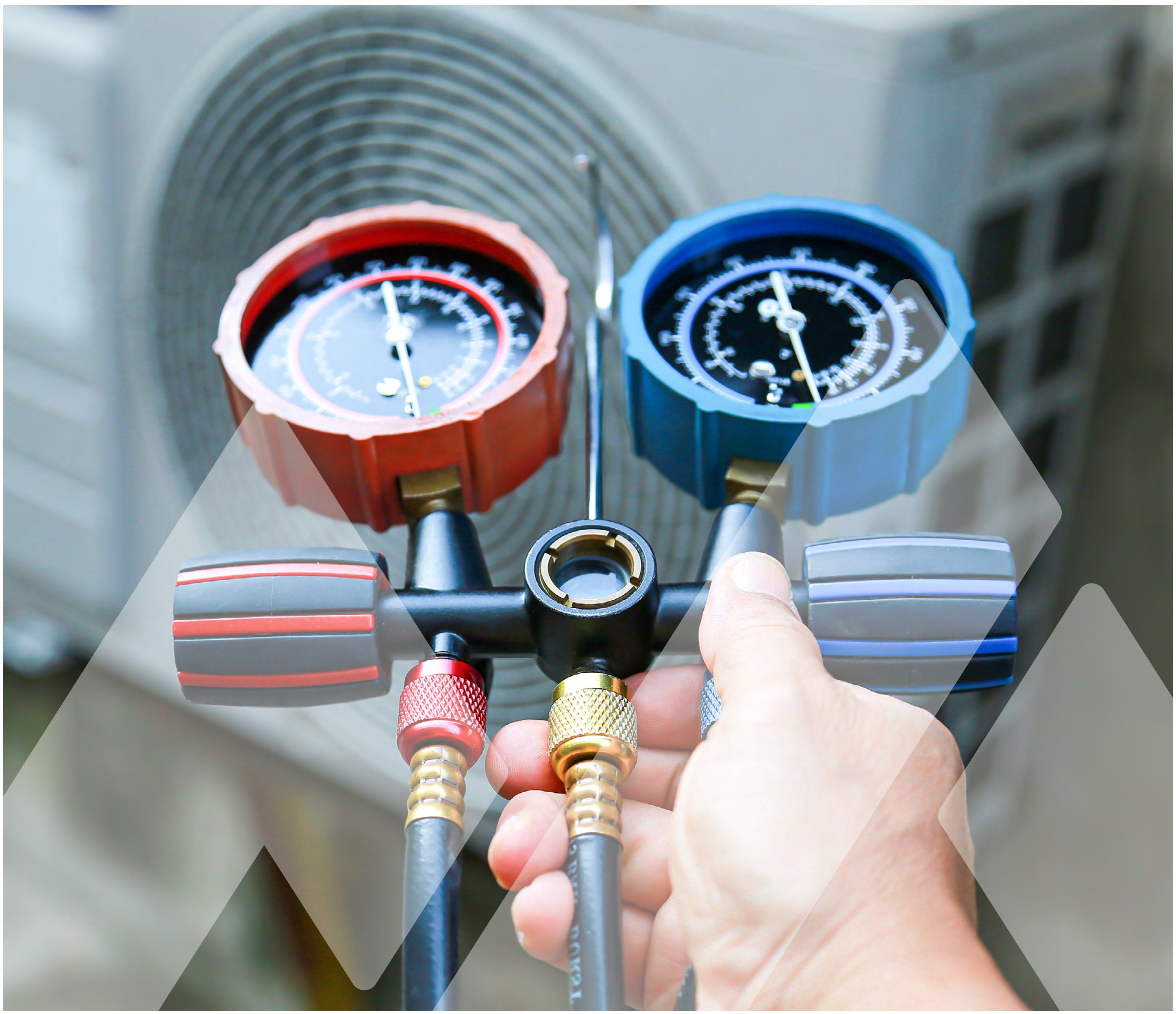
Refrigerant Reclamation

Assessing Potential Emissions Impact of R-410A Refrigerant Reclamation in the United States' Residential HVAC Sector



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Executive Summary

In the United States, the air-conditioning and heat pump (ACHP) sector is undergoing a transition period as refrigerant demand for heating and cooling grows, while supply of the high global warming potential (GWP) refrigerants decreases due to the US Environmental Protection Agency's (EPA's) phasedown of HFCs. Life-cycle refrigerant management (LRM) practices, which include recovery and reclamation, will be critical to manage gaps between supply and demand and mitigate the emissions associated with refrigerant supply.

Reclamation can support the transition to HFC substitutes by bolstering the current supply of HFCs with recovered and reclaimed refrigerants from existing systems. Stimulating recovery and reclamation efforts can minimize disruption to the current capital stock of ACHP equipment, enabling continued use with existing refrigerant supplies until the equipment's end of life. It can also help manage supply shortages of virgin refrigerants, and insulate the industry against price spikes that could affect the servicing of existing systems that use HFCs.

The residential sector is of particular importance because it holds the largest installed base of ACHP equipment in the country, and it currently relies on the high-GWP refrigerant R-410A. The EPA Technology Transition Rule will prohibit new residential equipment from using R-410A beginning in 2025, meaning the sector will transition to lower-GWP substitutes. However, R-410A will still be needed to maintain existing residential equipment through the end of its useful life, especially where early retirement of equipment using R-410A may not be possible.

As the production and consumption quantities for HFC refrigerants decline in line with phase down targets, recovery and subsequent reclamation of R-410A can serve as an alternative to production of virgin R-410A to meet the servicing demand of residential ACHP equipment. However, one of the key prerequisites for incentivizing reclamation — either via regulation or other market mechanisms such as carbon markets — is articulating its environmental benefits compared with the continued use of virgin refrigerant.

To illustrate the greenhouse gas (GHG) emissions impact of reclaimed refrigerant we developed a model that estimates the impact of fulfilling R-410A aftermarket demand (i.e., for servicing existing equipment) using a combination of virgin and reclaimed refrigerant while R-410A is phased out in favor of lower-GWP refrigerants.

Our analysis shows that life-cycle emissions from reclaiming R-410A are less than half of those from virgin production, per pound (lb.) of R-410A supply, when considering production, destruction, and reclamation processes, as well as supply chain losses. Maximizing reclamation of R-410A, compared with current reclamation rates, to meet servicing demand of the residential ACHP sector can lower cumulative emissions over the next 20 years — the expected lifetime of the last R-410A residential ACHP equipment — by 7.7 million metric tons CO_2 equivalent (Mt CO_2e). This is equivalent to taking 1.8 million passenger cars off the road for one full year. The largest opportunity for emissions reduction occurs in the next decade when the most virgin supply of R-410A could be displaced with reclaimed R-410A.

Refrigerant recovery — a precursor to achieving maximum refrigerant reclamation — remains very low in the United States today; only 1.6% of HFCs sold in 2020 came from reclamation. The report highlights financial and logistical barriers to recovery, and policy best practices from different regions around the world to tackle those barriers.

While this report highlights R-410A, in part because R-410A is the most common refrigerant that will be recoverable from residential equipment in the near future, these barriers are relevant to all HFC refrigerants in the sector. Implementing a robust set of policies and procedural interventions can facilitate a higher rate of refrigerant recovery through behavioral changes at the industry, contractor, and consumer levels, minimizing venting of refrigerant to the atmosphere and facilitating reclamation and destruction where applicable. These changes will be crucial to scale the adoption of reclaimed refrigerant in the United States, which impacts not only the R-410A market but the success of the broader industry transition to lower-GWP refrigerants.

Glossary

Aftermarket demand: The refrigerant required to service and maintain the installed equipment base through its useful life.

Allowance or quota: The authorization from the EPA to use a quantity of HFCs. The EPA issues a fixed number of allowances per calendar year to limit the import and use of HFCs to enforce the phasedown of usage in accordance with the American Innovation and Manufacturing (AIM) Act. Allowances fall into two categories: production allowances limit the production of bulk HFCs, and consumption allowances limit the use of bulk HFCs (produced domestically or imported).

Blending: Mixing of virgin refrigerant at high-purity standard with lower-purity or out of balance refrigerant to increase purity above the Air Conditioning, Heating, and Refrigeration Institute (AHRI) 700 standard requirements.

Destruction: For HFCs, destruction means using physical or chemical processes to decompose the HFCs. Destruction of HFCs prevents them from entering the atmosphere, although they can create toxic byproducts that need to be managed.

Global warming potential: The measure of atmospheric warming impact of a ton of gas emitted to the atmosphere over a fixed time period, relative to that of a ton of CO_2. The EPA's allowances for production and consumption of HFCs are measured in terms of CO_2e, which are calculated using the GWPs of individual HFCs.

Leakage: The rate at which ACHP equipment loses refrigerant to the atmosphere during its useful life. The leak rate is expressed as a percentage of the equipment's full charge.

Mixed refrigerant gas: Gas collected in cylinders with multiple species mixed together. This can occur when gas is recovered from equipment with different refrigerants in them.

Reclamation: Reprocessing of recovered refrigerant to the specifications outlined in the AHRI 700 standard (i.e., purity standard for virgin refrigerant).

Recovery: Removal of refrigerant from equipment without necessarily testing or processing it. Recovery in the context of this report occurs at the end of life of equipment.

Recovery loss: Loss of refrigerant to the atmosphere during recovery process.

Recycling: Reuse of refrigerant where refrigerant is removed from equipment and cleaned (but not to the standard of reclamation) and then reused in equipment of the same owner. In general, recycled refrigerant loses some moisture, acidity, and particulate matter.

Shipping bulk transfer: The transfer of refrigerants to and from large-scale storage containers (ISO containers) used for overseas shipments.

Stockpiling: Gas purchased during times of greater supply and held in reserve by producers, distributors, or contractors.

Venting: Intentional release of refrigerant into the atmosphere.

Virgin refrigerant: Refrigerant produced from raw material. R-410A is synthesized from hydrogen fluoride and other petrochemical compounds.

Introduction

For over a century, refrigerants have been essential to the operation of air-conditioning and refrigeration systems that are integral to modern life. However, during the past four decades, growing concerns about environmental safety and the climate impact of refrigerants have driven significant changes in their use. The Montreal Protocol of 1987 required the phaseout of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants due to their harmful effects on the ozone layer. Furthermore, the Kigali Amendment to the Montreal Protocol of 2016 established a phasedown schedule for HFCs with high GWP.

In 2020, the United States enacted the AIM Act,[1] which de facto aligned with the phasedown schedule of the Kigali Amendment (ratified by the United States in 2022). The AIM Act authorizes the EPA to address HFC refrigerants in three ways: (1) phasing down production and consumption, (2) maximizing reclamation and minimizing releases from equipment, and (3) facilitating the transition to next-generation technologies through sector-based restrictions.

As the EPA implements rules to address HFCs and identifies alternatives to high-GWP HFCs, it is also evident that a dominant share of future air-conditioning and refrigeration equipment will continue to operate based on the vapor-compression principle, which relies on HFC refrigerants today. Moreover, the transition to clean energy through the increased use of heat pumps for heating, cooling, and hot water applications is expected to further increase the demand for HFC and substitute refrigerants in the future.

Given the declining production of high-GWP HFCs and the continued (and possibly increasing) use of HFC refrigerants, a supply-and-demand mismatch is possible in the near future. Life-cycle refrigerant management (LRM) practices, which include recovery and reclamation, will be critical to manage this disparity.

The residential sector is particularly important in the context of this changing dynamic as it holds the largest installed base of ACHP equipment in the country. The sector relies on the high-GWP refrigerant R-410A, which accounts for 85% of all refrigerants used in the sector today.[2]

However, the EPA Technology Transition Rule will prohibit new equipment from using R-410A beginning in 2025, meaning the sector will transition new equipment to lower-GWP substitutes, while also needing to maintain existing equipment.[3] Without a drop-in substitute that can be used in existing R-410A equipment, as the production and consumption quotas for HFC refrigerants decline, a gap between the demand for R-410A to service existing ACHP equipment and the available supply of virgin R-410A will emerge.

To meet the servicing demand of residential ACHP equipment amid an anticipated supply crunch, recovery and subsequent reclamation of HFCs including R-410A refrigerant at equipment end of life will become an important alternative to production of virgin refrigerant. However, one of the key prerequisites for incentivizing reclamation — either via regulation or other market mechanisms such as carbon markets — is articulating its environmental benefits compared with the continued use of virgin refrigerant.

To understand the emissions impact of refrigerant reclamation for R-410A, Section 1 of this report examines the impact of fulfilling R-410A aftermarket demand using virgin and reclaimed refrigerant as R-410A is phased out in favor of lower-GWP refrigerants. This section discusses the methodology developed for the emissions model and aims to provide an understanding of the environmental benefits of reclaimed refrigerant under different scenarios.

Section 2 explores the barriers that deter the expansion of refrigerant reclamation. Refrigerant recovery — a precursor to achieving higher rates of refrigerant reclamation — remains very low in the United States and only 1.6% of HFCs sold in 2020 came from reclamation.[4] This section evaluates good policy practices from around the world and offers policy recommendations to enhance recovery and, consequently, reclamation efforts. While this report highlights R-410A, as the majority of refrigerant that will be available to recover from retirement of residential equipment in the near future is R-410A, these barriers are relevant to all HFC refrigerants and must be overcome to realize the environmental benefits from reclamation at large.

The report concludes by discussing the key highlights and presenting a window of opportunity that the United States must seize by increasing refrigerant reclamation to reduce GHG emissions. This will be crucial if the United States is to meet the goals of the AIM Act and Kigali Amendment to the Montreal Protocol.

SECTION 1

Evaluating the Climate Impact of Refrigerant Reclamation

This section evaluates the life-cycle emissions of producing and using reclaimed R-410A refrigerant to meet the servicing need of existing ACHP equipment. It then compares this with producing and using virgin R-410A refrigerant to meet that demand in the context of constraining supply of virgin HFCs in the market aligned with the phasedown schedule of the AIM Act.

An emissions model is developed to assess the estimated life-cycle emissions impact of producing virgin versus reclaimed R-410A refrigerant, normalized to one unit of refrigerant supply, for use in ACHP equipment. The model is expanded to apply the life-cycle emissions on a unit basis to the full installed base of residential ACHP equipment that will demand R-410A refrigerant for its servicing to determine the potential cumulative emissions impact associated with increased use of reclaimed refrigerant.

Methodology

This study assesses the emissions associated with R-410A supply in the residential ACHP sector of the United States, drawing on findings from existing literature on life-cycle emissions from refrigerants. We define the functional unit for the emissions analysis as 1 pound (lb.) of R-410A supply. Emissions for each step along the supply chain are normalized to this functional unit.

For this analysis, we assume that emissions from the destruction of refrigerant at equipment end of life are allocated to the life-cycle emissions of virgin refrigerant. Although we recognize that reclaimed refrigerant will also be destroyed after a certain number of reuse cycles, the model assumes that refrigerant reclamation displaces virgin production, and thereby does not contribute to the need for additional refrigerant destruction. This assumption is reflected in the pathways on the left and right sides of Exhibit 1, where the destruction emissions are associated with the virgin production portion of the supply chain rather than being tied to reclamation.

The model also assumes that the production of a unit of virgin refrigerant will eventually be recovered and sent to the destruction facility for proper disposal at the end of life,[5] rather than entirely being vented to the atmosphere.[i] The emissions impact of reclamation is estimated assuming that equipment does not retire early due to R-410A supply constraints or does not have an extended lifetime because of use of reclaimed refrigerant.[ii] Rather, this study highlights reclamation as an important intervention for climate and for market stability within the typical lifetime of equipment.

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i Although section 608 of the Clean Air Act prohibits individuals from venting refrigerants and their substitutes during service, maintenance, and disposal of ACHP equipment, the industry estimates that close to 90% of refrigerant in end-of-life equipment is vented to the atmosphere in the United States.

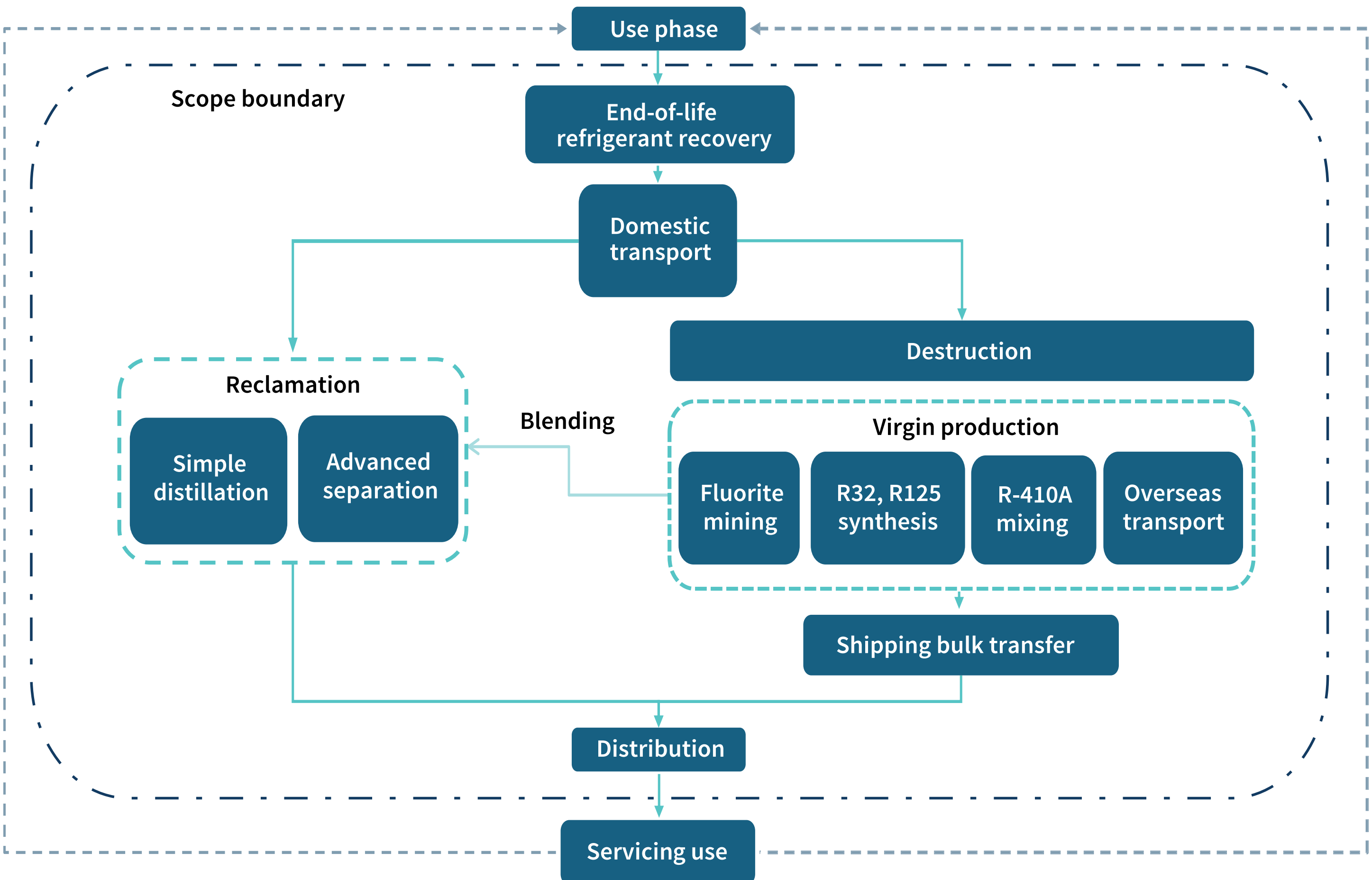
ii We acknowledge that early retirement of high emitting equipment and recovery of the refrigerant can minimize the R-410A being released to the atmosphere. However, we do not include this outcome in this report to isolate the impact of reclamation compared to virgin production. Future areas of study could include the emissions impact of early retirement of R-410A equipment, as well as its financial and logistical implications for consumers.

R-410A Supply Chain and Boundaries

Exhibit 1 shows the steps considered in the life-cycle emissions analysis. Each step of the supply chain contributes to the life-cycle emissions of R-410A.

The analysis starts with the end-of-life refrigerant recovery and ends with refrigerant being put to service. All parts between the start and end points — including domestic transportation, destruction, production, and reclamation — are included in the analysis. The analysis also assumes that all refrigerant, at the end of life of equipment, is recovered and sent to a reclamation or destruction facility. The system boundary excludes other pathways in practice today such as recycling and venting.

Exhibit 1 System boundary for emissions analysis



RMI Graphic. Source: RMI analysis

Emissions from each step are estimated based on emissions factors available in literature. Although alternative pathways exist for treating end-of-life R-410A, such as advanced methods for recovering constituent parts from refrigerant blends,[6] these are beyond the scope of this analysis. Additionally, this analysis looks only at the emissions and does not address any non-GHG environmental impacts such as water use and land degradation due to mining.

A list of key assumptions for the emissions analysis can be found in the *Appendix.*

Projected Supply and Demand of R-410A

Total aftermarket supply and demand of R-410A for residential ACHP equipment servicing is estimated using data on current equipment stock in the United States,[iii] average charge size per equipment unit, servicing requirements for each type of equipment, and average retirement rate. Total equipment stock in the United States is based on the 2020 Residential Energy Consumption Survey from the Energy Information Administration.[7] The stock is segmented into central units and noncentral (which include mini-split and window) ACHP units because of differing charge sizes and characteristics, amounting to approximately 93.3 and 51.6 million central and noncentral units in 2020.[8]

Projections for annual R-410A ACHP stock and retirements are based on equipment installation year and lifetime through 2045, which is the assumed retirement date for all equipment. The analysis excludes extended lifetime of equipment due to reclamation. Exhibit 2 lists the key assumptions in the analysis pertaining to the ACHP equipment stock.

Exhibit 2 Key assumptions for ACHP equipment in the emissions analysis

Equipment type	Charge size (pounds)	Annual leakage rate (%)	Average lifetime (years)	Maximum lifetime (years)
Central	8.2	10	15	20
Non-central	3.7	5	10	20

RMI Graphic. Source: EPA, https://epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annexes.pdf#page=244; and LBNL, https://eta-publications.lbl.gov/sites/default/files/lbnl-1003671.pdf.

Refrigerant demand for servicing installed residential ACHP equipment is estimated based on the average amount of refrigerant leaked between two consecutive events of servicing, which we assume as every 2.5 years.[iv] The model assumes that during each service, refrigerant would be filled to its initial charged amount. Thus, the annual demand for the sector in a given year is calculated by multiplying the refrigerant demand per equipment undergoing servicing by the total amount of ACHP equipment (excluding the equipment that retires in that year).

The maximum quantity of R-410A that can be reclaimed and supplied into the market in a given year is derived from the charge at end of life per equipment that undergoes retirement, multiplied by the total number of equipment retirements in a given year.

iii Aftermarket is defined here as the refrigerant required to service and maintain the installed equipment base through its useful life.

iv The assumptions for annual leakage rate and servicing are based on estimates from the literature, manufacturer recommendations, and industry experts. However, there is limited data on the frequency of servicing, the charge remaining at time of servicing, and the frequency of catastrophic failure of equipment. Future research on real-world behavior of equipment could help validate these assumptions and refine estimates of reclamation potential.

For the analysis, we assume an ideal recovery scenario in order to evaluate the maximum supply of recovered and subsequently reclaimed R-410A, even though recovery rates in the US residential sector are significantly low today. In an ideal recovery scenario almost all of the refrigerant is recovered from the equipment (not including losses in the recovery process). Cross-industry reclamation is not considered; reclaimed refrigerant within the ACHP sector is assumed to remain internal to the sector.

Maximum supply of virgin refrigerant is limited by EPA HFC consumption allowances. Allowances are not formally allocated to subsectors and availability of allowances for one subsector will depend on transition to lower-GWP substitutes in other sectors. Thus, for this model we assume that a fixed percentage of each year's consumption allowances will be used by the residential ACHP sector over the next 20 years. We estimate this allocation to be at 44% based on the percentage of R-410A produced compared with other HFCs in 2022.[9]

We also assume the consumption allowances are initially used to meet first-charge requirements of new ACHP equipment using lower-GWP virgin refrigerants (in line with the Technology Transition Rule) and only the balance allowance is used to produce the virgin R-410A required for servicing needs.[10] We use R-454B as a representative lower-GWP refrigerant to calculate these consumption allowances.[v]

Based on the model developed, the first-charge requirements of new ACHP equipment are estimated to be 14 Mt CO_2e in 2025,[vi] increasing annually at a sectoral growth rate of 2%.[11] In a given year, these first-charge requirements are subtracted from the consumption allowances allocated to the residential sector per the previous paragraph.[vii] The resulting difference is the maximum potential virgin supply of R-410A in a given year. Based on these assumptions, this supply is estimated to decrease from 70 Mt CO_2e in 2025 to 3 Mt CO_2e in 2045 as consumption allowances decrease and first-charge needs for new equipment increase and take precedence.

In reality, we recognize that the market dynamics will continue to change as the industry works toward managing the R-410A supply against the declining allowance quotas under the AIM Act. Pricing of lower-GWP refrigerants versus R-410A, variation in sector growth rate, and transition to low or ultralow-GWP refrigerants in other sectors, would affect how allowances are used within the residential ACHP sector.

There is also evidence that stockpiling of HFCs occurs, particularly in times when policy mandates are anticipated to constrain the supply; this would have an impact on the allowances that would need to be "used" in a given year to satisfy demand.[12] The size of stockpiles of R-410A specifically are not clear, but the 2022 EPA data suggests that there could have been up to 42,870 t of R-410A in end-of-year inventories.[13] These complex market factors are not included in the model because they can impact the scaling of refrigerant reclamation. However, we attempt to demonstrate the opportunity reclamation presents in mitigating market scarcity and reducing GHG emissions, making the overall transition to lower GWP refrigerants more successful.

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v Many manufacturers have committed to R-454B as the next refrigerant in US residential products, including **Johnson Controls** and **Trane**, although manufacturers such as **Daikin** have committed to R-32 in the near term, and additional low or ultralow-GWP alternatives will likely enter the market in the longer term.

vi Note the EPA uses "MMT CO_2e" as the abbreviation for million metric tons CO_2 equivalent when issuing allowances.

vii Imports of pre-charged equipment are not subject to the allowance allocation rules. However, due to limited data on future imports of pre-charged equipment, this is not considered in the model.

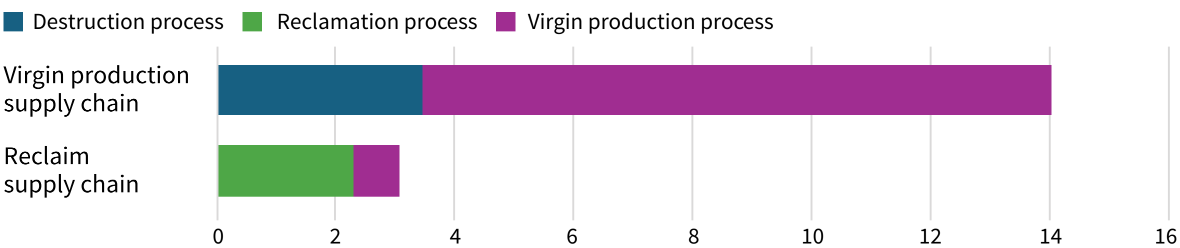
Life-Cycle Emissions: Reclaimed and Virgin Refrigerant

Based on emissions associated with each step of the production process for virgin and reclaimed refrigerant R-410A (as shown in Exhibit 1), and emissions in their respective supply chain, the life-cycle emissions per unit of refrigerant supplied (functional unit) were evaluated (see Exhibit 3a and 3b). Exhibit 3a compares the reclamation process with the virgin refrigerant production process. Exhibit 3b adds emissions from other parts of the supply chain, including losses from shipping bulk transfer and recovery, and ground transportation. Shipping bulk transfer losses occur only in the virgin production scenario because it is assumed that virgin production occurs overseas and is consolidated in the United States. These losses are assumed to be 1% to 3% of the shipped mass.[14]

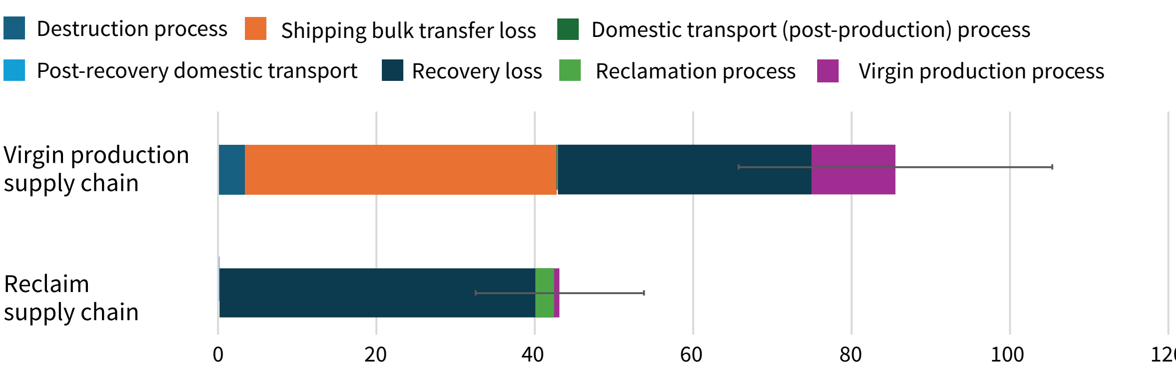
Exhibit 3

Emissions from supply of 1 pound of reclaimed and virgin R-410A (kg CO_2e)

3a:



3b:



Note: The error bars represent a range of emissions linked to uncertainty in domestic transport efficiency, destruction process type, and reclamation process efficiency found in the literature.

RMI Graphic. Source: RMI analysis

This analysis suggests that the emissions associated with the refrigerant reclamation process are dramatically lower — between 75% and 82% — compared to the virgin refrigerant production (and its destruction). However, losses in the supply chain, downstream from virgin production, and both up- and downstream from the reclaimer affect the total emissions significantly because of the high GWP of R-410A. Overall, from a lifecycle emissions standpoint including supply chain emissions, supplying one unit of reclaimed R-410A for servicing of existing ACHP equipment has 47%–70% lower emissions compared with virgin R-410A.

The emissions results are most sensitive to the following factors:

1. **Refrigerant loss during bulk storage container transfer and recovery**: Testing a range of refrigerant loss rates of 1%–3% for bulk storage transfer and a total of 0.5%–3% for recovery results in life-cycle emissions from virgin production of 19–55 kg CO_2e per pound R-410A, and life-cycle emissions from reclaimed refrigerant production of 5.8–29 kg CO_2e per pound R-410A.

2. **Reclamation process types**: Emissions associated with producing reclaimed refrigerant are dependent on the purity and mixing of recovered refrigerant. If the recovered refrigerant batch is largely comprised of a single type of refrigerant gas (in this case R-410A), a simple distillation process is usually sufficient to produce a reclaimed refrigerant.

However, if the recovered refrigerant batch comprises a mix of different refrigerants and impurities, processing usually requires multiple stages of distillation that can result in 70% higher emissions compared with the simple distillation process. Depending on the reclamation process used, the life-cycle emissions for production of reclaimed refrigerant varies 2%–3% in total. This is relatively small due to the dominance of emissions from losses mentioned in the previous point, but in all cases remains lower than production of virgin refrigerant.

Across all sensitivities considered, life-cycle emissions of reclaimed R-410A are consistently lower than virgin R-410A as indicated by the existing literature.

Any amount of refrigerant loss within the supply chain dominates the total life-cycle emissions for both virgin and reclaimed refrigerant. Reducing these losses for higher-GWP refrigerants like R-410A is critical to reduce the overall environmental impact.

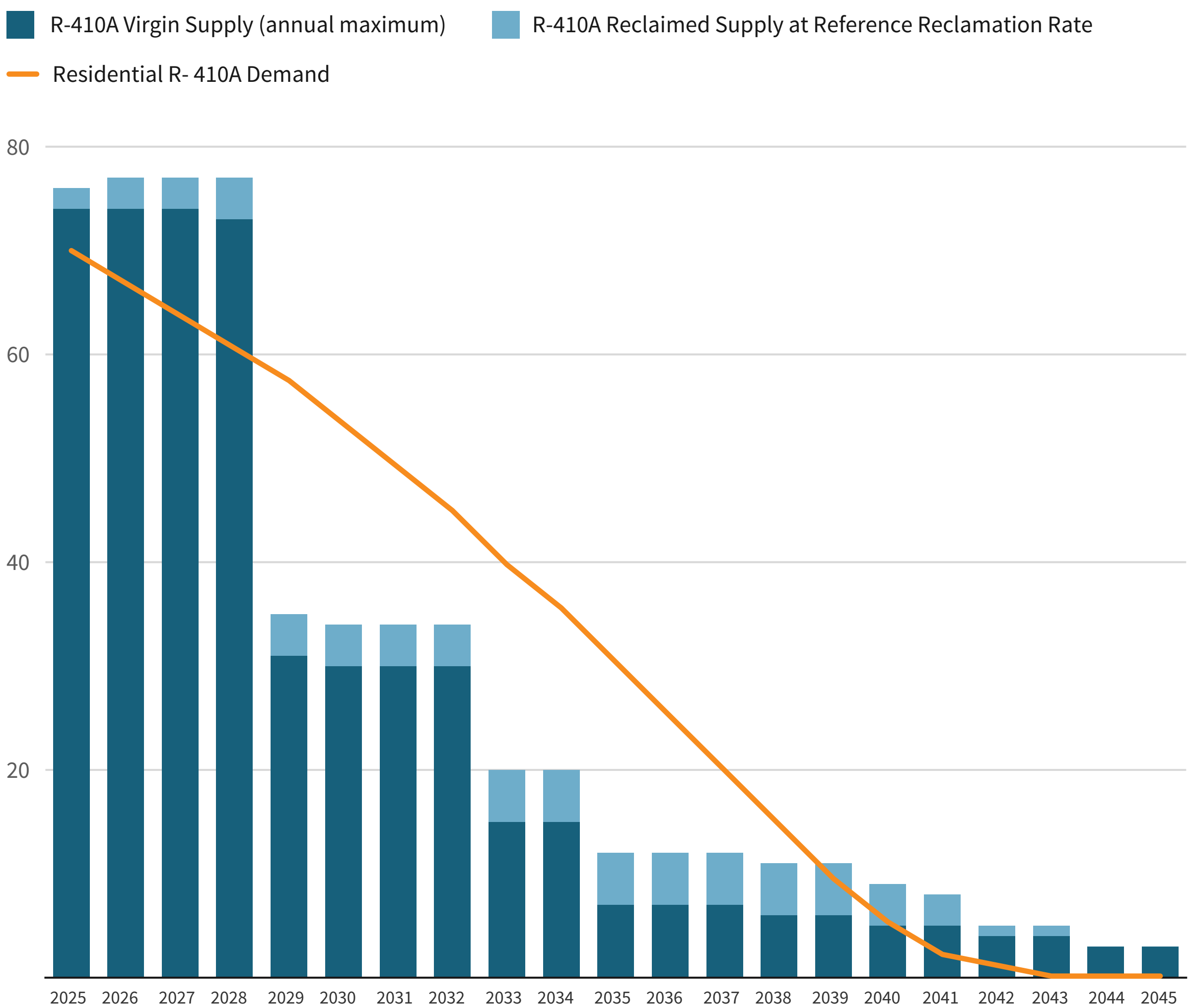
Assessing the Climate Impact of Adoption of Reclaimed Refrigerant at Scale

To contextualize the emissions impact of using reclaimed refrigerant R-410A to service residential ACHP equipment at the scale of the US market, we estimate the refrigerant demand from this segment over the next 20 years.

In Exhibit 4, the demand for the refrigerant R-410A for servicing existing ACHP equipment is shown against the estimated maximum supply of R-410A — comprised of maximum annual virgin refrigerant supply (based on the methodology described above) and reclaimed R-410A supply at a reference reclamation rate. We estimate this reference reclamation rate to be 10%, based on the mass reclaimed in 2022 and total recoverable mass in retiring equipment that year.[15]

The virgin supply assumed to be allocated to residential sector R-410A is estimated to be 74 million lb. in 2025 (~70 Mt CO_2e),[viii] decreasing to 3 million lb. by 2045 (~3 Mt CO_2e) as the demand for refrigerant for the first charge of new equipment eclipses the decreasing AIM Act allowances and fewer allowances would remain for R-410A production. The demand for R-410A refrigerant to service the ACHP equipment declines steadily from approximately 67 million lb. in 2025, as existing equipment continues to retire. By 2045, the servicing demand for R-410A is projected to reach zero, implying all installed residential ACHP equipment using R-410A will be retired by then.

Exhibit 4 Residential R-410A annual supply and demand (million lbs. R-410A)



Note: R-410A demand against maximum annual virgin supply and reclaimed supply does not include stockpile.

RMI Graphic. Source: RMI analysis

viii Using a 100-year GWP for R-410A of 2088, based on the Intergovernmental Panel on Climate Change's Fourth Assessment Report.

The gap between annual supply and demand in Exhibit 4 shows that R-410A servicing demand exceeds the available supply in several years, particularly when restrictions on virgin supply of R-410A come into effect according to the AIM Act phasedowns, such as 2029 and 2033.

These gaps could lead to price hikes for R-410A, equipment inefficiency due to insufficient servicing, and even early retirement of equipment that may lead to unexpected consumer costs. Supply and demand gaps will likely be met in part by stockpiles but underscore the value of increased reclamation to meet servicing needs and avoid shortages. Reclamation offers a path for less reliance on virgin refrigerant, with the added benefit of reduced life-cycle emissions.

The model analyzed three scenarios with varied supplies of reclaimed and virgin R-410A refrigerant to illustrate possible GHG impacts of increased reclamation:

1. **Reference scenario**: In the reference scenario, reclaimed supply is limited to 10% of the R-410A available for recovery from retiring equipment as described above, and the reclamation rate does not improve over time. The remainder of the demand is met by virgin R-410A. In this scenario, stockpiles of virgin R-410A meet any gaps where annual consumption allowances are inadequate to meet demand.

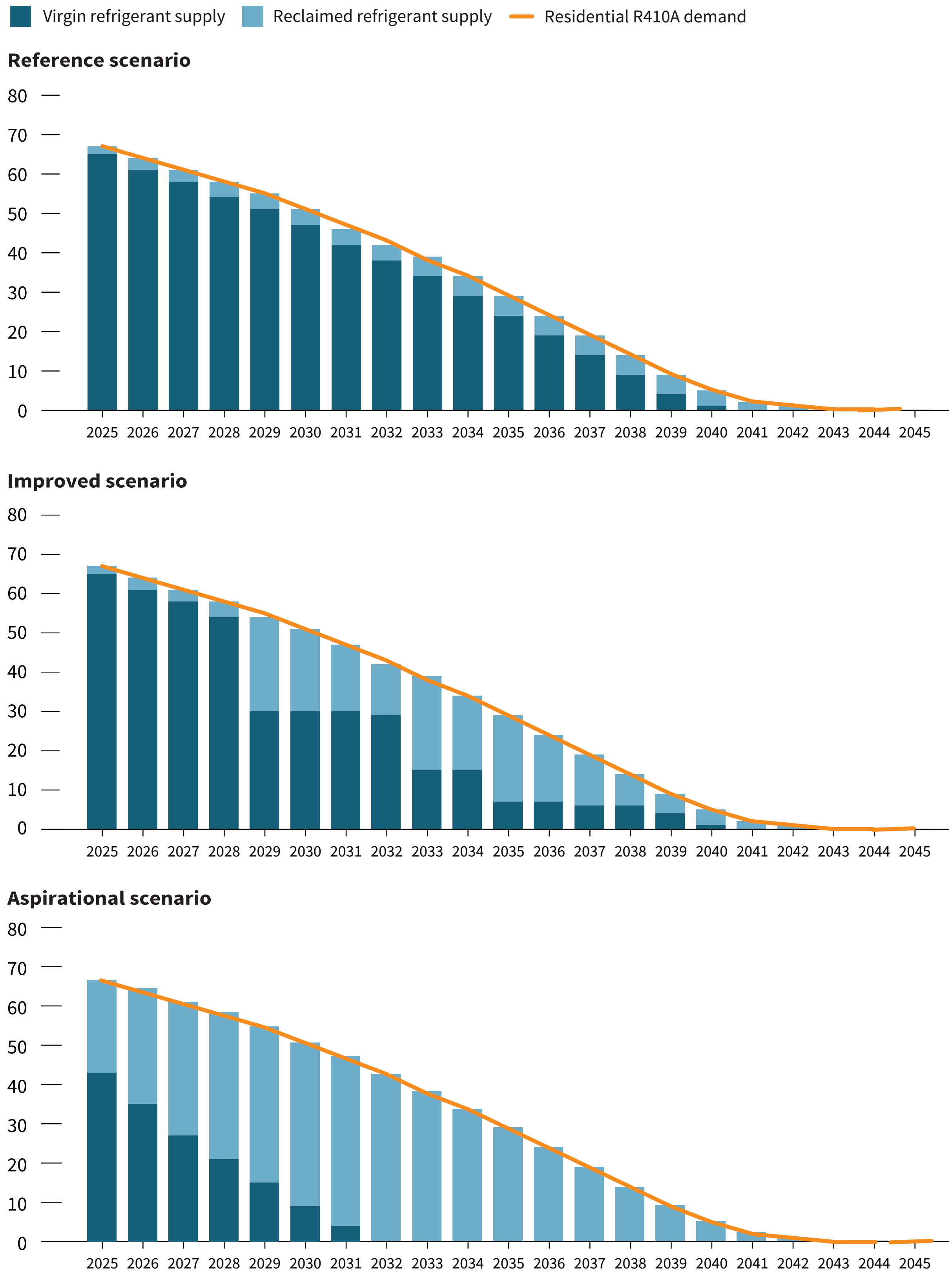
2. **Improved scenario:** Under this scenario, demand is initially met by virgin R-410A until the annual virgin supply maximum (consumption allowance) is reached. The remaining demand is fulfilled by reclaimed R-410A, rather than by stockpile; this means that in years with the largest gaps between virgin supply and demand a higher reclamation rate is necessary to meet the demand.

3. **Aspirational scenario:** In this scenario, 100% of R-410A from retiring equipment is recovered, reclaimed, and reused in the market to meet the servicing demand of ACHP equipment. Any remaining demand is then met with virgin R-410A production, if permitted through consumption allowance.

These scenarios highlight a theoretical range of reclamation and virgin supply, acknowledging that current recovery rates are very low in the US residential sector and that cost dynamics between R-410A and other HFCs not considered here would affect their supply. Exhibits 5–7 depict the total supply and demand of virgin and reclaimed refrigerants under the reference, improved, and aspirational scenarios described above.

In the improved and aspirational scenarios, the fraction of R-410A in retiring equipment that must be reclaimed to meet demand is particularly high in years where the virgin supply decreases due to allowance step-downs. Over time, between the scenarios graphed, the proportion of demand being met by reclaimed refrigerant supply increases as constraints on virgin refrigerant supply become increasingly limited.

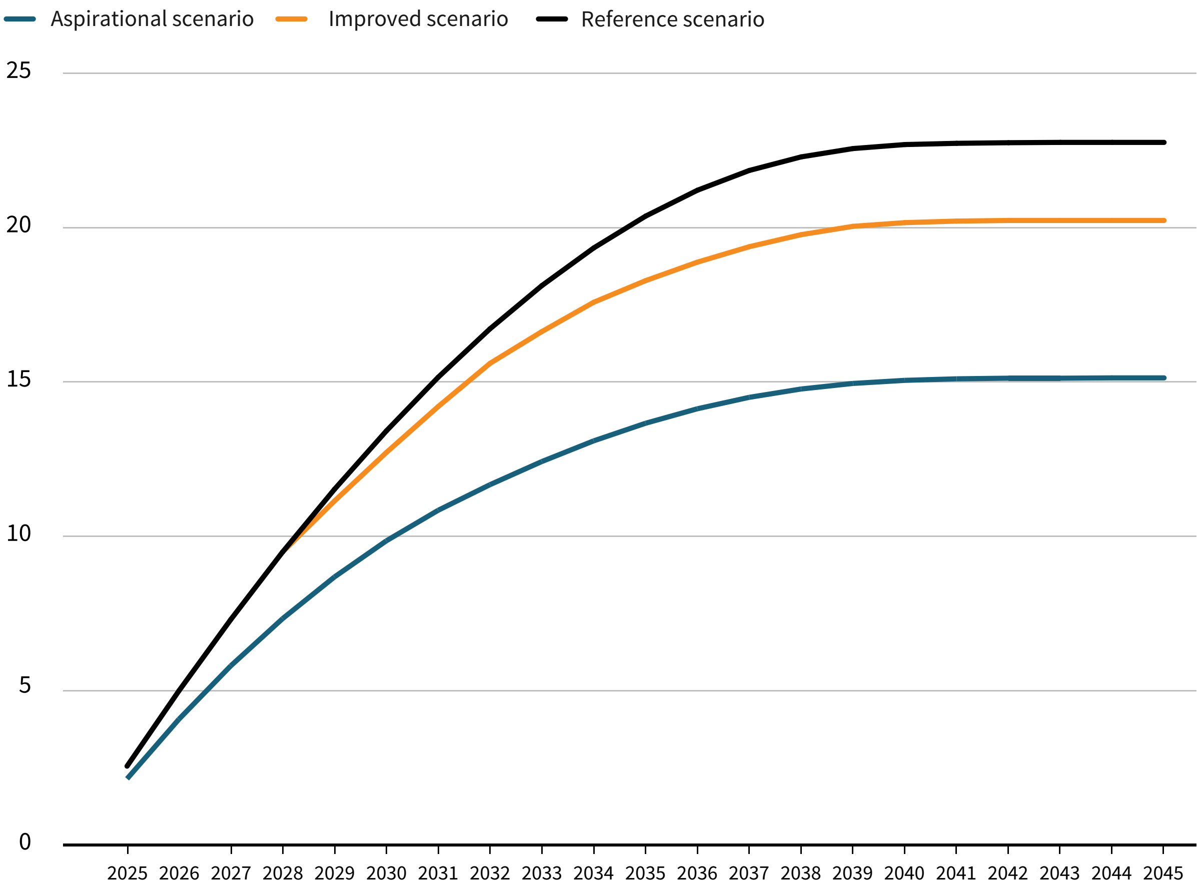
Exhibit 5 Modeled scenarios for varying supply of virgin and reclaimed R-410A refrigerant (million lbs. R-410A)



RMI Graphic. Source: RMI analysis

Exhibit 6 shows the cumulative emissions from R-410A supply for meeting the servicing demand under all three scenarios, and the magnitude of emissions impact from increased reclamation.

Exhibit 6 Cumulative emissions 2025-2045 from the three scenarios (Mt CO_2e)



RMI Graphic. Source: RMI analysis

Cumulative emissions in the improved and aspirational scenarios are 5% (1.1 Mt CO_2e) and 35% (7.7 Mt CO_2e), respectively, which are lower than the reference scenario. The improved and aspirational reclamation scenarios show a difference in cumulative emissions of around 5 Mt CO_2e, which is similar in order of magnitude to the emissions in both these scenarios in 2025 and 2026 combined. As the limit on virgin production is reached, the annual supply of reclaimed refrigerant converges in all scenarios, meaning the associated annual emissions after 2040 also converge.

In all three scenarios, the cumulative emissions curves start to flatten beyond 2040 as the demand for R-410A wanes and virgin production is most severely limited. This indicates that prioritization of reclamation in the near term — even when consumption allowances are higher than demand — can bring the largest emissions reduction opportunity.

This outcome was tested against a few sensitivities. The cumulative emissions are most sensitive to refrigerant loss rates along the supply chain (which affects the emissions intensity of R-410A supply) and equipment leakage and maintenance rates, which have an impact on the total demand projection of R-410A. This means:

- Varying the refrigerant loss rates along the supply chain results in cumulative emissions in the reference scenario of 13.6–42.2 Mt CO_2e, compared with the cumulative emissions in the improved and aspirational scenarios of 8.4–30.7 and 6.7–27.2 Mt CO_2e, respectively.

- Lowering the R-410A servicing demand by reducing equipment leakage rates to 5.3% and 0.6% for central and noncentral equipment, and maintenance frequency of five-year intervals, results in reference scenario cumulative emissions of 8.9 Mt CO_2e. This can be compared with the cumulative emissions from the aspirational scenario of 5.6 Mt CO_2e. Under a lower demand case, maximizing reclamation in the aspirational scenario results in a 45% emissions reduction relative to the reference scenario. With lower demand, reclaimed refrigerant can supply a larger proportion of that demand and therefore reduce virgin refrigerant supply needs compared with the baseline demand case.

Key Takeaways

1. Emissions from the production process alone for R-410A reclamation are 75%–82% lower than production of virgin R-410A per unit of refrigerant supply. The environmental impact of reclamation can be further improved as reclaimers measure and improve energy efficiency and innovate the reclamation processes.

2. When including the supply chain emissions beyond only the production processes, life-cycle emissions from refrigerant reclamation are still lower than virgin production by 47%–70% per unit of refrigerant supply.

3. Due to the high GWP of the refrigerants, losses in the supply chain dominate the life-cycle emissions of both virgin and reclaimed refrigerant. Reducing losses throughout the supply chain for higher-GWP refrigerants like R-410A is critical to reduce the environmental impact and increase the relative emissions benefit of reclamation.

4. Considering the future demand for servicing residential ACHP equipment and constraining supply of R-410A, maximizing the use of reclaimed refrigerant would avoid 7.7 Mt CO2 e cumulatively through 2045 compared with emissions associated with reference scenario. This is equivalent to the emissions reduction that would result from taking 1.8 million passenger cars off the road for one full year.[16]

5. The majority of these emissions’ reduction opportunities are expected in the next decade, highlighting the importance of increasing reclamation efforts now to make a substantial impact. Doing so also helps establish market dynamics and infrastructure for future refrigerant reclamation initiatives, making the overall transition to lower GWP refrigerants more successful. “

Recovery is foundational to achieving the emissions impact from reclaimed refrigerant. State and federal policies can be important levers to enable higher refrigerant recovery. The following section will discuss the policy lessons and best practices from several US and international jurisdictions to improve recovery rates that ultimately help enable a pathway for increased refrigerant reclamation.

SECTION 2

Enabling Higher Refrigerant Recovery and Reclamation through Policy and Best Practices

Introduction

We propose 10 targeted recommendations to address the barriers to higher refrigerant recovery and reclamation rates in the US residential sector. These recommendations are informed by best practices in domestic and international policy and regulatory frameworks, and by in-depth interviews with global experts in LRM and regulation of HFCs and other ozone-depleting chemicals.

Methodology

The US EPA has identified seven major barriers and key challenges to increased refrigerant recovery and reclamation, namely:

1. Contamination and accommodating blends and mixed cylinders
2. Price of refrigerant
3. Market demand for reclaimed refrigerant
4. Release events over useful life and disposal of equipment
5. End-of-life leakage
6. Technician outreach and cost penalty of returning refrigerant
7. Destruction of HFCs

To identify the domestic and international best practices and policies that have been successful in overcoming these barriers in a range of jurisdictions, the RMI team researched and analyzed refrigerant management in three US states (California, Washington, and New York) and 10 countries (Australia, Canada, Denmark, France, Italy, Japan, New Zealand, Norway, Poland, and the UK), and conducted video interviews with 12 experts representing industry, industry associations and nonprofits from the United States, the UK, Australia, Japan, and Germany. The RMI team administered online surveys for two experts from the United States and Indonesia who were unable to accommodate video interviews.

Full details of the stakeholder interviews and survey methodology can be found in the *Appendix*.

Stakeholders interviewed and surveyed highlighted seven major challenges with recovering refrigerant. In addition, they provided recommendations for strategies to overcome one or more of these barriers. The challenges are:

1. On-site recovery
2. Market forces
3. Data gaps
4. Contaminated and mixed gases
5. Enforcement
6. Continued education and training for contractors
7. Consumer behavior and education

Experts' suggestions were supplemented with research on current best practices adopted by various regulatory and enforcement regimes around the world. Based on our research, stakeholder interviews, and analysis of best practices, this report proposes 10 policy and procedural recommendations to support an increase in refrigerant recovery in the US residential market. These recommendations, along with the rationale and potential challenges to implementation, are discussed at the end of this section.

Challenges, Policy Interventions and Best Practices

On-Site Recovery

Issue: There is a high opportunity cost for contractors to recover refrigerant because:

1. Refrigerant recovery is very time consuming.
2. There is a lack of financial compensation for contractors who recover refrigerants.

Air conditioner repair is highly seasonal, and thus contractors face annual constraints of extremely narrow windows of time combined with a high demand for their services. Although some companies and jurisdictions such as Australia and New Zealand compensate contractors per kilogram of recovered refrigerant they return (see Exhibit 7), the smaller size of residential units (compared with commercial refrigeration units) results in a smaller quantity of refrigerant recovered per unit, making it challenging to achieve an economically viable rate of recovery.

Exhibit 7 shows that methods to improve recovery rates can include curbside recovery funded by manufacturer fees (e.g., New York) or a system where residents deliver air-conditioning units directly to recyclers for recovery (e.g., Japan).

Exhibit 7 Best practices for on-site recovery

Australia

Australia's industry stewardship organization Refrigerant Reclaim Australia offers contractors a rebate of $3/kg for returned refrigerants, paid for by an extended producer responsibility program that requires manufacturers to pay a deposit. However, as recovery can take up to an hour, and residential systems in Australia only contain 1-2 kg of refrigerant, this incentive is more of a side benefit than adequate compensation for contractors' time.

New Zealand

New Zealand's Cool-Safe is funded through carbon credits and recently increased their rebate from $25/kg to $40/kg to help meet a target of 90% reduction in GHG emissions from HFCs by 2035.

Japan

In Japan, residential consumers return air-conditioning units directly to recyclers, who then recover refrigerant at a central facility.

New York City

New York City charges manufacturers a $15 fee per unit to fund an end-of-life refrigerant recovery program where Department of Sanitation workers recover refrigerant curbside before air conditioners are recycled.

Note: Limited to specific types of units suitable for recycling and recovery in Japan and New York.

RMI Graphic

Market Forces

Issue: Existing market forces prevent higher rates of refrigerant recovery. For example:

1. Large-scale refrigerant reclamation is hindered by the (comparatively) inexpensive prices of virgin refrigerant in the United States.

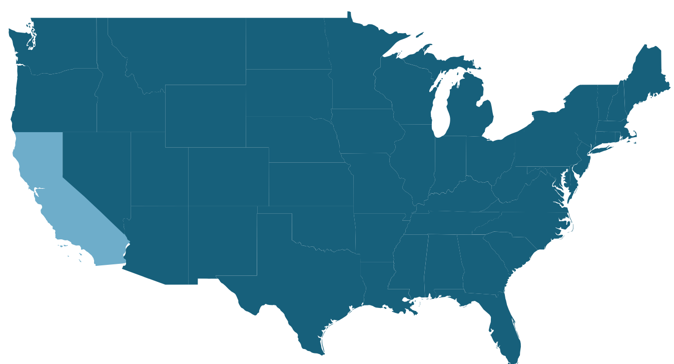
2. Currently, there is a lack of sufficient market incentive for use of reclaimed refrigerant in most of the United States, such as minimum use requirements for reclaimed refrigerant or a price reduction from virgin refrigerant. In addition to resolving these challenges, it will also be important for US regulatory authorities to carefully calibrate market incentives to prevent prolonging the use of equipment with high-GWP refrigerants past their intended lifetimes. Exhibit 8 shows potential solutions and best practices.

Exhibit 8

Best practices for market forces

Europe

European countries have adopted several mechanisms to improve refrigerant recovery, including the exemption of reclaimed refrigerant from F-Gas quotas, and exemption of recycled gas from taxation of refrigerants in Norway, Denmark, and France. Additionally, Europe completed an R-22 (HCFC refrigerant) phasedown without extending equipment lifetimes by banning service with virgin gas in 2010, along with a ban on reclaimed gas in 2015.



Canada

Canada bans all import, export, and production of HFCs outside of a few specific exceptions.

California

California's R4 program requires the use of reclaimed gas in servicing equipment, the only program we found to do so.

RMI Graphic

Data Gaps

Issue: The absence of uniform standards and requirements for data collection, reporting, and auditing of usage, transportation, and recovery of various types of refrigerants further complicates many of the existing challenges of regulating and enforcing refrigerant recovery and reclamation. Even in jurisdictions that have mandated record keeping, the lack of a standardized reporting methodology and centralized database combined with the absence of regular auditing processes results in extremely limited transparency. The absence of standardized and centralized records maintained by a federal regulatory agency such as the US EPA has also contributed to a highly fragmented understanding of the manner and use of refrigerants, which has not been conducive to advancing national recovery and reclamation goals. Exhibit 9 shows potential solutions and best practices.

Exhibit 9 Best practices for data gaps

Poland

Poland has developed a mandatory online reporting system for servicing equipment that is automatically connected to a government database, allowing for centralized data management and greater transparency.

Australia

Australia maintains centralized, digital databases for record keeping that can receive real-time data from contractors using smartphone-enabled tracking tools, such as Gas2Go®. Additionally, Refrigerant Reclaim Australia's augmented reality app supports ongoing contractor education and training.

RMI Graphic

Contaminated and Mixed Gases

Issue: The prevailing culture among contractors that is driving low recovery of refrigerants needs to be addressed by overhauling existing standard operating procedures (SOPs), along with updated training to resolve the issue of contaminated and mixed gases. Currently, a majority of contractors work on multiple types of systems with different types of refrigerants, and they do not typically have the ability to transport enough cylinders to recover each type of gas in a separate cylinder. Although cost penalties for returning cylinders with mixed refrigerants have been significantly mitigated due to the improved economics of advanced separation techniques, the perception of a potential risk of being charged for returning mixed-gas cylinders still drives contractor behavior, which contributes to a lower recovery rate. Exhibit 10 shows potential solutions and best practices.

Exhibit 10 Best practices for contaminated and mixed gases

Japan

Japanese regulators have found that requiring end consumers to return air-conditioning units to recyclers increases both the percentage and purity of recovered refrigerants by allowing refrigerant recovery to occur at centralized facilities. While not as effective from an emissions standpoint, reclaimers in Japan also reduce the cost of reclaiming mixed gases through destroying any recovered refrigerant that is under 99.5% purity.

RMI Graphic

Enforcement

Issue: The absence of enforcement of antiventing regulations in the United States is further exacerbated by the lack of mandatory reporting, auditing, and data transparency on the number of refrigerant systems in the United States (see Exhibit 11 for best practices). Multiple experts noted that an industry-wide awareness of a lack of enforceable regulations heightens the challenge and contributes to already low rates of recovery by contractors.

Exhibit 11 Best practices for enforcement

Poland

Poland's mandatory tracking system (mentioned previously, in the "Data Gap" best practices) also increases enforceability.

United Kingdom

UK's certification body, REFCOM, inspects businesses every three years to ensure compliance.

RMI Graphic

Continued Education and Training for Contractors

Issue: Currently, federal service technician certifications in the United States do not expire and have no requirements for continuing education or updated training (see Exhibit 12 for best practices). Some state licenses do expire, and others require continuing education, but differing regulations between states have led to a patchwork of requirements. This lack of standardized, updated training requirements results in the continuation of outdated techniques and incorrect perceptions, such as the belief that servicing equipment with reclaimed gas will void equipment warranties.

As discussed in earlier sections, service technicians often do not recover refrigerants during maintenance due to an entrenched culture that does not prioritize recovery. Additional hurdles include logistical and cost challenges with the number of cylinders required to properly separate gases, lack of proper recovery equipment, and continued perceptions that contractors may be charged for returning mixed gases.

Exhibit 12

Best practices for continued education and training for contractors

UK's certification body, REFCOM, requires companies to register to prove personnel are adequately trained and possess the necessary equipment to recover refrigerants.

RMI Graphic

Consumer Behavior and Education

Issue: Finally, to increase recovery rates, consumer behavior and deficiencies in existing knowledge gaps must be addressed. Few US consumers are aware that technicians are legally required to recover refrigerants, and most consumers are not aware of, nor do they understand, why recovery increases the cost and time of maintenance, an issue that could be rectified through educational literature for homeowners (see Exhibit 13). Furthermore, as reclaimed refrigerant becomes more prevalent, additional consumer education will be necessary to refute the common misunderstanding that, "reclaimed gas is technically inferior to virgin gas."

Exhibit 13

Best practices for consumer behavior and education

Australian contractors provide homeowners with educational literature explaining why refrigerant recovery is important for reducing climate-warming and ozone-harming impacts.

RMI Graphic

Recommendations

The following lists RMI's 10 recommendations to improve recovery rates and the viability of refrigerant reclamation in the United States, the rationale behind each recommendation, and possible challenges to implementation.

Recommendation 1: Improve financial compensation for gas recovery for contractors or transfer the responsibility of gas recovery to specialized technicians.	
Rationale	Recovery rates are likely to increase dramatically if contractors are adequately compensated. Alternatively, shifting this job to technicians who are solely responsible for gas recovery could alleviate contractors' time and cost burdens.
Challenges to implementation	(1) Increased rebates or other compensation for contractors who recover gas may make reclaimed refrigerant uneconomical without other complementary market levers. (2) Contractors may object to new technicians taking over certain aspects of their jobs if it results in reduced compensation.
Recommendation 2: Improve US contractor accountability and training through the standardization of licensing requirements across states to include license expiration and/or mandatory continuing education requirements.	
Rationale	Stronger licensing and certification requirements will help ensure that contractors remain more up to date on industry SOPs and developments.
Challenges to implementation	(1) Changing licensing requirements may be difficult to implement because of contractor pushback, legislative delays in nationwide enforcement, and rollouts. (2) This move can exacerbate the issues of financial and time constraints by requiring contractors to get and pay for continued education and training. (Note that the financial burden may be offset with workforce development incentives.)
Recommendation 3: Centralize and standardize data collection, reporting, and auditing on a state and national-level and improve gas tracking/labeling and record keeping.	
Rationale	Mandating real-time data collection, reporting, and auditing of how refrigerants are used, transported, and disposed of will increase accountability and improve refrigerant life-cycle management.
Challenges to implementation	A statewide and/or nationwide mandate and rollout will require significant state-level and national-level coordination and legislation.

Recommendation 4: Institute an eventual R-410A phaseout (beginning with virgin refrigerant, followed by reclaimed refrigerant).	
Rationale	Sending market signals for a phasedown far in advance will reduce stranded assets and ensure equipment with high-GWP refrigerants does not continue operation after intended lifetime.
Challenges to implementation	Actual supplies of virgin and reclaimed refrigerant may be artificially decreased earlier than the sunset date due to industry aversion to stranded assets, leading to shortages.
Recommendation 5: Propose the final EPA rule to require the use of reclaimed refrigerant gas while servicing existing residential ACHP equipment/units, rather than for new equipment/units.	
Rationale	Requiring reclaimed gas in new equipment creates a supply issue because not enough gas is reclaimed. Rather, requiring reclaimed gas in servicing of existing equipment limits demand and ensures the gas is eventually phased out as equipment is retired.
Challenges to implementation	There will be a large initial supply constraint for reclaimed refrigerant as reclamation increases from current levels.
Recommendation 6: Ensure equipment is not used beyond its intended lifetime by increasing efficiency requirements, offering utility financing, and increasing "cash for clunkers"-type trade-in programs.	
Rationale	Programs incentivizing newer equipment will help lower the burden of technology transition to lower-GWP equipment.
Challenges to implementation	(1) These programs are expensive, and some require legislation. (2) Measures may not increase reclamation rates but will help ensure reclamation does not extend the use of high-GWP equipment.
Recommendation 7: Centralized refrigerant recovery from end-of-life equipment where possible (e.g., window units).	
Rationale	Centralized reclamation reduces time burden for contractors on site and can be done more efficiently.
Challenges to implementation	(1) The majority of residential systems in the United States are split systems, making end-of-life recovery challenging. It can be an option for self-contained units like window ACs, which are still common in many regions, but it would require a large change in contractors' SOPs. (2) End-of-life equipment is often scrapped/recycled for parts and materials. Centralized recovery would require a holistic program design that benefits all stakeholders.

<table>
<tr><td colspan="2">Recommendation 8:
Allocation of state- and federal-level funding to hire specialists to manage and maintain centralized refrigerant data and support auditing and enforcement activities.</td></tr>
<tr><td>Rationale</td><td>A dedicated workforce for improving and standardizing record keeping, auditing, and enforcement of regulations on a state and/or national level will be essential to making regulations enforceable and meeting critical climate goals.</td></tr>
<tr><td>Challenges to implementation</td><td>(1) Authorization of budget and personnel requests would require bipartisan consensus in many state-level governance structures and in national legislative bodies.
(2) This intervention would require significantly more training of enforcement and operations personnel to carry out the various data management, monitoring, auditing, and enforcement activities.</td></tr>
<tr><td colspan="2">Recommendation 9:
Mandate the creation of state-level and nationally administered databases for record keeping that can be updated in real time by contractors and/or technicians in the field via specialized apps on smartphones.</td></tr>
<tr><td>Rationale</td><td>Real-time, mandatory data collection by contractors and remittance of data to centralized record keeping on databases that are managed by governmental regulatory bodies will drastically improve data gathering, accountability, and enforcement.</td></tr>
<tr><td>Challenges to implementation</td><td>(1) Implementation requires dedicated resources, staffing, and systemized setup of auditing and enforcement processes by a federal government agency, which may be a lengthy (and costly) process.
(2) This would require federal or state-level mandates to incentivize compliance that would significantly affect recovery rates and result in major improvements in data collection and reporting.</td></tr>
<tr><td colspan="2">Recommendation 10:
Develop reporting methods like mobile phone applications with a uniform design/interface so that all contractors are collecting the same type of data and transmitting it in a standardized format that is receivable by the central database managed at a state or federal level.</td></tr>
<tr><td>Rationale</td><td>Standardizing and simplifying the method of data gathering and reporting will reduce the burden on contractors in the field and improve the ability of state and federal regulators to track gas recovery</td></tr>
<tr><td>Challenges to implementation</td><td>Development of state or federal level reporting systems is slow and can result in interfaces that are not intuitive.</td></tr>
</table>

SECTION 3

Looking Ahead

This analysis of the life-cycle emissions impacts of refrigerant reclamation and virgin refrigerant production, as well as refrigerant reclamation related policies, finds that emissions associated with a unit of reclaimed R-410A are significantly lower than those from production of a unit of virgin R-410A. Increasing R-410A reclamation to meet residential servicing demand will lower cumulative emissions over the next 20 years, especially in the near term. Additionally, reclaimed refrigerant will be required to meet the servicing demand for equipment using R-410A under increasingly constrained supply. Implementing a robust set of policies and procedural interventions can facilitate a higher rate of refrigerant recovery and reclamation through behavioral changes at the industry, contractor, and consumer levels.

The refrigerant landscape continues to evolve as the industry adopts changes through national- and state-level policies on recovery, refrigerant transition, and mandated reclamation requirements proposed by the EPA.[17] We recognize that complex market dynamics will emerge that will impact the scaling of refrigerant reclamation and demand of different refrigerants, especially as ultra-low GWP refrigerants also enter the market at different rates. Still, there is a critical opportunity reclamation presents in mitigating market scarcity and reducing GHG emissions, making the overall industry transition to lower GWP refrigerants more successful.

Appendix

Model Assumptions

	Baseline Scenario Key Assumptions
Production	• All R-410A is assumed to be produced in China because China produces the majority of HFCs[18] and life-cycle emissions data is available for China. This ignores differing emissions factors for North American production. • Emissions estimates for production are cited using the estimate provided for R-410A consumption in Europe.[19] Emissions factors for production include overseas shipping. The transport emissions are not adjusted based on distance to different ports in the United States, and are instead based on shipping distances from China to Europe. • Due to data availability, emissions factors are based on the European grid, which has lower average emissions intensity than the US grid. Electricity accounts for only a fraction of the energy used in refrigerant production. • Upstream emissions of methane associated with production of HFC precursors such as dichloromethane are not factored into this study due to data limitations.
Destruction	• Emissions estimates for destruction use the estimate for gaseous/fume oxidation at a European facility.[20] This is only one of the processes used in the United States, and thus the analysis assesses the sensitivity to a range of destruction process emissions factors for which data is available. • Emissions from refrigerant destruction are allocated to virgin production because any unit of virgin refrigerant produced will need to be destroyed at the end of life. • The emissions factor in the data source includes a "credit" for recovery of useful byproducts, which is ignored in the emissions factor used in this report. This process also assumes hydrochloric acid and hydrogen fluoride byproducts from destruction are usable and are removed rather than treated as waste.[21]
Reclamation	• Emissions estimates for reclamation use processing type estimates. Examples include an emissions factor for mixed-gas separation associated with a batch distillation facility in Europe, and an emissions factor for single species gas processing (higher purity) associated with a simple distillation facility in Japan.[22] • The model assumes 60% of reclaimable refrigerant undergoes only simple distillation, whereas the remaining 40% undergoes advanced separation. • The model assumes that recovered refrigerant is entirely reclaimable. The process does not reject refrigerant, despite waste generated during the process. The emissions factor in the Yasaka et al.[23] study includes a "credit" for recovery of useful byproducts, which is ignored in the emissions factor used in this report.

	Baseline Scenario Key Assumptions, continued
Recovery	• This model assumes all refrigerant is recoverable, but there is some loss in the process of refrigerant evacuation. We estimate this loss at 2% (range is 0.5%–3% in the literature).[24]
Transportation	• Domestic distribution is assumed to not be included in the emissions factors associated with production, reclamation, and destruction and therefore accounted for independently. The analysis assumes domestic transportation from shipping port to refrigerant distributor and point of recovery to destruction/reclamation facility occurs by truck. Emissions factors of truck transport were taken from Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies model (GREET).[25] • For recovery, this ignores any minimum mass of consolidated refrigerant in a single location needed for shipping but applies a flat emissions factor to each unit of refrigerant retired.
Transfer	• EPA supply chain report suggests that there is a transfer loss of 1%–3% between bulk storage containers (such as ISO containers for overseas shipment) and cylinders, so this factor is applied to virgin refrigerant being shipped from overseas.[26]

Additional Methodology Details

Sectors Represented by Interviewees

In an attempt to gather viewpoints from a wide variety of industry stakeholders, our team reached out to experts associated with many different sectors. These included the refrigerant industry, including industry advocacy associations for contractors, distributors, and practitioners in general, as well as industry consultants, nongovernmental environmental research and advocacy organizations, an international development agency, a software vendor, and a manufacturer. We also reached out to a US federal regulatory agency but were unable to obtain an interview.

List of Stakeholders Interviewed

Sector	Name	Title	Organization
Industry association	Alex Ayers	Vice President of Government Affairs	Heating, Air Conditioning and Refrigeration Distributors International
Industry association	Barton James	President and CEO	Air-Conditioning Contractors of America
International development agency	Bernhard Siegele	Program Manager	Deutsche Gesellschaft für Internationale Zusammenarbeit
Industry association	Kylie Farrelley	General Manager	Refrigerant Reclaim Australia
Industry association	Dr. Greg Picker; Mark Vender	Chair; Advocacy and Policy Manager	Australian Institute of Refrigeration, Air-Conditioning and Heating
Industry	Ray Gluckman	Consultant	Gluckman Consulting
Industry	Tim Thurnham	Consultant	Eider Consulting
Nongovernmental organization (NGO)	Dr. Richie Kaur	Senior Superpollutant Reduction Advocate	Natural Resources Defense Council
Industry manufacturer	Anonymous	—	Anonymous

Survey Instrument

For experts who were unable to participate in a video meeting, our team provided the option to fill out an online survey with the same list of questions asked of interviewees. The survey was made available through Google Forms.[27] We received two responses via the survey:

Sector	Name	Title	Organization
NGO	Tilden Chao	Associate	Carbon Containment Lab
Industry software vendor	Louis Potok	CEO and cofounder	Recoolit

Interview/Survey Questions

Why are recovery and reclamation rates so low?

1. Are there particular recovery/reclamation challenges specific to the residential sector?
2. What existing policies (in your state/country/jurisdiction) make recovery and reclamation more difficult?
3. What additional market mechanisms (federal and state policies, buyback programs, training, etc.) would enable more recovery and reclamation?
4. How could accountability for venting/recovery be improved?
5. What solutions (technology, policy, etc.) could address the issue of reclaiming contaminated/mixed gas?
6. Are cost penalties for mixed-gas returns still an issue? Will market prices fix this or are more policies required?
7. How do we boost HFC recovery in order to service current/legacy equipment without extending the use of this equipment past the intended lifetime?
8. What role do different actors in the refrigerant value chain have or need to play to improve recovery/reclamation?
9. What are the costs associated with reclamation? What price does refrigerant need to be in order to make reclamation economical?
10. Are there experiences/learnings from HCFC phasedown/phaseout that can be applicable to the HFC phasedown in order to avoid bad practices and price hikes that could otherwise impact the economics of reclamation?

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19 Yasaka et al., "Life-Cycle Assessment of Refrigerants."

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