Carbon Containment Lab

POLICY BRIEF

Opportunities for Alternative Cooling Technologies in the HFC Transition

August 1, 2024

Prepared following the 46th Open-Ended Working Group Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

Executive Summary

Alternative Cooling Technologies (ACTs) are cooling systems and methods that do not require the use of any fluorinated substance, including "not-in-kind" alternatives to vapor compression. ACTs already play an essential role in the transition away from hydrofluorocarbons (HFCs), and they continue to make rapid technological advances. Scaling ACTs will be necessary to comply with existing and future climate regulations (including the global phasedown of HFCs), as well as to increase the ambition of these regulations. The role of not-in-kind substitutes in the phaseout of ozone-depleting substances set a compelling precedent for the role that ACTs can play in the HFC phasedown. Maximizing the climate and environmental benefits of ACTs will require active leadership and support from Parties to the Montreal Protocol. We recommend that policymakers take the following three actions:

1. Leverage and expand ACT technical expertise within the Montreal Protocol Technology and Economic Assessment Panel (TEAP);
2. Request a TEAP report on the state of ACTs and opportunities to accelerate their deployment; and
3. Play an active role in developing and scaling up ACTs, including through disbursement of the Multilateral Fund toward pilot projects and the adoption of ambitious national policies.

Introduction

This year, the hydrofluorocarbon (HFC) transition mandated by the 2016 Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer ("the

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Protocol") entered a critical phase marked by production and consumption freezes for Article 5 Group 1 Parties and the beginning of baseline-setting for Group 2 Parties.[1] Despite the added challenges posed by the COVID-19 pandemic, parties to the Protocol are on track for global compliance — an encouraging sign for international governance and Earth's atmosphere. The phasedown of HFCs mandated by the Kigali Amendment, if accomplished, will avoid up to 0.5°C of projected warming by 2100.[2]

This success, however, is not yet guaranteed. The market transformation under the Kigali Amendment will require that **the Protocol aggressively pursue a broad portfolio of substitutes** for HFC-based applications, including air conditioning and refrigeration, insulating foams, solvents, and fire suppressants. These substitutes range from super-efficient hydrocarbons and low-Global Warming Potential (GWP) fluorinated substances to novel and innovative approaches. The HFC phasedown can move at the speed replacements become available and feasible, and there is no single replacement for every application. **The more different types of substitutes are available, the faster and more efficient the transition will be.**

This policy brief, compiling key takeaways from a Side Event at the Protocol's 46th Open-Ended Working Group Meeting, argues for the more ambitious deployment of one class of innovative replacements: **Alternative Cooling Technologies (ACTs)**, a subset of not-in-kind substitutes that encompasses cooling methods not requiring the use of *any* fluorinated substances ("F-Gases"). ACTs can both aid compliance and acceleration of the phasedown — an urgently needed goal as other international efforts to control and reduce emissions of greenhouse gases fail to move at the pace required to stay below 1.5°C warming.[3] **ACTs can enhance the overall climate mitigation of the HFC transition, such as in cases where existing low-GWP substitutes continue to face barriers to deployment, particularly in the near term.** ACTs also may enable further improvements in equipment energy efficiency and eliminate the potential for leaks of refrigerant gases from equipment. ACTs are not exclusive of existing substitute refrigerants, but they clearly have a role to play in accelerating and sustaining the HFC transition to climate-friendly refrigerant technologies.

New technological breakthroughs, policies, and market incentives all have a role to play in scaling ACTs and maximizing the climate benefits of the Kigali Amendment. Below, we

[1] United Nations Environment Programme, "Frequently asked questions relating to the Kigali Amendment to the Montreal Protocol" (2017). https://ozone.unep.org/sites/default/files/2020-01/FAQs_Kigali_Amendment.pdf.
[2] Guus J. Velders, *et al.*, *The large contribution of projected HFC emissions to future climate forcing*, 106 Proceedings of the National Academy of Sciences 10949 (2009).
[3] United Nations Framework Convention on Climate Change, *Global* Stocktake, November 2023. https://unfccc.int/topics/global-stocktake.

situate ACTs within the context of the broader HFC transition, examine how prior examples from the ODS phase out can inform ACT deployment, and present steps that the Parties can take to facilitate their development.

What are Alternative Cooling Technologies (ACTs)?

Alternative Cooling Technologies are any cooling systems or methods that do not require the use of fluorinated substances. ACTs include natural refrigerants such as ammonia, iso-pentane, propane and CO_2; solid state alternatives to vapor compression such as barocaloric, elastocaloric, magnetocaloric, and thermoelectric materials; and design approaches such as passive cooling and cold ocean and ground water (Figure 1). ACTs are a subset of "not-in-kind" (NIK) substitutes within the cooling sector — defined generally by the Protocol's Technological and Economic Advisory Panel (TEAP) as any method "different… from the commonly applied principle" — and are as much a complement to existing substitute refrigerants as they are an alternative to them.

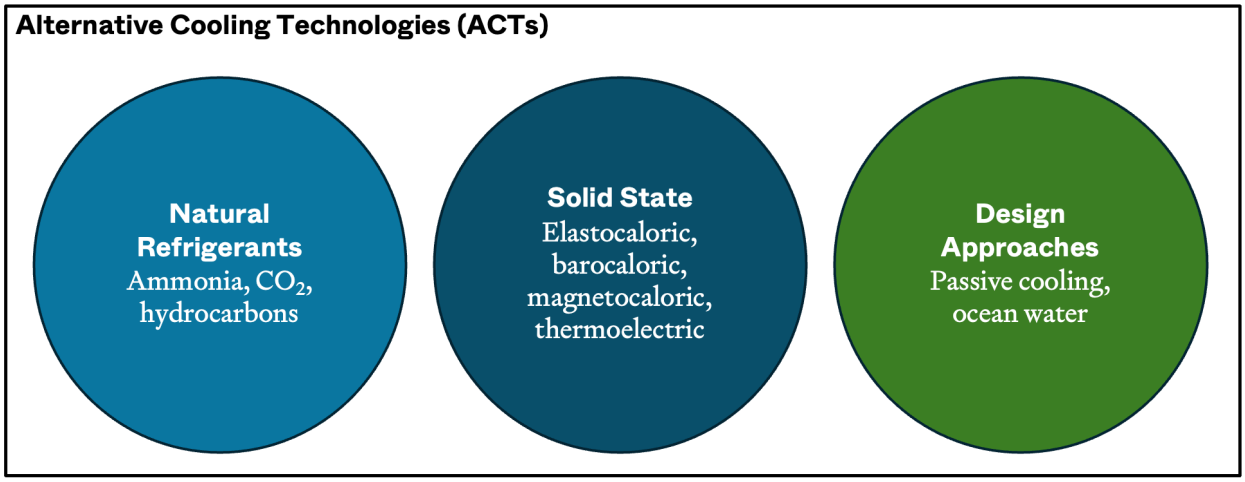

Figure 1. *Alternative Cooling Technologies encompass a wide variety of approaches, including natural refrigerants and "not-in-kind" technologies such as solid state alternatives.*

Because ACT encompasses a broad range of technologies under this definition, the Protocol must establish a standard and comprehensive set of environmental and economic metrics by which ACT solutions may be assessed. Possible metrics for comparison among emerging ACTs — as well as between ACTs and fluorinated options — include:

- Global Warming Potential (GWP)
- Life Cycle Climate Performance (LCCP)
- Coefficient of Performance (COP)
- Operational Lifetime Cost (OLC)

Regardless of specific criteria chosen, Parties should look for next-generation HFC substitutes and alternatives that can deliver greatest climate and environmental benefits safely, quickly, and at affordable cost.

What lessons can prior controlled substance phaseouts offer for the development of ACTs?

The role of NIK replacements in the phaseout of ozone-depleting substances (ODS) serves as a helpful precedent for the work that ACTs can now accomplish.[4] When work on the Protocol originally began, dozens of sectors and thousands of applications relied on chlorofluorocarbons (CFCs), halons, and other ODS for thousands of applications. NIK alternatives pursued during the initial phaseout of CFCs include hydrocarbon (HC), ammonia, and CO_2 refrigerants and foam-blowing agents; aqueous cleaning and no-clean soldering; HC, stick and spray alternatives to aerosol products; eliminating frivolous uses; measures aimed at halting discharge testing and training with halons; and numerous other environmentally superior solutions to limiting the use and emissions of ODS.

Across many core sectors, including fire suppressants, solvents, and some chiller technologies, NIKs played an essential role in both achieving compliance and accelerating the phaseout. Over 90 percent of the pre-Protocol ODS solvent usage, for example, was reduced through conservation and substitution with NIK technologies from 1987 to 1999.[5] Likewise the use of NIK alternatives to halons grew to "comprise approximately 51 percent of the former halon market."[6]

All of these NIK solutions were pursued at the same time as the more familiar "in-kind" alternatives: HFCs and HCFCs. Now, as these fluorinated gases are being replaced, the Protocol should ensure that it is considering and supporting NIK replacements across all sectors — particularly in heating and cooling, where global demand is growing most rapidly.[7]

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[4] TEAP Task Force Decision XX/8 Report, "Assessment of Alternatives to HCFCs and HFCs and Update of the TEAP 2005 Supplement Report Data," May 2009, 87. https://ozone.unep.org/sites/default/files/2019-05/teap-may-2009-decisionXX-8-task-force-report.pdf.

[5] TEAP Decision XXIII/9 Task Force Report, "Additional Information on Alternatives to Ozone-Depleting Substances," Volume 2, May 2012, 5. https://ozone.unep.org/sites/default/files/2019-05/teap-task-force-XXIII-9-report-may2012.pdf.

[6] TEAP Decision XXIII/9 Task Force Report, 4.

[7] Guus J. Velders, *et al.*, *Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFC) emissions*, Atmospheric Environment (2015).

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Why are ACTs important in the HFC phasedown and eventual phaseout?

Since the Montreal Protocol's adoption in 1987, air conditioning and refrigeration equipment manufacturers — as well as technology providers for other sectors — have transitioned to substitutes well ahead of mandated schedules, mostly as a practical matter and to minimize regulatory risk. Partly as a result, the Protocol's phasedown schedules have been continually amended and adjusted to accelerate these transitions. For example, in 1987 the Montreal Protocol required a 50 percent phase*down* of CFC production and consumption by 2000 in developed countries; by 1992, this had been accelerated to a 100 percent phase*out* by 1996. Overall, Parties have adjusted the Protocol six times to accelerate phasedown schedules.[8]

Accordingly, under the Kigali Amendment, the upstream supply of virgin HFCs will contract significantly over the next 5 to 10 years, putting pressure on air conditioning and refrigeration manufacturers to discontinue high-GWP HFCs and transition to substitutes, potentially ahead of the Amendment's schedules.

ACTs already play an essential role as one such class of substitutes, and they continue to make rapid technological advances. Natural refrigerants, for example, have present an ultralow GWP alternative to HFCs in small refrigeration equipment, and their use in the air conditioning sector continues to grow.

Another promising set of ACT materials, elastocalorics—which stretch and compress specialized metal alloys to provide heating and cooling without vapor compression — was named one of the Top 10 Emerging Technologies of 2024 by the World Economic Forum.[9] Every incremental increase in ACT development and implementation frees up production and consumption allowances, lessens the compliance burden, and reduces the need for fluorinated gases.

Beyond compliance, ACTs can play a significant role in increasing the ambition of the phasedown. At current schedules, refrigerants equivalent to 90 billion metric tons of carbon dioxide (tCO_2e) are in or will enter into the installed bank by 2100.[10] The development of ACT approaches, when coupled with Lifecyle Refrigerant Management (LRM) actions such as leak reduction, refrigerant recovery, reclamation, and destruction, are a complete and

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[8] Stephen O Andersen et al., "Ozone Layer, International Protection," in Max Planck Encyclopedia of Public International Law. Oxford University Press (2021). https://opil.ouplaw.com/view/10.1093/law:epil/9780199231690/law-9780199231690-e1767.

[9] Mine Orlu and Wilfried Weber, "Elastocalorics," in Top 10 Emerging Technologies of 2024, World Economic Forum, June 2024. https://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_of_2024.pdf

[10] Christina Theodoridi, *et al.*, "The 90 Billion Ton Opportunity" (2022), https://us.eia.org/wp-content/uploads/2022/10/Refrigerant-Lifecycle-FullReport-6Spreads-PRINT.pdf.

viable set of strategies for minimizing and managing this bank. **LRM and ACTs work in tandem** — the former ensuring adequate supply of fluorocarbons for the servicing of existing equipment while the latter creates climate-friendly, non-fluorinated substitutes — to achieve and go beyond the Protocol's requirements.

Institutions currently pursuing or planning measures that go beyond Kigali Amendment requirements can similarly look to ACTs to achieve their policy aspirations. Both the United States and the European Union, for example, have recently established forthcoming GWP limits on refrigerants in new air conditioning and refrigeration equipment. Some policymakers have further signaled their ambition to lower these limits to less than 10 by the end of the decade. These goals are achievable, but they will require a portfolio of technologies that vary based on equipment type, size, and location. Current low-GWP options, while all crucial to the transition, pose some safety, toxicity, or engineering complications which may not be resolved in time to meet a 2030 deadline.[11,12]

What national policies may drive ACT development and deployment?

1. The United States

The American Innovation and Manufacturing Act of 2020 (AIM Act) and the U.S. Senate approval of ratification of the Kigali Amendment in 2022 mean the United States will phase down HFC production and consumption to 15 percent of baseline levels by 2036.

In addition, the AIM Act authorizes the U.S. Environmental Protection Agency (EPA) to restrict the use of certain HFCs in certain equipment – *e.g.*, prohibiting the use of a refrigerant with a GWP greater than 700 in air conditioning equipment manufactured after January 1, 2025. Such restrictions will hasten transitions to substitutes with lower GWPs in the 2020s, and EPA is free to continue to lower GWP thresholds in future regulatory actions as new substitute technologies become available.[13]

The AIM Act also authorizes EPA to establish new rules for refrigerant management, with a final regulation expected in September 2024. This regulation will target leak prevention and detection and likely promote the use of reclaimed refrigerant in servicing equipment and,

[11] U.S. EPA, OAR. "Refrigerant Safety." Overviews and Factsheets, November 5, 2014. https://www.epa.gov/snap/refrigerant-safety.
[12] ATMO Network, and Thomas Trevisan. "Overview of PFAS Refrigerants Used in HVAC&R and Relevance of Refrigerants in the PFAS Restriction Intention." Presented at the 45th Open-Ended Working Group for the Montreal Protocol, Bangkok, Thailand, July 3, 2023. https://ozone.unep.org/system/files/documents/OEWG45_ATMO_sidevent.pdf.
[13] U.S. EPA, OAR. "Technology Transitions Program." Other Policies and Guidance, November 30, 2022. https://www.epa.gov/climate-hfcs-reduction/technology-transitions-program.

potentially, charging new equipment. Unlike the production and consumption phaseout, which imposes compliance obligations on chemical producers, and GWP limits on new equipment, which impose compliance obligations on equipment manufacturers, these management requirements will impose compliance obligations primarily on downstream end-users. Those affected by management requirements include supermarket chains, data centers, and any other corporate entity utilizing air conditioning and refrigeration equipment in their businesses, such as in climate-controlled warehouses, office buildings, and vehicle fleets.

Under the Clean Air Act, EPA also regulates the use of substitute refrigerants.[14] Where a substitute is flammable or toxic, EPA often imposes conditions and other restrictions to ensure consumer and worker safety. These restrictions can impact equipment design and certification under various standards, such as those promulgated by UL Solutions. EPA also can impose compliance obligations on technicians, building owners, and others for using substitutes with safety risks.

The U.S. Securities and Exchange Commission (SEC) finalized new GHG emissions reporting rules in March 2024 that would require publicly traded entities to disclose information about climate-related risks reasonably likely to have material impact on their business, results of operations, or financial condition and certain climate-related financial statement metrics in audited financial statements.

These reporting requirements include GHG emissions as a proxy for a company's exposure to climate-related risks. Entities will be required to disclose direct emissions (Scope 1) and indirect emissions from purchased electricity or other forms of energy (Scope 2). The final SEC guidance does not require disclosure of emissions from upstream and downstream activities in its value chain (Scope 3).[15] However, California enacted a suite of laws in late 2023 that include Scope 3 emissions reporting obligations.[16] And while not mandated at a federal level, many companies are voluntarily tracking their Scope 3 emissions and making commitments to mitigate them.

Moreover, the high GWP of HFC refrigerants and the energy-intensive nature of air conditioning and refrigeration equipment mean that a company's approach to heating and cooling could feature prominently in its emissions reporting. These emissions, now that they are mandated to disclose for public companies, may influence investor, regulator, and

[14] U.S. EPA. "Significant New Alternatives Policy (SNAP) Program." Significant New Alternatives Policy (SNAP) Program. Accessed July 16, 2024. https://www.epa.gov/snap.
[15] Deloitte. "Comprehensive Analysis of the SEC's Landmark Climate Disclosure Rule." Heads Up. Deloitte, April 8, 2024. https://dart.deloitte.com/publications/deloitte/heads-up/2024/sec-climate-disclosure-rule-ghg-emissions-esg-financial-reporting.
[16] Gibson Dunn. "California Passes Climate Disclosure Legislation." Gibson Dunn (blog), September 30, 2023. https://www.gibsondunn.com/california-passes-climate-disclosure-legislation/.

activist perceptions of that company's climate commitments and, especially, level of exposure to climate-related risks.

2. The European Union

European Union (EU) member states are Parties to the Kigali Amendment. Currently, the EU has enacted one of the most ambitious HFC phasedown policies in the world. Additionally, like the United States, the European Commission, through its F-Gas Regulation, has established a range of GWP thresholds for air conditioning and refrigeration equipment and is also seeking to regulate certain HFCs as hazardous chemicals under its REACH regulations.[17]

The EU is pushing for enhanced energy efficiency across the economy, but with particular focus on the building sector and, by extension, heating and cooling equipment, via its Energy Efficiency Directive, Energy Performance of Buildings Directive, Smart Financing for Smart Buildings Initiative, and New Electricity Market Design. Other efforts include non-legislative actions such as developing a toolbox of measures to facilitate renovation in multi-apartment buildings and promoting proven energy efficiency models for publicly owned educational buildings and hospitals.[18]

EU regulations also require reporting on GHG emissions and corporate reduction strategies, which in some cases is significantly more extensive than proposed requirements in the United States. These requirements include the Non-Financial Reporting Directive, Corporate Sustainability Reporting Directive, and Sustainable Finance Disclosure Regulation.[19]

3. Additional Opportunities

A total of 160 countries have ratified the Kigali Amendment, including Australia, Brazil, Canada, China, India, Indonesia, Japan, South Africa, and South Korea – effectively ensuring its universal application.[20] A special provision of the Kigali Amendment prohibits trade with "non-Parties" to the amendment after 2032, meaning any jurisdiction that is not a Party to the amendment will be cut off from global trade in HFCs.

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[17] European Commission. "Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on Fluorinated Greenhouse Gases, Amending Directive (EU) 2019/1937 and Repealing Regulation (EU) No 517/2014." EUR-Lex, February 20, 2024. https://eur-lex.europa.eu/eli/reg/2024/573/oj.
[18] European Commission. "Energy Efficiency Directive." Energy efficiency - targets, directives, rules. Accessed July 16, 2024. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.
[19] European Commission. "Corporate Sustainability Reporting." Company reporting. Accessed July 16, 2024. https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en.
[20] United Nations Environment Programme, "All ratifications" (2024). https://ozone.unep.org/all-ratifications.

This provision, plus more than three decades of effective implementation of the Montreal Protocol's earlier control measures, mean that the phasedown of HFC production and consumption is all but assured. This underscores the importance of identifying, evaluating, and transitioning HFC substitutes in the immediate term for any entity that relies on air conditioning and refrigeration (and other HFC-based applications, such as insulating foams, solvents, and fire suppressants) as part of its business operations. Countries early in the HFC phasedown – particularly Article 5 countries – also have an opportunity to leapfrog HFCs by integrating ACTs into new building design.

4. Future Law & Regulation

Scaling ACTs will require the broad participation of stakeholders, including NGOs, industry, and policymakers.

a. Activism & Advocacy

Many environmental groups and pro-climate policymakers remain active at international, national, and especially sub-national levels, are seeking additional regulatory requirements to speed the transition from HFCs into the most climate-friendly substitute technologies possible.

b. Sub-National Measures

Sub-national measures facilitating the HFC phasedown are too numerous to summarize here, but they are evidence that HFC transitions are likely to happen well ahead of the Kigali Amendment's phasedown schedule. Some sub-national measures will potentially require high levels of climate performance in any new air conditioning and refrigeration equipment – *e.g.*, refrigerants that have 0 GWP, are non-flammable and non-toxic, do not leak, and can be recovered successfully at the end-of-life of equipment that is substantially more energy efficient than its predecessors.

For example, the State of New York proposed in December 2023 a second set of GWP limits for the late 2020s and early 2030s for most air conditioning and refrigeration applications that would prohibit the use of refrigerants with a GWP greater than 10 in new equipment.[21] California is considering similar future regulatory measures, and other progressive states, provinces and cities can be expected to follow suit in the coming years.

c. Other Regulatory Drivers

The drive to decarbonize buildings is increasingly influencing public and private procurement standards that prioritize lowest GWP options for refrigerants and energy

[21] NYS DEC. "Climate Change Regulatory Revisions." Amendments to Part 494, Hydrofluorocarbon Standards and Reporting, March 2024. https://dec.ny.gov/regulatory/regulations/proposed-emergency-recently-adopted-regulations/climate-change.

efficient air conditioning and refrigeration equipment. For example, the LEED building standard considers refrigerant management in existing buildings and new construction.[22,23] Military procurement also can have a profound effect on markets for next generation technologies, given the size and breadth of cooling applications in defense-oriented industries.[24] Apart from current and prospective regulatory regimes, it may be the case that greater integration of decarbonization goals into procurement processes will provide sufficient "pull" to speed the commercialization of ACTs.

How can the Montreal Protocol and other international institutions help advance ACTs?

1. Leverage and expand ACT technical expertise within the TEAP

The TEAP, particularly through the work of its Technical Option Committees (TOCs), has provided regular updates on the status of various alternatives to controlled substances since the Montreal Protocol's inception.

The TOCs have done an admirable job compiling and presenting high-level updates on the *current* technology readiness level (TRL) and commercial availability of NIK alternatives, which broadly include ACTs. However, many ACTs — particularly non-vapor-compression technologies — are still emergent and rapidly developing. The TEAP should therefore expand its ACT technical capacity so that it is able to compile and present forecasts of ACT development, as well as recommendations to the Parties on policies or investments that can support ACT technologies as relevant to meeting policy goals. Currently, institutions and individuals both inside and outside the Protocol community lack an objective, comprehensive, expert source of truth related to the state and future of ACTs. TEAP has the opportunity to fill this vacuum.

2. Request a TEAP report on the state of ACTs and opportunities to accelerate their deployment

Particularly if leveraging additional ACT expertise (either in the form of appointments or a special task force), TEAP is poised to author an authoritative and highly impactful report on ACTs. To be of greatest value to the Parties, such a report should include:

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[22] U.S. Green Building Council. "Fundamental Refrigerant Management." LEED v4. Accessed July 16, 2024. https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-86.

[23] U.S. Green Building Council. "Refrigerant Management." LEED v4.1. Accessed July 16, 2024. https://www.usgbc.org/credits/residential-%E2%80%93-single-family/v41-21

[24] For historical precedent in the ODS transition, see "Ch. 6: Military Pathfinder Leadership" in Stephen O. Andersen & Gonzalez, Marco, *Protecting the Ozone Layer: Condensed Second Edition* (2023).

- Descriptions of ACTs by application, as well as indicative examples
- Recommendations for a set of metrics by which Parties can assess ACTs technologies against each other and in-kind alternatives, as well as evaluation of those metrics for leading or emerging options
- Current policy barriers preventing the development or deployment of ACTs
- Possible financing mechanisms for the more rapid development and uptake of ACTs

3. Play an active role in developing and scaling up ACTs

Once informed by the TEAP, Parties will be prepared to determine the best mechanisms by which to leverage ACTs for Kigali Amendment compliance and increased ambition. Possible measures may include:

- Statement of support for transition to ACTs wherever feasible
- Adoption of national or subnational policies like those outlined above
- Disbursement of the Multilateral Fund toward ACT pilot projects or to building capacity in relation to ACTs
- Formal acceleration of phasedown schedule, or transition from a phasedown to a phaseout, enabled by a broad portfolio of alternative technologies

Conclusion

The success of the Montreal Protocol in protecting the climate and the stratospheric ozone layer rests on its ability to drive transitions to substitutes and alternatives across a wide range of applications. It is technically and economically feasible to move faster to phase down — and, eventually, phase out — HFCs. This can be accomplished by elevating the importance of non-fluorinated ACTs alongside other HFC policy imperatives such as strengthening LRM practices and policies.

In order to ensure that the Parties understand and take advantage of the immense opportunity presented by ACTs, the Montreal Protocol should move now to expand ACT expertise within its technical bodies and begin compiling authoritative, forward-looking reports. The time has come to raise the profile of the role of ACTs in facilitating compliance with and movement beyond the Kigali Amendment's requirements and to meet the full climate potential of this most important agreement.

About the Carbon Containment Lab

The Carbon Containment Lab (CC Lab) is a 501(c)(3) nonprofit that supports the development, testing, and implementation of novel and neglected climate solutions. The CC Lab is actively engaged within the Montreal Protocol and has become a thought leader for financing for lifecycle refrigerant management and the deployment of alternative cooling

technologies. The CC Lab was founded at the Yale School of the Environment in 2020 and spun out into an independent nonprofit in 2024.