Yale Carbon Containment Lab

BACKGROUND PAPER

Lifecycle Refrigerant Management: Maximizing the Atmospheric and Economic Benefits of the Montreal Protocol

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SUMMARY: Realizing the full potential of the Montreal Protocol to protect the climate and ozone layer requires consideration of controlled substances' complete lifecycle: from production and use to leak reduction, recovery, reuse, and environmentally sound disposal. This coordinated approach — known as lifecycle refrigerant management (LRM) — can generate significant ozone, climate, and equity benefits at low cost. This paper discusses LRM best practices and their potential impact in preparation for the Thirty-Fifth Meeting of the Parties.

Introduction

The Kigali Amendment to the Montreal Protocol is a significant step toward reducing global emissions of hydrofluorocarbons (HFCs). Full implementation of HFC production and consumption phasedowns will prevent an estimated 0.5 degrees Celsius of atmospheric warming by 2100.[1] This avoided warming adds to the tremendous environmental benefits of the Montreal Protocol's phaseout of ozone-depleting substances (ODS).

Realizing the full potential of the Montreal Protocol to protect the climate and ozone layer, however, requires consideration of controlled substances' complete lifecycle: from production and use to leak reduction, recovery, reuse, and environmentally sound disposal. Downstream management of refrigerants — known as "lifecycle refrigerant management" (LRM) — can aid Montreal Protocol compliance and serve the treaty's guiding purposes: stratospheric ozone protection and global climate change prevention.[2,3]

The opportunity for LRM is large. Global emissions of HFCs are still rapidly growing due to replacement of ODSs and increasing adoption of air conditioning, heat pump, and refrigeration technology. Today, the amount of ODS and HFCs in operating equipment ("installed refrigerant bank") totals 24 billion tonnes of carbon dioxide equivalent (tCO_2e) globally. The installed bank is expected to grow to 61 billion tCO_2e by 2050 and 91 billion tCO_2e — nearly three years' worth of global energy sector emissions — by 2100, even with full Kigali Amendment compliance and the ongoing hydrochlorofluorocarbon (HCFC) phaseout.[4] Without proper lifecycle management of refrigerants in use today and in the future, these gases will inevitably be destined for the atmosphere.

Though the term "lifecycle refrigerant management" is relatively new, many of its pillars – such as technician training, refrigerant recovery and reuse, and environmentally sound destruction – are familiar to the Montreal Protocol community. The Multilateral Fund and Assessment Panels have, over the treaty's thirty-year history, addressed each of these topics in isolation. As the Protocol begins a challenging phase, with Article 5 countries entering HFC phasedowns and approaching the full phaseout of HCFC consumption, now is the time to build and implement a unified Montreal Protocol LRM strategy that can aid treaty compliance. In a critical decade for both the ozone layer and global climate, LRM can ensure the Montreal Protocol continues its planet-saving legacy.

[1] World Meteorological Organization (WMO), "Scientific Assessment of Ozone Depletion: 2018, World Meteorological Organization, Global Ozone Research and Monitoring Project," 2018, https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf.
[2] Christina Theodoridi et al., "The 90 Billion Ton Opportunity" (EIA, NRDC, IGSD, 2022), https://us.eia.org/wp-content/uploads/2022/10/Refrigerant-Lifecycle-FullReport-6Spreads-PRINT.pdf.
[3] Initiative on Fluorocarbons Life Cycle Management, "Resource Book for Life Cycle Management of Fluorocarbons" (Climate and Clean Air Coalition: Japan Ministry of the Environment, 2022), https://www.ccacoalition.org/resources/resource-book-life-cycle-management-fluorocarbons-good-practice-portfolio-policymakers.
[4] Theodoridi et al., "The 90 Billion Ton Opportunity."

What is the business-as-usual refrigerant lifecycle?

The current refrigerant lifecycle is far from circular, with several deficiencies that increase emissions, waste refrigerant resources, and make Montreal Protocol compliance more challenging. Today, business-as-usual practice occurs as follows:

- **Refrigerants are produced** and charged into new equipment during the manufacturing process.
- Over the operating lifetime, **equipment leaks** refrigerant, which compromises performance, energy efficiency, and equipment lifetime.
- **Service technicians recharge leaky equipment** with virgin refrigerant.
- When equipment reaches the end of its useful life, **the remaining refrigerant is commonly released** ("vented") to the atmosphere. Although venting is explicitly illegal in many countries, compliance is difficult to monitor and enforce. Often, recovering refrigerant also poses a net cost to technicians, in part because there are small and undeveloped end markets for recovered refrigerants.
- New equipment is installed, **charged with virgin refrigerant**

What is lifecycle refrigerant management?

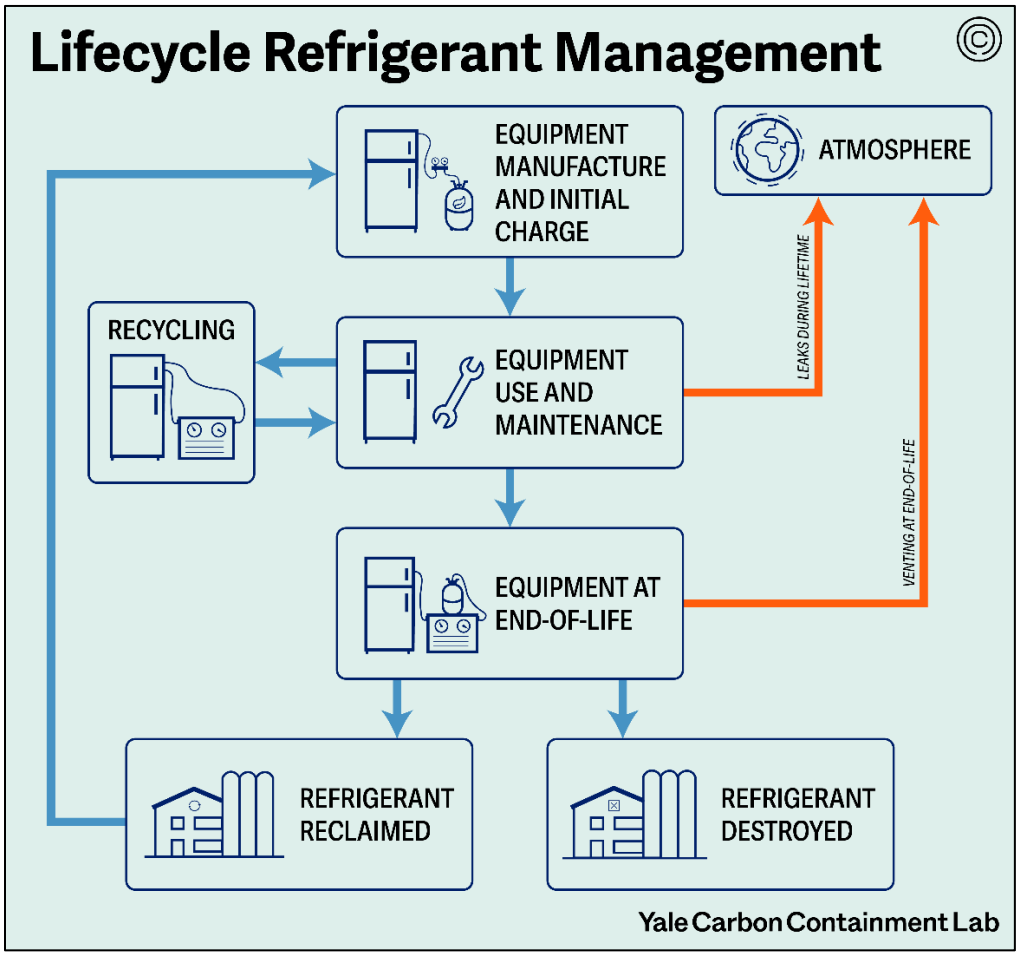


Figure 1: Lifecycle Refrigerant Management. Caroline Benedetti, Yale Carbon Containment Lab.

Refrigerant management best practices can be implemented at every stage of the lifecycle with **existing technology and at low cost**. Available strategies include:

- Maintaining accurate and comprehensive **refrigerant bank inventories** and emissions estimates.
- Implementing best practices for installation, servicing, and monitoring to **reduce leakage** during the operating lifetime of cooling equipment.
- Ensuring **refrigerant recovery** at equipment end-of-life.
- **Recycling or reclaiming** used refrigerant to decrease demand for virgin refrigerant production and create end markets for recovered gases.
- **Destroying** recovered refrigerant for which there is little or no demand with environmentally sound technology.
- Transitioning to equipment using **lower Global Warming Potential refrigerants**. This equipment, beyond having less impact on climate from refrigerant leakage and venting, also tends to be more energy efficient.

What are the benefits of lifecycle refrigerant management?

Improved understanding of banks and emissions

Accurate inventories support decision-making in all aspects of LRM. Information on the installed bank size and its mix of refrigerant species inform the implementation of recovery, reclamation, and destruction. In turn, emissions forecasts help guide prioritization of sectors and regions with the biggest potential impact. High-quality inventories also help establish baseline emissions estimates, which are a prerequisite to many forms of climate finance.

Conservation of energy and resources through leak reduction

Reducing refrigerant leakage from operating equipment can generate large climate benefits and savings at the same time. Leak reduction measures reduce emissions and conserve refrigerant while increasing equipment operating efficiency (resulting in meaningful energy savings). Leak reduction becomes more material to equipment owners' bottom lines when the price of refrigerant increases during phasedowns.

Improved refrigerant recovery rates

Refrigerant recovery is the precursor to reclamation and destruction. Currently, refrigerant recovery happens inconsistently when technicians repair or service cooling equipment, and seldomly at equipment end-of-life. Low refrigerant recovery rates arise because there are few end markets for recovered refrigerant and low capacity to monitor and enforce refrigerant venting prohibitions. LRM focuses on building the infrastructure and incentives to recover refrigerant at scale, including creating end markets for recovered gases and equipping technicians with the tools and capabilities to properly service and decommission equipment.

Circular economy through recycling and reclamation

Refrigerant recycling and reclamation are important processes that conserve the amount of refrigerant used to service operating equipment. Refrigerant reclamation — the process of chemically refurbishing used gases to virgin purity standard — can play an especially important role in ensuring an orderly phasedown of ODS and HFCs by increasing the supply of otherwise scarce

gases. Without enough reclaimed gas, equipment owners may experience supply shortages, high prices, and price volatility for fluorocarbons. With adequate levels of recycling and reclamation, policymakers may also feasibly pull forward phasedown schedules without fear of causing significant price spikes or supply shortages.

Safe and climate-friendly disposal to ensure permanent emissions reductions

Environmentally sound destruction of ODS and HFCs is the critical final measure in preventing refrigerant emissions. Destruction using technologies approved by the Technology and Economic Assessment Panel (TEAP) breaks fluorocarbons into their chemical constituents while safely handling toxic byproducts, permanently preventing damage to the ozone layer and environment.[5] Countries should pursue destruction where there are otherwise small or absent end markets for recovered and reclaimed refrigerants. Projects on the carbon market have successfully monetized the destruction of recovered refrigerant and ODS stockpiles, providing incentives for upstream refrigerant recovery and financing for abatement.[6]

Increased training to facilitate additional technology transfer

Proper training and education for service technicians is the cornerstone of LRM implementation. Training is important not only to minimize emissions from the equipment lifecycle, but also to facilitate the uptake of new, lower-Global Warming Potential refrigerants, which often operate at different temperatures and pressures. The ability to service the new generation of more climate-friendly equipment creates jobs and is a critical step in enabling the HFC phasedown.

Conclusion

Implementing LRM at scale aids Montreal Protocol compliance. Leak reduction, recovery, and reclamation reduce the need for virgin refrigerant production, ensuring Parties meet their phasedown requirements at reasonable cost. Adequate supply of reclaimed refrigerant can also allow countries to raise ambition by accelerating their phasedown schedules. Additionally, verified, environmentally sound destruction can unlock climate finance by permanently reducing emissions from the installed bank – financing which can then be used to fund the entire refrigerant management ecosystem and accelerate the transition to climate-friendly technologies. Above all, LRM furthers the core functions of the Montreal Protocol: to protect the ozone layer and prevent climate change.

To ensure Parties incorporate LRM best practices into the final stages of the HCFC phaseout and the entire HFC phasedown, the Montreal Protocol community should make LRM discussion and planning a priority at the Thirty-Fifth Meeting of the Parties. We welcome LRM's inclusion as Item 16 on the Meeting's Provisional Agenda, and we look forward to supporting these efforts.

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[5] Helen Walter-Terrinoni and Helen Tope, "Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances," Report of the UNEP TEAP (Technology and Economic Assessment Panel, April 2018), https://ozone.unep.org/sites/default/files/2019-04/TEAP-DecXXIX4-TF-Report-April2018.pdf.

[6] "Fact Sheet on Existing Fluorocarbon Credit Methodologies" (Yale Carbon Containment Lab, May 24, 2023), https://carboncontainmentlab.yale.edu/publications/refrigerant-credits-fact-sheet.

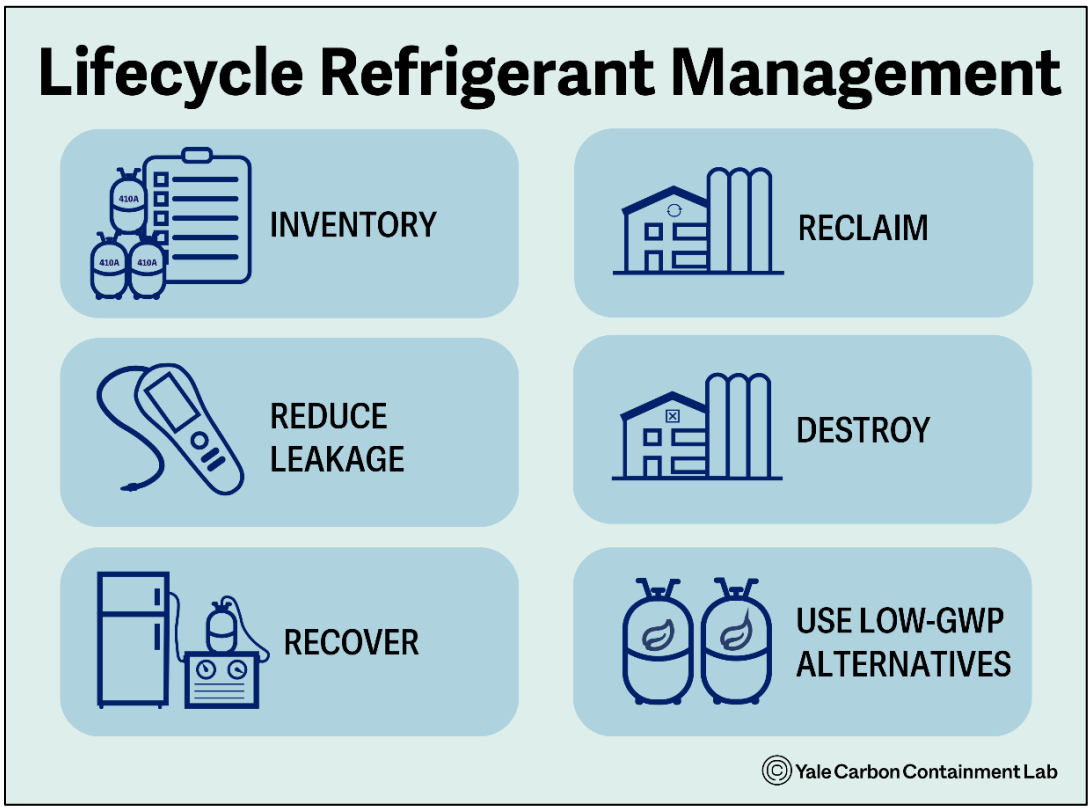


Figure 2: Lifecycle Refrigerant Management Actions. Caroline Benedetti, Yale Carbon Containment Lab.

About the Yale Carbon Containment Lab

The Yale Carbon Containment Lab (CC Lab) is a gift-funded nonprofit at the Yale School of the Environment in New Haven, Connecticut, USA. The CC Lab's mission is to develop and implement novel and neglected solutions to climate change, spanning three mitigation pathways: biologic, geologic, and anthropogenic. In its anthropogenic program, the CC Lab focuses on refrigerant gases and the development of financing mechanisms to scale refrigerant recovery and abatement. Read more about the CC Lab's refrigerant workstream here: https://carboncontainmentlab.yale.edu/projects/refrigerants

Resources

Initiative on Fluorocarbons Life Cycle Management. "Resource Book for Life Cycle Management of Fluorocarbons." Climate and Clean Air Coalition: Japan Ministry of the Environment, 2022. https://www.ccacoalition.org/resources/resource-book-life-cycle-management-fluorocarbons-good-practice-portfolio-policymakers.

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