Military Leadership Spun Off to Civilian Sectors Protects Global Security

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Abstract

The stratospheric ozone layer protects Earth against the harmful effects of ultraviolet (UV) radiation that causes skin cancer and cataracts, suppresses the human immune system, damages agricultural crops and natural ecosystems, and deteriorates the built environment. A low carbon dioxide equivalent ($CO_{2\text{-eq}}$) atmosphere protects Earth against the harmful effects of global warming, violent weather, droughts, floods, species extinction, and human mass migration. The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) has phased out 99% of controlled ozone-depleting substances (ODSs), and the ozone layer is on the path to recovery. Because ODSs are also powerful greenhouse gases (GHGs) the phaseout protected climate so far more than all actions under other climate treaties.

In 1987 when the Montreal Protocol was agreed, every weapon and its support system worldwide depended on ODSs for manufacture, use, or service. Examples include chlorofluorocarbon (CFC) solvents for electronics and aerospace, methyl chloroform for manufacture of solid rocket motors, halon for fire protection of occupied spaces and aircraft fuel tanks, and refrigerants to cool equipment and personnel. Military organizations also used ODSs in its facilities, infrastructure, and consumer goods – in the same ways as civilian sectors.

To protect the ozone layer and to comply with the Montreal Protocol, military organizations around the world partnered internally, with each other, and with civilian organizations to avoid duplication of effort, to achieve economy of scale, and to speed commercialization through government procurement of the superior next-generation technology.

The outcome was that the technical performance of military systems was maintained or improved, costs were often reduced, and the industrial base made more resilient because militaries took advantage of this opportunity to more closely align its processes with commercial practices and eliminate military-specific practices. One measure of this extraordinary contribution to protection of the ozone layer is that military experts, organizations, and their contractors earned more United States Environmental Protection Agency (US EPA) and United Nations (UN) Awards for Implementing the Montreal Protocol than any other sector (Andersen and Gonzalez 2022; Andersen, 1998).

This paper recalls and documents the military leadership under the Montreal Protocol, presents indicative case studies of how technical performance of military systems was maintained or

improved by adopting newer technologies, and summarizes key lessons from military leadership in protecting the ozone layer. In addition to collaboration on technology development and demonstration, between 1991 and 2009, military organizations from various countries came together to conduct seven workshops specifically to review military ODS uses, share experiences with alternatives, and compare policy approaches to extract and share best practices. Lessons such as this can be applied to developing and adopting technologies that displace the need to emit greenhouse gas while improving the performance of military systems and reducing operating costs.

With time running out to slow self-reinforcing feedbacks and avoid climate tipping points, it is critical that global military leadership recognize it is in their self-interest to help prevent and mitigate the worst effects of climate change. These effects on military operations and national security are well known and extensively studied. It's not a question of if, but a question of when. It should not be difficult for the military to reclaim the constructive role they played to eliminate ODS, to catalyse worldwide partnerships, and to share the tasks of developing and deploying innovative solutions to shared technical challenges. It's critical at this juncture for military leaders to adopt the same model with the same sense of urgency to preserve their own operational effectiveness and their own national security.

Success of the Montreal Protocol

The success of Montreal Protocol has saved millions of lives, maintained and improved productivity of agriculture and fisheries, and protected natural ecosystems (Lochhead and Hunt-Grubbe 2019). By any measure the Montreal Protocol is a success (UNEP et al. 2022; Gonzalez and Picolotti 2022; Andersen and Gonzalez 2022; DeSombre 2000; Albrecht and Parker 2019; Andersen et al. 2018; Andersen, Halberstadt, and Borgford-Parnell 2013; Le Prestre, Reid, and Morehouse 1998). Remarkably, the 1987 Montreal Protocol and its framework agreement the Vienna Convention for Protection of the ozone layer were agreed and commenced long before the science was certain, and the technical solutions were available under what has come to be known as '*The Precautionary Principle* ' (Morris et al. 2022; Willi et al. 2021; Jacobs 2014; Barrett 2003; Benedick 1998; Biermann 1996; Freestone and Hey 1996).

- ✓ The Montreal Protocol is the first treaty to achieve universal ratification, only one other treaty has since achieved this benchmark (Gonzalez and Picolotti 2022),
- ✓ Every party is typically in full compliance with control measures,
- ✓ More than 99% of ozone-depletion potential (ODP)-weighted ODS production and consumption has been phased out under the Montreal Protocol (Willi et al. 2021),

- ✓ Not-in-Kind (NIK) substitutes and alternatives have replaced about 85% of applications originally using ODSs, with fluorocarbon substitutes replacing just 15% (Seidel et al. 2016; Andersen, Sarma, and Taddonio 2007). After the Kigali Amendment most of the 15% now using HFCs are expected to use NIK replacements such as hydrocarbons with the remainder replaced with HFCs and hydrofluoroolefins (HFOs) typically with much lower GWPs than the ODSs replaced,
- ✓ ODS abundance in the atmosphere is declining (WMO et al. 2022),
- ✓ Chlorine-equivalent concentrations have peaked below the ozone tipping point and are declining (WMO et al. 2022),
- ✓ The stratospheric ozone layer is on the path of recovery to 1980 levels by mid-century and to 1960 levels a century later (WMO et al. 2022),
- ✓ Phaseout of ozone-depleting GHGs has accomplished more climate protection than all other efforts by humans combined (Andersen and Gonzalez 2022; Willi et al. 2021; Hoag 2013; Velders et al. 2007; Ramanathan 1975),
- ✓ Replacement technology is typically environmentally superior in every metric , including carbon footprint (Andersen, Taddonio, and Sarma 2007; Andersen and Morehouse 1997),
- ✓ Overall cost of ownership of replacement technology is comparable to ODS-based technology, and
- ✓ The Montreal Protocol also has catalysed improvements in the energy efficiency of cooling equipment during refrigerant transitions (Dreyfus et al, IEA & UNEP).

World Avoided, World Enjoyed

Life on Earth would have been nearly impossible due to stratospheric ozone depletion and global warming were it not for: 1) the boycotts and bans of CFC aerosol products in the 1970s; 2) the global phaseout of CFCs and halons under the 1987 Montreal Protocol; 3) the continuous strengthening of the Montreal Protocol after 1987 by amendments to add to the list of controlled substances and the adjustments to accelerate ongoing phaseouts including the acceleration of the HCFC phaseout in 2007, which was the first step in transforming the Montreal Protocol into a treaty that explicitly required mandatory actions for climate protection; and 4) the 2016 Kigali Amendment to phase down HFCs, which further transformed the Montreal Protocol to a climate treaty with accomplished ozone co-benefits ((Andersen and Gonzalez 2022; Young et al. 2021; Xu et al. 2018).

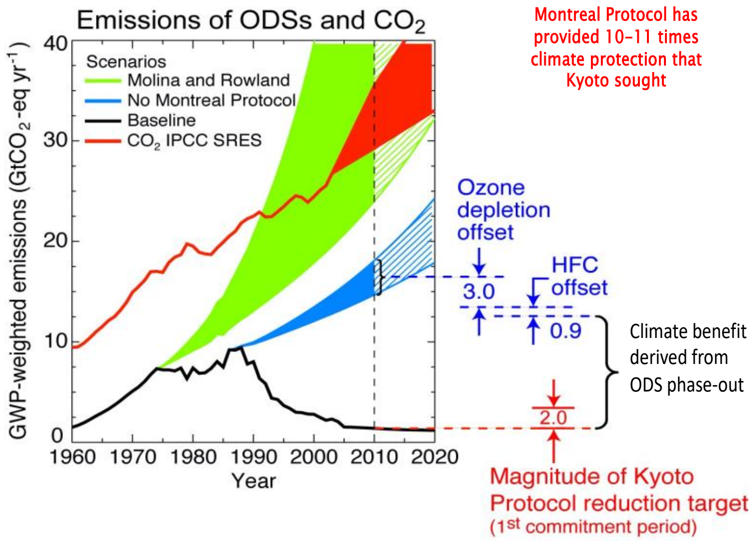
The '*World Avoided*' is a metric used to quantify the benefits of halting the use of ODSs that are also GHGs (Newman and McKenzie 2011; Newman et al. 2009; Morgenstern et al. 2008; Netherlands NEA 2007; Prather et al. 1996).

> Environment Canada estimated that benefits to agriculture, forest, fisheries, and the built environment exceeded the total cost of Montreal Protocol implementation by US$ 235 billion (Armstrong, 1998).

Without the market and Montreal Protocol response to the Molina and Rowland warning, human life on land would be nearly impossible due to high UV radiation and climate forcing. Without the GHG emissions reductions achieved by the Montreal Protocol; key climate tipping points would have been exceeded by the late 1990s.

> '(Without the Montreal Protocol ODS phaseout) The year is 2065. Nearly two-thirds of Earth's ozone is gone – not just over the poles, but everywhere. The infamous ozone hole over Antarctica, first discovered in the 1980s, is a year-round fixture, with a twin over the North Pole. The UV radiation falling on mid-latitude cities like Washington DC, is strong enough to cause sunburn in just five minutes. DNA-mutating UV radiation is up more than 500 percent, with likely harmful effects on plants, animals, and human skin cancer rates…In the 2050s…ozone levels in the stratosphere over the tropics collapse to near zero in a span of six years…the rapid, near-total ozone destruction is similar to what happens over Antarctica today.' (Newman et al. 2009).

Figure 1



Source: (Velders et al. 2007)

Figure 1 (above) graphs the carbon equivalent GHG emissions of ODSs with and without the consumer boycotts from 1978 to 1988 and with and without the Montreal Protocol from signing in 1987 through 2020 relative to actual fossil fuel and biomass CO_2 emissions. The impacts of stratospheric ozone depletion and climate change are continuously expanded and elaborated by the Montreal Protocol Environmental Effects Assessment Panel (UNEP 2022).

The '*World Enjoyed*' is the metric defined in *35th Anniversary Protecting the Ozone Layer* to describe and quantify the benefits of replacement technology that is environmentally superior in every metric, typically satisfying updated and more stringent safety standards, and comparable in terms of cost of ownership (Andersen, Sarma, and Taddonio 2007). The important benefits of superior replacement technology (Andersen and Gonzalez 2022; Parson 2003; Andersen, Sarma, and Taddonio 2007; Andersen et al. 2018) include:

1) Replacements for CFCs in metered dose inhalers for treatment of asthma and chronic obstructive pulmonary disease provide far more precise in therapeutic dose from the first puff to the last (Tope 2022).

2) Replacements for ethylene oxide/CFC hospital sterilization offers a choice of higher efficacy against increasing virulent bacteria and viruses, faster sterilization during emergencies when medical device inventory is limited, and lower doses of the hazardous ethylene oxide active sterilizing ingredient (Andersen, Sarma, and Taddonio 2007).

3) No-clean soldering produces solder joints with near-zero failure over the life of the product and far less hazardous lead solder dross. Near zero failure is particularly valuable for safety systems in a wide range of civilian, industrial, and military applications. No-clean soldering facilitated the phaseout of lead solder and inspired super-integration of electronics with fewer components, lighter weight for lower carbon footprint, and even greater reliability (Canan and Reichman 2017).

4) Replacement refrigeration and air-conditioning equipment has higher energy efficiency, reliability, and technical performance (Andersen and Morehouse 1997).

5) Some replacements for ODS refrigerants produce less vibration and noise, which is an advantage for refrigeration and air-conditioning equipment in occupied spaces and in military applications to minimize detection signature.

6) In the complete redesign of refrigerators for ozone-safe refrigerants, engineers updated consideration of the science of food preservation and adopted combined optimal temperature and humidity to preserve food longer with reduced nutrition loss (Andersen, Sarma, and Taddonio 2007).

7) Air-conditioner engineers updated the science of comfort based on temperature, humidity, and airflow as well as targeted cooling rather than controlled ambient temperature only, resulting in faster comfort at less energy use as well as higher alertness and creativity (IEA and UNEP 2020).

8) Replacement of halon computer centre fire protection with water is just as effective at lower cost. This triggered a realization that extinguishing computer centre fires was less financially important than maintaining continuous computer operation, which shifted attention to backup facilities with automatic switching in case of fire or other computer damage.

9) Fire-proofing computer facilities with instantaneous transfer of operations to backup facilities has proved more cost effective with much less business interruption than use of halons for fire suppression.

10) Containment, recovery, and recycling of refrigerants to avoid emissions also improves the precision of recharge by weight and volume, producing the highest possible cooling capacity and energy efficiency.

11) Thermal insulating foam blown with hydrocarbons, water, and CO_2 exhibits comparable thermal resistance and superior installed performance because better foam expansion

fills voids in the corners of insulated refrigerators and freezers more completely than CFC foam.

12) Near-zero waste manufacturing turns all inputs to valued product and avoids disposal of unusable resources that may otherwise become hazardous waste or landfill.

13) Refrigerant containment and smaller refrigerant charge implemented to reduce ozone-depleting and GHG emissions through financial incentives from higher refrigerant cost and government regulations against intentional venting.

14) Replacements for cooling equipment and thermal insulating foam were made more energy efficient with superior design, inherently efficiency of replacement chemistry, improved manufacture, and proper installation and service.

15) Professional organizations like SAE International supported the industry through standards on precision leak detection, permeability of flexible hoses, and performance of joint seals.

HFC GHGs are since 2016 controlled by the Montreal Protocol through the Kigali Amendment. This enables Parties to avail themselves to the same scientific, technology and economics assessment and cooperation mechanisms as they currently use to control ODSs. It also places HFCs under the same kind of enforcement mechanisms as alternatives become available.

While military research and development was not central to the development and commercialization of some of these applications, military adoption of the alternatives in areas such as sterilization and insulating foams provided early confidence to commercial users and helped accelerate broad adoption.

Introduction

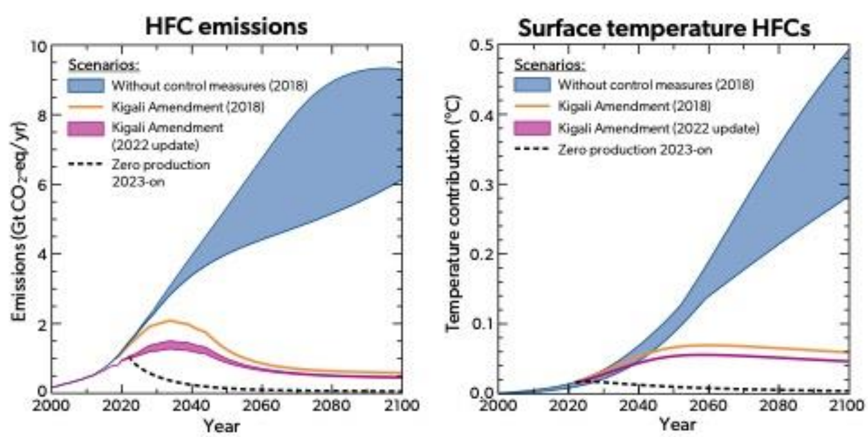
Global warming is being propelled by continued GHG emissions and self-reinforcing feedbacks like the thawing of Arctic permafrost, which produces additional emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which in turn, further heats the planet. Continued warming increases the risk of pushing past irreversible and catastrophic tipping points in the climate system (Klose et al. 2021; Wunderling et al. 2021; Lenton et al. 2019; Ramanathan et al. 2017). The unprecedented heat waves, wildfires, droughts, and other many recent weather disasters are only a preview of future life on Earth (Miller, Dreyfus, and Andersen; 2022; Molina et al. 2020; Xu et al. 2013; Molina et al. 2009;).

These climate tipping points can only be avoided by three simultaneous actions accomplished as quickly as possible (Miller, Zaelke, and Andersen 2021; Dreyfus et al. 2022):

- A 10-year Sprint to drastically cut methane and black carbon emissions while phasing down hydrofluorocarbons (HFCs) under the Montreal Protocol,
- A 30-year Marathon to get to net zero CO_2 emissions by 2050, and
- An Ultra-Marathon to remove a significant amount of the CO_2 and CH_4 already in the atmosphere, continuing well beyond 2050.

Thanks to the 2016 Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer and leadership countries phasing down faster and further, the world has taken a fast start to reducing the use of HFC super climate pollutants, now under a mandatory phasedown over the next 3 decades (Zaelke, Durwood, and Nathan Borgford-Parnell 2015; Velders et al. 2009).

Figure 1. HFC Emissions and Global Average Surface Temperature



Source: WMO et al. (2022).

But more can and must be done. HFC phase down can be started earlier and accelerated to phase out at superior technologies emerge and parallel efforts to upgrade the energy efficiency of cooling equipment and thermal insulating foam could double the climate benefits of the HFC phasedown (Dreyfus et al. 2020). In addition to speeding up HFC phasedown while increasing energy efficiency, the Montreal Protocol could provide additional climate and environmental benefits by controlling ozone-depleting GHG N_2O and by narrowing the feedstock exemption that allows ODS and HFC in the production of plastics that pollute oceans, rivers, land, and atmosphere (Andersen et al. 2021b; Daniel et al. 2010).

This paper examines lessons learned from the partnerships organized by the United States Department of Defense (US DOD) and US EPA that officially including military organizations and military contractors from Australia, Bahrain, Canada, Denmark, France, Germany, India, Italy, Netherlands, Norway, Saudi Arabia, Singapore, Sweden, Switzerland, Thailand, Vietnam, and the Union of Soviet Socialist Republics (Andersen, Sarma and Taddonio 2007; Andersen and Sarma 2002; Andersen, Morehouse, and Miller; 1994). Unofficially, the partnerships included participation from many more countries including global participation in seven international military conferences on the importance of military organizations in protecting the ozone layer and climate (1991 Williamsburg Virginia, 1994 Brussels, 1997 Washington DC, 1998 Brussels, 2001 Brussels, 2008 Paris, and 2009 in Williamsburg).

The lessons of successful collaboration of military organizations worldwide through the 1990s for the phase out of ODSs could be applied to military compliance with the phase down of hydrofluorocarbons (HFCs) under Montreal Protocol's 2016 Kigali Amendment, which do not deplete the ozone layer but are significant GHGs (King, Morehouse, and Andersen; 2022). During the early years of the Montreal Protocol HFCs were necessary to rapidly replace ODSs but are no longer needed because environmentally superior replacements are available in most sectors and applications, or soon to be available (IPCC and TEAP 2005).

Military organizations worldwide were once significant users of ODSs in a variety of high-precision weapons applications. These included inertial guidance systems for aircraft and missiles; fire safety systems for ships, aircraft, and armoured vehicles; in the manufacture of solid rocket motors; and in many other military-unique applications (King, Morehouse, and Andersen 2022; Andersen, Sarma, and Taddonio 2007; Andersen, Morehouse, and Miller 1994).

Extensive Halon Use in Military Tactical Vehicle and Aircraft

Halons, for example, were used extensively in both tactical vehicles and military aircraft given their rapid extinguishing performance should a fire erupt due to combat operations or mechanical failure. Table 1 elaborates the details of the military halons use in aircraft, ships, and other military vehicles.

Table 8.
Indicative Halon Use in Combat Vehicles, Ship, Aircraft and Tactical Facilities

	Army	**Navy**	**Air Force**
Ground Armoured Vehicles	• Crew compartments • Engine compartments	• Crew compartments • Engine compartments	
Shipboard	• Maritime craft	• Flammable liquid storerooms • Fuel pump rooms • Emergency generator rooms	
Aircraft	• Engine nacelles • Auxiliary Power Unit (APU) compartments	• Engine nacelles • Dry bays • Fuel tanks • Crew compartments	• Engine nacelles • Dry bays • Fuel tanks • Weapon bays • Cargo bays
Facilities	• Communications shelters	• General facilities	• General facilities
Hand-held Extinguishers	• Air / ground / maritime		• Multiple uses

Source: Department of Commerce (2007)

The military also used ozone-depleting solvents in a variety of manufacturing and maintenance cleaning processes concerned with precision equipment where contamination could lead to a loss of reliability. Other CFCs like CFC-114, used for refrigeration and air conditioning, were particularly suited for cooling in naval vessels due to their compatibility with cooling equipment and a contribution to reducing acoustic signatures. Andersen and Sarma 2002) reported that in the late 1980s, the US DOD, together with many other military organizations, recognized their high level of ODS dependence and the potential negative impacts to mission, logistics and cost should access and availability become problematic; and they began to act. Consequently, the US DOD and many other military organizations became motivated to find ways to either phase out ODSs or sharply reduce their use.

Given the extensive ODS use in mission-critical applications, militaries could have pursued exemptions from their national governments under the guise of readiness, but they did not choose this path. There was an emerging recognition at the time within DOD that environmental security was an essential element of national security. There was also a growing appreciation that in the absence of a robust commercial market for these consumable chemicals, the global supply chain would disappear rendering manufacturing lines and maintenance procedures unsupportable for high-value operational systems. The logical path forward was to find alternatives at a speed and scale linked to the Montreal Protocol phaseout schedule. In light of these realities, a broad global cadre military leaders embraced the inevitability of change and sought to phase out ODSs by finding alternatives (Andersen and Sarma 2002). There were several reasons why global military organizations choose to be part of the solution to stratospheric ozone depletion including: 1) diplomatic policy for every government agency to faithfully fulfil its treaty obligations, 2) recognition of the inevitability of future supply chain challenges and increasing costs driven by a global industrial base shift toward the use substitutes and alternatives to ODSs, 3) scientific confidence in atmospheric and terrestrial science of ozone depletion and climate change from classified investigations and cooperative research with civilian government scientific investigations[1], and 4) engineering confidence that a fresh look at technology would identify ODS replacements with superior in operating performance, reliability, reparability, durability, and cost.

The phase out ODSs in military applications was successful due to 1) the effectiveness of early and sustained internal leadership, 2) cooperation with military and civilian centres of engineering excellence worldwide, and 3) the use of innovative procurement policy to find and reward technically and environmentally superior alternatives and substitutes to ODSs that satisfied or exceeded performance requirements. This chapter concludes that leadership, policy, and networking remain viable tools for military organizations to again use to address the Kigali Amendment.

Fluorocarbon Industry Claims of ODS Technical Superiority Quickly Debunked

When the Montreal Protocol was signed in 1987 many military specifications (MilSpecs) were prescriptive in requiring the use of ODSs. One author of this paper (E. Thomas Morehouse) with colleagues in the US Air Force demonstrated that halon use and emissions need not be exempted from the Montreal Protocol. And another author of this paper (Stephen O. Andersen) and colleagues in the Industry Cooperative for Ozone Layer Protection and the Montreal Technology and Economic Assessment Panel Solvents Technical Options Committee (TEAP STOC) debunked the myth that CFC-113 cleaned electronics better than substitutes and alternatives (Andersen, Taddonio and Sarma 2007; Andersen, Morehouse, and Miller 1994).

> <u>Halon Debunked</u>: The fluorocarbon industry had promoted halon as a '*wonder gas* that was colourless, odourless, low-toxicity, and left no corrosive residue after extinguishing

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[1] For example, scientific investigations of thermal and acoustic ocean conditions only explained by global warming and shared instruments and space platforms for atmospheric research validating atmospheric mixing, chemical reactions, and atmospheric fate of manufactured chemicals.

a fire. The marketing strategy was to portray halon as the end-all and be-all fire protection chemical. Tom Morehouse's breakthrough contribution sprang from careful data collection that determined that over 90% of US Air Force halon emissions was for testing, training, leakage, and accidental discharge and that halon was far from infallible in extinguishing the fires where it was deployed (Morehouse and Taylor, 1990). The Air Force fresh look at halon fire protection inspired International Business Machines (IBM) to promote water as their choice for superior protecting of computer centres and to promote redundant computer backup centres at two or more locations as the ultimate protection against the consequences of fire. The USA DOD Defense Logistics Agency (DLA) in cooperation with the Australian DOD and Victoria state EPA commercialized halon recovery and recycle. They developed best practices resulting in near zero processing and storage emissions and commercialized a plasma destruction technology to destroy halon too contaminated for use or amounts in excess pf quantities needed to support the few critical application where replacements were not yet available. These typically involved small quantities of halon stored in canisters and released only in the event of a fire on high priority, highly integrated weapons platforms, such as aircraft, ships, or armoured vehicles. The US Navy also developed and implemented halon recycling and shared technology and training worldwide. By 1992 global military and civilian industry using halon were confident enough in halon banking and alternatives to recommend that the Montreal Protocol phase out production in 1994 in developed countries (non-Article 5 Parties).

CFC-113 Solvent Debunked: The fluorocarbon industry had promoted CFC-113 as the '*ultimate solvent*' that was aggressive against soil leaving little contamination but compatible with materials used in aviation and electronics. However, just four months after the signing of the Montreal Protocol American Telephone and Telegraph (AT&T) announced a nature-based cleaner (Terpene) that cleaned as well or better than CFC-113 at equal or lower cost and with no ozone impact and de minimis climate impact. Once US DOD shifted from prescriptive specifications requiring CFC-113 solvents to performance specifications based on cleaning efficiency and product reliability, aqueous, semi-aqueous, and hydrofluorocarbon (HCFC) options were certified by the US DOD as superior and rapidly commercialized. Within two years the government-industry partnership called the Industry Cooperative for Ozone Layer Protection (ICOLP) invented, patented, commercialized, and then donated to free public domain use '*no-clean soldering*' that avoid ODSs while almost eliminating solder joint failure with co-benefits of less solder waste, which lowered the cost of solder recycle. Meanwhile, DuPont and other fluorocarbon suppliers began promoting CFC-113 reformulations with alcohol touting emissions less damaging to the ozone layer while non-flammable and with equivalent cleaning performance. Electronics and aerospace companies slower to switch to replacements for CFC-113 demonstrated dramatic reduction in emissions with welded rather than threaded CFC supply pipe fittings and improved and enclosed vapor degreaser apparatus.

No-clean soldering became the inspiration for no-clean metal stamping where aqueous cleaning processes were used to clean metal prior to coating with aqueous based paint that was compatible with any residue from cleaning. In another innovation companies embraced machine processes where cutting oil became the flushing fluid to remove metal filing, with filtered cutting oil constantly recirculated, filtered, and reused.

What was significant was that methodical technology identification using metrics of environmental acceptability and testing for performance at military centres of engineering excellence was simultaneously creating the demand for sustainable technology and proving the products that would be welcomed under the new performance based MilSpecs.

Military and Civilian Ozone Champions Joined Forces

Thus, military leadership and technical innovation inspired companies and their suppliers in both civilian and military markets to revaluate their assumptions regarding the essentiality of ODSs and to broaden their search for replacements to include not-in-kind technology, emission reduction, and doing without. Collaborations among end users of OSD with common challenges were forming worldwide to reduce or eliminate dependence on ODSs. Trade magazines, engineering associations, trade associations and other stakeholders went public to share information to avoid duplication of effort, speed commercialization, and achieve economy of scale for the best technologies.

The US EPA and ICOLP with Thai Airways International and the Government of Thailand organized a tiger team of experts from military and civilian aircraft maintenance facilities to write a handbook on servicing aircraft without ODSs. Each participating organization took on a category of CFC and methyl chloroform use from the most elegant applications such as cleaning gyroscopes to the simple applications of cleaning leather and fabric upholstery (US EPA et al., 1993; Zatz and Chanvinij, 1994). Breakthroughs included 1) the discovery that the Lufthansa approach to cleaning and refurbishing engine turbine blades without CFC somehow made Magnaflux and other inspection techniques more reliable in finding hairline fractures that could end in catastrophic engine failure; 2) the realization by the US Air Force and Navy that landing gear manufactured by the same supplier was cleaned with a wide range of solvents at different facilities and with no technical advantage of the CFC-113 or methyl chloroform processes; and 3) the finding that electronics assembly techniques according to outdated MilSpecs such as requiring conformal coatings after soldering actually reduced the reliability of solder joints while increasing the cost of repair.

The US DOD, US EPA, and the National Aeronautics and Space Administration (NASA) organized a tiger team of all the companies manufacturing solid rocket motors. Almost immediately, it was realized that the manufacturing techniques had evolved independently without the advantage of disclosing and sharing best practices. One or more of the solid rocket motor suppliers had ODS-free techniques for each of the hundreds of identified applications as solvents, diluents, and dispersants, and in coatings and adhesives. The collaboration included a comprehensive comparison of cleanliness and other performance testing including laboratory apparatus and calibration (Whitaker, Clark-Ingram, and Hessler, 1997) as well as a handbook for manufacturing solid rocket motors without ODSs (EPA, NASA, and DOD, 1995).

Military Systems and Operations

A combination of factors led to the successful implementation of the Montreal Protocol by many military organizations. The increasingly alarming scientific prognosis for the ozone layer and the rapid development and adoption of high performing and affordable new technologies were certainly critical factors. But the structure of the Montreal Protocol itself enabled all of this by creating a continuous process of updating the provisions of the Montreal Protocol using inputs from governments, industry, consumers, non-governmental organizations (NGOs), and military organizations – a process the United Nations Environment Programme (UNEP) calls '*Start and Strengthen*' (Andersen et al. 2021b; Parson 2003; Benedick, 1998;).

It is significant that military leadership in protecting the ozone layer was both good for the environment and good for miliary organizations. Adopting new technologies enhanced readiness, saved money, modernized the industrial base, strengthened military cooperation among nations, and assured continued availability of consumables necessary to sustain critical systems. Military collaboration with industry, other government agencies, and NGOs also established their credibility among the Parties to the Montreal Protocol, national environmental authorities, and the public. This became very valuable during those few times when critical weapons programmes needed a temporary exemption from Montreal Protocol deadlines and unanimous agreement among parties was required. The good work done by military organizations around the world did not go unnoticed.

Examples of military leadership include:

- Changed military manufacturing and maintenance standards fast enough to allow weapons suppliers to seamlessly transition. This was accomplished through a fundamental revision in the approach to how the military established specifications; moving from prescriptive specifications that explicitly required the use of ODSs to performance standards that measured how the end-product performed against specific metrics measured in a specific way. Moving to performance-based standards opened the door to more rapid adoption of technical innovation by commercial suppliers. In several cases, it allowed companies to stop operating two different manufacturing lines to produce the same product, one compliant with prescriptive specifications for military customers and one using accepted best industry practice for civilian customers.

- Worked closely with military organizations worldwide, including traditional adversaries, to coordinate choices of replacement technology. Collaboration between military organizations of countries with strained relations is highly problematic and rarely occurs. However, preserving the ozone layer was something virtually all countries could agree on, and technologies to displace ODS did not confer any military advantage of one country over another. As a result, traditional adversaries were able to collaborate, initially through the UNEP process and later through bilateral or multilateral cooperative agreements, to address specific common ODS uses. Some believe these collaborations fostered trust and opened avenues for dialog on other national security issues.

Tangible Benefits to Militaries from Stratospheric Ozone Protection Leadership:

- Montreal Protocol Essential Use Exemptions (EUEs) were quickly granted for manufacture of solid rocket motors including for the Space Shuttle and Titan; the search for replacement technology brought together experts from many militaries and their suppliers to share best manufacturing practices.
- In the US, the US EPA expedited certification of the Joint Strike Fighter (F-35 Lightning II) lower emissions profile in the spirit of trust and collaboration engendered through their shared experience addressing the Montreal Protocol challenge. This certification was considered important to overseas sales so far to nine partners of the North Atlantic Treaty Organization (NATO) and six non-NATO partners).
- Uncertain how to manage the emergence of surplus halon as many civilian users found alternatives and wishing to avoid the need to seek critical use exemptions, some militaries helped create organizations to collect and repurpose them for critical uses. One of the first such organizations was the UK Halons Users National Consortium (HUNC) co-founded by Marion McQuaide of the UK Royal Navy and a TEAP Halons Technical Options Committee (HTOC) member.
- Prescriptive specifications governing the use of conformal coatings for electronic devices were eliminated when commercial partners demonstrated the presumed protection provided to solder joints from corrosion was made worse by trapping moisture and corrosive residue under the conformal coating.

- Prescriptive specifications requiring the use of CFC-113 solvents for cleaning certain precision parts were eliminated when commercial partners demonstrated the alcohol in the solvent blend cleaned the part and the CFC ingredient served no essential function. Ultimately, aqueous cleaning and no-clean soldering techniques replaced most solvents in the manufacture of military electronics.
- Replacing CFC-based cleaning technologies with superior manufacturing technologies eliminated multiple manufacturing steps, leading to a smaller facility footprint, fewer consumable materials needed, faster production line, higher reliability, and less cost; this led to a change in maintenance procedures that produced similar outcomes at all levels of maintenance.
- These activities created new professional networks that endured long after ODSs were phased out, facilitating more frequent exchange of best practices. The most formalized of these is the US Navy Clearinghouse, managed by Peter Mullenhard, that matched DOD problems to experts that had solved a similar problem.

In addition to its outward facing leadership, military organizations used a variety of traditional tools to implement the ODS phaseout including adopting new policies, incorporating Office of the Secretary of Defense alternatives into training programmes, and adopting ways of achieving Montreal Protocol compliance into direct military-to-military cooperation programmes, partnerships with intergovernmental military organizations (e.g., NATO, Association of Southeast Asian Nations -- ASEAN), and working closely with other government agencies and industry (Andersen, Sarma, and Taddonio 2007). One conspicuous focal point in organizing global military cooperation was US Air Force Deputy Assistant Secretary for the Environment Gary D. Vest, a strong proponent for both environmental restoration and proactive actions to protect the environment (Bidlack 1996). In 1986, Gary Vest recruited E. Thomas Morehouse (co-author of this publication) to spearhead military support for stratospheric ozone protection. It is significant that Vest and Morehouse were more successful in early reduction of military use than were similar efforts for civilian applications.

Actions pioneered in the ODS phase out are being replicated for climate protection, and particularly for HFC phase down. For example, in the United States DOD leveraged policy with Instruction 4715.06, 'Environmental Compliance in the United States', which called for the elimination of ODSs in military use (US DOD 2018). This policy was further strengthened by DOD procurement practices as detailed in the Defense Federal Acquisition Regulation (DFAR) subpart 223.803, which prohibited contracts from including any specification or standard requiring the use of an ODS unless authorized by a general officer or Senior Executive Service (SES) member (a civilian general officer equivalent) (US DOD 2022). Further, this early success by DOD gave US EPA information that was helpful for developing ODS phaseout policy and organizing collaborative efforts with the private sector.

In the 1990s, a series of military focused handbooks addressing the management of ODS uses were published. These handbooks were made available for US and international ODS users. Of note are the publications 'Maintaining Military Readiness by Managing ODS' (UNEP and MLF 2000) and 'Ozone Protection and National Security: A Military Perspective - Toolkit for Defense Forces' (Singh, Kumar, and Bagai 2010). Both publication present methodology that militaries could use to address readiness and mission concerns while working to phase out or eliminate ODSs and incidentally or intentionally protect climate.

It is also notable that publications on technology and management to protect the stratospheric ozone proliferated into the wider military literature (e.g., Kumar 2012; Kumar 2011). and became part of war college curriculum on climate and its associated stratospheric ozone layer (Pollock and Ellis 2021). It is also notable also that global industry played a significant role. Some contend industries that were end users of ODS were particularly vested as the Montreal Protocol as it provided both an opportunity for the introduction of new technology as well as an opportunity to advise governments on ways to best meet Montreal Protocol goals (Haas 2019). Others also point out that the constructive participation of industry was based on a wide range of factors beyond a professed motivation to protect the ozone layer (Berkman 1989; Kerr 1989).

Factors cited as behavioural influencers include avoidance of rigid regulatory requirements and pursuit of a positive reputation and goodwill. In essence, the Montreal Protocol compelled protection of the ozone layer, but industry had a dominant voice in creating the technical means by which it would be achieved. Both protectionist companies invested in the status quo and entrepreneurial companies seeing opportunities in change had their say. Because of the procedural mechanisms enacted by the Montreal Protocol, the parties were able to consider the merits of all arguments as they met to debate and decide adjustments and amendments to the treaty's control measures. Here, militaries played crucial roles as both providers of research to develop new technologies as well as test beds to validate their technical and economic performance. Collectively the literature points to the decades after the signing of the Montreal Protocol when a nexus of activity-built momentum within militaries and beyond combined to fulfil the vision of the former UNEP Director Mostafa K. Tolba. Tolba often characterized the Montreal Protocol as founded on a '*Start and Strengthen'* principle (Canan and Reichman 2017; Kaniaru, Shende, and Zaelke 2007).

More indicative Examples of Leadership Successes:

- The US Air Force was an early advocate of the Montreal Protocol, for example by staffing a display on technologies to reduce and replace the use of halon at the September 1987 meeting where the Montreal Protocol was signed. DOD quickly adopted this leadership approach across all services and all ODS controlled by the Montreal Protocol.

- It was quickly discovered that chemicals to be controlled by the Montreal Protocol had important military service uses that were often similar or identical to the uses in the other services, other nations' militaries, other government agencies and to a wide range of commercial and industrial sectors.
- DOD scientists across all the military services confirmed the validity of the underlying science of stratospheric ozone depletion that was motivating the Montreal Protocol ambition for a fast phase out of ODSs.
- Military technical experts recognized that the Montreal Protocol presented an opportunity to improve DOD systems by comparing the efficacy of ODS-based industrial process that had been in use for decades with new alternatives. They welcomed the invitation to participate with other technical experts from around the world solving similar problems through the Montreal Protocol TEAP and its Technical Options Committees (TOCs).
- Military leaders saw an opportunity to improve environmental performance on an issue of global importance in a way that improved manufacturing base efficiency and reduced costs.

Military ODS Phaseout Strategy

Over time, DOD's phaseout strategy became inculcated in its body of strategic, policy and guidance documents. Policy guidance cascades through the military organizations via an established system of '*issuances*' or '*directives*' outlining what is required by order of the president (commander in chief), office of the secretary of defence, international treaty agreement, or legislation to initiate, govern or regulate the actions or conduct within a given services scope of responsibility (e.g., DOD, n.d.). The importance of environmental security, the need to comply with the Montreal Protocol, use of funding for development and testing to validate and deploy alternatives, and requirements to report progress all became part of the policy that permeated through the Department.

Over time, military organizations established mutually constructive partnerships with industry, environmental authorities, and environmental NGOs, producing relationships of trust that endured long after specific ODS dependencies had been resolved.

Military momentum for further international cooperation grew as alternatives and substitutes for ODS proved technically and economically superior. Relationships within NATO, ASEAN and with other external military counterparts were strengthened through the common experience of solving shared dependencies on ODS. Successful policy documents were also informally shared among military organizations through international military conferences and workshops and through participation in the Montreal Protocol process.

Military Networking Domestically and Internationally

National defence organizations worked closely with their national environmental, energy, science, technology, and other relevant agencies to leverage each other's technical expertise. In addition, various military organizations regularly sponsored members of UNEP TEAP and its subordinate TOCs and Task Forces (TFs) for access to share the latest technical information and knowhow to improve processes, specifications, procurement actions, and policies that enabled migration from traditional ODSs to chemical substitutes and not-in-kind alternatives.

TEAP participation provided a ready-made, global network of experts who shared common ODS uses and worked collaboratively to identify alternatives that were technically and economically viable for both developed and developing countries. It was, and remains, available for DOD to join. TEAP participants and their application specific TOCs came from developed and developing countries, representing industry, academia, NGOs, governments, and military organizations. At times TEAP relationships produced ad-hoc collaborative research, testing, prototyping, and demonstration programmes that accelerated adoption of alternatives in areas such as electronics and aerospace manufacturing, flexible and rigid foams, halons, refrigeration, air conditioning, and heat pumps. These interactions led to important technological breakthroughs, which also helped facilitate a rapid global acceptance of ODS alternatives. As a result of participation by military experts on TEAP and TOCs, essential use exemptions were more easily agreed by the Parties to the Montreal Protocol when military organizations from multiple countries concurred that an alternative to a shared use was not yet available.

Military participation in the Montreal Protocol also catalysed international interactions among senior defence officials with environmental and facility portfolios, which may not have otherwise taken place. For example, UNEP, US EPA, US DOD, and other military organizations sponsored seven workshops on stratospheric ozone and climate protection. For example, the 2001 workshop in Brussels that brought together more than 160 military officers from 33 countries to share perspectives and efforts at climate protection (Singh, Kumar, and Bagai; 2010).

Networking with other military organizations is further illustrated by the efforts of the US DLA ODS Strategic Reserve Office (SRO). The mission of the SRO is to maintain a supply of recycled ODSs of sufficient quantity and quality to meet mission essential requirements. There are several reasons that maintaining recycled ODS are important. In some cases, alternatives to ODSs have not yet been developed or are not feasible due to the small quantities required relative to the investment needed to implement alternatives. This is particularly true in high cost, highly integrated major legacy weapons systems. Examples include 1) methyl chloroform used in the manufacture of solid rocket motors, 2) CFC-114 used in the refrigerant on refrigeration and air-conditioning equipment in some large naval ships and 3) halons used in various aircraft, ships, and ground vehicles where escape in case of fire is not an option. Where possible, operational practices were improved and machines developed to capture the ODS for testing, storage, reuse, and when necessary, destruction, by the SRO. These measures often reduced atmospheric emissions to negligible amounts. The SRO served not just American military needs, but other allied militaries and government agencies on an as-needed basis.

Networking and cooperation were also key to resolving issues that arose when regulations had not anticipated military-unique situations. For example, when the European Union required decommissioning of non-essential halon systems, it prohibited the export to avoid the material being redirected to unnecessary uses elsewhere for monetary gain. The consequence of the no-export rule was that unscrupulous enterprises in Europe merely discharged the halon rather than pay the high costs of proper destruction. US DLA had no contract mechanism in place to destroy ODSs in Europe, so the US EPA intervened with the government of the Netherlands in a technology demonstration to shift halon into the Netherlands banking system where a destruction contract was in place. In return, DLA experts assisted in redesigning the European halon banking system based on their own lessons learned for near-zero emissions in recovery, purification, and long-term storage prior to availability of alternatives in unique military applications. Thus, military organizations supported the European Union goal of minimum halon emissions in decommissioning non-essential halon applications and all military partners accomplished their objectives at lower cost and higher environmental benefits and with lasting network benefits to resolve any future problems with other ODSs.

The 2016 Kigali Amendment

The Kigali Amendment requires the phase down of HFCs that are ozone safe and were initially used as a replacement for refrigerants, aerosol propellants, halons and in the manufacture of thermal insulating foams. However, HFCs are powerful GHGs with a high global warming potential (GWP) and are key contributors to climate change. Militaries around the world continue to use large amounts of HFCs but the current control schedule will phase down about 85% of GWP-weighted quantities by mid-century with a likelihood of phaseout of all but essential uses once technologies are commercialized and implemented.

Lessons learned through the Montreal Protocol ODS phaseout experience can be applied here as well, as global military seeks to both develop new technologies and provide testbeds to demonstrate their efficacy through coalitions with like-minded industry partners.

Case Study of Global Military Advisory Council on Climate Change (GMACCC) Leadership on the Kigali Amendment

A year before the Kigali Amendment was agreed retired Lt-Gen Tariq Waseem Ghazi, a former defence secretary of Pakistan and retired Air Marshal A.K. Singh, a former Commander-in Chief of the Indian Air Force who had gotten to know each other while serving on the GMACCC persuaded the Prime Ministers of Pakistan and India to join forces in support for a phase down the HFC GHGs under the Montreal Protocol (Ghazi and Singh 2015).

> *As former senior military officers in Pakistan and India, we consider climate change and its accelerating impacts to present an imminent threat to global peace and security that requires immediate action. To this end, we are principal participants in the Global Military Advisory Council for Climate Change (GMACCC), a group comprised largely of former senior military officers dedicated to understanding and reducing the security threat presented by climate change, which has escalated from a 'threat multiplier' that exacerbates security threats, to a direct cause of resource conflicts in countries with weak capacities and governance challenges.*
>
> *Fast action is needed to cut HFCs to counter the double-barrelled assault of self-amplifying climate feedbacks, starting with mitigating the melting Arctic sea ice. The shrinking ice shield is reflecting less heat back into space, and causing more to be absorbed by the exposed ocean. This has added a quarter as much global warming since 1979 as carbon dioxide, the main greenhouse gas causing at least half of all warming.*
>
> *We urge our leaders, and negotiators and technocrats who have made the Montreal Pro-tocol the most successful of the world's environmental treaties, to continue their leadership and conclude the HFC amendment to mut-ual satisfaction when the parties meet next month. The leaders can then bring this success to the Paris negotiations for a new UN climate treaty in December, as a model of multilateral success that is possible when an agreement is fair, equitable and just for all parties.*
>
> Lt-Gen Tariq Waseem Ghazi (Pakistan, retired) & Air Marshal A.K. Singh (India, Retired)

Case Study of Military Support for US Compliance with the Kigali Amendment

In the US, there was bipartisan Congressional enactment of the American Innovation and Manufacturing Act (AIM) directing EPA to phase down the production and consumption of HFCs at least as rapidly as the schedule of the Kigali Amendment. Building on this foundation the January 2021 release of Presidential Executive Order 14008, 'Tackling the Climate Crisis at Home and Abroad,' placed climate change at the centre of US foreign policy and national security. Further, this Executive Order directed the US Department of State to pursue efforts to ratify the Kigali Amendment therefore providing a more precise linkage for US phasedown of HFC usage. This linkage was further supported by the March 2021 US Interim National Security Strategy Guidance (INSSG), which challenged the whole of the US government to address climate change through both adaptation and mitigation (The White House 2021). Collectively, the AIM Act, Executive Order 14008 and the US INSSG direct the US DOD to contribute to the continued success of the Montreal Protocol. Lessons learned by the US DOD, as well as by all militaries of the world, from the ODS phaseout can now also be applied to the phaseout of HFCs.

Military Leadership on the Montreal Protocol Built and Strengthened Important Diplomatic Relationships

There is no doubt that the ODS phaseout would have taken longer and been more expensive without the extraordinary contributions of military organizations. Military contributions included policy support; research, development, commercialization, and procurement; replacement of barriers with incentives for new technology; testing and training; and technology cooperation and deployment. Without global military leadership, the ODS phaseout may have been too slow to avoid ozone and climate tipping points.

Weapons systems phased out ODSs with overall improvement in readiness, reliability, technical performance, and cost. Global military leadership earned the respect of the United Nations, national governments, and citizens worldwide, winning more United Nations and US Environmental Protection Agency Awards than any other sector.

A unique characteristic about climate change that was not present with ozone layer depletion is the punishing impact on prosperity in both developed and developing countries.

Military Lessons from ODS Phaseout Relevant to HFC Phasedown Under the Kigali Amendment

Military personnel involved in military ODS phaseout have described a series of steps that were used to understand the nature and scope of the problem, develop plans to find solutions and to implement those solutions. Their approach leaned heavily on finding others trying to solve the same problems and creating collaborative and equitable partnerships. Steps included:

- Assign someone with appropriate authority to be in charge, secure a leadership commitment to prioritize success and build a plan.
- Determine the size of the problem – identify current uses of the Kigali chemicals and notify the organizations with responsibility for those processes of Kigali controls and compliance requirements. Work to identify other organizations with the same or similar uses for the chemicals and develop research, development, and testing programs to find suitable alternatives. This can include other military organizations, government agencies or industry. Coordinate work to avoid duplication of effort and to minimize the time and cost to find and implement solutions.
- Reducing use where possible can produce quick wins; this is always the easiest first step. For example, in the early 1990s, DOD discovered that over 90% of its halon use was for testing new systems and training. Inexpensive inert gases were quickly found to work for those purposes and halon use and atmospheric emissions dramatically declined almost immediately.
- Organize conferences and workshops to bring militaries and their suppliers together to share information. Be mindful of the financial incentives of chemical suppliers to maintain markets and focus on not-in-kind alternatives.
- Leverage the UNEP TEAP and their TOCs networks to accelerate the creation of networks.
- Identify mission-critical, military-unique uses that require a '*go it alone*' approach; establish the appropriate research investment programme to pursue solutions and reach out to other military organizations where appropriate.
- Expand the scope of the existing SRO to include Kigali chemicals that meet the criteria for establishing a strategic reserve.
- Measure, monitor and report progress at the highest appropriate command level.

Military Organizations Poised to Engage in Halting Climate Change

The prevailing military consensus is that climate change is a national and global security threat multiplier that impacts fixed bases and mobile assets, readiness, deployment, operations, and outcomes. Nations are vulnerable during violent storms and when supplies are depleted survival comes by rescue and humanitarian missions. Worst of all, climate change exacerbates risks and instability in fragile states and regions. One measure of the high recognition of climate change as a national and global security priority is that the latest United States National Security Strategy (White House, 2022) calls out climate change threats an unprecedented 63 times.

Conclusion

The process of military organizations partnering with each other and with civilian authorities and experts to find solutions to HFC phase down is no different than was used for ODS phaseout. Key elements include understanding the nature and scope of the problem, eliminating unnecessary emissions by policy, partnering with other users confronting a like or similar problem, making use of existing resources such as the UNEP TEAP and its TOCs, and maintaining leadership focus and commitment. The relationships gained through broad engagement with other militaries, government agencies, suppliers and NGOs will pay dividends beyond the environmental protections.

Among the many opportunities:

> Engage the Montreal Protocol, its National Ozone Units, its Implementing Agencies to find synergy and to avoid duplication of effort.
>
> Share military analysis of regional risk with local authorities and citizens to plan for resilience.
>
> Cooperate on selecting energy-efficient, low-GWP next-generation cooling technology matched to local climate and carbon intensity of electricity .

Combine military, government, and civilian demand for bulk procurement of superior technology at favourable cost and logistics, particularly when best technology is not available locally.

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Atul Bagai is head of UNEP's Country Office in India where he has initiated some path-breaking initiatives. His work on supporting the Government to develop a policy on Sustainable Public Procurement has been pioneering. The pilot on procurement of green and super-efficient ACs through the Government's marketing e-portal is a first of its kind. Atul joined UNEP's Ozone Action programme as the Regional Officer for South Asia in 2000 and served as Senior Regional Coordinator to build the capacity of subregional networks in Asia and enable them to meet the compliance targets under the Montreal Protocol. In that capacity, he spearheaded and led some innovative initiatives with the Executive Committee of the MLF including designing and developing synergies between ODS phase out and climate protection in Maldives and Bhutan; green procurement policies in Mongolia taking into account phaseout of ODS as a legislation; a study of carbon credits and ODS destruction in Nepal; and, most recently, the Hydrochlorofluorocarbon Phaseout Plan (HPMP) for India that included energy efficiency and the cold chain. Prior to joining UN Environment, Atul Bagai worked with the Government of India for 17 years in senior positions including Chief of Staff for the Ministry of Finance and Ministry of External Affairs. Atul Bagai earned a postgraduate degree in history from the University of Delhi.

David M. King has worked for more than 40 years in the US DOD in Acquisition; Requirements Determination; Joint Capabilities Integration and Development System; and Planning, Programming, Budgeting and Execution. For the Office of the Secretary of Defense he was a key contributor to the 2022 DOD National Defense Strategy. He currently serves as a program analyst assigned to Headquarters US Africa Command in Stuttgart, Germany. Mr. King is a graduate of Georgetown University and the United States Air Force Academy. He was on the 2022 National Defense Strategy Core Writing Team for the Office of Secretary of Defense (OSD), including extensive work on climate security. David King served 27 years on active duty achieving the rank of colonel in the US Air Force. David King earned a Master of Science, International Emergency and Disaster Management, Georgetown University Washington, DC; Master of Public Policy, Emergency and Disaster Response, Metropolitan College of New York; Master of Science, Logistics, Air Force Institute of Technology, Dayton, Ohio; Master of Education, Vanderbilt University Nashville, Tennessee; and Bachelor of Science, United States Air Force Academy, Colorado Springs, Colorado.

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ACRONYMS

AIM	American Innovation and Manufacturing Act (USA)
ASEAN	Association of Southeast Asia Nations
CFC	chlorofluorocarbon
CH_4	methane
CO_2	carbon dioxide
$CO_{2\text{-eq}}$	carbon dioxide equivalent
DLA	Defense Logistics Agency (USA)
DOD	Department of Defense
EPA	Environmental Protection Agency
GHG	greenhouse gas
GMACCC	Global Military Advisory Council on Climate Change
GWP	global warming potential
HFC	hydrofluorocarbon

HFO	hydrofluoroolefin
HUNC	Halons Users National Consortium (UK)
IBM	International Business Machines
ICOLP	Industry Cooperative for Ozone Layer Protection
IEA	International Energy Agency (United Nations)
IGSD	Institute for Governance & Sustainable Development
INSSG	Interim National Security Strategy Guidance (USA)
IPPC	Intergovernmental Panel on Climate Change (UN)
N_2O	nitrous oxide
NASA	National Aeronautics and Space Administration (USA)
NATO	North Atlantic Treaty Organization
NGO	non-governmental organization
NIK	not-in-kind
NOAA	National Oceanographic and Atmospheric Administration (USA)
NREL	National Renewable Energy Laboratory (USA)
NSS	National Security Strategy
ODP	ozone-depletion potential
ODS	ozone-depleting substance
OSD	Office of the Secretary of Defense (USA)
SRO	Strategic Reserve Office (US DOD DLA)
STOC	Solvents Technical Options Committee (Montreal Protocol)
TEAP	Technology and Economic Assessment Panel (Montreal Protocol)
TF	Task Force (TEAP Montreal Protocol)
TOC	Technical Options Committee (TEAP Montreal Protocol)
UN	United Nations
UNEP	United Nations Environment Programme
US	United States
UV	ultraviolet
WMO	World Meteorological Organization (UN)

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