Yale Carbon Containment Lab

WORKSHOP REPORT

MAXIMIZING THE CLIMATE BENEFITS OF THE HFC TRANSITION

Fast Action for Short-Lived Climate Pollutants & Clean Technology Investment

Yale School of Environment, New Haven, Connecticut – 14 March 2023

1. INTRODUCTION

Fast action on short-lived climate pollutants is the surest way of slowing climate feedback loops, forestalling tipping points, and buying time to scale and develop technology. It also provides greater opportunities to enhance resilience and adaptive capacity in the face of increasingly severe climate impacts. The transition away from hydrofluorocarbons (HFCs) is a key component of the fast action agenda. This report outlines important lessons from the history of success that the HFC transition builds upon and provides expert recommendations for how its speed and efficacy can be maximized.

One of the most instructive examples of fast action in the face of a global atmospheric environmental threat is the Montreal Protocol, negotiated in 1987 to combat the destruction of the stratospheric ozone layer by chlorinated and brominated compounds such as chlorofluorocarbons (CFCs). At the time, these compounds were widely used in tens of thousands of applications around the world, including in refrigeration and air conditioning.

Within 20 years, despite few substitute technologies commercially proven at its inception, the Montreal Protocol phased out more than 90 percent of nearly 100 ozone-depleting substances (ODS). Today, after 35 years, nearly 99 percent of ODSs are gone, and the stratospheric ozone layer is on a path to recovery.[1]

The Montreal Protocol also significantly delayed the onset of major climate impacts, since many ODSs are greenhouse gases thousands of times more potent than carbon dioxide on a ton-for-ton basis. The Montreal Protocol's phase out of ODSs over the past 35 years, in addition to protecting the stratospheric ozone layer, prevented an amount of warming equal to that caused over that same time by carbon dioxide.[2] In other words: but for the Montreal Protocol, the climate impacts forecast for 2050 would have arrived in 2000.

Recent scientific analysis calculates that the Montreal Protocol will avoid up to 2.5° C of warming by the end of the century: 1.5° C from phasing out ODS and HFCs, and up to 1° C from protecting forests and other carbon sinks from increased ultraviolet radiation due to ozone layer depletion.[3]

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[1] World Meteorological Organization (WMO), Scientific Assessment of Ozone Depletion: 2022, GAW Report No. 278, 509 pp., WMO, Geneva, 2022. Available at https://csl.noaa.gov/assessments/ozone/2022/downloads/2022OzoneAssessment.pdf

[2] Velders, G. J., Andersen, S. O., Daniel, J. S., Fahey, D. W., & McFarland, M. (2007). The importance of the Montreal Protocol in protecting climate. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(12), 4814–4819. Available at https://doi.org/10.1073/pnas.0610328104

[3] Young, P.J., Harper A.B., Huntingford C., Paul N.D., Morgenstern O., Newman P.A., Oman L.D., Madronich S., and Garcia R.R. (2021) *The Montreal Protocol protects the terrestrial carbon sink*, Nature 596: 384-388.

And the Montreal Protocol has still more – significantly more – to contribute to the fight against climate change.

In addition to its climate benefits, the Montreal Protocol has demonstrated an effective model of industry engagement and civil society leadership across technology evaluation and selection, financial support, and compliance assistance. This efficacy – rare among multilateral environmental agreements – is what made it so attractive to proponents of climate action in the mid-2000s seeking to make an end-run around the political roadblocks facing most other climate mitigation initiatives. It also catalyzed investment in innovation, created markets for new technologies, and accelerated global adoption of these technologies in astonishingly short periods of time.[4]

For the past 15 years, a series of victories under the Montreal Protocol – both internationally and especially in the United States – has produced significant and, in some respects, unmatched levels of climate mitigation. These victories featured uncommon alliances between industry and environmental groups, Republicans and Democrats, and developed and developing countries – confounding expectations, defying conventional climate political norms, and creating new opportunities for climate mitigation.

These international and U.S. victories do not always grab headlines, and even when they do, they are often overshadowed by the broader challenges posed by climate change. But they hold vital lessons for further cuts in emissions of short-lived climate pollutants and faster transitions to clean energy technologies. These victories are as follows:

- The HCFC adjustment decision in 2007 avoids approximately 16 billion tons of carbon dioxide-equivalent (CO_2eq) by 2040, **roughly five times the climate mitigation achievable under the first phase of the Kyoto Protocol.**[5]

- The Kigali Amendment of 2016 phasing down hydrofluorocarbon (HFC) production and consumption **avoids up to 0.5° C of projected warming by 2100.**[6]

- The American Innovation & Manufacturing Act of 2020 (AIM Act) represents **the most significant change to federal environmental statutory law** since The Clean Air Act Amendments of 1990 – granting incontrovertible authority to the U.S. Environmental

[4] *See* Annex A on the cost effectiveness of the Montreal Protocol and funding through its financial mechanism, the Multilateral Fund.
[5] OzonAction Programme. (2008). OzonAction: Special Issue Dedicated to HCFC Phase out: Convenient Opportunity to Safeguard the Ozone Layer and Climate (OzonAction) [Special Issue]. https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/3139-e-oanhcfcspecialissue.pdf
[6] World Meteorological Organization (WMO). Scientific Assessment of Ozone Depletion: 2018, World Meteorological Organization, Global Ozone Research and Monitoring Project – Report No. 58, 2018, 588 pp., Geneva, Switzerland. Available at https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf

Protection Agency (EPA) to act on HFCs and their substitutes, implement the Kigali Amendment, and eliminate emissions from appliance leaks and at equipment end-of-life, **which globally constitute an additional 91 gigaton CO_2eq climate mitigation opportunity.**[7]

- The U.S. Senate bipartisan vote in favor of Kigali Amendment ratification in 2022 marks the **first approval of a climate treaty** since the Senate's 1994 unanimous vote on the U.N. Framework Convention on Climate Change (UNFCCC).
- The Inflation Reduction Act of 2022 (IRA) **unleashes more than $379 billion, and more likely closer to $800 billion,** in spending programs for clean energy deployment and climate mitigation. The IRA creates new opportunities to speed the transition from HFCs into climate-friendly heating and cooling technologies.

Broader efforts contributing to the IRA aside, this run of success rests largely on the sturdy foundations of the Montreal Protocol – the treaty that works.

There is more to be had from this spate of climate victories. The Montreal Protocol, the AIM Act, and the IRA can be harnessed to deliver even more near-term climate mitigation.

2. WORKSHOP OBJECTIVES

Two dozen legal, policy, financial, and technical experts gathered at Yale University on March 14, 2023, for a one-day workshop entitled *Maximizing the Climate Benefits of the HFC Transition*. The list of participants is appended to this report.

The overall objective of this gathering, supported by the Energy Foundation and hosted by the Yale Carbon Containment Lab at the Yale School of the Environment, was to develop a new, ambitious policy agenda to guide advocacy efforts and investment opportunities created by the HFC transition, with a view toward maximizing its climate and environmental justice benefits.

The discussion took an integrated view of the HFC transition, including the overall environmental performance of air conditioning, refrigeration, and heating equipment in homes and businesses; building management and design; and the responsible lifecycle management of refrigerants in operating equipment.

The discussion also considered other opportunities to leverage recent successes under the Montreal Protocol and related to HFCs to address other short-lived climate pollutants, such as methane and other fluorinated compounds, particularly those used in semiconductor manufacturing.

[7] Theodoridi, C., Starr, Christina, Hillbrand, Alex, Mahapatra, Avipsa, & Taddonio, Kristen. (2022). *The 90 Billion Ton Opportunity*. https://us.eia.org/wp-content/uploads/2022/10/Refrigerant-Lifecycle-FullReport-6Spreads-PRINT.pdf

The workshop was organized into three parts, with each part featuring a short presentation and facilitated discussion, as well as two special presentations on fast action climate mitigation and clean technology investment opportunities. The agenda is appended to this report.

- *Part One* – Implementing the AIM Act To Maximize Its Climate Benefits
- *Part Two* – Using IRA Funding To Accelerate the HFC Transition & Enhance Electrification
- *Part Three* – Leveraging U.S. Leadership To Enhance Fast Action

Each part was led by a facilitator with relevant substantive expertise. State and local issues were addressed throughout Part One and Part Two. Carbon finance considerations and clean technology investment opportunities were addressed throughout the dialogue.

3. WORKSHOP OUTCOMES AND RECOMMENDATIONS

The workshop identified the following opportunities for further action to maximize the climate benefits of the HFC transition.

These opportunities are predominantly focused on federal and state actions in the United States, but also can complement relevant actions at the international level under the Montreal Protocol, including via financial assistance from the Multilateral Fund (MLF) and technical assessment by the Technology and Economic Assessment Panel (TEAP).

1. Accelerate the transition to next-generation refrigerant technologies

1.1. Assure that codes, regulations, standards, and purchasing specifications are in place to support the rapid transition to next-generation refrigerants, and that the U.S. EPA is fully staffed to implement the AIM Act.

1.2. Identify opportunities for the U.S. to support Article 5 Parties under the Montreal Protocol to "leap frog" high Global Warming Potential (GWP) refrigerants and transition to next-generation technologies (*i.e.*, very low or zero GWP refrigerant applications that also meet or exceed existing criteria for safety, management, and energy efficiency).[8]

[8] The term "next-generation technology" is aspirational in nature, encompassing both available and still to be developed heating and cooling technologies whose environmental performance would surpass current and even prospective regulatory standards for climate, health and safety, management, and energy efficiency.

1.3. Catalyze cleantech investment in the heating and cooling sector to accelerate building decarbonization and the deployment of next-generation technologies.

2. Enhance refrigerant recovery, reclamation, and destruction

2.1. Develop and expand public and private procurement policies and programs that stimulate sustainable demand for reclaimed refrigerant (as well as the recycling of decommissioned equipment).

2.2. Direct IRA funding to expand domestic refrigerant recovery capabilities, *e.g.*, section 50123 on State-Based Home Energy Efficiency Contractor Training Grants, allocating $200 million to states to provide "training and education to contractors involved in the installation of home energy efficiency and electrification improvements."

2.3. Develop, launch, and scale carbon credit methodologies to incentivize recovery, reclamation, and/or destruction of ODSs and HFCs, as applicable, with the appropriate guardrails to ensure additionality and permanence.

2.4. Enhance monitoring and reporting requirements at international and national levels, as applicable, to prevent cheating if recovery, reclamation, and destruction are incentivized.

2.5. Develop refrigerant recovery, reclamation, and destruction capabilities in Article 5 Parties via MLF projects and other internationally funded efforts, particularly in dense urban areas with fast-growing refrigerant consumption.

3. Expand programs and other requirements based on the cost savings and enlarged profit margins from eliminating air conditioning and refrigeration equipment leaks

3.1. Expand outreach and other educational efforts promoting the significant economic benefits of detecting and preventing refrigerant leaks, particularly among large-scale end users of air conditioning and refrigeration equipment.[9]

[9] According to the Ratio Institute, air conditioning and refrigeration equipment leaks approximately 25 percent of refrigerant on average. With average refrigerant charge sizes for commercial end users of 2,000 pounds, for virtually all commercial end users, investing in leak prevention and detection is significantly cheaper than recharging equipment with new refrigerant. In supermarkets alone, refrigerant recharge costs reduce profitability by approximately 5 percent (or $474 million) annually. *See also Leak Reduction Initiative,* North American Sustainable Refrigeration Council *at*

3.2. Improve reporting and disclosure requirements for refrigerant emissions in Scope 1 and, as applicable, Scope 3 accounting.

3.3. Require that total refrigerant charge and type be recorded with Scope 1 emissions accounting, and ensure that leaks, other emissions, and refrigerant recharge quantities are included.

4. Integrate refrigerant transitions with energy efficiency and building decarbonization programs and appliance efficiency standards

4.1. Enable a holistic approach for the simultaneous reduction of direct (refrigerant-related) and indirect (energy-related) emissions by harmonizing building energy codes and fire codes at the state and local levels.[10]

4.2. Support State Energy Offices in developing IRA-funded programs that incorporate reward mechanisms for low-GWP equipment and appliances that exceed minimum requirements under the EPA's AIM Act regulations.

4.3. Encourage regulators to approve, and energy efficiency implementers to deploy, programs that reduce refrigerant leakage and offer reclamation and early replacement of high-GWP refrigerant equipment.

4.4. Encourage EPA to incorporate a recognition program into ENERGY STAR for appliances that use climate-friendly refrigerants and large equipment using climate-friendly refrigerants and built-in leak detection technology; concurrently, encourage states to adopt appliance standards and procurement specifications that advance these requirements.

4.5. Coordinate with local real estate boards and their members to disseminate technologies and best practices that improve energy efficiency standards for air conditioners, refrigerators, and heat pumps.

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https://static1.squarespace.com/static/55a672f1e4b06d4dd52f83de/t/63322ee52c88c55724e4fcf4/1664233193104/NASRC_LeakReduction_Final_b.pdf.

[10] As a possible approach to tackling indirect emissions, consider an emissions intensity standard for building types on a square foot basis. For example, the Ratio Institute estimates an average 40,000 square foot store represents approximately 4,000 metric tons of CO_2eq in annual emissions. Under an emissions intensity standard, such a store would need to detect and prevent leaks to limit emissions to 0.1 metric tons per square foot.

5. Utilize the Montreal Protocol to accelerate action on other fluorinated GHGs and target other climate pollutants

5.1. Amend the Montreal Protocol to include N_2O, which is both an ODS and a powerful greenhouse gas, and if reduced like the other ODSs, will enhance the rate of recovery of the stratospheric ozone layer and avoid additional warming.[11]

5.2. Develop an AIM Act approach for fluorinated compounds used in domestic microelectronics manufacturing and data centers and seek to internationalize such an approach in ways that support U.S. trade policy per the CHIPS and Science Act.

5.3. Pursue a Montreal Protocol-style agreement for methane using the lessons learned from the ODS phaseout and the HFC phasedown.

5.4. Improve and extend enhanced producer responsibility schemes to reduce export of environmentally harmful used or refurbished equipment, and to improve refrigerant recovery rates for appliances at end-of-life.

6. Expand public funding and mobilize private capital to support the implementation of the Montreal Protocol and its implementation domestically to advance climate objectives

6.1. Replenish the MLF's funding levels to US $1 billion, plus an additional US $500 million for energy efficiency initiatives.[12]

6.2. Require the expenditure of IRA funding (including the Greenhouse Gas Reduction Fund administered by U.S. EPA) related to the HFC transition, such as manufacturing subsidies, energy efficiency, and other air conditioning and

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[11] Portmann R. W., Daniel J. S., & Ravishankara A. R. (2012) *Stratospheric Ozone Depletion Due to Nitrous Oxide: Influences of Other Gases*, Philos. Trans. R Soc. Lond. B Biol. Sci. 367(1593): 1256–1264, 1262 ("By 2008, anthropogenic N_2O was the most significant ozone-destroying compound being emitted. Owing to the phase-out of anthropogenic halocarbon emissions, it is likely to become even more dominant in the near future."). *See also* Porter I. (2019) *Mitigation of Nitrous Oxide Emissions*, Presentation at 31st Meeting of the Parties to the Montreal Protocol; World Meteorological Organization, United Nations Environment Programme, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, & European Commission (2022) *Scientific Summary: Scientific Assessment of Ozone Depletion 2022,* Global Ozone Research and Monitoring Project Report No. 278, 1-509, 60; Ravishankara A. R., Daniel J.S., and Portmann R. W. (2019) *Nitrous Oxide (N2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century*, Science, 326(5949): 123-125.

[12] The real value of MLF contributions has declined significantly over time. The total MLF budget in 1994 was $510 million in 1994 dollars, which would be $925 million in 2021 dollars, whereas the total 2021 budget was $540M in 2021 dollars, which would be $298M in 1994 dollars.

refrigeration system upgrades and replacements, to be consistent with the broader goals of the HFC transition, including allowing for the further development and deployment of next-generation refrigerant technologies.

6.3. Leverage private capital in carbon markets to achieve emissions reductions that would otherwise not have been possible, absent a carbon market incentive.

4. CONCLUSION

This report reflects the views of many of the workshop's participants and, given the intense scrutiny such views received during the discussion at Yale University, is meant to provide validation and help accelerate their deployment in concrete actions and initiatives.

Much of what is reported here represents the ongoing work of participants and their respective organizations, much of which is commonly accepted as essential to avoiding climate tipping points over the next decade and buying valuable time for longer-term energy transitions.

Some ideas may be novel, lesser known, or even controversial. Here, the Montreal Protocol's recent history remains instructive: as recently as the mid-2000s, the very idea the Montreal Protocol could be used to combat climate change, *e.g.*, by accelerating the HCFC phase out and by phasing down HFCs, was largely unknown or readily dismissed.

And yet, the ability of the Montreal Protocol to foster cooperative efforts among industry, investors, environmental groups, and governments brought disparate interests together and produced unexpected victories for the climate, both under the Montreal Protocol and across the climate policy spectrum.

However much the workshop's participants might differ on details, they all heartily agreed: more is possible and more is necessary – starting with the ideas summarized in this report.

Kroon Hall

Yale University School of the Environment

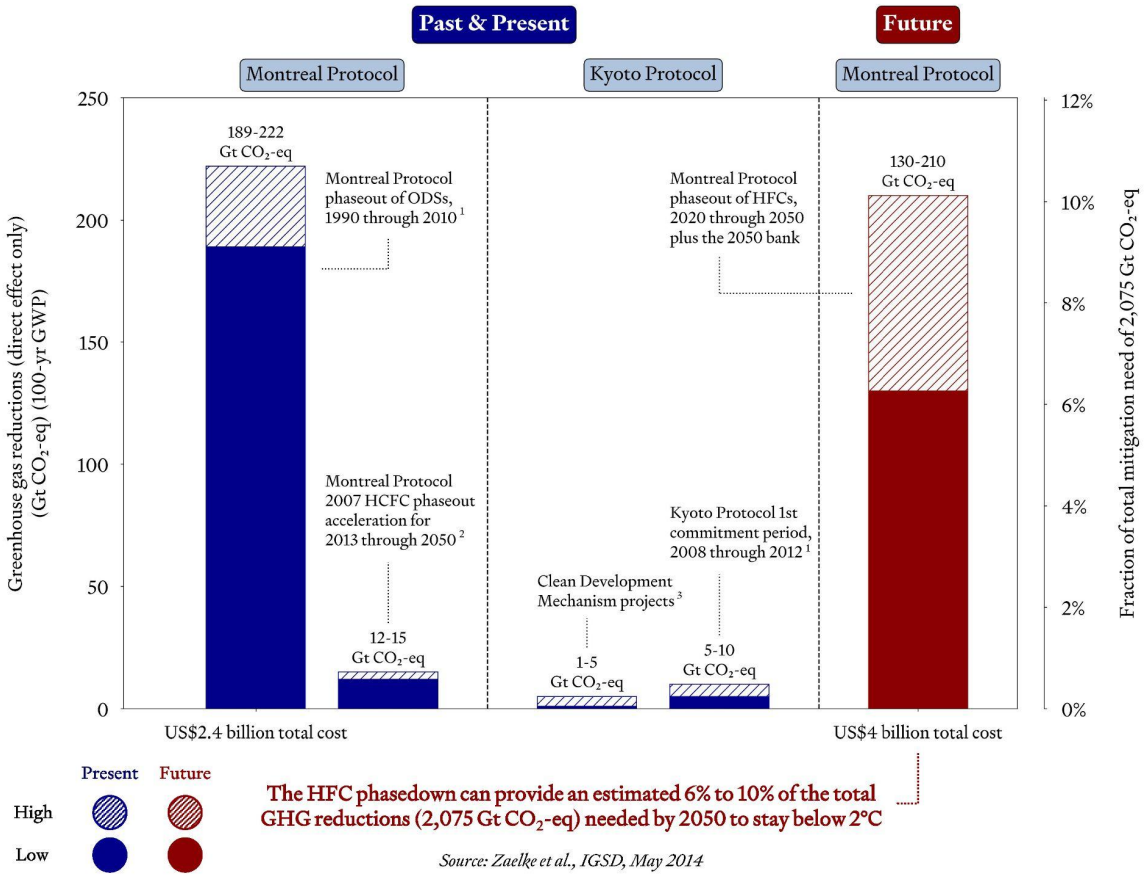
New Haven, Connecticut

14 March 2023

ANNEX A

MLF cost per tonne of CO_2-eq reduced 1991-2010 by the Montreal Protocol

Estimated Emissions Reductions Associated with Major Treaties



Repair of the stratospheric ozone layer has been achieved at a cost under the MLF of $4.5 billion provided to developing country Parties to assist with their incremental cost of compliance, some of which has yet to be disbursed.[13] Climate benefits were initially provided at no additional cost to ozone protection; but even assuming that all the costs 1991-2010 were assigned to climate, the 188–222 gigatons of CO_2eq in emissions reductions achieved during that period were achieved at less than US$0.01 per tonne of CO_2 reduced.[14]

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[13] Multilateral Fund for the Implementation of the Montreal Protocol (2022) *Report of the ninetieth meeting of the Executive Committee*, UNEP/OzL.Pro/ExCom/90/40. http://www.multilateralfund.org/90/default.aspx

[14] Zaelke et al. (2018) *Primer on HFCs: Fast Action under the Montreal Protocol can limit growth of hydrofluorocarbons (HFCs), prevent 100 to 200 billion tonnes of CO2-eq by 2050, and avoid up to 0.5 of warming by 2100*, Institute for Governance & Sustainable Development. Chart data from Zaelke et al. (2014). Prepared by Dr. D. Fahey based upon UNEP (2012) The Montreal Protocol and the Green Economy: Assessing the contributions and co-benefits of a Multilateral Environmental Agreement, 53 (Figure 3: Climate protection from the Montreal Protocol and Kyoto Protocol); *and* Velders G. J. M., *et al.* (2014) *Growth of climate change commitments from HFC banks and emissions*, Atmos. Chem. Phys. 14:4563-4572, 4568. Internal citations: (1) Velders G. J. M., *et al.* (2007) *The importance of the Montreal Protocol in protecting climate*, Proc. Nat'l. Acad. Sci. 104(12):4814–4819; (2) UNFCCC (2014) CDM Insights: Project Activities (data as of 31 May 2016); (3) Velders G. J. M. *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. 106(27):10949–10954. (Estimates are for direct emissions and do not include indirect benefits from improvements in

Yale Carbon Containment Lab

WORKSHOP AGENDA

08:30 **Welcome & Introduction**

Dean Takahashi, Carbon Containment Lab, Yale School of the Environment

08:40 **The Fast Action Imperative**

Durwood Zaelke, Institute for Governance & Sustainable Development

09:00 **Implementing the AIM Act To Maximize its Climate Benefits**

Moderated by Scott Stone, Glencoe Strategies

10:00 **Coffee Break**

10:30 **Using IRA Funding To Accelerate HFC Transitions & Enhance Electrification**

Moderated by Christina Theodoridi, Natural Resources Defense Council, and Avipsa Mahapatra, Environmental Investigation Agency

12:30 **Venture Capital Decision-Making for Climate Technology Investments**

William Lese, Braemar Energy Ventures

13:00 **Leveraging U.S. Leadership To Enhance Fast Action Globally**

Moderated by Tilden Chao, Carbon Containment Lab, Yale School of the Environment

14:15 **Identifying New Opportunities To Collaborate**

Moderated by Maas Goote, former EU Lead Negotiator, UNFCCC

14:45 **Concluding Remarks**

Dustin Maghamfar, Energy Foundation

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energy efficiency or other lifecycle emissions reductions.). *See also* WMO & UNEP (2014) Assessment for Decision-Makers: Scientific Assessment of Ozone Depletion: 2014, ES-2.

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Jonathan Tan, Ratio Institute

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