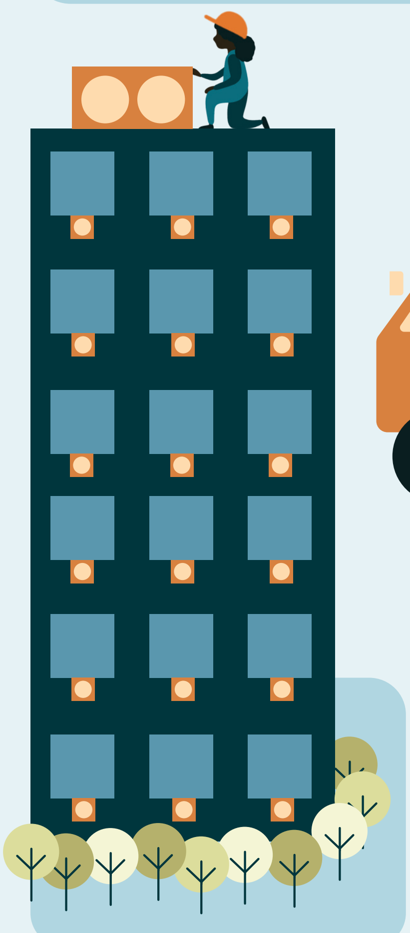
THE 90 BILLION TON OPPORTUNITY



LIFECYCLE REFRIGERANT MANAGEMENT (LRM)

How minimizing leaks and maximizing reclaim can avoid up to 91 billion metric tons CO_2-eq emissions

AUTHORS
Christina Theodoridi, Natural Resources Defense Council (NRDC)
Alex Hillbrand, Natural Resources Defense Council (NRDC)
Christina Starr, Environmental Investigation Agency (EIA)
Avipsa Mahapatra, Environmental Investigation Agency (EIA)
Kristen Taddonio, Institute for Governance & Sustainable Development (IGSD)

TECHNICAL ADVISORS
Bruce Ernst, A-Gas, Inc.
Scott Stone, Glencoe Strategies LLC
Brian Coleman, Hudson Technologies, Inc.
Benjamin Klein, Invariant LLC

EIA: **www.us.eia.org**
IGSD: **www.igsd.org**
NRDC: **www.nrdc.org**

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Executive Summary

Today, built into each cooling appliance and insulating foam in nearly every household, building, and car in America and across most of the world, there sits a type of fluorinated gas called a hydrochlorofluorocarbon (HCFC) and/or a hydrofluorocarbon (HFC).

When leaked out into the atmosphere, HCFCs cause depletion of Earth's ozone layer and both HCFCs and HFCs are extremely potent climate warmers. Pound for pound, these chemicals warm the climate several thousands of times as much as carbon dioxide.[1] In total, the U.S. installed base of HCFCs and HFCs is equivalent to 3.6 billion CO_2-equivalent metric tons today, mostly in use as refrigerants. Globally, it is approximately 24 billion.[2]

The primary global environmental policy on fluorocarbons is implementation of the Montreal Protocol, which focuses on gradual reductions in the production, import, and use of these gases in the future. To date, however, the policies have not gone to sufficient lengths to prevent emissions, and thus environmental harm, from the HCFCs and HFCs of the past, *i.e.*, those already out in the world.

A global phasedown of HFCs has recently begun under the Kigali Amendment to the Montreal Protocol. The American Innovation and Manufacturing (AIM) Act, enacted by Congress in December 2020, implements it in the United States.

But barebones implementation of the Kigali Amendment and other Montreal Protocol requirements doesn't go far enough, neither in the United States nor the rest of the world. For example, by 2050 the prescribed HFC reduction schedule will have allowed 3.6 billion CO_2-equivalent metric tons to be sold into the U.S. market, effectively doubling from today's levels the potential climate harm requiring mitigation.[3] The HCFCs and HFCs of the past, and the HFCs that have yet to enter the market must not leak into the atmosphere. **If we meet this opportunity to prevent emissions from existing equipment, we'll avert as much warming as *two years* of President Biden's economy-wide greenhouse gas annual emissions target for 2030**. The numbers are even greater globally, where these transitions are earlier in their processes: 61 billion CO_2e metric tons by mid-century and 91 by century's end (cumulatively).

There is a huge opportunity for chemical producers, equipment manufacturers, federal and state policymakers, major corporations, and maintenance professionals to come together to prevent as much of these potent chemicals as possible from making it into the atmosphere. This report makes a first attempt at laying out the starting point for an approach, referred to here as **Lifecycle Refrigerant Management (LRM).**

> **“In total, the U.S. installed base of HCFCs and HFCs is equivalent to 3.6 billion CO_2-equivalent metric tons today, mostly in use as refrigerants. Globally, it is approximately 24 billion.”**

LRM focuses on avoiding and reducing refrigerant leaks, promoting refrigerant recovery, and increasing reclamation rates to mitigate unnecessary refrigerant use and emissions. The U.S. Environmental Protection Agency (EPA) has ample authority under the AIM Act to successfully pursue many aspects of LRM. The recently passed Inflation Reduction Act also provides significant additional funding to implement and operationalize the AIM Act and other opportunities to advance LRM including through green bank programs, heat pump and efficiency incentives. Many of the measures described here should be considered for adoption by EPA as the AIM Act and the IRA are operationalized.

EPA cannot do it alone, however. Successful LRM will rely on a variety of stakeholders each playing distinct roles: regulators setting mandates, legislatures and other well-resourced entities offering financial incentives, and industry members adapting their practices in favor of the types of interventions we recommend in this paper.

Nor can the U.S. alone collectively meet the 91 billion metric ton opportunity – not even close. Global leadership on LRM is badly needed, and for the U.S. to serve that role, action must start at home.

We identify six pillars to the LRM approach described in brief here.

1 **ENHANCE PRODUCT STEWARDSHIP.** Most LRM best practices – leak repair, refrigerant recovery and proper disposal – must be ultimately carried out by the entity least responsible for introducing those materials into the economy: service professionals. Government or private entities can set up programs to help increase the responsibility of those higher up the supply chain, such as chemical producers and equipment manufacturers, to provide for economically and technically feasible LRM. This may be arranged voluntarily at first, or mandatorily, and is a good candidate for a pilot state program.

2 **INCREASE REFRIGERANT RECOVERY, RECLAMATION AND REUSE.** At the end of an appliance's life, the refrigerant should be recovered and sent to a company that cleans and resells it, a process called reclamation. Reclamation relies on refrigerant recovery for a steady supply of refrigerant so emphasis must be placed on making recovery of old refrigerant at end of life economical and enforceable. The reclamation industry itself needs investment and expansion to meet growing demand. Companies and regulators should require that certain equipment use only reclaimed refrigerant, whether by voluntary commitment or mandate, to increase demand for reclaimed refrigerant.

3 **LEAK REDUCTION.** If they are not well maintained, cooling appliances leak refrigerant slowly but continuously. Targeting low leak rates is an extremely high priority for LRM because they can lead to large climate benefits at low cost. Companies should pursue operational emission reductions as voluntary targets, and regulatory requirements should ensure that systems meet minimum standards. In some cases, leak reduction incentives by electric utilities may be appropriate. Operators and technicians should also adopt best practice leak monitoring and repair practices.

4 **REPORTING AND ENFORCEMENT.** Stakeholders frequently report that a lack of enforcement aids and abets improper LRM practices in the field, including violations of existing law regarding refrigerant management. Redoubled effort to monitor and enforce LRM provisions, with modernized technologies and approaches, is needed to ensure fair play and an even playing field for all.

5 **WORKFORCE DEVELOPMENT.** A well-trained, specialized workforce is the bedrock of LRM. Technicians that handle refrigerants should be recertified by EPA based on the latest standards of practice, with ongoing learning and development opportunities to follow. LRM is also a critical cornerstone of efforts to reduce the emissions footprint of buildings, an opportunity that calls for a concerted approach to recruiting and retaining talent.

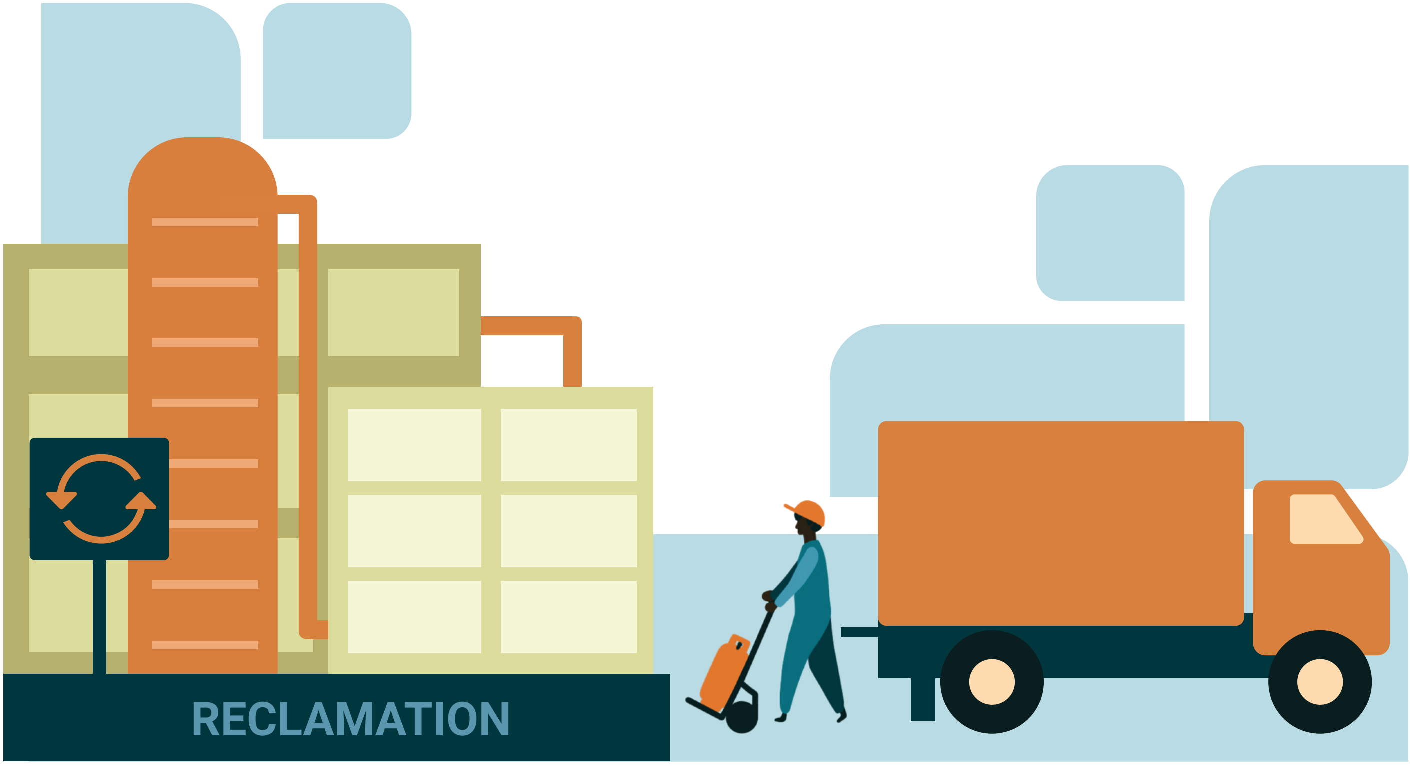
6 **INSTALLATION AND SERVICING.** Installation is the starting point of HVACR equipment's life, and LRM cannot be achieved without proper installation and verification. Servicing practices, such as the widespread technique of topping up leaky systems without repairing the underlying leaks, should be discouraged and avoided whenever possible.

> **In brief, installation, leak reduction, and recovery all need to be improved for residential systems, commercial system owners and operators should focus on reducing operational leaks, and the vehicle industry should focus on limiting use of small refrigerant cans and emissions upon vehicle disposal.**

Within these six pillars, myriad policies and actions are available to advance LRM through regulatory actions, financial incentives, and voluntary action by the private sector. Each system category calls for a different mix of these approaches. In brief, installation, leak reduction, and recovery all need to be improved for residential systems, commercial system owners and operators should focus on reducing operational leaks, and the vehicle industry should focus on limiting use of small refrigerant cans and emissions upon vehicle disposal. In each sector, much greater use of reclaimed refrigerant is needed. It is also of first and foremost importance that stakeholders in every sector adopt climate-friendly new equipment whenever a product is being replaced; this report, however, focuses on reducing emissions from older equipment prior to replacement, so this issue is not discussed at length here.

Each of these outcomes should be pursued through a mix of regulatory, incentives-based, and voluntary leadership programs. The extent to which these approaches are regulatory in nature, for example, EPA or state agencies should take the lead in implementing them. EPA has clear authority to promulgate regulations addressing LRM under the AIM Act in addition to expanding existing and new voluntary partnership programs.

Simultaneously, state agencies can lead on innovative approaches to LRM that may eventually pave the way for new federal policies. Similarly, companies have a role to play in piloting beneficial approaches to help build the evidence base of achievable and practical refrigerant management interventions. Some of the following concepts are also well suited to corporate commitments and should become a pillar of corporate sustainability programs.



Introduction

Preventing the atmospheric release of refrigerants, many of which are thousands of times more powerful than carbon dioxide at warming the planet, yields significant climate benefits.[4]

In the United States, minimizing leaks from refrigerators and air conditioners and ensuring the recovery, reclamation, and destruction of refrigerants at equipment end of life could avoid the atmospheric release of 9.2 billion metric tons of CO_2-equivalent ($GtCO_2e$) by 2100.[i] Globally, refrigerant management could avoid the gradual release of up to 91 $GtCO_2e$ this century — nearly three times global energy-related carbon dioxide emissions in 2019.[5]

Addressing leaks and recovery of refrigerant complement the benefits of phasing down new HFC production under the Kigali Amendment to the Montreal Protocol, which alone is expected to avoid 80 $GtCO_2e$ through 2050 globally.[6] The benefits of refrigerant management are additional to the benefits of the phasedown.

Significant reductions in refrigerant emissions are technically and economically feasible. In many cases they can be accomplished with existing federal and state legal authority. Domestically, it is a readily achievable and significantly impactful opportunity for U.S. climate leadership. Internationally, this is an area of potentially significant future policy interest under the Montreal Protocol. However, many of the challenges for successfully managing refrigerants are very different in the developing world than in the U.S. This report focuses on U.S. opportunities as a first step towards a redoubled international effort to meet the opportunity.

This report was prepared by experts from several prominent environmental groups in consultation with a variety of industry stakeholders to start a dialogue and to catalyze action in the United States on **Lifecycle Refrigerant Management (LRM)**. The ultimate objective of LRM is to ensure that no molecule of refrigerant, once produced, is released into the atmosphere.

This report details many of the best strategies, techniques, requirements, and practices for pursuing LRM at federal and state levels through regulatory and non-regulatory means and, in the private sector, through environment, social, and governance (ESG) initiatives and other voluntary programs.

The contents of this report are intended as a starting point for federal and state policymakers, particularly at the U.S. Environmental Protection Agency (EPA) as the agency looks to wield the considerable authority granted to it by Congress under the AIM Act specifically for the pursuit of LRM.

As stated in subsection (h) of the AIM Act, "[f]or purposes of maximizing reclaiming and minimizing the release of a regulated substance from equipment … [EPA] shall promulgate regulations to control, where appropriate, any practice, process, or activity regarding the servicing, repair, disposal, or installation of equipment … ."

This plenary authority to phasedown hydrofluorocarbons (HFC) and the immediacy of the opportunity for U.S. climate leadership from Congress underscores both the importance of LRM to achieving the policy goals in the United States and on the international stage.

Time is of the essence. The HFC phasedown will drive near-term demand for reclaimed refrigerant to unprecedented levels, creating a singular opportunity over the next several years for LRM to achieve its full potential as a climate mitigation tool.

The time is also ripe for increased global action, an opportunity the U.S. has the chance to seize and advance. The measures in this report are not sufficient to transform the whole globe towards successful LRM. However, to be an effective champion of LRM, every stakeholder in the U.S. must first set about adopting best practices here at home.

The commencement of federal and state regulatory proceedings for LRM will smooth the transition in the refrigerant market to climate-friendly substitutes, focus the attention of the private sector on integrating LRM into ESG initiatives, and jumpstart global engagement on this issue at the Montreal Protocol. **But to fully realize LRM's significant climate benefits and support a smooth start to HFC reductions under the AIM Act, new regulatory programs and other efforts must be finalized no later than the start of 2024.**

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[i] 1 gigaton (Gt) = 1 billion metric tons. Based on author calculations, see "Essential Background".

Essential Background

A 91 GIGATON U.S. CLIMATE LEADERSHIP OPPORTUNITY

Preventing the atmospheric release of ozone depleting substances (ODSs) and HFCs yields significant climate benefits, above and beyond those of the Kigali Amendment. With a U.S. commitment to tackle its own refrigerant management challenges and with a global diplomatic push to put in place the necessary support framework for other nations to do the same, emission reduction targets around the world could be met and enhanced through LRM.

Table 1: Cumulative future bank of ODSs[7] and HFCs [8], emissions of which may be avoided through proper LRM (In addition to benefits of the Kigali Amendment)

ODS & HFC Refrigerants ($GtCO_2e$)	Current	Through 2050	Through 2100
United States	3.6	6.9	9.2
Global	24	61	91

In the United States, the current ODS and HFC bank within existing appliances amounts to approximately 3.6 $GtCO_2e$ – roughly equal to tailpipe emissions from about half of U.S. passenger vehicles each year. By 2050, total volumes of ODSs and HFCs double from today's level, rising to approximately 9.2 $GtCO_2e$ by 2100.

A robust LRM regime would make it possible to prevent the release of a significant portion of the approximately 61 $GtCO_2e$ of ODSs and HFCs in use or expected to be produced by 2050. By 2100, the global total rises to approximately 91 $GtCO_2e$ – nearly equal to three full years of global energy-related carbon dioxide emissions today.

The United States can seize a significant new leadership opportunity by demonstrating LRM at home, speeding the country's attainment of its national, economy-wide 2030 emission reduction target of 50 percent of 2005 levels – and championing it in international forums.

THE ROLE OF RECLAMATION IN PREVIOUS REFRIGERANT TRANSITIONS

Over the last 35 years, the Montreal Protocol has prioritized constraining upstream production and consumption of ODSs such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons, and generally not acted to mitigate the atmospheric impact of fluorocarbons already produced and circulating in the economy.[9]

This was not without reason, as leak repair and recovery can sometimes bedevil national and sub-national regulators, given the difficulty in crafting appropriate financial incentives and enforceable requirements for the many millions of air conditioners, refrigerators, and other appliances out there and the many thousands of contractors that service them. It is easier to police chemical producers and importers that are far fewer in number.

But the Kigali Amendment to the Montreal Protocol's phasedown of HFCs, now underway in the United States and throughout most of the rest of the world, changes the game considerably, particularly for the recovery, reclamation, and destruction of refrigerants.

With ODS refrigerants, the gradual but accelerating production and consumption phase out created markets for substitutes that did not deplete the stratospheric ozone layer – namely, HFCs. Back then, reclamation was a relatively straightforward technical process that sustained older equipment through end of life, providing a respectable commercial model for small businesses on the margins of the fluorocarbon transitions of the

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1990s and early 2000s. These businesses then received a modest boost in the 2010s with the advent of carbon offset methodologies for CFC and HCFC destruction.[10]

THE ROLE OF RECLAMATION IN THE TRANSITION AWAY FROM HFCS

The HFC transition presents materially different circumstances for recovery and reclamation. The Kigali Amendment's phase*down*, rather than phase*out*, reflects the current technological reality that many HFC substitutes still, in fact, contain HFCs, but are either blended with other substances to produce compounds with lower global warming potentials (GWPs) or which are themselves pure, lower-GWP species of HFCs. In both cases, previous-generation refrigerants can and should be recycled into the next generation, a practice that should be much more predominant than during previous transitions.

The HFC phasedown is thus an important occasion the reclamation industry must rise to. There will be challenges. For example, on the technology side, the reclamation equipment needed – which must be able to separate complex collections of gases, including ODSs and HFCs returned in a single tank – is becoming increasingly sophisticated, with separation technologies evolving to the point that few small businesses have the capital to build or maintain and operate at scale.

The game is also changing for equipment owners, operators, and technicians. For a variety of reasons, prior transitions haven't resulted in sufficient incentives to properly install and maintain heating, ventilation, air conditioning, and refrigeration (HVACR) equipment with very low leak rates, or to always recover refrigerant at end of life.[11] This is true despite requirements under Sections 608 and 609 of the Clean Air Act[12] placing some limits on the leakiness of equipment and a blanket prohibition on venting refrigerant, whether an HFC or an ODS is at hand. Indeed, leaking and venting ODS and HFC refrigerants has been common practice simply because it's cheaper and easier than doing the right thing.[13]

Today, there are growing economic benefits of minimizing leaks and maximizing reclamation. As the phasedown gets underway, HFC prices have begun to rise and, with them, so has the incentive to hang on to the HFCs you do have – to repair your leaks – and to recover refrigerant during major repairs or at the end of equipment life. For those avoiding leaks, a penny saved is a penny earned, and reclaimers can also earn a good margin selling reclaimed HFCs.

The incentives to plug leaks and reclaim will redouble under the ambitious slope of the HFC phasedown schedule, which calls for a step down to 60 percent of the baseline period beginning in 2024.[14] The market for HFCs will be tight in that year and for the next few, as the production and import of newly produced HFCs are constrained while high volume refrigerant-using sectors such as stationary air conditioning and commercial refrigeration transition en masse in the mid-2020s to lower GWP refrigerants. The market signals will be unambiguous and unrelenting: over the next 15 years, leak mitigation and a growing supply of reclaimed HFCs will ease demand for virgin HFCs and moderate the impact of the phasedown on prices.

> **"Previous-generation refrigerants can and should be recycled into the next generation, a practice that should be much more predominant than during previous transitions."**

For the reclamation industry, these signals call for investment in the advanced equipment for separation and purification of more complex chemical compounds, which are necessary for a major expansion of domestic reclamation capacity in the coming years. For commercial owners of refrigeration and air conditioning (AC) equipment, the market is calling for investments in improving system leak tightness to avoid the wasteful practice of purchasing increasingly costly and scarce refrigerant to replace gas that has leaked out and to maximize the benefit of the refrigerant recovered at equipment end of life.

Regulatory intervention is also critical, both to raise the profile of reclamation and leak reduction as legitimate policy tools in the fight against climate change and to kick the aforementioned drivers of investment and other market incentives into gear.

Indeed, the authority provided in the AIM Act shows that Congress recognized the limitations in the current regulatory landscape and desired EPA to take whatever steps as may be necessary for reclamation and leak reduction to play a central role in the HFC phasedown. Destruction, too, has a part to play in ensuring that once a refrigerant cannot be reclaimed further or is no longer needed, that few, if any, remaining ODSs and HFCs find their way into the atmosphere.

Lifecycle Refrigerant Management (LRM)

OVERVIEW

At its heart, the principle underlying LRM is simple: every molecule of refrigerant, once produced, should be prevented from making its way into the atmosphere.

LRM is predicated on the recovery and reclamation of used refrigerants over the course of a refrigerant transition, allowing their reuse in servicing existing equipment and also in new equipment. As a result, it hinges chiefly on the proper handling of refrigerants to minimize atmospheric releases, such as through leaks or from venting during servicing or at equipment end of life. It also depends on the destruction of refrigerants when they are no longer able to be reclaimed or are otherwise no longer needed.[15]

In practice, LRM means preventing and plugging leaks in refrigeration and air conditioning equipment and, at equipment end of life, recovering the refrigerant and either reclaiming it for reuse or destroying it completely.

LEAK REDUCTION

Refrigerant gases are emitted in the largest volumes from two main stages in the life cycle: operational refrigerant leaks from existing refrigeration and air conditioning equipment and disposal of equipment at the end of their useful life.[16]

Reducing leaks is a primary pillar of LRM. For many equipment types, more than half of all refrigerant used in the equipment over the course of its life is lost to leaks and thus not available for recovery and reclamation. For leaky, large installations, such as commercial refrigeration systems, the figure can be many times that: for example, a facility that leaks 25% of its refrigerant annually (an oft-quoted number for supermarket systems) will leak out *five times as much refrigerant* over the course of its life as will be available to recover at when it is eventually retired. If we can't stop leaks, then we can't achieve LRM.

Installation is also a factor to consider, mainly because proper installation is the starting point of a unit's leak tightness performance. Proper installation is critical for the unit to maintain leak tightness and energy efficiency throughout its life. But improving installation practices only helps going forward; it doesn't help mitigate the risk of all the equipment already installed in the field, which is principally where the most potentially harmful fluorocarbon banks are to be found.

RECOVERY

Before a refrigerant can be reclaimed and reused, it first must be recovered from existing equipment and transported to a reclaimer. Recovery would typically happen during a major equipment servicing event or at the end of its life. But, in many cases, there are other priorities at the time – such as removing large equipment and quickly installing a replacement – and refrigerant is vented to the atmosphere rather than properly collected.

Venting is direct harm to the environment, but – importantly – recovered gas is also the raw material needed for production of reclaimed refrigerant. The biggest potential untapped source of recovered gases today is equipment being retired at end of life. Overcoming the barriers to widespread proper recovery and return of old refrigerant gas is also a primary pillar of LRM and of this report.

RECLAIM

Reclamation is the re-processing and upgrading of a recovered controlled substance through such mechanisms as filtering, drying, distillation and chemical treatment in order to restore the substance to a specified standard of performance.

Federal law mandates that reclaimed refrigerant must reach at least the purity specified in the AHRI Standard 700-1993 specifications and then be verified before it can be sold.[17] This process must be done by an EPA certified reclaimer.[18] Reclamation requires specialized machinery not available at a particular job site, so generally technicians will recover the refrigerant and then send it either to a reclaimer or back to the refrigerant manufacturer.

There are around 50 Certified Reclaimers in the United States. The vast majority are small businesses, spread across 25 states. In 2020, EPA reported approximately 14 million pounds of fluorocarbon gases had been reclaimed.[19] HFCs accounted for 5.5 million pounds.

This represents just 17 percent of the estimated 33 million pounds of HFC refrigerants potentially recoverable from retired U.S. equipment in 2020.[20] The quantity of potentially recoverable HFCs is anticipated to grow to over 50 million pounds by 2025, with the largest growth segment coming from residential stationary air conditioning.[21]

For ODSs, which have been widely used as pure substances, the reclamation process is fairly easy. Pure substances are typically filtered, dried, tested to ensure they meet the target specifications and then resold. Since these substances are essentially single molecules when recovered, there is no need to separate different types of molecules from one another prior to purification and resale.

However, typically a certified reclaimer will receive a range of recovered refrigerants – CFCs, HCFCs, and HFCs – and, often, comingled in the same cylinder. Reclaiming from this mix involves a process known as fractional distillation, whereby various temperatures and pressures are used to separate one type of refrigerant molecule from another. The individual "streams" of single refrigerant types can then be collected into separate vessels for further blending or resale.

For HFCs, fractional distillation is required in virtually all cases, given that most HFCs are blends of three or more individual compounds. The exception is refrigerant used in mobile air conditioning systems (which are typically single-component, e.g., HFC-134a or HFO-1234yf) that can be recovered and recycled at auto repair facilities with proper equipment.

Fractional distillation relies on the boiling point and gas vapor pressure differences between all the refrigerant molecules. For example, at one specific temperature and pressure one type of refrigerant molecule will boil and "split away" as a vapor from the others that require different temperatures and pressures to boil. The first boiling refrigerant type can be collected as a pure vapor, and then condensed into a pure liquid. This separation of components can continue in the same way, utilizing different temperatures and pressures for the other components of the original mixture.

Fractional distillation, commonly referred to as separation, is typically performed in large, vertical cylindrical columns known as "distillation or fractionation towers" or "distillation columns" with varying diameters and heights. The distillation towers have liquid outlets at intervals up the column which allow for the withdrawal of different fractions or products having different boiling points or boiling ranges.

In a separate step, the components can then be blended into industry standard refrigerant blends. Virgin or reclaimed pure makeup gas is often added to rebalance blends to the appropriate ratios but should not be used to dilute impurities until the specified purity standard is reached.

DESTRUCTION

For any refrigerant gas that is not emitted directly to the atmosphere – and none should be – the ultimate end of life phase is destruction. Destruction of a fluorocarbon means using any of a variety of processes to convert the fluorocarbon into CO_2, HX, or X2 (X = Br, Cl, F).[22] The latter two molecular forms are not organic and thus not generally considered to be persistent in the environment, but they can be highly toxic.[23] As a result, great care should be taken to avoid potential health impacts of stack emissions at destruction facilities on surrounding communities.

Several destruction methods have been developed and approved for use during the phaseouts of ODSs, including incineration, destruction via other manufacturing processes such as cement making, submerged combustion, plasma, catalytic dehalogenation, superheated steam reactions, and more. U.S. EPA has also evaluated and approved these techniques for ODSs and, more recently, HFCs. To be approved by EPA, destruction efficiency must exceed 99.99 percent.[24] Only a subset of these can permissibly be used to destroy HFC-23, the most strongly bonded HFC molecule.

As the HFC phasedown gets underway, destruction of HFCs may initially be limited, with a heavier focus on reclamation and reuse to service the installed base. However, ultimately, scaling up destruction will be essential to avoiding most emissions and must be closely considered and integrated into policy measures designed to tackle LRM. Policy interventions may be needed to make scaled up destruction economically sustainable as an alternative when reclamation is not practical. In the near term, there should be a strong focus on destruction of remaining ODSs, where a shrinking installed base of equipment is nearing retirement.

This report does not provide an exhaustive investigation into issues related to fluorocarbon destruction. Additional work may be needed to shed light on the various comparative advantages and disadvantages of different approved fluorocarbon destruction technologies and to the potential risks to human health and the environment that those may present.

Cross-Cutting Actions & Opportunities for LRM

Many approaches to advancing LRM are general in nature and can be applied to many facets of the refrigerant-using industry. This section of the report presents policy recommendations and other opportunities that cut across various sectors of refrigerant use. These include measures that promote leak reduction as well as the recovery, reclaim, and, where appropriate, destruction of refrigerants as part of a broader LRM regime.

PRODUCT STEWARDSHIP

Product Stewardship, often referred to as extended producer responsibility, is an environmental management strategy holding that whoever designs, produces, sells, or uses a product takes responsibility for minimizing its environmental impact throughout all stages of the product life cycle, including end of life management. Responsibility is shared, but the greatest responsibility lies with whoever has the most ability to affect the full life cycle environmental impact of the product. This is most often the producer of the product, though all within the product chain of commerce have roles.

The refrigerant value chain is a long sequence that starts with chemical manufacturers and then passes to original equipment manufacturers (OEMs), distributors, contractors and HVACR professionals, and ends with consumers and service technicians. At each point in this value chain, a product with potential to damage the climate is being sold and bought, without any reasonable expectation that it will be subsequently recaptured and properly disposed of. In practice, it falls to the service technicians at the end of the chain – arguably the least powerful of these entities – to bear the cost of recovery. It should come as no surprise that this rarely works as planned.

A common approach to encouraging recycling is the payment of an upfront deposit that is then returned upon recycling the product. This concept may offer a powerful tool to this effort to incentivize refrigerant recovery. Similar product stewardship programs have been specifically employed with refrigerants in other countries to increase recovery, reclamation and destruction.

A major barrier to recovering a large quantity of used refrigerant gas is the inherent cost in person-hours to recover it and transport it to a suitable wholesaler (and, eventually, reclaimer or destroyer). A sufficiently large reward for doing so could go a very long way in making sure it happens. Without such a reward the economics are loaded against success; labor and transportation costs are high, while refrigerant costs (and thus value) have historically been quite low.[25]

One approach to incentivizing recovery and defraying costs could include a deposit/refund scheme requirement for bulk retail refrigerant sales by distributors and wholesalers. Recovered refrigerant returned to refrigerant distributors would receive a refunded deposit or credit toward future sales, while deposits would be retained by distributors for unreturned quantities that have been emitted. Unreturned deposit funds would be earmarked to pay for costs associated with collection, transport, reclamation, and destruction.

> **“One approach to incentivizing recovery and defraying costs could include a deposit/refund scheme requirement for bulk retail refrigerant sales by distributors and wholesalers.”**

Another approach would be to establish a pool of funds that helps internalize the costs of recovering ODSs and HFCs as well as certain other costs associated with transport, reclamation, and destruction. This pool of funds would be paid into by those extracting value from the sale of the gas and paying out to those obligated to recover, collect, and recycle/dispose of it. Such a program could be set up by mandatory regulation or voluntarily by self-interested parties, driven by the desire, for example, to reduce the carbon impact of a company’s operations. EPA’s broad authority to manage refrigerants under the AIM Act is sufficient to entertain regulatory actions of this nature.

Extended producer responsibility programs where manufacturers and distributors agree to take back or assume responsibility for recovered refrigerant at the end of a product's life could also help to mitigate intentional refrigerant venting, by providing technicians with a place to take contaminated refrigerant without having to assume financial responsibility for its disposal.[26] Such practices already in place in some jurisdictions worldwide should be evaluated by and incorporated into ESG metrics for companies whose products contain HFCs or ODSs. Reclaimers could play a prominent role in administering this type of program, as they are the entity at the end of the refrigerant recovery chain.

A smart incentive could also be implemented that would reward the technicians and technician companies that have performed well on refrigerant recovering metrics reported to EPA under the AIM Act. EPA, for example, collects data from technicians on rates of disposal for HFCs and ODSs, and also refrigerant delivered to reclaimers. EPA could evaluate all verified reports of disposed refrigerants and pay a cash reward to those entities returning the most recovered refrigerant, or those who most increase the amounts recovered (*i.e.*, the most improved player). In addition to the monetary incentive, the rewards should be made public to advertise both the companies' performance and the benefits of best practices. The benefit of positive publicity would add to the appeal and reach of the incentives.

EXPAND RECOVERY & RECLAIM CAPACITY

The U.S. reclamation industry is transitioning from simpler, ODS-oriented reclamation technologies to more sophisticated fractional distillation approaches, which are necessary to reclaim HFCs.

Fractional distillation requires both a technology investment in distillation expertise and capital investment in separation towers. As yet, most certified reclaimers have not invested in this process and, as a general matter, lack the capital assets or technological capacity to do so. Most are small businesses with limited capacity to invest.

Current total reclamation production across the 50 certified reclaimers in 25 states is a fraction of what will likely ultimately be needed during the HFC phasedown. Additional capacity can be brought online fairly quickly – constructed in less than a year, for example – and so can be flexible in growing in capacity to meet the expanding scale of the need. Ideally, HFC reclamation capacity would grow in lock-step with the gradually increasing supply pressure of the HFC phasedown.

As the HFC phasedown begins, there is not yet enough reclamation capacity (in the form of fractional distillation towers) to keep up with the projected spike in demand for reclaimed refrigerant. Even if there were enough capacity, there would likely not be enough raw, used refrigerant arriving at reclamation facilities to make use of it. Policy interventions must therefore be two-pronged, and support simultaneously the expansion of fractional distillation capacity and the proper recovery and return of used HFCs.

> **"Policy interventions must therefore be two-pronged, and support simultaneously the expansion of fractional distillation capacity and the proper recovery and return of used HFCs."**

Federal and state government, as well as private stakeholders have a role to play in bolstering recovery and reclamation of refrigerant and can consider the following cross-cutting measures as a starting point.

FINANCIAL & TECHNICAL ASSISTANCE. Financial assistance to support this transition and expansion of the reclamation industry would greatly speed up the process and ensure a positive outcome. Technical assistance may have a role to play, as fractional distillation is more complex than preceding techniques. Financial support may be more directly impactful, including loan guarantees or low-interest financing on expanded distillation tower capacity.

REDUCE EMISSIONS DURING RECLAMATION. There is evidence of substantial emissions of ODSs and, to a lesser extent, HFCs, from several U.S. refrigerant reclamation companies. The vast majority of these emissions can be traced to "downpacking" (*i.e.*, where the gas contents of large cylinders are repackaged into multiple smaller cylinders) and storage. At a typical reclamation facility, used refrigerant – the raw material for reclamation – waits in storage prior to being reclaimed, potentially for a significant period of time. Large storage vessels have pressure relief valves that need to be periodically checked, maintained, or replaced in order to avoid risk of rupturing. Reclaimers should put in place an ongoing process to monitor refrigerant inventory and perform routine preventive maintenance on all storage vessels to avoid failures resulting in fluorocarbon emissions. Further, EPA should consider requiring such maintenance practices of certified reclaimers.

RECLAIM NODA. As a useful predicate to any expanded effort to promote LRM, EPA should seek to bolster its data regarding how much end users of refrigeration and air conditioning equipment utilize reclaimed refrigerant, either when servicing or as a primary source of refrigerant for the equipment — or both. EPA should issue a Notice of Data Availability (NODA) to collect data and determine how much each user of refrigerants relies on reclaimed refrigerant.

The primary targets for this NODA would be entities with significant refrigeration and/or air conditioning footprints, such as supermarket chains or commercial building owners. A secondary target would be equipment manufacturers themselves, particularly with regard to reliance on reclaimed refrigerant to charge equipment. EPA should further work to track this information in the future.

> **"A requirement to use reclaimed refrigerant instead of virgin material in a specific sector or sub- sector would go a long way towards building a market for reclaimed refrigerant and avoiding unnecessary emissions of virgin HFCs."**

RECLAMATION RATIO. The reclaiming process involves the use of some virgin refrigerant, with reclaimers varying, potentially widely in the ratio of new-to-reclaimed refrigerant they use. As noted, virgin or reclaimed pure makeup gas is often added to rebalance blends to the appropriate ratios but should not be used to dilute impurities until the specified purity standard is reached.

Although the scarcity of virgin refrigerant imposed by the HFC phasedown will encourage efficient use of virgin material for reclamation, it would be wise to eliminate the practice of blending larger quantities of virgin components with recovered refrigerants to dilute impurities, and instead provide support for the growth of the reclamation industry. While such an approach may initially prove a cost-effective way to reuse recovered material, this would be undesirable in that it would discourage the needed increased investment in fractional distillation capacity and limit a potential market transformation toward using as close as possible 100% reclaimed refrigerant.

EPA and other regulators may therefore want to consider imposing a reasonable guardrail in the form of a maximum cap on the ratio or percentage of virgin material by weight of refrigerant advertised as having been "reclaimed." Such a guardrail should balance the needs and fractional distillation capacity of both large and small reclaimers for a certain amount of virgin material to be used in restoring to the specification needed for various HFC blends. In the case of the California Air Resources Board's recent consideration of requiring some reclaimed refrigerant use in new equipment, a cap of 15% virgin refrigerant content by weight was delineated.[27] At a minimum, EPA and other regulators should closely monitor the quantities of virgin material being used in production from reclamation as part of its monitoring of HFC production and consumption and discourage the practice of blending recovered refrigerant.

REQUIRED USE OF RECLAIMED REFRIGERANT IN EQUIPMENT. A requirement to use reclaimed refrigerant instead of virgin material in a specific sector or subsector would go a long way towards building a market for reclaimed refrigerant and avoiding unnecessary emissions of virgin HFCs. Such an approach is consistent with the AIM Act authorizing EPA to restrict "fully, partially or on a graduated schedule, the use of a regulated substance in the sector or subsector… ."[28] Regulatory requirements should be put in place requiring that reclaimed refrigerant be charged into a portion of or certain types of equipment, such as air conditioners and refrigeration products.

RECLAMATION IN NEW EQUIPMENT. A reclamation requirement for new equipment will further help mitigate the climate impact of sectors that are transitioning away from very-high-GWP substances to mid-GWP substances as part of the HFC phasedown. Air conditioning and heat pumps are a good example of this: HFC-32 and R-454B, the two most likely candidates for next-generation refrigerants, are comprised mostly (100 percent and

69 percent, respectively) of HFC-32, a constituent (50 percent) of the previous-generation R-410A. It would be far preferable for that HFC-32 to be reclaimed from old R-410A than newly produced.

To date, it has been very uncommon to use reclaimed refrigerant in new equipment shipped from the factory. The reasons are several, including the fact that the generation of refrigerants in equipment reaching end of life is not the same as the current generation refrigerants. Another potential reason is concerns about purity. These are, however, unfounded. Unlike virgin refrigerants, which have not been required to meet a particular purity standard until finalization of the recent EPA allocation rule, reclaimed refrigerant in the U.S. must meet AHRI 700 purity specifications and have needed to for a long time.[29] Use of reclaimed refrigerant in new air conditioners and heat pumps has also been successfully executed on a voluntary basis in Europe.[30]

> **“To date, it has been very uncommon to use reclaimed refrigerant in new equipment shipped from the factory.”**

The California Air Resources Board has finalized a similar requirement under its Refrigerant Recovery, Reclaim, and Reuse Requirements (R4) Program.[31] It will require air conditioning manufacturers to utilize reclaimed refrigerant equivalent to 10-25 percent of their total use of HFC-410A during the years 2023, 2024, and 2025, leading up to the mandatory transition to lower-GWP substances.[32] Although this only requires that manufacturers "purchase and use" reclaimed refrigerant in a certain amount and does not specifically require it be charged into new equipment, it is anticipated that meeting the requirement will involve some amount of reclaimed refrigerant use in new equipment, whether factory or field charged.

A federal requirement regarding mandatory use of reclaimed refrigerant in new equipment should be long-term and designed primarily to utilize components of recovered R-410A from the air conditioning sector, although it may also be applied in other sectors. Under such a requirement, manufacturers of air conditioning or refrigeration equipment would be required to purchase and use a certain proportion or quantity of recovered and reclaimed substances in their overall HFC consumption. The required proportion of reclaimed use would be based on an assessment of the availability of recovered and reclaimed substances in a given sector or subsector. Manufacturers would report on reclaimed refrigerant use and be subject to third party verification of the same.

Such an approach would help bolster reclaimed refrigerant use among equipment manufacturers, growing the reclaim market beyond its existing use mainly in the servicing sector. New equipment not using HFCs that are components of older generation refrigerants (e.g., R-410A components) would naturally be exempt from any such requirement, which may also serve as an additional incentive to manufacturers to transition to climate-friendlier substitutes more quickly.

RECLAMATION IN EXISTING EQUIPMENT. Regulatory bodies can also consider prohibiting virgin HFC use above a certain GWP limit for servicing existing high-volume refrigeration or air conditioning equipment. This approach has similar advantages to that regarding new equipment, but has the potential disadvantage of placing the requirement on the servicing sector and/or end user. Under such a program, use of virgin refrigerant would be prohibited at a certain date, and reclaimed refrigerants would continue to be permitted for a longer, but finite, period of time. For example, in the European Union, a ban on virgin HFCs with a GWP greater than 2500 in refrigeration equipment containing more than 40 tonnes CO_2e refrigerant was implemented beginning in 2020, wherein the use of reclaimed HFCs is permitted until 2030.[33] This approach reduces consumption of virgin high-GWP HFCs while encouraging use of reclaimed refrigerants and retrofit/replacement of equipment with lower GWP alternatives. Such requirements restricting the use of virgin refrigerant should also be considered for servicing existing automotive air conditioning equipment given the availability of recoverable HFC-134a.

The intent of such prohibitions is not to make existing equipment obsolete, but rather to discourage investment in new HFC-containing equipment where alternatives already exist. The graduated approach will bolster reclamation in the near term and allow end-users to adopt better and newer technologies in their future equipment investments.

REFRIGERANT PROCUREMENT AND EQUIPMENT PERFORMANCE STANDARDS. Large purchasers and operators of buildings and vehicles using HFCs and ODSs should set refrigerant procurement standards and existing equipment performance standards to enhance life cycle refrigerant management. Entities in this category include the federal and state governments, private companies, other private and public organizations such as academic institutes, and others.

In this section, "refrigerant procurement standards" mean commitments to purchase large quantities of reclaimed refrigerant. Broader refrigerant procurement standards should also focus on purchase of new equipment using low-GWP refrigerants, which has been their area of focus historically. "Equipment performance standards" means leak characteristics and disposal practices related to existing refrigeration and air conditioning installations.

> **Large purchasers and operators of buildings and vehicles using HFCs and ODSs should set refrigerant procurement standards and existing equipment performance standards to enhance LRM.**

There are two chief aims of taking this approach. First, as with several other approaches in this section, commitments to purchase large quantities of reclaimed refrigerant (*e.g.*, by committing to service equipment only with reclaimed refrigerant) is valuable as a demonstration of growing market demand for reclaimed substances. With such demand demonstrated, reclamation companies will be more easily able to secure investment capital for additional fractional distillation capacity and other expansion aspects. As noted, using reclaimed refrigerant also ultimately displaces demand for virgin refrigerant, which is a net environmental benefit.

Recent updates to the U.S. Federal Acquisition Regulation (FAR) have incorporated improved refrigerant management and the use of reclaimed (instead of virgin) HFCs as examples of sustainable procurement.[34] Contractors are now required to keep track of and report on the amounts of HFCs added or removed during routine maintenance, service, repair, and disposal of all government equipment, appliances, and supplies. The reporting requirement applies only to equipment or appliances normally containing 50 pounds or more of HFCs or refrigerant blends containing HFCs. Publication of data and information on initial results and impact of these changes and potential for future impact would be an encouraging next step.

For further procurement guidance, institutions and companies may look, for example, to recent guidance from the Sustainable Purchasing Leadership Council, a group of over 160 organizations with global reach and $600 billion in collective purchasing power, which published an updated guide in 2021.[35] This guide advises corporations to (1) adopt an HFC policy that incorporates responsible refrigerant management (including the use of reclaimed refrigerant wherever possible), and (2) to specify low-GWP refrigerant alternatives when purchasing or replacing equipment.

LEAK REDUCTION

LEAK RATE TARGETS. Performance standards for existing equipment – e.g., standards governing leak rates and disposal practices – have the potential to immediately reduce refrigerant emissions and subsequent demand for refrigerant to fill leaky systems. There is significant room for improvement in this area; as noted, major appliance categories leak as much as 1-5 times their proper full refrigerant charge over the course of their lifetimes.[36]

But not every facility is so bad. For example, roughly one-third of the commercial refrigeration installations nationwide maintain leak rates of *half* the national average.[37] This pool of facilities with a good leak performance can be expanded by regulations and incentives that aim to normalize the best practices they use to drive down their leaks. EPA has in the past applied maximum leak rates to large facilities using ODSs and, for a time, HFCs, although regulations on the latter have since been repealed.[38]

This topic will be explored in much greater depth in the next section of this report, which addresses each sector of equipment in detail.

VALVES, FITTINGS, AND JOINTS. Most ODS and HFC leaks occur at valves, fittings, or joints of refrigeration and air conditioning equipment. Thus, they present a good thematic area of LRM to consider unto themselves.

In this case, solving the small problems can go a long way to reaching the bigger goal. For example, there is evidence that a changeout of all fittings in a commercial refrigeration facility – not, in and of itself, a particularly expensive or difficult task – is the single most cost-effective way to reduce refrigerant emissions.[39] Identifying incentive-based or regulatory opportunities to require this type of retrofit can help entities get it done. It's a win-win, due to its low cost and high benefit of reducing costly refrigerant refills because of leaked-out refrigerant.

Relatedly, the first place to check a residential air conditioner for leaks is the brazed joints connecting refrigerant lines to indoor or outdoor equipment. Flared connections, a new type of connection that does not require brazing, are increasingly being used on high-efficiency air conditioning products to avoid brazing-related heat damage. However, removing brazing from the process – which avoids the chance of a faulty brazing job by a technician – may introduce its own basket of leak problems due to the lack of a metal-metal connection. Flare fittings may be likelier to loosen over time, increasing the chances of refrigerant leaks.[40] VRF-style commercial and residential systems can use dozens of flared connections, the failure of any one of which would result in a high degree of loss of refrigerant charge. More recently, non-flared compression fittings have been introduced in some models that obviate the need for special flaring tools.[41] The performance of these should similarly be evaluated.

Schrader valve failures are also frequently cited as a source of leaks from residential air conditioning equipment. Brass or steel Schrader valve caps, which are one part of the two-stage sealing process, are more resistant to contamination and thus more reliable.[42] A program to combat this with regular replacement or redesign would yield major dividends.

ENFORCEMENT

A robust enforcement mechanism is necessary to bolster refrigerant recovery practices in particular, and also to ensure compliance with all future regulatory requirements regarding LRM.

Enforcing the venting prohibition is particularly important and warrants redoubled attention. EPA can use the data it will now be collecting under the AIM Act to facilitate its enforcement approach in several ways. For example, currently, U.S. reclaimers are required to report the quantity of refrigerant they receive each quarter. In addition, at the end of each year reclaimers must report to EPA the quantity of each regulated substance held in inventory.[43] EPA, in other words, will have very good insight into how much refrigerant is flowing through reclaimers.

EPA today calculates a closely related value – how much refrigerant is available for recovery each year as appliances are retired – as part of the bottom-up "Vintaging Model."[44] EPA can compare the data received from reclaimers about the quantities of recovered refrigerant they are receiving to the value that the agency "expects" these reclaimers to receive based on the Vintaging Model. When significantly less recovered refrigerant reaches the reclaimers, EPA should investigate the situation more closely, including by evaluating any technician reports and/or records that may be material to the discrepancy.

Such a top-down/bottom-up verification approach could greatly improve EPA's understanding of rates of noncompliance with the venting prohibition. As it sets up such a program, EPA should also consider what penalties might be appropriate for noncompliance with the venting prohibition, such as monetary fines, certification penalties or ultimate revocation of Section 608 certification.

"A robust enforcement mechanism is necessary to bolster refrigerant recovery practices in particular, and also to ensure compliance with all future regulatory requirements regarding LRM."

EPA should consider extending the reporting requirements in place for reclaimers to wholesalers as well and include it in the comparative analysis described to better characterize the refrigerant supply chain and add a layer of enforcement.

Such an automated top-down/bottom-up verification approach could give EPA much better time resolution on potential noncompliance. As it sets up such a program, EPA should also set penalties for noncompliance with the venting prohibition, such as monetary fines, certification penalties or ultimate revocation of certification.[45]

Improved market intelligence would also help identify and halt incidents of noncompliance stemming from repeated bad actors. A system that collects anonymous tips or whistleblower complaints about violations of the venting prohibition should be set up, with matching enforcement resources to follow up on potential incidents. This type of intelligence gathering has helped officials around the world implement the Montreal Protocol since its inception, but to date has not been trained on this particular aspect of the issue.

TECHNICIAN CERTIFICATION & WORKFORCE DEVELOPMENT

U.S. HVACR technicians are required to undergo official certification. EPA currently requires that any person who maintains, services, repairs, or disposes of equipment that contains refrigerant must be certified following the requirements of section 608 of the Clean Air Act.[46] Technicians need to be certified once and are not required to undergo continuing education or training, and certifications are rarely, if ever, suspended or revoked.

> **“Technicians need to be certified once and are not required to undergo continuing education or training, and certifications are rarely, if ever, suspended or revoked.”**

UPDATED TRAINING COURSES. In many cases, refrigerant regulations, industry best practices, and the characteristics of refrigerants have changed significantly since initial certification and will continue to advance into the future. In particular, the widespread adoption of climate-friendlier, ozone-safe refrigerants – many of which bear an ASHRAE 2L flammability rating – will necessitate greater care on the part of regulators and industry to ensure safe working conditions for technicians and, in turn, safe products for consumers. To keep up with these advancements, training materials must be refreshed to include the latest updates to safe handling practices and the potential environmental, health, and safety impacts of various refrigerants.

Continuing education requirements for technicians to maintain their certification status would also be helpful to maintaining a skilled workforce, including additional online coursework, practicums, symposium attendance, and more. For example, every five years technicians could be asked to complete a short online course covering the latest updates in the sector and then take an online exam to maintain their certification status.

TECHNICIAN RECERTIFICATION. Periodic recertification for technicians to maintain their certification status should also become mandatory. At the very minimum, technicians should be required to recertify once in the near future to become adept at use of flammable refrigerants. Because certification has financial cost associated with it, there is an opportunity for philanthropic foundations or even private enterprises to provide no- or low-cost training materials. In the case of enterprises providing low-cost certification, newly certified technicians could reimburse the program upon securing a job based on that certification, as is currently a trend in other industries such as computer programming. Those technicians who are recertifying could pay a reduced fee, as is often the case with renewals of a variety of types of registrations and certifications.

TECHNICIAN AWARENESS RAISING. It is also important to build servicing industry awareness on the environmental and climate impact of refrigerants as well as the important role that technicians play in mitigating refrigerant emissions. Recovery best practices appear to be covered in some training materials; however, it is unclear how widespread use of those particular materials is.

ENFORCEMENT. There are also areas in which more concerted efforts at enforcement of regulations would help mitigate emissions. First, a system of penalties against one's certification, such as driver license points, for infractions related to HVACR servicing could be an important deterrent of bad behavior. Enforcement against entities may also need to increase, for example against online refrigerant retailers that sell to anyone rather than only certified technicians.

EMISSIONS WARRANTIES

The cost of HVACR leak inspection and repair is largely borne today by the end-user – that is, the homeowner or business – who, more likely than not, has little interest or expertise in refrigerant management and is generally sensitive to cost. And it is expensive, driven by the high cost of labor and, to a lesser extent, replacement parts.

Significant reductions in environmentally harmful emissions have been achieved in a different sector, motor vehicles, through regulations stipulating that emissions control systems be warrantied for a lengthy period by OEMs. In part, this program worked by placing a financial incentive in front of OEMs to make durable, low-emissions systems that need little servicing or maintenance. A similar opportunity is at hand in this industry.

Additionally, current equipment warranties provided by the manufacturer only cover parts and may not cover the whole system (*e.g.*, they may only cover the compressor). The cost of labor and refrigerant are not covered under manufacturer warranties. In some cases, a labor warranty may be offered by an HVACR manufacturer, but that's not always the case. Third party extended warranties and labor warranties offered by HVACR contractors may cover leak inspections and repairs. OEMs and technicians thus have the opportunity to gain a competitive advantage by expanding the scope of these warranties in the absence of further regulation in this area.

> **"Significant reductions in environmentally harmful emissions have been achieved in a different sector, motor vehicles, through regulations stipulating that emissions control systems be warrantied for a lengthy period by OEMs."**

Warranties can play an important role in encouraging regular compliance with servicing requirements and reduce barriers to cooling access. However, uncertainty around the scope, compliance requirements, and availability of warranties results in low adoption, leaving consumers perplexed and exposed to unanticipated repair costs. If they do not already, equipment manufacturers should, at a minimum, communicate the different coverage aspects of their warranties clearly to empower consumers to choose which available warranties best cover their needs. Manufacturers should also consider extending their warranties to cover labor and equipment costs for leak repairs before any potential regulatory program requiring it.

Inflation Reduction Act & HFCs

The Inflation Reduction Act (IRA) presents important opportunities to accelerate HFC emission reductions and improve LRM. It allocates over $38 million under the AIM Act, including $15 million for competitive grants for reclaim and innovative destruction technologies. EPA should also consider how to leverage funding for implementation and compliance tools to improve LRM, including new reporting and enforcement initiatives. HFC reductions and LRM should be fully integrated into implementation a number of other climate provisions under the IRA, such as deployment of funds for green banks and technology acceleration, heat pump and energy efficiency initiatives, Department of Energy financing for GHG mitigation, and others.

TABLE 2: Inflation Reduction Act Funding Opportunities to Reduce HFC Emissions and Enhance Lifecycle Refrigerant Management

IRA PROVISION	SUMMARY
AIM Act implementation **§ 60109**	• Implementation funds for the AIM act phasing down HFCs: $20 million through 2026 for EPA to carry out 42 U.S.C. § 7675(a)–(i), (k) • $3.5 million to deploy new implementation and compliance tools • $15 million for competitive grants for reclaim and innovative destruction technologies
Greenhouse gas reduction fund **§ 60103** **Department of Energy loans** **§ 50141**	• $27 billion for rapid deployment of low- and zero-emission technologies to spur 'green banks' or 'technology accelerator' programs across the country. $7 billion of this funding is directed to state, local and nonprofit entities to enable low-income and disadvantaged communities to deploy GHG-saving technologies, and $20 billion is directed to nonprofits leveraging private investment to spur green banks or accelerator programs to reduce emissions, of which $8 billion should go to low-income or disadvantaged communities. • Department of Energy is authorized to guarantee loans under 42 U.S.C. ¬ß 16513, for up to $40 billion for projects that avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of greenhouse gases • Implementers may wish to consider accelerating replacement of high-GWP equipment with low-GWP energy efficient technology, such as low-cost loans to grocery stores to make the switch to low-GWP equipment, or grants or forgivable loans to small or independent grocers serving low-income or disadvantaged communities to replace high-GWP equipment.
Heat pumps and efficiency incentives for buildings **§ 30001, § 13301, § 13302, § 13303**	• Provides $500 million to implement defense production act requirement for increased heat pump manufacturing, and increases tax incentives for heat pumps and other commercial and residential efficiency improvements. • Implementers may wish to consider encouraging manufacturers to utilize low-GWP refrigerants when scaling up heat pump production.

IRA PROVISION	SUMMARY
Reducing Air Pollution at Ports **§ 60102**	• $2.25 billion is appropriated to the Administrator of the EPA to award rebates/grants to purchase/install zero-emission port equipment and to develop climate action plans, with an additional $750 million appropriated to award grants/rebates with respect to ports located in designated areas covered by § 107 of the Clean Air Act. • Implementers may wish to consider opportunities to replace high-GWP equipment related to the cold chain, such as cold-storage facilities and equipment associated with ports.
Transportation and Infrastructure; Advanced technology vehicle manufacturing **§ 60501** **§ 50143**	• $1.893 billion is appropriated to the Administrator of the Federal Highway Administration to issue competitive grants relating to various transportation improvements, including grants related to the construction of tech/infrastructure to reduce transportation-related air pollution. • Implementers may wish to consider opportunities to replace or update high-GWP equipment related to the cold chain, such as refrigerated trucks. • $2 billion for grants to produce efficient hybrid, plug-in hybrid, electric, and hydrogen fuel cell vehicles under 42 U.S.C. 16062. • Implementers may wish to consider opportunities to encourage vehicle producers to use low-GWP refrigerants in heat pumps critical to EV thermal management for batteries and passenger cabins.
GHG air pollution plans and implementation grants & GHG reporting **§ 60114, § 60111**	• $250 million for EPA to issue grants to States for plan development, $4.75 billion to competitively implement plans. • $5 million for EPA to support enhanced standardization and transparency in corporate climate action commitments and plans to reduce GHG and progress. • Implementers should assure that HFC emissions are included in plans and reporting and encourage LRM.

LRM in Residential Refrigeration, Air Conditioning & Heat Pumps

Residential air conditioning is among the highest, if not the highest, single contributing sectors to overall HFC emissions through leaks and venting.[47] These systems are thus also among the largest sources of HFCs that may be tapped as a stream of recovered refrigerant to be reclaimed.

The residential sector also presents the greatest challenges for proper refrigerant management. Installation, servicing, and maintenance are performed by technicians with widely varying degrees of skill and training, often in harsh conditions, quickly, and with limited oversight, commissioning, or ability to observe the finished product operate over a period of time. Properly recovering refrigerant during servicing and end of appliance life is also much more labor intensive than simply cutting the refrigerant lines and letting the gas go.

To avoid unnecessary climate damage, ensure that these systems run efficiently, and reduce HFC demand for servicing, solutions for this critical sector are needed. This section of the report presents solutions tailored to this important sector's challenges. The measures proposed here cover the full lifecycle of residential appliances, from better installation, leak detection and repair practices to appropriate disposal at end of life.

DESIGN & INSTALLATION

Two important factors affecting appliances' susceptibility to leaks are manufacturer design and installation practices. First, broadly speaking, build quality matters. Better fittings, hoses, connections, compressor shaft seals & heat exchanger designs can help mitigate leaks. The residential equipment manufacturing sector could be encouraged to replicate best practices followed by other industries that have developed industry rating systems to estimate refrigerant leakage (*e.g.*, SAE J2727 for motor vehicles[2]). Then, even though certain installation recommendations may be provided by the equipment manufacturer, ultimate responsibility falls on the HVACR contractor to install equipment following best practices. The proposals that follow aim at strengthening installation practices to ensure leak-resistant systems.

Leak-resistant performance is important going forward even as lower-GWP refrigerants are introduced because next-generation alternatives continue to have significant GWP (~500-750) and are mildly flammable.

i. REGULATORY MANDATES & REPORTING

DESIGN & MANUFACTURING. Although typical split air conditioning systems must be field-installed and charged, most components of residential cooling systems are actually preassembled by OEMs. OEMs should take concrete steps to minimize their systems' proclivity to refrigerant leakage, including by pressure testing or other comparable steps. A review of common leak sources in residential ACs suggests, for example, that many metal joints within the indoor and outdoor refrigerant coils themselves are not strong enough and typically fail over years of exposure to operational vibration, weather, etc. Better fittings, hoses, connections, compressor shaft seals & heat exchanger designs can help mitigate leaks. Extended producer responsibility for refrigerants or mandatory emissions-related warranties would help increase manufacturer attention on these issues.

TIGHTNESS VALUE AND TESTING FOR NEW INSTALLATIONS. Improper installation practices result in leak-prone systems. A properly installed system will likely have fewer leaks throughout its useful life. To ensure consistent best practices in equipment installation, environmental regulators should devise and require minimum quality standards for installation. For example, EPA could establish a minimum refrigeration circuit tightness value and require practices such as pressure testing at high pressures for long wait times and pipe dehydration before refrigerant is added to the circuit. Values for new residential installations would then be reported to EPA along with other refrigerant-related data that technicians must keep. EPA already has broad authority to regulate installation under subsection (h) of the AIM Act, which it could rely on to establish these standards.

COMMISSIONING. More ambitious installation requirements would yield significantly greater benefits.

[2] SAE International is a global standard setting organization for specific applications, including motor vehicles.

For example, best, though rare, practice is to "commission" residential air conditioning systems. Commissioning is done, however, for most commercial systems. General commissioning would evaluate performance well beyond aspects directly related to refrigerant system performance, including parameters such as duct tightness, vibration isolation, airflow delivery, sizing, and more. Routine commissions would deliver major additional benefits to system energy performance, and applicable regulations should be devised in coordination with energy efficiency authorities, or the Department of Energy (DOE) in the U.S. context.

IOT-PLATFORM FOR REPORTING. To track and enforce these practices and standards, internet-of-things (IOT)-enabled tools could be developed to streamline reporting more easily. Refrigerant gauge sets, for example, that communicate with the cloud could allow technicians to validate and report the vacuum performance of newly installed HVACR systems to demonstrate that they comply with a minimum tightness value. Approaches like these could be piloted by "reach" or "green" energy codes before being scaled for widespread adoption.

REPORTING OF BAD INSTALLATIONS. Since appropriate installation practices are crucial in ensuring leak-resistant systems, government agencies could establish an accountability mechanism where technicians can report equipment discovered at point of service that appears to not be installed in accordance with manufacturing guidelines. This information could reveal trends in inappropriate installation practices that need to be addressed and help agencies identify potential actors who are not complying with the requirements.

ii. FINANCIAL INCENTIVES

Financial incentives have often focused on rewarding homeowners, or the contractors and/or distributors who supply systems to homeowners, for selecting or selling more energy efficient equipment. However, growing awareness of the importance of proper installation to the energy efficient operation of air conditioning and heat pump systems has led some financial incentive programs (typically sponsored by utilities) and voluntary programs, such as ENERGY STAR Verified HVAC Installation (ESVI), to target proper installation instead of just equipment energy rating.[48] These quality installation programs could provide an excellent opportunity to address refrigerant best practices too, given that loss of refrigerant charge leads to significant loss in efficiency.[49] Such programs often address issues such as proper refrigerant charge but can and should be expanded to include best practices for minimizing leaks, and a refresher for technicians on proper use of refrigerant recovery/recharge equipment as required by law.

iii. PRIVATE SECTOR & OTHER VOLUNTARY PROGRAMS

OEM DESIGN. Equipment manufacturers can demonstrate corporate leadership by committing to manufacture equipment that meets or exceeds high energy efficiency standards while also utilizing refrigerants with the lowest feasible global warming potential and with the lowest possible leakage rates. Manufacturers can also work with their distribution networks to assist in the collection and reclamation or disposal of refrigerant and play a key role in educating technicians around the best possible practices to install and maintain systems to minimize refrigerant leaks.

> **Manufacturers can also work with their distribution networks to assist in the collection and reclamation or disposal of refrigerant and play a key role in educating technicians around the best possible practices to install and maintain systems to minimize refrigerant leaks.**

Voluntary programs – such as ESVI, which is jointly run by EPA and DOE – should pay more careful attention to proper refrigerant management; companies that purchase such equipment and utility energy efficiency programs can then be encouraged to adopt and require such practices. Complying installers could be rewarded with recognition and contract preference for doing so.

Several commercial air conditioning and heat pump models in Europe and, increasingly, Japan include automatic leak detection and IOT-enabled daily reporting.[50] As those technologies mature and reach economies of scale, they should be introduced in residential-focused equipment as well. In particular, variable refrigerant flow systems, which bear a higher price tag to start with and may pose a greater risk of major leak events, should incorporate these technologies as soon as is practicable.

These leadership approaches are particularly important prior to the introduction of regulatory measures requiring them.

SERVICE & MAINTENANCE

Refrigerant leaks during an equipment's useful life must be meaningfully addressed to avoid unnecessary refrigerant emissions.

i. REGULATORY MANDATES & REPORTING

RESTRICTIONS ON TOPPING OFF REFRIGERANT. Topping of refrigerant – *i.e.*, refilling a system that presumably has refrigerant leaks without fixing those leaks – is bad practice for the environment and, in the long run, the consumer. Thus, sensible restrictions should be placed on the recharging of equipment. Unless a leak check has been completed and any leaks have been repaired, technicians should not top off systems, as a general matter. To this end, for example, EPA could require that a system being evacuated for work must undergo a pressure test to demonstrate that the system meets a certain allowable tightness value and report the value to the IOT-enabled system. This would not address systems not being evacuated, however.

> **"Topping of refrigerant – i.e., refilling a system that presumably has refrigerant leaks without fixing those leaks – is bad practice for the environment and, in the long run, the consumer."**

DISCLOSURE OF SERVICING OPTIONS TO CUSTOMERS. An outright ban on topping off may prove not cost effective in all cases. Requiring consumers to bear the higher upfront costs to repair a system may pose a concern for equitable cooling access. Depending on the system, its location, and the location of the leak, an inspection and repair may be financially burdensome, especially if the expense was unanticipated. EPA should consider a requirement that servicing personnel provide owners with a written disclosure that informs the equipment owner of their options, including the cost to conduct a leak check and for the potential repair, alongside potential long term cost implications of not repairing the system (*e.g.*, ongoing refrigerant top off service call costs, risks of catastrophic compressor failure, *etc.*). EPA can specify a standard disclosure and require that servicing companies maintain records of such disclosure being provided to the customer.

Another strategy, already discussed in detail in the cross-cutting section, is to require the use of reclaimed refrigerant when servicing existing equipment. This action can reduce consumption of virgin high-GWP HFCs while encouraging use of reclaimed refrigerants.

END OF LIFE

Appliances often reach the end of their useful life with refrigerant still contained in the refrigeration circuit. This refrigerant must always be recovered and disposed of appropriately under U.S. law; however, only in a small minority of instances is this actually done.[51] EPA estimated in 2016 that this practice results in annual emissions of 960 ODP tons and 49.5 MMTCO_2e from mid-sized appliances (between 5-50 pounds of refrigerant charge).[52]

There are several barriers to proper disposal of residential appliances. Chief among them is that recovering refrigerant from cooling equipment is more difficult than the alternative, which is simply to open the valves or cut the lines and let the refrigerant escape to the atmosphere. For decommissioning residential units, vacuum pumps and tanks must be carried to the site and time spent pumping down refrigerant. The system must be further processed back at the technician's shop, and then the old refrigerant aggregated and taken to a refrigerant wholesaler or reclaimer, which in many cases charge fees for disposal.

There are additional challenges for "white goods" (movable, plug-in appliances), which are otherwise not the focus of this section. First, consumers are not always aware of the environmentally harmful nature of the refrigerant and other materials contained in their equipment, so do not take appropriate precautions as to where they dispose of them. Secondly, information about appliance disposal and who is responsible for it is often hard to come by. Thirdly, recycling services often charge consumers for pick-up and disposal. Consumers often choose to abandon the appliances or dispose of them in the local landfill. These barriers must be lifted to ensure that all appliances are disposed of safely and in an environmentally conscious manner.

i. REGULATORY MANDATES & REPORTING

In many jurisdictions, releasing ODSs and HFCs is prohibited. In the United States, venting ODSs and HFCs is prohibited by the Clean Air Act's "venting prohibition," found in section 608. EPA in 2016 imposed several requirements to shore up compliance with the venting prohibition, which applies to both ODSs and HFCs. Although that regulation faced legal challenge and partial rollback in 2020, these particular requirements have remained legally in force and continue to do so following the 2020 final revision regulation promulgation.[53] These rules require that service technicians maintain records of appliances disposed of and quantity of refrigerant, type, destination, and more. EPA further explained in that regulation that it would subpoena records kept by technicians in the event that it discovers other evidence that noncompliance is occurring.

As previously noted, under the AIM Act, EPA will now also be receiving reports from reclaimers about how much used refrigerant they are receiving, which should be equivalent to the sum of all the technician reports of refrigerant quantities properly disposed of.[54] EPA should use a top-down/bottom-up approach and compare these two figures – the refrigerant totals technicians report bringing to reclaimers, and the used refrigerant totals reclaimers report receiving – to make sure all entities are properly reporting. EPA should further compare these reports to what quantity of disposed-of refrigerant it would 'expect', based on the Vintaging Model, which tracks exactly these types of market trends with very high precision. Whenever sufficient inconsistency arises, EPA should investigate the situation as one of possible noncompliance.

FEES ON APPLIANCES TO COVER DISPOSAL. Separate from this discussion of refrigerant disposal, appliances themselves have limited value at end of life, comprised largely of the value of scrap metal and a few other materials. As noted, however, proper disposal has associated costs incurred by the disposal company or retailer who picks-up the old appliances. Government agencies can require that a modest fee be added at the time of purchase to cover end of life refrigerant management costs. This upfront fee decreases the incentive for consumers to violate disposal rules. Alternatively, disposal costs could be built into the cost of appliances. In both cases, it's important to ensure that the fees collected directly or indirectly are made easily available to the technicians and distributors responsible for recovering and transferring the refrigerant to reclamation or destruction facilities.

> **"In regions that have instituted deposits on refrigerant or extended producer responsibility schemes, refrigerant recovery rates are higher than in other regions, such as the United States, where such financial incentives are generally absent."**

ii. FINANCIAL INCENTIVES

As long as AC technicians have an economic incentive to vent instead of recover refrigerant, venting is highly likely to continue, even if it is prohibited by law or regulation. Clever rewards programs could help boost refrigerant reclamation rates. For example, rewarding technicians and technician companies that perform best with regards to end of life disposal may help encourage better practices. Workforce development funding may also be appropriate.

Financial incentives designed to encourage technicians to recover instead of vent refrigerant could prove transformational in this sector and increase compliance with laws prohibiting refrigerant venting. In regions that have instituted deposits on refrigerant or extended producer responsibility schemes, refrigerant recovery rates are higher than in other regions, such as the United States, where such financial incentives are generally absent. To be effective, such financial incentives must be significant enough to cover the incremental costs to AC companies, including: additional technician time and labor to collect refrigerant, incremental refrigerant recovery equipment costs, and fees associated with return of refrigerant for reclamation, if any.

UTILITY PROGRAMS. Utilities in the United States spend over $5 billion annually on energy efficiency programs and incentives.[55] Historically, utility funded programs to remove inefficient appliances that over-burdened the grid have been successful in incentivizing appropriate disposal of refrigerant. Those programs have waned in recent years, however, since many of the most inefficient appliances have been removed from the appliance stock. But these programs may be set for a revival: the country's largest utility regulators, such as the California Public Utilities Commission, have recently mandated that efficiency program administrators must also incorporate refrigerant GHG impacts in their program design and evaluation.[56] Until recently, utilities could not count the GHG benefits from helping customers reduce high-GWP refrigerant emissions toward their program's benefits and cost-effectiveness requirements; with California's new order, that has changed.

The strongest incentives in the United States have been those with clear and detailed websites, responsive help-lines, large and permanent rebates (typically in the $40-$50 range), and eligibility to dispose of more than one appliance per year. Any utility program that provides incentives for the replacement of refrigerant-containing appliances must include a requirement for proper recovery of the refrigerant in the system being retired and strive to include all these characteristics that have made some of these programs successful. Successful reboots of these programs may also find additional sources of value, which could include the value of the refrigerant as a source for reclamation.

INCENTIVES FOR REFRIGERANT RECOVERY EQUIPMENT. Financial support to help deploy the necessary physical infrastructure for widespread refrigerant recovery, transport, and reclamation could be very beneficial. Recovery equipment appears to be needed widely across the HVACR servicing industry, and so too investments to shore up the reclamation industry itself and equip its member companies with suitable capacity.

There are some recent examples. The AIM Act authorized $5,000,000 annually for the period between 2021 and 2023 for grants to be given to small businesses to purchase recovery, recycling, and reclamation equipment for mobile air conditioning.[57] This incentive is important for bolstering the ability for recovery and processing of refrigerant while alleviating capital expense burdens for small businesses who may need to upgrade their equipment to meet the new requirements under the phasedown. Government incentives for similar aspects of refrigerant management could be beneficial.

iii. PRIVATE SECTOR & OTHER VOLUNTARY PROGRAMS

PRODUCER RESPONSIBILITY/TAKE BACK PROGRAMS. Voluntary corporate initiatives around extended producer responsibility that can be undertaken by a range of actors including refrigerant producers, wholesalers, equipment manufacturers, servicing companies, and retailers to recover refrigerants have been discussed previously in more detail under crosscutting measures.

INFORMATION TO CONSUMERS ON DISPOSAL & RETAILERS' ROLES. Most of this report focuses on professionally-installed HVACR equipment, which is largely handled by dedicated technicians. For white goods, which consumers typically dispose of themselves, clear, succinct and easily accessible information around disposal will drive more consumers to responsibly get rid of their old appliances. Retailers are well-suited to provide this information since they are the main entity within the supply chain that interacts directly with consumers. Retailers should package information about local incentives and proper disposal practices at the point of purchase. HVACR retailers can also equip service technicians with simple information stickers or refrigerator magnets to place on existing refrigerant containing equipment after servicing that gives contacts and instructions for proper disposal. In addition, retailers should collect old appliances upon the sale of a new refrigerator or air conditioner. This type of program has proven useful in the United Kingdom and the United States where some retailers that participate in the EPA Responsible Appliance Disposal (RAD) program offer to collect and recycle your old appliance if you purchase a new one from them.[58,59]

CREATE DATABASE OF DISPOSAL PRACTICES & CONTACTS. Companies should coordinate with national and local agencies to create a database for useful contacts and instructions. A simple QR code displayed on informational material, stickers, magnets, and retailer stores can link consumers to that database where they can seamlessly find how to dispose of their equipment.

LRM in Commercial Refrigeration, Air Conditioning & Heat Pumps

Commercial cooling equipment includes large refrigeration systems (*e.g.*, supermarkets), stationary air conditioning systems (*e.g.*, large multi splits, variable refrigerant flow (VRF)), and building chillers. These large, expensive and complex systems are professionally designed and installed and contain many dozens, hundreds, or—in the case of large supermarket refrigeration systems—several thousand pounds of refrigerant. Existing federal policies such as the Significant New Alternatives Policy (SNAP) rules prohibit the use of high-GWP HFCs in most new commercial refrigeration systems and several low-GWP alternative technologies are available in the market.[60] These factors, in combination with the HFC phasedown currently underway, will result in fewer new high-GWP installations in the coming years.

However, systems are often in use for decades, and large systems like supermarket systems typically leak 25 percent of refrigerant annually, so it is crucial to reduce refrigerant leakage from existing large commercial systems, especially in the retail food sector.[61,62] Although these systems require professional design and installation, they are often maintained less rigorously than they should be, especially at smaller businesses.

> **“Next generation commercial air conditioning such as VRF systems also present new challenges in this space, as they contain large volumes of refrigerant circulating throughout the whole system.”**

Under Section 608 of the Clean Air Act, EPA has placed requirements capping allowable leak rates, calling for periodic leak checks, and more, applicable to these equipment classes. As of today, the most significant of these requirements apply only to ODS-containing systems; regulatory revisions extending the requirement to HFCs were previously in effect but rolled back for a variety of legal and political reasons. Now, equipped with expansive authority to regulate HFC management under the AIM Act, EPA should turn its attention to regulating existing sources in this sector.

Next generation commercial air conditioning such as VRF systems also present new challenges in this space, as they contain large volumes of refrigerant circulating throughout the whole system. Proper installation and maintenance will be crucial to avoid leaks, and both manufacturers and regulators should ensure that there are strict leak prevention requirements in place for these systems.

DESIGN & INSTALLATION

Installation of commercial-scale equipment, both for refrigeration and air conditioning, tends to be of a higher quality than in the residential sector. There are a number of reasons for this, but they mostly follow from the fact that larger projects require greater sophistication in engineering, planning and execution, must meet additional regulatory and permitting requirements, and other related factors.

The design and system types chosen for commercial systems, however, can potentially be a strong driver for future leak tightness performance. For example, large centralized remote refrigeration systems involve significant refrigerant piping and joints and are more prone to having high leak rates than a distributed or micro-distributed system which relies more heavily on self-contained, or standalone, equipment. During the design engineering phase, it is important to make system-level decisions that will result in less proclivity to refrigerant emissions throughout a system's life.

Commercial air conditioning design choices can also significantly impact future leak tightness performance. Large, centralized chiller plants managed by professional building staff tend to be less leak-prone than rooftop air conditioning units, which are exposed to the elements, a variety of vibrations, and other factors that contribute to high leak rates over time. Another system type, VRF systems, are comprised of a web of dozens to hundreds of indoor fan coils, connected by up to thousands of feet of refrigerant piping, each of which has several flare connections, a type of piping connection that is at elevated risk of leaking over time if not properly installed. And, in a VRF system, a leak anywhere in the system results in the possibility of the entire system's refrigerant charge being leaked out. VRFs, perhaps above all other system types, require careful design, installation, and servicing.

i. REGULATORY MANDATES & REPORTING

Today there are a number of regulations governing design and installation of commercial systems. In general, building code certification, permitting, and new system commissioning is required by local jurisdictions for these types of installations.

EPA also maintains a list of refrigerants that are permissible for use in new and retrofitted commercial refrigeration systems under the Significant New Alternatives Policy (SNAP) Program.[63] EPA is also expected to be revising the permissible list of refrigerants in response to petitions from stakeholders as part of a broader effort to establish so-called "sector-based controls" under the AIM Act.[64]

> **Additionally, utilities are an emerging potential source of financial incentives to help large commercial customers transition to low-GWP refrigerants in advance of regulatory deadlines.**

New regulatory requirements for installation of commercial refrigeration and HVAC equipment would go a long way towards ensuring that proper practices are followed. EPA should use its section (h) AIM Act authority to set in place mandatory guidelines for installation of commercial refrigeration and HVAC systems similar to those outlined in the section of this report focused on residential equipment, but tailored to the commercial sector.

ii. FINANCIAL INCENTIVES

Financial incentives to help large commercial systems transition to low-GWP refrigerants, particularly in supermarkets, have started to emerge. For example, California established the F-Gas Incentive Program (FRIP) which promotes the voluntary adoption of new, climate-friendly, low global warming potential refrigerant technologies.[65] The first round of FRIP grants supported the food retail sector's transition to lower global warming potential refrigerant technologies. Increased funding, if approved, would expand its offering and impact.[66] The California Air Resources Board, which administers FRIP, also put together a guide to financial assistance for large refrigerant users.[67]

Additionally, utilities are an emerging potential source of financial incentives to help large commercial customers transition to low-GWP refrigerants in advance of regulatory deadlines. Until recently, utilities could not count the GHG benefits from helping customers reduce high-GWP refrigerant emissions toward their program benefits and cost-effectiveness requirements, but that is starting to change.

iii. PRIVATE SECTOR & OTHER VOLUNTARY PROGRAMS

Similarly to residential systems, equipment manufacturers should take concrete steps to minimize their systems' proclivity to refrigerant leakage. In the commercial refrigeration sector where store layout and design can differ considerably, this could involve work to develop a common set of guidelines and best practice industry standard for leak tight systems. A similar exercise could benefit commercial air conditioning systems as well. Where feasible, such industry guidelines should be incorporated into other net-zero building standards encompassing cooling and heating systems.

As noted, some commercial air conditioning and heat pump products include automatic leak detection and IOT-enabled reporting. As this technology appears nascent at this time, manufacturers should consider adopting these technologies to keep ahead of the curve and in anticipation of customers becoming more demanding on climate-related product performance.

SERVICE & MAINTENANCE

As noted above, on average, commercial refrigeration systems lose 25 percent of their refrigerant charge per year.[68] With over 63,000 supermarkets and grocery stores across the country,[69] this is a major sector that must grapple with how to best minimize leaks. Since emissions from these types of equipment occur primarily during the operational phase of their lives, several of the following recommendations focus on minimizing those releases.

> **Industry has demonstrated time and again that significantly lower leak rates are achievable, beneficial for system performance, and cost effective.**

i. REGULATORY MANDATES & REPORTING

Section 608 of the federal Clean Air Act imposes leak repair requirements for systems containing an ODS refrigerant charge over 50lbs. At a minimum, all requirements under section 608 should be expanded to apply to systems using ODSs and HFCs. Both refrigerant categories have significant environmental impact and measures to avoid their release to the atmosphere should apply to both. Relatedly, California's Refrigerant Management Program sets leak rate standards for large refrigeration systems (>50 pounds) using either ODSs or HFCs but does not do so for large air conditioning systems.[70] That program and similar state-level ones should address both classes of equipment.

PROACTIVE LEAK MITIGATION & PERIODIC CHECKS. Proactive leak mitigation strategies such as replacing small diameter copper lines or minimizing flare connections can address system weaknesses that are prone to leaks. Currently, EPA regulations require periodic leak inspections every three months to a year only once a system has exceeded a trigger rate and until it is demonstrated that the system isn't leaking over the trigger rate for over a year. This measure is lax as it only applies to systems that exceed a certain, and large, leak rate. EPA should do away with refrigerant leak thresholds and instead require owners and operators of large refrigeration and air conditioning systems to put in place good refrigerant management practices regardless of baseline leak rates that enable proactive leak detection and repair before small leaks become major ones.

Industry has demonstrated time and again that significantly lower leak rates are achievable, beneficial for system performance, and cost effective. Several food retailers have demonstrated that lower leak rates can be achieved with the right corporate policies in place.[71] Reportedly, more than 33 percent of the retail food market is already reporting leak rates under 12 percent, with companies like Giant Eagle and Meijer reporting leak rates as low as 7-8 percent.[72,73,74] Commercial systems should be required to undergo periodic leak inspections (e.g., monthly) to catch leaks early, prior to system failure. Leaks often start small and increase over time. In addition, when leak checking a large system such as a supermarket the entire system must be leak checked since several leaks may be occurring simultaneously. Leak tests should always check points in the system that have a high probability of leaking and require the regular replacement of Schrader valve caps, tightening TEV stems and replacing caps and o-rings (neoprene o-rings shrink or swell depending on type of refrigerant and tightness) and elbows since thermal expansion and vibration reduce their durability.[75]

For commercially owned air conditioning and refrigeration equipment, and in particular large multi-split designs such as VRF systems that may be prone to larger leaks, EPA could make leak repair prior to recharging systems mandatory. Similar to the recommendation for residential appliances, it could be required that a system being evacuated for work must undergo a pressure test to demonstrate that the system meets a certain allowable tightness value and report the value to the IOT-enabled system.

AUTOMATIC LEAK DETECTION. Regulatory bodies could also consider establishing universal leak detection requirements, such as installation of automatic leak detection systems (ALDS). Similar requirements are in place in California, and in several countries including the European Union.[76] ALDSs should be made mandatory by a certain date for systems containing a refrigerant charge over 300 pounds, as well as high probability leak systems for comfort cooling (e.g., VRFs). EPA can work with leak detection system manufacturers to set robust specifications for the detection systems, including alarm thresholds lower than 10ppm. Many leaks present themselves at levels less than 10ppm, but constitute significant leaks disbursed over time in a large volume of space.[77] An ALDS system may detect a leak, but if not set to alarm the end-user until a leak reaches a higher critical threshold, no action will be taken to respond. Proactive data driven technologies employing sensor and software driven monitoring of refrigeration systems are a new innovation that can monitor receiver levels and other system performance indicators and serve as an early warning system for detecting and addressing leaks, allowing goal setting of achieving leak rates as low as 5%.[78]

RECORDKEEPING & REPORTING. EPA maintains a Central Data Exchange (CDX) system where reclaimers report electronically the amount of refrigerant reclaimed each year. EPA should consider expanding this system to allow service technicians and system operators to keep records and report the leak rates and recharge of large commercial cooling systems. The California Air Resources Board has maintained the Refrigerant Registration and Reporting (R3) web-based system for a decade, where companies that own refrigeration facilities register, keep their servicing and ALDS system records, and report annually.[79] The R3 registration and reporting system enables reporting on a range of information and data including system type, refrigerant used, details of any leaks detected, action taken to repair a leak, quantity of refrigerant purchased and added to a system, recovered from the system, and total quantity of each type of refrigerant stored at the facility or another location, or delivered for reclamation or destruction. While California's statewide R3 program applies only to large refrigeration systems, the South Coast Air Quality District has applied a similar electronic reporting requirement for air conditioning systems greater than 50 pounds under its Rule 1415.[80] EPA should consider setting up a similar system nationally for commercial refrigeration and air conditioning systems.

Lastly, and importantly, the option to mandate use of reclaimed refrigerant when servicing commercial cooling equipment has been discussed in detail in the cross-cutting section. This option would help boost reclaim and encourage gradual retrofitting of old, leaky systems that use high-GWP refrigerants.

ii. PRIVATE SECTOR & OTHER VOLUNTARY PROGRAMS

UPDATE AND EXPAND GREENCHILL. EPA partners with grocery retailers in a voluntary program called the GreenChill Partnership, which has shown that proactive refrigerant management can have a significant reduction in overall leak rates while also saving the refrigeration sector millions of dollars in lost refrigerant costs. GreenChill supermarket partners have achieved average 13 percent leak rates, about a 50 percent reduction compared to the sector's average.[81]

EPA should continue to build on and expand this successful model to address LRM challenges, by:

1. levelling up the ambition and scope of its supermarket leak program where feasible and offering targeted outreach and assistance to small and independent grocers;
2. expanding voluntary partnership activities in other sectors and equipment types, including light commercial refrigeration, residential appliance retailers, and servicing contractors;
3. targeting partnership efforts toward increased end of life refrigerant recovery rates and reclamation aspects of LRM; and
4. including participation by EPA certified reclaimers in GreenChill to properly account for gas that is recovered to ensure it is reclaimed so it can be reused.

LEVELLING UP. Certain aspects of existing GreenChill reporting and data sharing should become mandatory for all large retailers, even those not participating in the program, and new, more ambitious elements added to the voluntary program. This type of approach is common for long-running voluntary leadership programs: start, and then strengthen, requirements, and gradually add what were once the ambitious voluntary requirements to the mandatory pool of standards everyone must meet.

For years, EPA has gathered data and input from participants of the GreenChill program on leak rates, repair measures, and interventions that have achieved significant emissions reductions. Food retailers participating in the GreenChill program are required to report leak data for systems exceeding 50 pounds of refrigerant charge and are encouraged (but not required) to report data for smaller self-contained units.[82]

Participants then receive a customized data report that helps them assess their refrigerant management performance relative to their peers. These reports are not made public, but EPA has the ability to use this information to benchmark where the average supermarket currently stands and where it can go. EPA should analyze which of the measures employed achieved the most substantive leak reductions and publish aggregated data. Based on the information that will emerge from such an analysis, EPA should consider updating the GreenChill program to reflect current and ambitious refrigerant management practices. For example, the requirements for achieving GreenChill store certification could be levelled up to recognize a higher standard of achievement.

Publication and sharing of other data and metrics, such as on average GWP of refrigerants used in all stores, and levels of refrigerant recovery and reclamation could also be incorporated, as well as recognition and rewards for purchasing and using reclaimed rather than virgin refrigerants.

TARGETED SUPPORT FOR SMALL AND INDEPENDENT RETAILERS. Small independent retailers may be less well equipped and have fewer resources to implement leak mitigation strategies. Yet according to the National Grocers Association, independent grocers represent over 21,000 stores in the United States.[83] One potential means of reaching these end-users may be through a voluntary outreach and educational program, potentially as an extension of the EPA GreenChill Partnership program in coordination with state and local agencies and a future "Civilian Climate Corps." Such a program could be designed to offer leak detection, guidance on best practices, store certification assistance, and potentially even free facility-wide leak repair to small and independent grocers. For example, a trained group of Civilian Climate Corps could conduct outreach to small independent grocers in low-income and minority communities offering free leak inspections, with additional financial assistance and technical guidance available in partnership with the EPA GreenChill Partnership to mitigate any leaks. Such outreach could encourage these grocers to join EPA's GreenChill Partnership and work toward long term reductions in their overall leak rates.

> **"Expanding GreenChill's scope to engage with other types of partners beyond the supermarket sector could significantly enhance the program's continued impact and help address other aspects of LRM."**

LIGHT COMMERCIAL REFRIGERATION AND APPLIANCE RETAIL SECTOR. Expanding GreenChill's scope to engage with other types of partners beyond the supermarket sector could significantly enhance the program's continued impact and help address other aspects of LRM. This may include partnership engagement with other major corporate end users or retailers using light commercial refrigeration equipment, such as restaurant chains and other food/beverage retailers outside of the grocery sector and appliance retailers.

Retailers of household appliances such as domestic refrigerators often offer to pick up a customer's old appliance. Increasing reporting and recognition of efforts to verify that refrigerant is recovered and reclaimed from old equipment as part of these services could be a source of additional data and emission reductions. EPA's Responsible Appliance Disposal (RAD) program is estimated to cover less than 5% of household refrigerators disposed of annually.[84] Replication of a national GreenChill recognition model for achievement could significantly broaden retailer participation in end of life recovery and reclamation activities.

SERVICING TECHNICIAN GREEN CERTIFICATION/ PARTNERSHIP. The servicing contractor and distributor sectors could also benefit from a partnership based approach to recognize and reward best practices in LRM. For example, EPA should consider creating a voluntary green label certification for HVACR servicing companies that meet certain best practices for re-training, installation, servicing, and refrigerant recovery and disposal. Such a label could be recognized by climate-conscious consumers in the same way EnergyStar is recognized today, in selecting a company to service their equipment. Top performers in such a program, for example those achieving the highest levels of verified refrigerant recovery and reclaim or highest proportion of technicians re-trained in leak tight installation practices and servicing low-GWP equipment, could also be eligible for additional incentives and rewards.

OTHER INCENTIVE PROGRAMS. Grocers and other commercial businesses located in California may also be eligible for financial incentives under the F-gas Reduction Incentive Program (FRIP) or utility efficiency programs for technologies and actions to reduce leaks or switch to low GWP refrigerants. As reducing leaks has energy efficiency co-benefits, some utilities such as Vermont Efficiency have piloted customized incentives for maintenance and servicing to reduce refrigerant leaks.[85] More information and data should be developed to support the design of incentive programs rewarding both indirect and direct emission benefits of such activities. Other states or countries could consider similar incentive programs too.

END OF LIFE

Recovery of refrigerant during decommissioning of commercial refrigeration systems is common practice in the United States with estimated end of life loss rates ranging from 20-34 percent, far lower than that for residential systems.[86] That's likely because commercial equipment is professionally owned and operated and contains large refrigerant charges. It can also be legally reused by the same owner in another refrigeration system without being reclaimed, thereby avoiding the purchase of additional refrigerant. Therefore, when such a system is decommissioned, the technicians arrive prepared to recover the refrigerant and are more motivated to do so because of the substantial available charge. This is not the case, however, for the substantial quantity of commercially-owned, self-contained equipment used in supermarkets, small grocery stores, and other commercial retail such as convenience stores, which face similarly high end of life loss rates as other small residential cooling appliances of nearly 100 percent.

CORPORATE LEADERSHIP

This area is of particular promise for voluntary leadership by corporate end users such as supermarkets to both increase demand for reclaimed refrigerant and ensure all refrigerant is recovered, particularly from retired self-contained equipment. Through preferential purchasing of reclaimed refrigerant instead of virgin refrigerant to service existing equipment, corporate end users can increase demand for reclaimed refrigerant. Further opportunities exist in working with contractors to ensure refrigerant is recovered from disposed self-contained equipment either by removing refrigerant on site before disposal or verifying later recovery and delivery for reclamation or destruction.

LRM in Mobile Vehicle Air Conditioning & Heating Pumps

Nearly 100 million vehicles are manufactured worldwide each year.[87] Air conditioning is increasingly a worldwide standard feature in new vehicles for occupant safety and comfort, as well as for critical functions like defogging windshields. In electric vehicles, air conditioning systems are increasingly transitioning to heat pump technologies (essentially an air conditioner that has the ability to reverse and provide heating) to save battery life and extend vehicle range in cold weather, as electric vehicles do not have available waste heat from an internal combustion engine.

Since the abandonment of CFCs in the 1990s, vehicles almost universally used HFC-134a refrigerant.[88] Leaks of HFC-134a (which has a 100-year GWP of 1300) from vehicle air conditioning systems and service were large: in the early 2000s, they were estimated to account for approximately 47 percent of global GWP-weighted HFC emissions.[89] This motivated regulators in Europe and elsewhere to prohibit the use of refrigerants with a global warming potential over 150 in new vehicles, starting around 2013.[90] Today, most new light duty vehicles sold in Europe, North America, Japan, and other developed countries use HFO-1234yf refrigerant, which has a GWP of less than 1. However, China—currently the world's largest automotive market—continues to use HFC-134a refrigerant, as does India and many other developing countries.[91]

Additionally, there are hundreds of millions of older vehicles on the road worldwide that still contain HFC-134a,[92] making proper refrigerant management in automotive AC servicing and end of life a key opportunity to reduce HFC emissions worldwide.

DESIGN & MANUFACTURING

i. LAWS AND REGULATIONS APPLICABLE TO DESIGN & MANUFACTURING OF MOBILE AIR CONDITIONING SYSTEMS

In the EU and other regions, lawmakers and regulators have chosen to simply ban high-GWP (GWP>150), which hastened the transition to low-GWP solutions.[93]

Authorities that have not yet prohibited the use of high-GWP refrigerants in automotive climate control systems should do so. Using a low-GWP refrigerant mitigates the environmental impact of refrigerant leaks. In the United States, regulators opted for a more flexible credit-based approach, which has since been replicated in other parts of the world. Like all refrigeration and air conditioning sectors, the automotive sector realized it could significantly reduce refrigerant leakage by using better fittings, hoses, connections, compressor shaft seals & heat exchanger designs.[94]

Since the early 2000s, the automotive sector has significantly decreased the operational refrigerant leaks that occur in mobile AC systems, thanks to thoughtful application of an industry-developed scale for equipment leak tightness (known as SAE J2727: Mobile Air Conditioning Systems Refrigerant Emission Charts) and an innovative credit scheme that rewards manufacturers for making systems less leak-prone and/or for utilizing lower-GWP refrigerant.[95] Environmental authorities may wish to consider a similar approach to reward manufacturers of stationary AC equipment for utilizing lower-GWP refrigerant and making their equipment more leak-tight.

Reporting mandates played an important role encouraging transparency and improving leak-tightness: for example, the state of Minnesota pioneered mandatory leak-tightness reporting for high-GWP refrigerants, and this transparency led the industry to identify and make improvements.[96] Authorities seeking a market-based, transparency-focused approach to encourage leak-tight equipment manufacture may wish to consider similar refrigerant leak tightness disclosure.

SERVICE & MAINTENANCE / END OF LIFE

Many developed countries restrict the sale of refrigerant to qualified technicians, require the use of refillable refrigerant containers instead of disposable containers, and mandate refrigerant recovery and/or recycling. Those who do not already do so should consider adopting these requirements for the mobile AC sector as well. It is notable that the automotive industry has determined that properly recycled refrigerant may be used in vehicle AC systems, without needing to first send it to a reclaimer. Refrigerant recovery and recycling machines are widely available and are used in professional mobile AC servicing shops worldwide.

> **Limiting the sale of refrigerant to qualified MVAC professionals with access to proper refrigerant recovery and recycling machines reduces these risks to consumers, motorists, and the environment…**

However, in some countries — including the United States — anyone can buy refrigerant for an automotive AC system in a disposable container (sometimes called a "small can"). This invariably results in additional emissions: most individuals do not have the tools necessary to fix a leaky system, so any refrigerant "topped up" will eventually leak back out. Do-it-yourselfers are also very likely to emit refrigerant by making mistakes in the topping up process. Some small cans have a valve that is supposed to seal in any unused refrigerant, but unfortunately the sale of "side tappers" that defeat this emission control device have proliferated, defeating the purpose. Sadly, many counterfeit "refrigerant" products are marketed to unsuspecting people who believe they are purchasing R-134a or R-1234yf, but actually may be purchasing a cocktail of illegal chemicals or even flammable gases.[97] Limiting the sale of refrigerant to qualified MVAC professionals with access to proper refrigerant recovery and recycling machines reduces these risks to consumers, motorists, and the environment.[98]

FINANCIAL INCENTIVES

i. DESIGN & MANUFACTURING

In the United States, EPA and California's flexible approach to offering credits toward vehicle GHG standards for adoption of better leak-tight technologies and low-GWP refrigerants offered a powerful financial incentive for manufactures to make the transition. Air conditioning and refrigerant improvements were, for the most part, very cost-effective compared to other investments to reduce vehicle GHG emissions. With the advent of electric vehicles, manufacturers may have an easier time meeting GHG targets, rendering the credit-based approach less effective. With constrained supply of HFCs expected to increase prices, it may be financially advantageous in short order for global automakers to switch to the lowest-GWP options.

ii. SERVICE & MAINTENANCE / END OF LIFE

Refrigerant recovery and recycling equipment for the automotive AC sector can cost thousands of dollars. A shop that performs a lot of AC service may be able to recover this cost in savings on purchases of virgin refrigerant, but for others this cost may prove a substantial barrier to entry. Bulk purchasing or buyers' clubs organized by trade associations, governments, or large institutions may help individual AC shops reduce the cost of necessary recovery and recycling equipment. As previously noted, in the United States the AIM Act authorized $5 million annually for three years to help automotive AC shops purchase recovery & recycling equipment. As of the drafting of this report, those funds have yet to be appropriated, however.

Further, as long as small cans of automotive refrigerant are legal to purchase, there will be a strong financial disincentive for auto service shops to invest in recovery and recycling equipment if their competitors can simply add a can of refrigerant to top off a leaky system without fear of repercussions or enforcement. The practice of topping off is widespread. Although small cans of refrigerant are often exempted on the basis of allowing do-it-yourselfers

> **…as long as small cans of automotive refrigerant are legal to purchase, there will be a strong financial disincentive for auto service shops to invest in recovery and recycling equipment…**

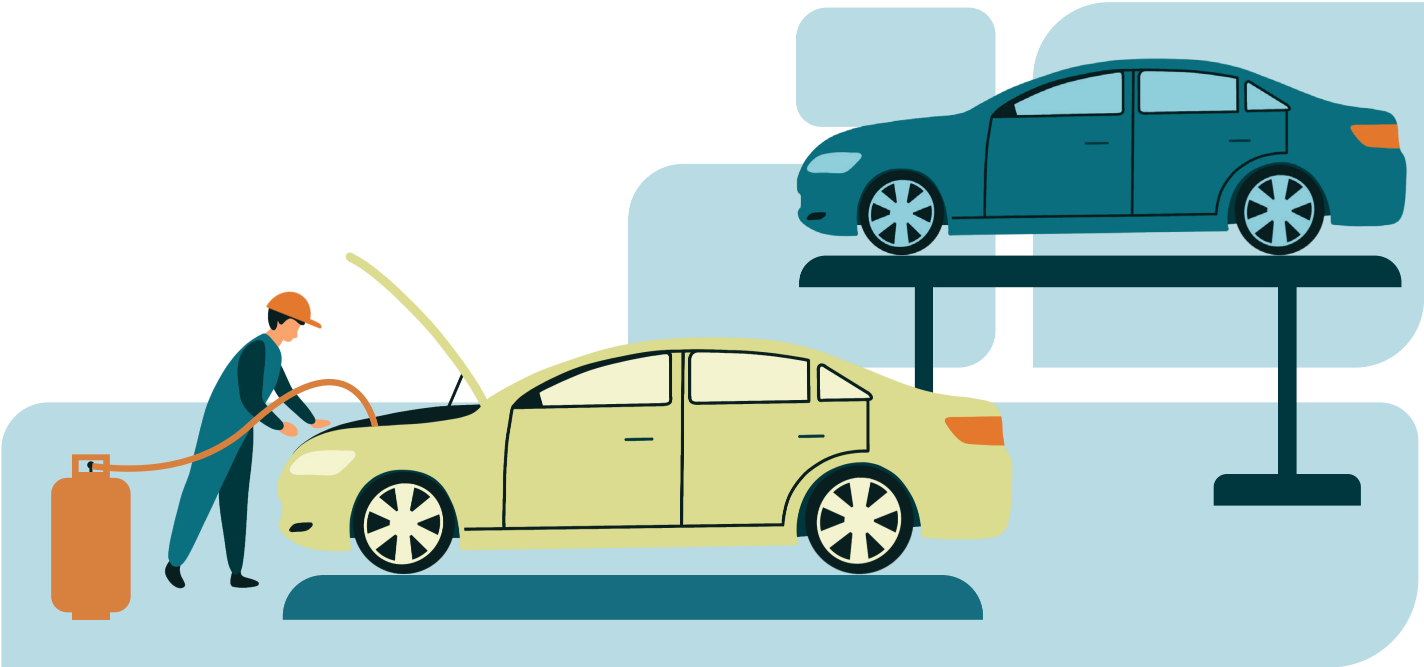
the ability to service their vehicle AC systems, the truth is that small cans of refrigerant are marketed to service professionals by chemical companies in trade magazines, even though these professionals could and should be using proper refrigerant recovery and recycling machines instead of just topping off systems from a disposable can.

Regulators should consider banning small cans of automotive refrigerants entirely. However, if their continued use is permitted, regulators may require the use of reclaimed refrigerant in all new sales of small cans containing HFC-134a for automotive uses. Regulators should also consider requiring the automotive servicing sector use reclaimed or recycled refrigerant in servicing existing systems, as previously detailed in the crosscutting section on reclaim in existing equipment.

CORPORATE LEADERSHIP

The automotive industry, in partnership with the EPA's Mobile Air Conditioning Climate Protection Partnership, the Society of Automotive Engineers (SAE), and the Mobile Air Conditioning Society (MACS) Worldwide, organized a series of cooperative research projects beginning in the 1990s and continuing through today.

These voluntary partnerships and research projects facilitated the introduction of new industry standards to measure and reduce refrigerant leakage, improved air conditioner energy efficiency; better servicing standards and techniques, and hastened the transition to new more climate-friendly refrigerants.[99] More of these types of collaborations focused on the vehicle technologies of the future – EVs using heat pumps with thermal management systems for batteries, etc. – will help take this industry into the next decades.



Conclusion

The climate benefits associated with LRM – which globally are expected to approach 91 $GtCO_2e$ based on our calculations – hinge on prompt action by governments and in the private sector to send clear and unambiguous signals to refrigerant markets that minimizing leaks and maximizing reclamation should be a policy priority and a central tenet of corporate ESG initiatives.

Several actions can yield significant climate benefits through the management of refrigerant banks. Comprehensive LRM – the mitigation of emissions throughout the refrigerant's lifecycle – will require the participation of multiple stakeholders. Policymakers across all levels of government must prioritize policies that enable LRM across different sectors and ensure accountability with best practices.

Private stakeholders must incorporate better practices in their operations, monitor and enforce their own policies and comply with regulatory requirements. Technicians and consumers are also indispensable to this effort and must be at the center of awareness raising and on-the-ground implementation.

"The climate benefits associated with LRM – which globally are expected to approach 91 $GtCO_2e$ based on our calculations – hinge on prompt action by governments and in the private sector to send clear and unambiguous signals to refrigerant markets that minimizing leaks and maximizing reclamation should be a policy priority and a central tenet of corporate ESG initiatives."

For this effort to be successful, interventions must be tailored to the needs and challenges of each sector. This report has set out to outline possible actions for the residential, commercial, and mobile cooling sectors, each with its own unique opportunities. Two stand out as particularly impactful and ripe for intervention:

1. **Refrigerant recovery from residential equipment and in particular air conditioning units. Refrigerant releases at end of life are far too common and can be mitigated through a handful of approaches that place technicians front and center.**

2. **Leak mitigation from large commercial cooling systems. Commercial systems carry a large refrigerant charge and often are prone to high leak rates. Preventing and promptly addressing leaks can have significant climate benefits and help the businesses' bottom line.**

The ideas discussed in this report reflect the thoughtful effort of the authors to creatively address refrigerant emissions from the cooling sector. Though not exhaustive, this wide array of proposed interventions can serve as fodder for further discussion and ultimately action. This is an area of climate action where we all have an opportunity to contribute to this 91Gt effort.

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