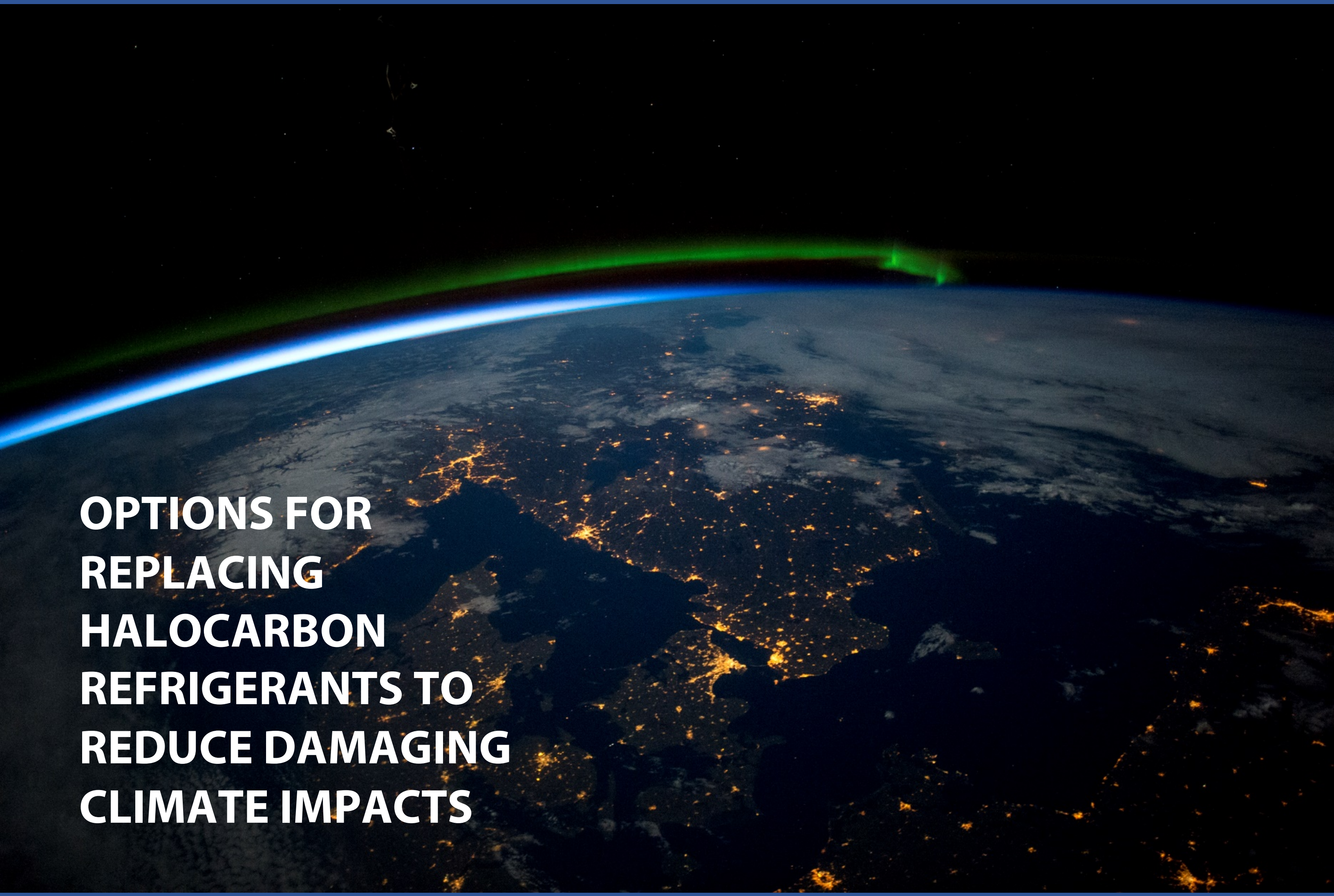


OPTIONS FOR REPLACING HALOCARBON REFRIGERANTS TO REDUCE DAMAGING CLIMATE IMPACTS

A best-practices manual for universities, corporations, and other institutions.

Wendy Jacobs
Adam Meier
Bridget Nyland
Debra Stump
Martin Wolf
Sejong Youn

This manual is not intended to operate as a substitute for legal representation and does not create an attorney-client relationship. It identifies legal issues to be aware of and offers general suggestions. Legal questions that may arise related to a specific project -- such as questions concerning the application of a state building code -- should be addressed to a lawyer with expertise in the geographic locale in which you are working. Please understand that laws vary from state to state and from locale to locale. Laws also frequently change so it is important to educate yourself about the current laws in the area in which you plan to work. This manual will help get you started. Neither the Clinic nor any of the authors assume any liability for actions taken (or not taken) by any party in reliance on this manual.

This manual is a project of the Climate Solutions Living Lab and the Emmett Environmental Law & Policy Clinic at Harvard Law School under the direction of Clinical Professor Wendy B. Jacobs. This manual was researched and prepared by Climate Solutions Living Lab students Adam Meier, Bridget Nyland, Martin Wolf and Sejong Youn, together with Professor Jacobs and Climate Solutions Living Lab Fellow Debra Stump. Any opinions expressed in the manual are those of the authors and not of Harvard University or Harvard Law School.

This manual is a work in progress; feedback is welcome. Questions or comments on this manual or on the Climate Solutions Living Lab can be directed to Professor Jacobs at wjacobs@law.harvard.edu.

Introduction

Halocarbons are manmade chemicals used in air conditioning and refrigeration equipment. Halocarbons are among the most potent greenhouse gases emitted. Their global warming potential is hundreds to tens of thousands of times higher than carbon dioxide, and the continued production and use of halocarbons poses significant climatic threats.

There are four categories of halocarbons, including halons, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). Each vary in their global warming and ozone depletion potentials. These gases will continue to be emitted into the atmosphere unless sustainably managed and disposed of.

Reducing emissions of halocarbons is ranked #1 by Project Drawdown as the solution that can produce the most carbon dioxide-equivalent emission reductions, if implemented at scale.[1] Solutions include ensuring that new cooling equipment does not contain halocarbons and the effective management of existing stocks of halocarbons. Minimizing leaks is one important step. The other vital step is ensuring halocarbons in existing equipment are recovered and destroyed (CFCs and HCFCs) or reclaimed (HFCs) when equipment reaches the end of its life, as most halocarbon emissions occur not from operating halocarbon-containing equipment, but following the end of equipment life during decommissioning or disposal. Opportunities currently exist to earn offset credits from reclaiming HFCs and/or using reclaimed HFCs in equipment.

While the production and use of CFCs and HCFCs are declining globally as a result of an international treaty, the use of HFCs and other halocarbons is still growing rapidly in the U.S. Halocarbon emissions in the U.S. increased by 248 percent from 1990 to 2016.[2] In addition, no federal framework exists to reduce emissions of halocarbons in the U.S., because the U.S. is not a party to the treaty phasing down halocarbons by cutting their production and consumption.[3] This absence of federal leadership creates an opportunity for U.S. institutions, such as universities, businesses, and state and local governments, to demonstrate leadership by taking action individually and through coalitions. Even though many institutions extensively use halocarbon refrigerants, alternatives do exist. By actively committing to reduce the use and emissions of halocarbons, an institution or coalition of institutions can show creative, science-based, fiscally pragmatic leadership, motivating others to act and creating significant greenhouse gas emission reductions through scale. This manual details the pathway for action.

---

[1] Project Drawdown, https://www.drawdown.org.

[2] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016," p. ES-9.

[3] The Kigali Amendment to the Montreal Protocol.

ROADMAP TO EMISSIONS REDUCTIONS

To reduce and eventually eliminate the use and emissions of halocarbon refrigerants:

1. Take inventory of all halocarbon-containing equipment and halocarbon emissions

1. Take inventory of all halocarbon-containing equipment and halocarbon emissions

✓ Take inventory of all equipment containing halocarbons. Include equipment with < 50 pounds of halocarbons.

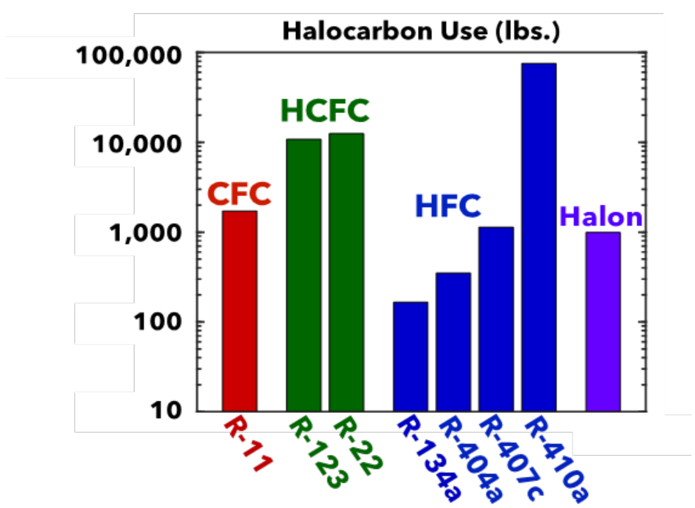
✓ Analyze the climatic impact of your institution's use of halocarbons by calculating the global warming potential (GWP) of the specific halocarbons in this inventory[4].

✓ Create a complete halocarbon *emissions* inventory for your institution.

A. Take inventory of all equipment containing halocarbons

Institutions currently keep inventories of equipment with 50 or more pounds of halocarbons, in order to comply with Clean Air Act rules regarding refrigerants. However, because institutions are not required to keep inventories of equipment containing less than 50 pounds of halocarbons, this means that institutions are missing opportunities to reduce or eliminate emissions from this equipment, which is often replaced in shorter intervals than larger equipment. Improved energy efficiency and technological innovations have led to replacement options that reduce or eliminate halocarbons in smaller refrigeration and cooling devices. With an inventory of *all* halocarbon-containing equipment, an institution will have a complete picture of the scope of the institution's use and potential emissions of halocarbons. One example of how an institution might analyze the refrigerants in use is shown in Figure 1, below. This inventory will be critical as an institution undertakes long-term capital planning and budgeting to reduce and eliminate halocarbons (addressed later in this manual).

Figure 1. Example halocarbon inventory for an institution,
showing total amounts of refrigerants contained in the institution's equipment.

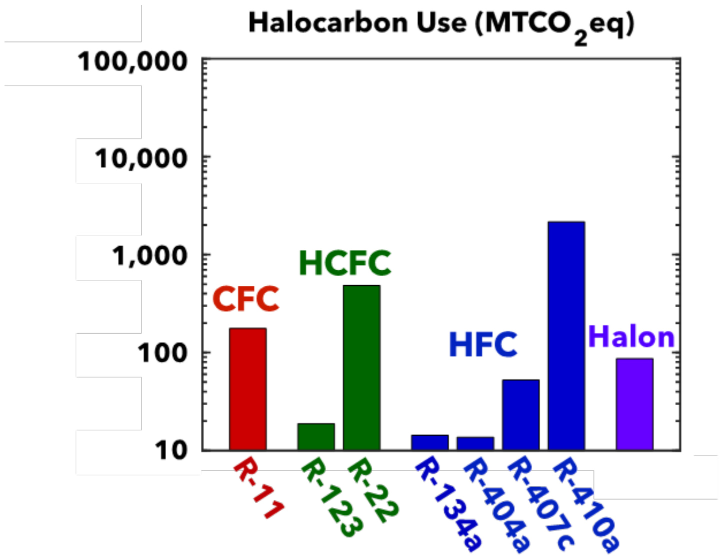


[4] Myhre, G., D. Shindell, F.-M. Bre on, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

B. Analyze the climatic impact of your institution's use of halocarbons

Next, the institution should calculate the climatic impact of its halocarbon inventory, using the total pounds of each type of halocarbon and the carbon dioxide equivalent global warming potential of each specific halocarbon.[5] Figure 2 is an example of an institution's analysis of the climatic impact of its halocarbon inventory.

Figure 2. Example analysis of the climatic impact of an institution's use of halocarbons, showing the equivalent carbon dioxide mass, in metric tons of carbon dioxide equivalence ($MTCO_2eq$), of an institution's refrigerant stock.

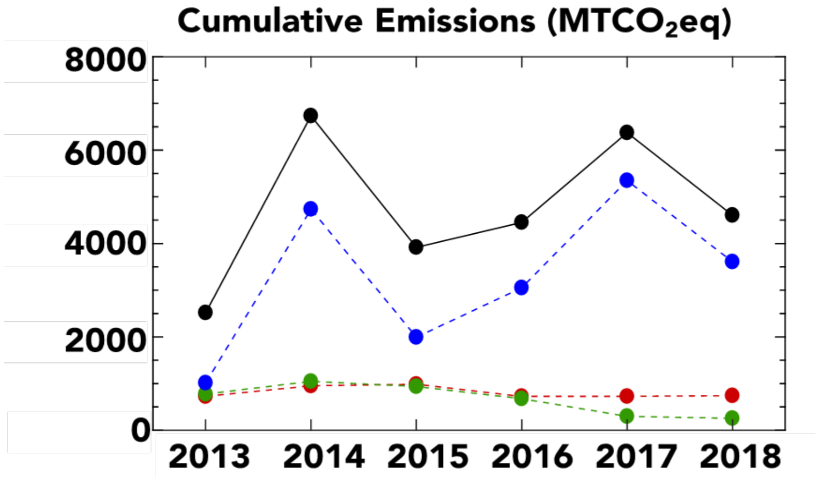


C. Create a complete halocarbon *emissions* inventory for your institution

In addition to creating an inventory of the total stock of halocarbons, it is vital to create an inventory of all halocarbon *emissions*. The best practice for such an inventory is to calculate emissions from each piece of halocarbon-containing equipment. This can be done using service contracts for the recharging/refilling of equipment during routine maintenance or for addressing larger, unexpected leaks from equipment. Figure 3 is an example halocarbon emissions inventory.

[5] Electronic Code of Federal Regulations. Title 40: Protection of Environment, Part 98 – Mandatory Greenhouse Gas Reporting; Subpart A – General Provision, Table A-1: Global Warming Potentials
https://www.ecfr.gov/cgi-bin/text-idx?SID=364a5fce8172ea4a303e405e64dfbce4&mc=true&node=ap40.21.98_19.1&rgn=div9

Figure 3. Halocarbon Emissions Tracked Over Time



Once these inventories are completed, an institution should then analyze the emissions inventory along with the institution's inventory of halocarbon stock and related GWP for each piece of equipment to create a plan for the upgrade and replacement of halocarbon-containing equipment. These data must be looked at together so an institution can prioritize in a way that will have the greatest impact on emission reductions at least unnecessary cost. Looking only at leak rates can also lead an institution to prioritize the piece of equipment with a lower overall impact. For instance, if a unit with 3000 pounds of halocarbons is leaking 20% annually (600 pounds/year), and a unit with 300 pounds of halocarbons is leaking 30% annually (100 pounds/year), prioritizing the unit with the higher leak percentage will lead an institution to upgrade the wrong piece of equipment. Similarly, looking only at the total pounds of halocarbons in a unit, without considering leak rates, can also be deceiving. If a large unit has a very low leak rate, an institution may reasonably decide not to prioritize upgrading such a unit, even though it contains a large stock of halocarbons, in favor of upgrading a smaller but leaky unit.

2. Implement best practices in halocarbon leak detection and repair

2. Implement best practices in halocarbon leak detection and repair

Greenhouse gas emissions occur when halocarbons are vented to the air, either accidentally, through leaks during equipment operation, and/or through servicing and equipment disposal. Implementing best practices in leak reduction, described below, is a crucial element to reducing these greenhouse gas emissions.[6]

- **Detect leaks more quickly**. Halocarbons are odorless and colorless and cannot be detected without instruments.
  - *Leak inspections.* If an institution suffers from high leak rates, monthly inspections may be warranted. Once leaks are under control, quarterly or biannual inspections may be more appropriate.
  - *Walk-throughs post-repair*. Best-in-class institutions request a walk-through with a hand-held leak detector to ensure the leak has been repaired and to catch other leaks early. This can be completed while the technician is waiting for the system to complete its initial cycling, making it a low-cost, high-reward strategy.
  - *Embedded leak detection systems*. Systems are available to directly monitor the concentration of refrigerants in the air. These can be either fixed or portable. Best-in-class systems can automatically link with central control systems. Refrigerant loss can also be inferred from changes in refrigeration system operations, which uses existing sensors and data that is already being collected (such as temperatures, pressures, and liquid levels), but it is harder to pinpoint a leak with this method, thus extending the emission.

- **Tackle leaks when they're identified**. While many institutions will wait to repair a leak because of the importance of running the system or because the leak is small, best practice is to immediately isolate the leak and call a technician, even if that requires temporarily isolating a unit.

- **Use secondary systems where possible**. Secondary refrigeration systems use less refrigerant and confine refrigeration to a single room. These systems tend to have lower leak rates; detecting and fixing leaks can also be easier.

- **Replace O-rings frequently in systems requiring high temperatures.**

- **Use loop piping, reduce the number of piping joints, and use valve caps.**

---

[6] Sources used to determine best practices were: Witman, K., 2018, *Five Simple Steps to Reduce Your Refrigerant Leak Rate*, available at https://blog.mybacharach.com/articles/definitive-guide-to-leak-rate-reduction/; Wallace, J., n.d. Industry Sets Sights on Reducing Refrigerant Leaks, *E360 Outlook*, available at https://climate.emerson.com/documents/v2-n2-reducing-refrigerant-leaks-en-us-103232.pdf; Maxson, S., 1999, *Preventive maintenance: Keeping refrigeration equipment in shape*, available at https://www.achrnews.com/articles/98243-preventive-maintenance-keeping-refrigeration-equipment-in-shape; U.S. EPA, 2011, *GreenChill Best Practices Guideline: Commercial Refrigeration Leak Prevention & Repairs*, available at https://www.epa.gov/sites/production/files/documents/leakpreventionrepairguidelines.pdf.

- **Set goals and track refrigeration use and other refrigeration-related key performance indicators**. Setting a goal for refrigerant leaks and then tracking progress toward that goal can significantly improve overall performance. Key performance indicators can include:
  - *Leak rate*. Best-in-class institutions will track leaks at the equipment level, including units using less than 50 pounds of halocarbon. Institutions should at least track leak rates at the institutional level.
  - *Pounds of refrigerant leaked*. Leak rates in percent of halocarbon charge can be deceiving when an institution has equipment of various sizes. If a unit with 3000 pounds of refrigerant is leaking 20% (600 pounds/year), but a 300-pound unit is leaking 30% (100 pounds/year), looking only at leak rates would have you prioritize the smaller unit when in fact the larger unit is leaking a larger amount. Leak rates must be looked at in parallel with amounts leaked per unit.
  - *Leak repair response time*. This will vary depending on what leak detection system an institution has. Tracking this number will impose a discipline around leak repairs, which can be one of the most significant ways to reduce leakage.

- **Engage in preventive maintenance**. Preventative maintenance provides benefits beyond reducing the likelihood of refrigerant leakage. It can also result in cost savings through enhanced system operating efficiency and extending the equipment's operational lifespan.
  - *Compressors*. Every six months, the electrical connections, electrical components, control system, oil levels, defrost controls, refrigeration line insulation, refrigerant level, system superheat, capillary and super hose lines, and valve caps and unit covers should be checked.
  - *Evaporators*. Every six months, the electrical connections, fan motors and blades, defrost heaters, drain pans, evaporator coil surface, and temperature glide should be checked.

3. Use reclaimed halocarbons when servicing equipment and reclaim or destroy halocarbons at the end of equipment life

3. Use reclaimed halocarbons when servicing equipment and reclaim or destroy halocarbons at the end of equipment life

Although the long-term goal is for an institution to retire all halocarbon-containing equipment, as a practical matter, most institutions will continue to use some of their existing halocarbon-containing equipment for many years. In addition to using best practices for leak prevention and detection, as described in Section 2 above, institutions can also reduce emissions by using reclaimed halocarbons when equipment is serviced and by ensuring that all halocarbons are recovered and reclaimed (HFCs) or destroyed (CFCs and HCFCs) when equipment reaches its end of life. Reclaimed halocarbons are used halocarbons that have been removed from equipment and processed to remove impurities, so that the reclaimed halocarbons are of equal quality to newly produced, "virgin" halocarbons. As CFC and HCFC production is now banned or is being phased down, institutions should opt to destroy their spent CFCs and HCFCs rather than recycling them. This action helps drive the market towards newer and more environmentally friendly alternatives.

Using reclaimed HFCs reduces greenhouse gas emissions, because these HFCs displace the new production of HFCs. Typically, when refrigeration systems are "charged" with refrigerants for the first time, or when the refrigerant in a system is refilled ("recharged") as the system leaks during normal operations, virgin HFCs, rather than reclaimed HFCs, are used. This is because virgin HFCs are often less expensive than reclaimed refrigerant. With no controls on the production or import of HFCs in the U.S., it is cheaper to manufacture new HFCs than to recover and reclaim used HFCs. However, unless HFCs are destroyed, all HFCs are eventually emitted to the atmosphere as potent greenhouse gas emissions. By displacing the production of new HFCs, the use of reclaimed HFCs lowers the total amount of HFCs in existence and therefore lowers eventual emissions.

The American Carbon Registry has developed a methodology to create voluntary carbon offsets through the use of reclaimed HFC refrigerants that would not occur in a business-as-usual scenario. At present, in the absence of controls on the production, import, or use of HFCs in the U.S., emissions reductions from the use of reclaimed HFC refrigerants are "additional".

This reclaimed HFCs offset methodology provides a near-term opportunity for institutions. Some states, including Massachusetts, are considering their own regulation of halocarbons. It is also possible that a future federal administration would ratify the Kigali Amendment and phase down the use of HFCs. Once controls are imposed on the production and import of HFCs, there will be incentives to reclaim HFCs, and HFC reclamation may then become "business as usual." Once HFC reclamation is business-as-usual, the ability to earn offset credits from reclaiming HFCs will no longer apply.

To make use of this offset opportunity, an institution should seek a refrigerant vendor that is already reclaiming HFCs (or selling reclaimed HFCs) under this methodology, or that is willing to work with the institution to begin using this methodology. The institution and the refrigerant vendor/reclaimer are free to determine their own structure for allocating the offset credits and revenue that may be earned from selling the credits, taking care to ensure no double-counting of the environmental attributes of the credits. For instance, if the institution wants to use the credits to offset its own emissions, this would be possible with careful contracting language between the institution and the refrigerant vendor to ensure that no other parties are claiming these offsets. Alternatively, if the institution wishes to earn revenue from selling the offset credits, this would also be possible, but in such a case the institution may not also claim the emission reduction against its own GHG emissions inventory.

4. Incorporate the phase-out of halocarbon-containing equipment in long-term capital planning and budgeting

4. Incorporate the phase-out of halocarbon-containing equipment in long-term capital planning and budgeting

✓ Make a plan for each piece of halocarbon-containing equipment

✓ Incorporate the eventual change-out of halocarbon-containing equipment in capital planning and budgeting

Because of the lengthy capital planning and budgeting processes required for the purchase of large cooling equipment, proactive planning is crucial. To assist in this planning, an institution can use the two frameworks provided below in Figures 4 and 5: the ***Selection matrix***, to help determine the best refrigerant for given applications, and the ***Prioritization matrix***, to help an institution prioritize and plan for the eventual elimination of HFCs from its equipment, taking into account costs, competing capital priorities, and other practical considerations.

Selection matrix

HFCs do not deplete the ozone layer, are not flammable, and can be used in all applications. These attributes have led to the widespread use of HFCs as replacements for CFCs and HCFCs, which are required to be phased out under the Montreal Protocol. HFOs and natural refrigerants can be used in many applications, but they have varying benefits and drawbacks. In some instances, as seen in the pilot project described in Section 6 below, the best option may be to replace high-GWP HFCs with lower-GWP HFCs.

Figure 4. Selection matrix of refrigerant characteristics for HVACR systems

	HFCs	HFOs	Natural Refrigerants
Application	Can be used in all applications	Newer: more common in HVAC and Auto	Currently limited to refrigeration
Energy Efficiency	Baseline	Generally Lower	Often more energy efficient
Flammability	Class 1	Generally Class 2L	Varies: Class 3 (propane) to Class 1 (CO_2)
GWP	High	Low	Very Low

Prioritization matrix

The following "stoplight" matrix can be used by institutions to develop a plan for deciding which equipment to upgrade and when. Pieces of equipment with many "green" attributes would be at the top of the list for quick action; equipment with many more "yellow" or "red" attributes will generally be expensive, logistically challenging, and require more planning, but this does not mean this equipment should be ignored. Rather, this means that a longer and more complex planning strategy will be required for the eventual upgrade of this equipment, along with continual assessment of the state of technology, changes in building codes, and regulatory requirements, which may move a "red" project into the yellow or green zone.

Figure 5. Prioritization matrix for deciding which pieces of cooling equipment to upgrade and when.

	Green	Yellow	Red
End of Life	< 5 Years	5-10 Years	>10 Years
Refrigerant	Halons, CFCs	HCFCs	HFCs
Ease of Upgrade	Drop-In Replacement	Equipment Change Out	Fire and Building Code Restrictions
Capital Cost	< $50,000	~$250,000	> $500,000
System Criticality	Serves as Back-Up Only	Runs in Parallel with other Units	Single Unit/Critical System
Ease of Service	Easily Accessed	Minor Physical Barriers to Access	Large Underground Units

Equipment with many attributes in the "green" category will be the low-hanging fruit. This includes equipment with regulated refrigerants (CFCs, halons, and soon HCFCs), as well as projects that are inexpensive and easy to implement.

Equipment with many attributes in the "yellow" category might include newer equipment, or equipment requiring more extensive change-out of piping and other construction-related elements. This may also include equipment that serves an important operation, in which case taking it offline presents larger logistical hurdles.

Equipment with many "red" attributes faces major barriers to near-term replacement. This includes very new equipment, equipment that requires building changes to replace (for example, building infrastructure may need to change to accommodate equipment using more flammable refrigerants), or the capital cost is for other reasons prohibitively expensive.

Using this prioritization matrix can help the institution inform budgeting and planning decisions. Larger equipment changes that cannot be paid for through operating budgets will need to be worked into longer-term master capital plans. Therefore, it is important for an institution to develop end-of-life and replacement scenarios for all major HFC-containing equipment well ahead of its actual end-of-life.

5. Explicitly address halocarbons in procurement documents and green building standards

5. Explicitly address halocarbons in procurement documents and green building standards

- ✓ Include halocarbon considerations in procurement documents for refrigeration and air conditioning equipment purchase and maintenance
- ✓ Include the global warming potential of refrigerants as a factor to be considered in the institution's green building standards

Institutions must consider many factors when purchasing new cooling equipment or replacing old cooling equipment. Safety, cost, ease of service, familiarity with particular manufacturers or refrigerant types, preferences for specific vendors, and logistics all factor into decisions on these purchases, which often entail large capital investments. Institutions with greenhouse gas-reduction and other sustainability goals are adept at prioritizing energy efficiency and other green building standards when selecting new equipment. However, many of these institutions are not aware of the full climate impacts of the refrigerants used in their new and existing cooling equipment.

Including specific language about refrigerants in procurement documents and building standards will ensure that non-halocarbon alternatives are considered in the procurement process and that institutions take account of the full climate impacts of their equipment choices. Below is sample language that an institution can adapt for its own use.

Sample procurement language for new equipment

One criterion that will be used to evaluate responses to [the institution's] request for proposals is the global warming potential of the refrigerant used in offered product(s) and services. Bidders shall identify the type, amount, and estimated annual leak rate of all refrigerants used in the offered product(s) and services. The bidder shall specify whether an offered product or service utilizes low/no-global warming potential (GWP) refrigerants, including but not limited to natural refrigerants such as propane, ammonia, or carbon dioxide, or hydrofluoro olefins (HFOs), or whether an offered product avoids the use of refrigerants through transformative technologies. If an offered product or service contains hydrofluorocarbon (HFC) refrigerants, the bidder shall warrant and confirm that any HFCs to be used are certified reclaimed HFCs and that it has the lowest-available GWP. The bidder shall provide evidence of the origin of the HFCs in any HFC-containing products. The bidder shall specify whether the offered product(s) shall include automatic leak detection systems to detect refrigerant leaks and shall provide technical details for any such automatic leak detection systems.

Sample procurement language for equipment maintenance

A key criterion that will be used to evaluate bids is the origin of the refrigerant used to refill ("recharge") refrigeration and air conditioning equipment during maintenance. If equipment being serviced contains hydrofluorocarbons (HFCs), bidders shall preference certified reclaimed refrigerant over virgin refrigerant. Recharging equipment with certified reclaimed HFCs displaces new production of virgin refrigerant, which can have beneficial long-term consequences of reducing greenhouse gas emissions. Recharging equipment with certified reclaimed HFCs may also allow our institution to earn offset credits through an approved carbon offset methodology. Bidders shall provide evidence of the origin of the HFCs in any HFC-containing products; for all reclaimed HFCs, bidders shall specify whether any other entity has earned or claimed offset credits from the reclamation of the HFCs and if so, how many and over what time span.

Sample green building standard language

Follow the U.S. Green Building Council's LEED guidance on Enhanced Refrigerant Management. This guidance supports early compliance with the Montreal Protocol while minimizing direct contributions to climate change. Consult the LEED guidance specific to your project type. Typically, LEED guidance on Enhanced Refrigerant Management provides two options for compliance. The first option is to use no refrigerants or low-impact refrigerants. Either no refrigerant is used, or if refrigerants are used, only refrigerants (naturally occurring or synthetic) that have an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of less than 50 may be used. The second option is to calculate the impact of the refrigerant used to ensure that it complies with the formula provided in the LEED guidance. Under this option, refrigerants for use in heating, ventilating, air-conditioning, and refrigeration (HVAC&R) equipment are selected to minimize or eliminate the emission of compounds that contribute to ozone depletion and climate change. The formula used to determine compliance takes into account GWP, refrigerant leakage rate, end-of-life refrigerant loss, equipment life, and other factors.[7]

[7] *See* the U.S. Green Building Council website, www.usgbc.org, for details on the LEED Enhanced Refrigerant Management standards. Examples of specific LEED credits are as follows: LEED O+M: Existing Buildings, LEED v4, at https://www.usgbc.org/credits/existing-buildings-schools-existing-buildings-data-centers-existing-buildings-hospitality-ex; LEED BD+C: New Construction, LEED v4, at https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-healthcare-data-centers-new-constru; and LEED ID+C: Commercial Interiors, LEED v4, at https://www.usgbc.org/credits/commercial-interiors-hospitality-commercial-interiors/v4-draft/eac5.

6. Implement pilot projects to demonstrate the benefits of and opportunities for reducing halocarbons

6. Implement pilot projects to demonstrate the benefits of and opportunities for reducing halocarbons

Pilot projects provide an opportunity for an institution to test ideas for reducing emissions of halocarbons. Pilot projects can help an institution gather data, disseminate knowledge and ideas among facilities and operations staff, and provide visibility for the institution's efforts. The following case study describes a planned pilot project at a university that will enable the university to analyze the energy efficiency benefits of replacements for high-GWP HFCs, test a new model for earning offset credits from using reclaimed HFCs, and develop ideas for similar projects that can be replicated across the university.

This case study demonstrates the usefulness of taking inventory of equipment with <50 pounds of halocarbon refrigerants (as explained earlier in this manual). While completing an inventory of halocarbon-containing equipment at a university, a team of researchers learned that a series of more than a dozen chillers containing HFCs were connected in a daisy chain in a university cafeteria. Each chiller contained HFCs with a very high global warming potential (20-year global warming potential >6000). However, since each chiller contained less than 50 pounds of HFCs, the units did not appear on the university's inventory of halocarbon-containing equipment. When the research team learned of this equipment and discussed it with facilities and operations experts at the university, they all worked together to design a pilot project to demonstrate the feasibility of reducing emissions from halocarbons at the university. This pilot project is described below.

Case study: Refrigeration systems on a university campus

A research team tasked with finding ways to reduce halocarbon emissions on a university campus identified a "daisy chain" series of refrigeration systems in a university cafeteria. These individual systems each service a separate food storage and preparation room. The systems use the gas blend R-404A as a refrigerant. Individually, no system uses > 50 pounds of refrigerant, but collectively, the units use > 300 pounds of R-404A. Although R-404A is a commonly used refrigerant, it is suboptimal in two ways. First, its GWP is higher than some other HFCs. Second, the refrigeration efficiency or coefficient of performance (COP) of R-404A is lower than some other HFCs, meaning more power is consumed to achieve the same cooling capacity. Despite these drawbacks, R-404A continues to be used as a refrigerant throughout the U.S. due to lack of awareness, human inertia, and technicians' unfamiliarity with available substitutes. The research team, together with facilities and energy experts at the university, identified two options to replace the R-404A.

Option 1. The R-404A in the current units could be replaced with another HFC exhibiting lower GWP and improved COP. The best replacement is R-442A. This gas is also an HFC blend, but is better formulated to maximize cooling capacity and minimize atmospheric warming. Its 20-year GWP of 3926 is 40% lower than the GWP of R-404A, which is 6437. Further, an R-442A system would consume 7-12% less energy.

This option would be a "drop-in replacement" that would entail minimal equipment modifications, such as replacing expansion valves and rubber gaskets. The replacement would involve minimal downtime for the equipment. While the project would involve some disruption to food service, such disruptions could be minimized by staggering the upgrade process. The team's initial estimates indicate that replacing the R-404A in all of the systems would pay for itself in a little over a year through increased energy efficiency.

Option 2. An alternative pilot project would replace the systems with systems using natural refrigerants, such as carbon dioxide. The individual systems could be replaced with new individual systems, or with a centralized unit servicing all of the cold rooms. This option would entail much higher capital costs and more complex and costly logistical issues. For instance, new piping may be required; since piping to the cold rooms is extensive and often buried within concrete or penetrating fire protective walls, this would entail significant additional expense. Replacement would likely disrupt food service for several weeks. While the climate benefits of this option would be 200% greater, the team determined that the increased climate benefits were unlikely to justify the large capital expenditures, particularly since the systems in question are fairly new (installed within the last 10 years).

Chosen option. Option 1 was found to be the preferred option. To provide the highest quality data for future projects, the team is recommending that the R-404A in only half of the systems be replaced, and metering equipment be placed on all of the systems. This will allow facilities and energy staff to collect actual data on the energy efficiency benefits of the replacement refrigerant, rather than relying on industry estimates. In addition, by replacing the refrigerant in only half of the units, disruptions to food service will be minimized. The team suggests that Option 2 then be implemented at the end of the 20-year lifetime of the current systems. For this to happen, the team emphasized that the eventual change-out to a non-HFC system would need to be included in master capital plans soon. Capital-intensive projects require at least five years of planning to be worked into master capital plans; proposals for changing out halocarbon-containing equipment with non-halocarbon equipment should be planned well in advance to be worked into master capital plans.

Soon after this pilot project was proposed and discussed at various university meetings, another cafeteria within the same university was found to have a very similar configuration, with a daisy chain of chillers, also each containing <50 pounds of halocarbons, serving individual cold rooms. A second pilot project at this location will provide yet more data, momentum, and visibility.

7. Consider making the “We’re Still in Kigali” pledge, to demonstrate leadership and inspire others to act

7. Consider making the "We're Still in Kigali" pledge, to demonstrate leadership and inspire others to act

- ✓ The *We're Still in Kigali* pledge is a commitment to a science-based drawdown of HFC stocks
- ✓ Adopting this pledge demonstrates leadership and motivates action by others

This recommendation draws on successful subnational pledge efforts among U.S. states, cities, businesses, and other organizations, reaffirming their commitment to the Paris Agreement following the U.S. withdrawal at the federal level. Such a pledge provides a framework for the institution's engagement and attention to this issue; demonstrates leadership and raises awareness about a vitally important climate issue; and, provides a model for others to adopt, which will increase the climate benefits of the pledge through scale and replication.

Institutions can engage their sustainability offices, facilities and operations departments, procurement offices, capital planning groups, and other relevant groups in making a voluntary pledge to comply internally with the Kigali timeline. By engaging multiple stakeholders, an institution can create a sense of shared ownership, momentum, and accountability. Once an institution has committed to this internal, voluntary drawdown of HFC stocks, the next step is to engage other institutions in larger partnerships. A meaningful response to the lack of U.S. ratification of Kigali will require a broad range of actors.