=e7bd0ba7-27bc-4b1f-9195-68b882ddc9d0%40sessionmgr108>
- Mihelcic, J. R., Crittenden, J. C., Small, M. J., Shonnard, D. R., Hokanson, D. R., Zhang, Q., et al. (2003, November 4). Sustainability science and engineering: The emergence of a new metadiscipline. *Environmental Science & Technology*, 37(23), 5314-5324. Retrieved January 5, 2008, from American Chemical Society database: <http://pubs.acs.org.ezproxy.lib.utexas.edu/subscribe/journals/esthag-a/38/free/es034605h.pdf?sessid=600613>
- National Aeronautics and Space Administration (NASA). (2001, May 30). *Ozone depletion, history and politics*. Retrieved January 21, 2008, from <http://www.nas.nasa.gov/About/Education/Ozone/history.html>
- Norval, M., Cullen, A. P., de Gruijl, F. R., Longstreth, J., Takizawa, Y., Lucas, R. M., et al. (2007, January 25). The effects of human health from stratospheric ozone depletion and its interactions with climate change. *Photochemical & Biological Sciences*, 6, 232-251. Retrieved January 11, 2008, from <http://www.rsc.org.ezproxy.lib.utexas.edu/ej/PP/2007/b700018a.pdf>
- Rotman, D. (2007, January). Remembering the Montreal Protocol. *Technology Review*, 110(1), 76-77. Retrieved January 3, 2008, from EBSCOhost database: <http://web.ebscohost.com.ezproxy.lib.utexas.edu/ehost/pdf?vid=3&hid=101&sid=ff1f95f7-6f0e-40fa-a674-9f20010d104b%40sessionmgr107>

- Rowland, S. F. (2001). Atmospheric changes caused by human activities: From science to regulation. *Ecology Law Quarterly*, 27(4), 1261-1293. Retrieved January 1, 2008, from EBSCOhost database: <http://web.ebscohost.com.ezproxy.lib.utexas.edu/ehost/pdf?vid=7&hid=114&sid=ecdc288e-25de-4861-a108-fd82092a40fb%40sessionmgr106>
- Rowland, S. F. (2006, February 21). Stratospheric ozone depletion. *The Royal Society*, 361(1469), 769-790. Retrieved January 4, 2008, from <http://journals.royalsociety.org/content/501842p67034t582/fulltext.pdf>
- Tsai, W.-T. (2005, December). An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs). *Chemosphere*, 61(11), 1539-1547. Retrieved January 21, 2008, from Science Direct database: http://www.sciencedirect.com.ezproxy.lib.utexas.edu/science?_ob=ArticleURL&_udi=B6V74-4G9R1H0-1&_user=108429&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000059713&_version=1&_urlVersion=0&_userid=108429&md5=e3f19d88f7615e21d23ad4b6de64a7ef
- United Nations Environment Programme (UNEP). (2000). *The Montreal Protocol on substances that deplete the ozone layer*. Retrieved January 21, 2008, from <http://ozone.unep.org/pdfs/Montreal-Protocol2000.pdf>