Closing the Loop: Lifecycle Refrigerant Management for Vermont's Residential Heat Pumps

Efficiency Vermont R&D Project: Greenhouse Gas Reduction

December 2025

Rose Wall authored this paper with significant contributions from Li Ling Young, Jake Marin, Nick Neverisky, Jerry Showman, Melissa Stewart, and Mac Roche.

20 Winooski Falls Way
Winooski, VT 05404

Contents

Glossary

Term		Definition
Efficiency Vermont's EEN (Efficiency Excellence Network)		A network of independent contractors and service providers committed to providing their customers the highest level of professional energy efficiency services.
GHG (greenhouse gas)		Gases that trap heat in the atmosphere, contributing to climate change.
HFC (hydrofluorocarbons)		Synthetic greenhouse gases used in refrigeration and air conditioning; thousands of times more potent than CO_2 and a major contributor to climate change.
Fugitive emissions		Releases of refrigerant into the atmosphere, often caused by leaks during installation, operation, and servicing.
GWP (global warming potential)		A measure of how much heat a greenhouse gas traps in the atmosphere relative to carbon dioxide (CO_2), which has a GWP of 1.
LRM (lifecycle refrigerant management)		A comprehensive approach to minimizing refrigerant emissions across all stages of a system's life—from manufacturing and transportation, to installation, operation, servicing, and end-of-life.
Refrigerant	Bank	The total quantity of refrigerant contained in equipment currently in use, stored, or awaiting disposal.
	Charge	The precise amount of refrigerant required for system operation.
	Destruction	The process of chemically eliminating refrigerants to permanently remove their climate impact.
	Reclamation	The process of cleaning and reprocessing refrigerant to meet purity standards for resale and reuse in other systems.
	Recovery	Safely removing refrigerant from a system, during servicing or decommissioning, to prevent atmospheric release. Refrigerant recovery is the precursor to recycling, reclamation, or destruction.
	Recycling	Reusing recovered refrigerant in the same system or under the same ownership, without meeting the purity standards required for resale.
	Venting	The illegal release of refrigerants into the atmosphere, which contributes significantly to GHG emissions.

Executive Summary

Heat pumps are central to Vermont's decarbonization strategy, offering well-documented climate benefits that will continue to improve as the market shifts to lower global warming potential (GWP) refrigerants. However, this transition does not address the climate liability in existing systems. Across Vermont, approximately 80,000 heat pumps and many legacy air conditioners contain refrigerants with GWPs thousands of times higher than CO_2's. Without intervention, they will continue to be managed as they have been for the past 50 years: inconsistently and often improperly. If mishandled, emissions from this existing high-GWP refrigerant inventory could erode the climate benefits of electrification.

Addressing this climate risk requires strategic interventions, such as contractor incentives, training, and standardized recovery practices, to make lifecycle refrigerant management (LRM) routine. This study focuses on LRM in residential and small commercial systems. Although these systems represent only a fraction of Vermont's total refrigerant inventory, they are an unaddressed problem with available market solutions.

Through contractor interviews, survey data, and literature review, the research identifies key barriers to recovery, including logistical challenges, equipment costs, documentation burdens, and cultural norms within the trade. It also highlights opportunities to improve outcomes through incentives, workforce training, public engagement, and policy innovation.

Key findings include:

- End-of-life refrigerant venting remains a major source of emissions.
- Operational leaks reduce system efficiency and increase energy use, yet are rarely addressed.
- Contractor engagement is essential, but current programs lack the tools, metrics, and support needed to drive behavior change.

To address these gaps, this paper proposes a suite of market transformation strategies, including:

- Integration of greenhouse gas metrics into performance frameworks
- Incentivized recovery, quality installation, and leak prevention and repair programs
- Equipment stipends and tool libraries
- Public awareness campaigns and contractor recognition programs

By embedding LRM into program design and contractor practices, Vermont can protect its climate investments and strengthen refrigerant stewardship.

Introduction

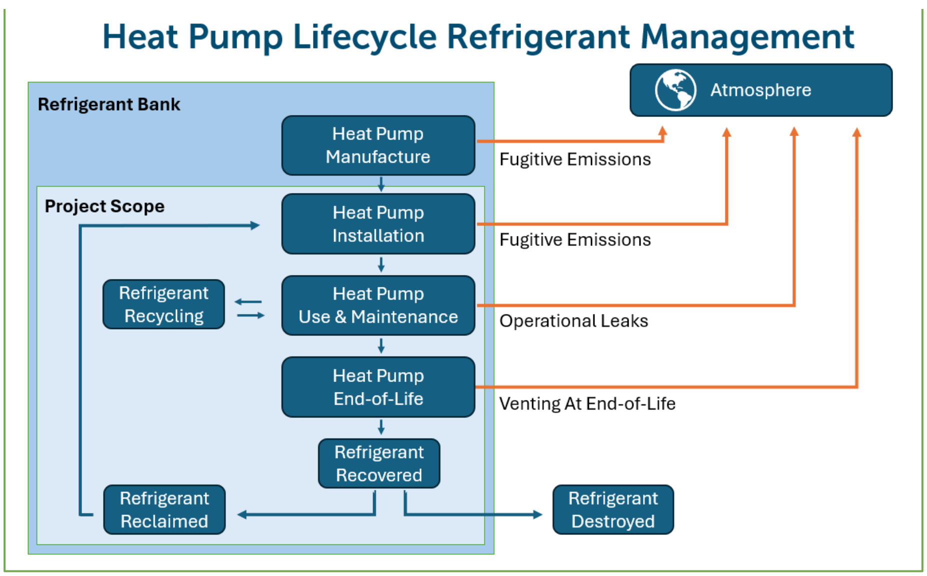
Refrigerants are chemical compounds essential to modern heating and cooling systems, but most in use today have global warming potentials (GWPs) thousands of times greater than that of carbon dioxide, making their containment a critical climate priority. Although designed for sealed systems, refrigerant emissions can occur at any stage, from transportation and installation to operation and end-of-life. If unmanaged globally, refrigerant emissions could add nearly 0.5°C of warming by 2050 (Vennamaneni, Muralidharan, & Ankit, 2025).

A key concept in understanding this climate risk is the refrigerant bank, the total quantity of refrigerant currently in equipment, storage, or awaiting disposal. This bank represents a latent source of greenhouse gas (GHG) emissions because every pound of refrigerant has the potential to be released if not properly managed.

This research centered on residential heat pumps in Vermont, a sector that often falls through the cracks of recovery infrastructure due to limited incentives, weak enforcement, and low market awareness. Detection is further complicated by the fact that charged refrigerants are colorless and odorless.

Lifecycle Refrigerant Management (LRM) provides a framework to address emissions across all stages of a system's lifecycle, from system development to end-of-life. Figure 1 illustrates when refrigerant releases can occur and which lifecycle stages this paper addresses.

Figure 1: Heat Pump Lifecycle Refrigerant Management



This image is adapted from one created by Caroline Benedetti, Yale Carbon Containment Lab (Mayhew, Chao, & O'Rourke, 2023)

The research team focused on two high-impact stages:

- Operational Leaks, which are often unnoticed until performance declines and costs rise.
- Venting at End-of-Life, when refrigerants are released instead of recovered.

The research team examined the LRM practices of HVAC contractors, who are positioned as the final gatekeepers of refrigerant containment, and increasingly shoulder the responsibility for managing these potent greenhouse gases. The team identified barriers, opportunities, and strategies to improve outcomes. Through stakeholder engagement, market analysis, and literature review, the researchers identified targeted interventions that support climate goals and a resilient supply chain. Contractors are essential partners in LRM, and this paper aims to identify strategies that support their success by reducing barriers and aligning incentives with best practices.

Background

The Greenhouse Gas Context of Heat Pumps and Refrigerants

Heat pumps deliver significant reductions in GHG emissions compared to fossil fuel heating systems. A typical residential heat pump consumes approximately 4,000 kilowatt-hours (kWh) per year, which corresponds to about 2,284 pounds of CO_2 emissions from electricity consumption annually, using an average emissions factor of 571 pounds of CO_2 per megawatt-hour (MWh) (Quach, 2024). However, the efficiency advantage of heat pumps—often expressed as a coefficient of performance (COP) of 3—means they can displace roughly 12,000 kWh of fuel energy, equivalent to 40.9 million British thermal units (MMBtu) of heating output. Compared with fossil-fuel systems operating at 85% annual fuel utilization efficiency, heat pump displacement of fossil fuels avoids significant carbon emissions. In practical terms, switching from fossil fuel heating to a heat pump can save between 3,352 and 5,592 pounds of CO_2 per year, depending on the type of fuel being replaced and the annual operating hours.

Despite this technical potential, empirical evidence indicates that heat pumps in Vermont are not consistently achieving expected levels of fossil fuel displacement. A recent evaluation commissioned by the Vermont Department of Public Service and conducted by a third-party consultant found that average heat pump utilization is significantly lower than modeled performance assumptions. The analysis attributes this underperformance primarily to balance point (or "turnover) temperatures, at which households switch from heat pumps back to fossil fuel systems, as well as fewer annual heat pump operating hours than anticipated. As a result, the realized GHG reductions from heat pump adoption are lower than their theoretical potential.

Table 1 illustrates the potential annual CO_2 savings that can be achieved by switching from fossil fuel heating to heat pumps, highlighting why heat pumps are a cornerstone of Vermont's electrification strategy.

Table 1: Estimated Annual CO_2 Savings from Heat Pump Adoption Compared to Fossil Fuel Heating

Displaced fuel type	Emissions factor (lbs. CO_2/MMBtu)	Emissions for 40.9 MMBtus (lbs. CO_2)	Adjusted for 85% efficiency	Net CO_2 emissions savings to replace fuel use with heat pump (lbs./year)
Natural Gas	117	4,785	5,636	3,352
Propane	139	5,685	6,676	4,392
Oil	161	6,585	7,876	5,592
Heat Pump	-	2,284	-	-

Vermont is a national leader in per capita adoption of heat pumps. Efficiency Vermont has incentivized over 78,000 heat pumps (Walke, 2025) and aims for 120,000 by 2030 (Efficiency Vermont, 2025). However, refrigerant emissions can diminish these GHG savings.

The Climate Risk of Refrigerant Emissions

A leak of 3 lbs. of R-410A (GWP 2,088) releases 6,264 lbs. of carbon dioxide equivalent (CO_2e), a metric that expresses the climate impact of different gases relative to CO_2. This amount can equal one to two years' worth of operational GHG savings from a typical heat pump compared to fossil fuels. Although a leak's absolute climate impact is fixed, its significance depends on how the heat pump is used. When a heat pump replaces most or all fossil-fuel heating, that leak represents a relatively small portion of the system's lifetime CO_2e benefits. However, in homes where the heat pump is used mainly for cooling—a common pattern in dual-fuel systems—even a single 3-lb leak can cancel out much of the expected climate benefit. (Efficiency Vermont, 2025).

Figure 2 and Figure 3 illustrate these dynamics for fuel oil and natural gas scenarios. In the first figure, the top line labelled "83,880" shows the cumulative CO_2e a cold-climate heat pump can offset over 15 years when replacing fuel oil with no refrigerant leakage. The next line down shows how a 3 lb. leak in year one, five, ten, and at the end-of-life, if the refrigerant is vented instead of recovered, reduces those savings. Gradual leaks may have a smaller immediate climate impact, but they also degrade COP over time, further reducing avoided emissions. This is not shown on the graph.

The third line shows the effect when the heat pump offsets only 50% of fuel use; refrigerant leaks erode a much larger share of the climate benefit. The lowest line, labeled "-4,050", represents a system with the same refrigerant-leak pattern but only 25% utilization (e.g., used primarily for cooling). In this scenario, the heat pump becomes a net CO_2e emitter rather than delivering net savings.

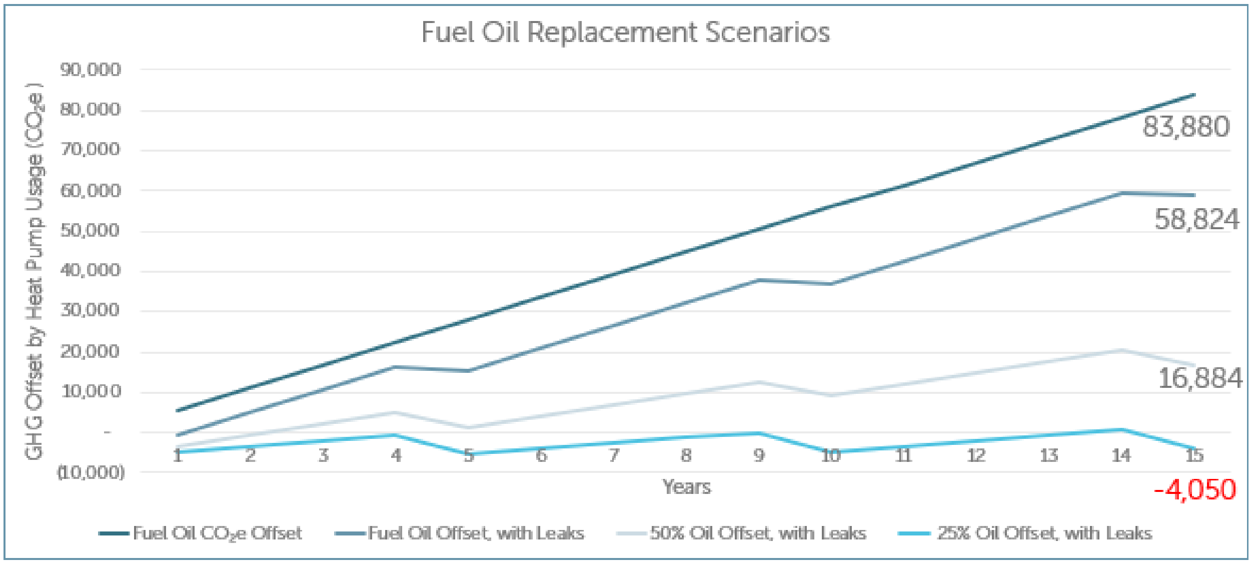


Figure 2: Impact of Refrigerant Leaks and Heat Pump Utilization on Lifetime CO_2e Savings When Replacing Fuel Oil

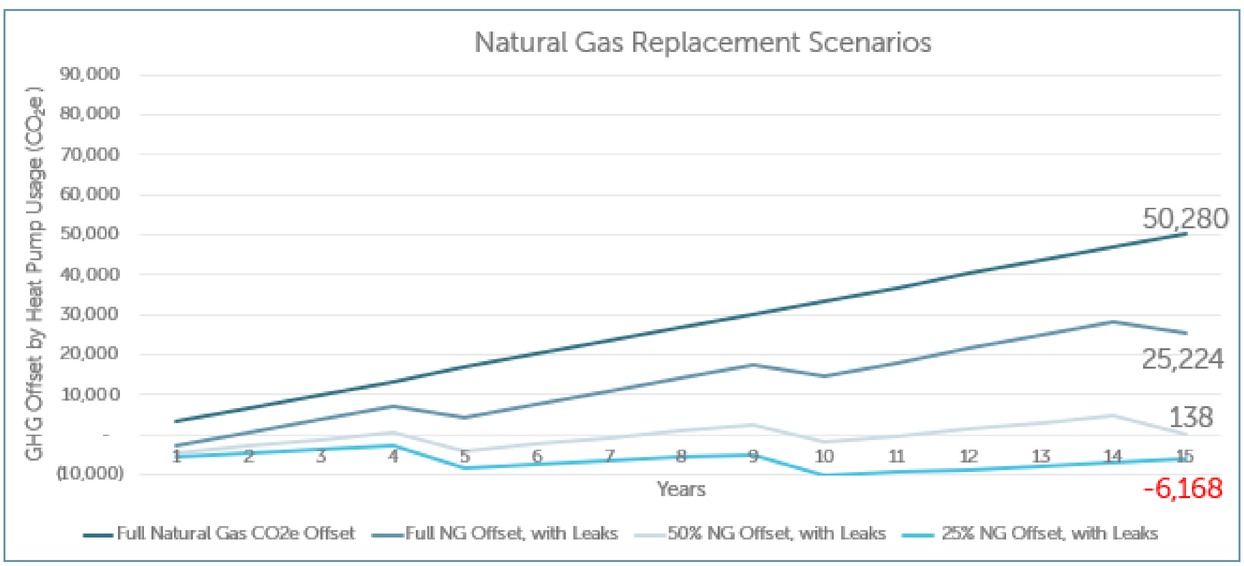


Figure 3: Impact of Refrigerant Leaks and Heat Pump Utilization on Lifetime CO_2e Savings When Replacing Natural Gas

This reality underscores the need for heat pump programs that combine efficient equipment, quality installation, maintenance, and proper decommissioning, with customer education on year-round use. Heat pumps are designed to heat and cool efficiently; using them for both purposes maximizes efficiency and reduces GHG emissions from fossil fuel use. Without this behavioral component, even small refrigerant leaks can erode the intended reductions in GHG emissions.

> Requirements for new system refrigerants do nothing to neutralize the climate liability locked in existing systems.

Vermont's installed residential heat pumps contain over 218,000 lbs. of refrigerant, equivalent to the annual emissions from approximately 47,400 gas-powered cars.[1] This figure only reflects heat pumps and significantly underestimates Vermont's total heating, ventilation, and air conditioning (HVAC) refrigerant inventory. Legacy air conditioning systems using high-GWP refrigerants such as R-22 (GWP 1,810) and R-12 (GWP 10,900) remain in service. Some have even been decommissioned but not deconstructed, sitting idle with their full refrigerant charge intact. These older systems often contain far larger refrigerant volumes than modern heat pumps, meaning their climate liability is orders of magnitude greater than emissions from recent installations.

Commercial and industrial systems are more likely to undergo refrigerant recovery due to stricter EPA compliance requirements and financial incentives tied to larger volumes of refrigerant. In contrast, residential heat pumps, which typically contain less than 10 lbs. of refrigerant, often lack the same financial or regulatory motivation (UNEP TEAP, 2024), making them a critical but under-addressed segment of the market. At these smaller charge sizes, EPA requirements are largely limited to the prohibition on intentional venting and recovery by certified technicians during service or disposal, while enhanced leak-rate thresholds, inspection mandates, repair deadlines, and recordkeeping or reporting obligations apply only to larger-charge systems above federal thresholds (EPA, 2025).

The reality is that no comprehensive dataset exists on the total installed refrigerant inventory in Vermont or the total amount of refrigerant being recovered annually.

While electrification offers long-term GHG reductions, unintended refrigerant emissions, mainly from high-GWP legacy systems, can undermine these benefits. Beginning in 2026, the American Innovation and Manufacturing Act (AIM) mandates that new heat pump installations use refrigerants with GWPs below 750, such as R-32 (GWP 675) and R-454B (GWP 466) (United States Environmental Protection Agency, n.d.). While this market transition marks progress, it also highlights the need to accelerate the adoption of natural refrigerants, such as CO_2 (GWP 1) and R-290 (GWP 3), which offer significantly lower climate impacts. Going forward, heat pumps will use lower-GWP refrigerants and have smaller charges; however, requirements for new

[1] Calculation assumes 78,000 heat pumps, each averaging 1.3 tons of cooling capacity. With an average refrigerant charge of 2.3 lbs. per ton, this totals 230,256 lbs. of refrigerant. Applying the GWP of R-410A (2,088 CO_2e per lb.) gives 480,774,528 lbs. CO_2e. This is 218,078 metric tons of CO_2e. Dividing by 4.6 metric tons per car per year equals ~47,400 gas-powered cars.

systems do nothing to neutralize the climate liability locked in existing systems, which pose a silent threat that will persist for decades unless acted upon.

Why Refrigerant Recovery Matters

The climate impact of refrigerants is both potent and preventable. Recovering refrigerant from a system is essential because venting it, an illegal practice, releases high-GWP GHGs that cannot be removed from the atmosphere and permanently removes them from the supply of future refrigerants.

Refrigerant recovery requires specialized tools, including recovery vacuum machines, refrigerant cylinders, hoses, and a scale, to safely capture and contain refrigerant during maintenance or at the system's end-of-life. Recovered refrigerants can follow one of three paths:

- Recycled: Returned to equipment under the same ownership.
- Reclaimed: Cleaned and processed for resale. Reclamation supports a circular refrigerant economy, reducing demand for virgin hydrofluorocarbons (HFCs). However, climate benefits are only realized when reclaimed refrigerants are used in systems with low leakage rates. Without complementary efforts in leak detection, prevention, and repair, reclamation may delay emissions rather than prevent them (Theodoridi et al, 2022).
- Destroyed: Incinerated, which removes the climate risk.

By treating refrigerants as climate-relevant assets rather than disposable materials, LRM ensures that refrigerant emissions do not erode the environmental benefits of electrification. These emissions are time-sensitive and under-addressed climate issues. Proactive LRM is essential.

Closing the Recovery Gap: Lessons from Global Leaders

The practice of venting—intentionally releasing a refrigerant charge into the atmosphere—remains endemic in parts of the HVAC industry, despite its significant climate impact. The U.S. Environmental Protection Agency (EPA) Section 608 regulations require technicians to recover high-GWP refrigerant during servicing or decommissioning, rather than vent it. However, enforcement is rare (UNEP TEAP, 2024). The U.S. lacks a national incentive structure to encourage refrigerant recovery, leaving compliance largely dependent on the behavior of contractors.

Globally, countries such as Japan, Denmark, Norway, Spain, Australia, and Canada have successfully increased refrigerant recovery by engaging contractors and introducing producer responsibility regulations, which fund refrigerant recovery, transport, and destruction through fees on virgin refrigerants (Environmental Investigation Agency, 2019). While these international models demonstrate what is possible, the U.S. recovery landscape remains fragmented and under-supported.

In the U.S., recovered refrigerant can be returned directly to EPA-certified reclaimers or to local refrigerant distributors, who then return it to their national partner organizations and on to EPA-certified reclaimers for processing. Contractors may be compensated for their returned refrigerant or required to pay a fee, and financial arrangements vary widely by business model.

However, there is no unified tracking system at the national or state level to monitor refrigerant purchases or returns by individual contractors or companies. Quantities are tracked only through distributor sales, and contractors may use different distributors for supply and return. This fragmented system and weak enforcement make it difficult to design effective programs to support recovery.

Market dynamics further complicate recovery. While the phasedown of high-GWP refrigerants is expected to eventually raise refrigerant prices, as with the R-22 phaseout and the resulting increase in reclamation, these price signals may come too late, after significant releases have already occurred. Current market conditions do not always make recovery and reclamation practical or cost-effective. Proactive program support can help bridge this gap, making recovery easier and more attractive, and ensuring benefits are realized sooner.

These systemic gaps create a landscape where policy alone cannot ensure refrigerant recovery. In practice, success depends on the individuals performing installation, servicing, and decommissioning. Contractors operate at the intersection of regulatory requirements and real-world constraints, making their role pivotal in determining whether recovery occurs or emissions are released.

> While no survey respondents or contractors interviewed for this project disclosed venting refrigerants, an illegal practice, several acknowledged awareness of others who either vent refrigerants or "top off" leaking systems without addressing the root cause.

Professional Climate Defenders: Contractors

Contractors are central to LRM because they interact with systems at every critical stage: installation, servicing, and decommissioning. Their technical expertise and direct customer relationships enable them to influence outcomes that protect climate investments. **Many contractors already demonstrate strong workmanship and compliance, and their role as trusted advisors makes them essential partners in the LRM process.**

However, these strengths coexist with systemic constraints that can hinder consistent LRM. Contractors often operate under tight timelines, variable site conditions, and limited visibility into long-term system performance. As noted by Theodoridi et al. (2022), "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."

Time pressures are a significant barrier to refrigerant recovery. In many parts of the industry, skipping recovery has become normalized, particularly as completing the next job is often more lucrative. While no survey respondents or interviewees for this project disclosed venting refrigerants (an illegal practice), several acknowledged awareness of others who either vent refrigerants or “top off” leaking systems without addressing the root cause. Efforts to increase recovery are seen as both time-consuming and costly (DNV, 2024). This is especially true when the refrigerant charge is small and its perceived value is low (UNEP TEAP, 2024). The time required to transport refrigerant adds to the overall burden (Theodoridi et al., 2022).

Technicians report logistical hurdles that discourage consistent recovery practices. Equipment and workflow challenges compound the issue. Recovery requires specialized tools—recovery machine, refrigerant scale, and refrigerant-specific recovery cylinders—that are expensive and often difficult to locate or transport (DNV, 2024).

Training gaps and persistent misconceptions also hinder progress. Meanwhile, the certification training that permits technicians to handle refrigerants varies widely in its emphasis on best practices for recovery (Muralidharan et al., 2024). These misunderstandings contribute to low recovery rates and missed opportunities for climate mitigation.

Vermont’s Market: Contractor Feedback and Systemic Barriers to Refrigerant Recovery

Building on the industry background, the research team combined desk review and stakeholder engagement to assess refrigerant recovery practices in Vermont. The team drew insights from industry publications, conference proceedings, and interviews with contractors and distributors. To complement the interviews, the team distributed an anonymous survey to HVAC and refrigerant professionals in Efficiency Vermont’s Efficiency Excellence Network (EEN). Though this approach provided valuable perspectives from engaged contractors, it likely does not represent the full spectrum of Vermont’s HVAC industry. The research methodology was designed to capture both technical and behavioral dimensions of refrigerant recovery, focusing on identifying barriers, opportunities, and real-world practices. The survey results and interviews revealed a complex mix of logistical, administrative, and cultural challenges that shape refrigerant recovery practices in Vermont.

Logistical Barriers

Returning recovered refrigerant emerged as the respondents’ most frequently identified challenge. Most contractors rely on local supply houses or distributors for refrigerant return, making these entities critical access points for compliant refrigerant management. Two large companies indicated that they work directly with a reclamation company, suggesting limited market penetration of this refrigerant-return option. Alternative methods, such as pulling refrigerant into a condenser and transporting it to a scrap yard for recovery and processing, were mentioned in interviews but rarely reported in the survey.

Respondents reported time constraints as another major barrier, particularly for smaller companies. Seventy percent of the respondents who cited time-related issues worked for companies with fewer than five employees. Storage limitations were more prevalent among larger firms, while equipment-related challenges affected both small and mid-sized companies.

Contractors cited a range of equipment-related challenges. One respondent noted that purchasing recovery equipment costs approximately $1,000, making early jobs unprofitable and deterring entry into recovery work even among motivated contractors. Other comments pointed to material failures in the HVAC equipment, with one contractor stating, "Your efforts would be much better spent working with manufacturers to improve coils, or regulations in that regard. People will hold onto a system until it leaks, then replace it. Therefore, there is virtually never any refrigerant left."

Cultural and Compliance Issues

Contractor attitudes toward accountability varied widely. Some respondents expressed frustration with peers who fail to prioritize proper practices, emphasizing that "professionals just need to care about their work and doing things right." Others noted that refrigerant recovery is already a legal requirement and should be treated as a baseline expectation, rather than something that requires incentives. Calls for stronger enforcement were common, with comments such as "refrigerant recovery is not optional" and "heavy fines for discharging refrigerant." One respondent even suggested "make it law," despite federal regulations already mandating recovery—highlighting the need for workforce training and a culture of compliance.

In contrast, three respondents reported no barriers to recovery. Two simply stated, "We follow it," while another noted, "It's what we do as needed to do things right," indicating that for some contractors, recovery is already embedded in standard operating procedures.

Although EPA Section 608 certification is a legal prerequisite for handling refrigerants, survey feedback indicates that fewer than half of companies reported full compliance, revealing potential gaps in ongoing training and accountability. Section 608 certification tests fundamentals but does not require continuing education or documentation to maintain certification for life. Although many professionals in the industry are highly trained and conduct high-quality work, Efficiency Vermont staff occasionally encounter professionals who are unaware of the GHG impact of refrigerants, suggesting that awareness and practices vary widely across the market.

Administrative Barriers

The smallest companies cited documentation burdens, showing how limited administrative capacity amplifies compliance challenges. Respondents described inconsistent recordkeeping and difficulty tracking refrigerant history across multiple service providers. Documentation challenges are more common in systems with a larger refrigerant charge than in smaller HVAC systems, but as HVAC refrigerant types diversify, this issue may become more widespread.

Policy experts emphasized a lack of comparative data across contractors, equipment types, and regions. They noted that the sector has limited insight into how much refrigerant different contractors recover, what distinguishes high-performers, and which tools or practices lead to better outcomes. This gap underscores the need for clearer benchmarks, shared reporting expectations, and case studies that help establish consistent, sector-wide data on refrigerant recovery.

Financial Perceptions

Only four respondents, all from companies with fewer than five employees, reported that recovery generates revenue. While this may reflect niche business models or specific service offerings, it reveals the limited financial upside most contractors currently perceive. Although respondents did not rank cost and training as top priorities in the multiple-choice responses, they repeatedly mentioned them as barriers in the open-ended comments.

The Case for Lifecycle Refrigerant Management Funding in Vermont

These barriers—logistical, cultural, administrative, and financial—reveal a systemic disconnect between regulatory expectations and field realities, underscoring the urgent need for market interventions. LRM requires coordinated action among regulators, state agencies, utilities, distributors, and contractors. Vermont needs a clear regulatory mandate and resources for LRM. Efficiency Vermont has the infrastructure to act, but success depends on regulators prioritizing this work and enabling programmatic support. Without dedicated goals and funding, this critical work will remain fragmented and underdeveloped.

Many residential heat pumps installed over the past decade that use R-410A refrigerant are approaching the end of their typical 15-year service life (Efficiency Vermont, 2025). Vermont began deploying cold-climate heat pumps at scale around 2015, with approximately 4,200 installed by 2016, positioning the late 2020s as the first period of widespread residential heat pump retirements (Energy Action Network, 2024). At the same time, the phasedown of high-GWP refrigerants is underway, and as the transition progresses, legacy refrigerant supplies will decrease, and costs are likely to rise. Without a targeted, time-bound LRM strategy, Vermont faces a risk of widespread venting and leakage, leading not only to preventable climate damage but also to higher repair and replacement costs for customers.

Metric Evolution for Comprehensive Impact

Efficiency Vermont's current GHG performance metric has a strong coincidence factor to measured energy savings, meaning emissions reductions are mostly claimed when they coincide with energy savings. To pursue refrigerant-focused initiatives that deliver significant climate benefits but limited or no direct energy savings would be an evolution from current practice and would necessitate input from regulators and policymakers.

Other jurisdictions have already made this shift:

- New York State Energy Research & Development Authority (NYSERDA) integrated GHG reductions into its performance framework alongside energy savings in response to New York's Climate Leadership and Community Protection Act.
- The District of Columbia Sustainable Energy Utility (DCSEU)[2] transitioned to a fully CO_2e-based performance metric to align with the District's climate and clean energy goals.
- California adopted the Total System Benefit (TSB) metric to replace traditional energy savings goals with a more comprehensive measure that includes GHG benefits.

These approaches offer a comprehensive, future-oriented view of climate impacts. Without such policy or regulatory frameworks in place in Vermont, incorporating refrigerant-focused initiatives that deliver significant climate benefits—even when they do not produce direct energy savings—would require a specific and compartmentalized role outside of traditional EEU services for the creation of electric system benefits.

Pathways to Market Transformation

Current heat pump programs in Vermont primarily focus on equipment purchase incentives, but they have little impact on post-sale activities. To capture the full efficiency, performance, affordability, and climate benefits of heat pumps, strategies must address the entire lifecycle, not just installation. This means designing comprehensive approaches for ensuring quality installation, responsible decommissioning of legacy systems, ongoing service and maintenance, and workforce training—while also engaging consumers to use heat pumps effectively for both heating and cooling.

Quality Installation and Applicable Decommissioning Incentive

HVAC installation is a technically complex process that involves precise load and distribution calculations, refrigerant line connections, and commissioning new equipment. Improper HVAC installation and end-of-life refrigerant venting undermine both efficiency and climate goals. Installation errors are widespread. The US Department of Energy estimates that "70–90% of residential HVAC systems have at least one performance-compromising fault, such as improper airflow or refrigerant charge" (Northeast Energy Efficiency Partnership, 2025). At the same time, the Environmental Investigation Agency reports that "the largest source of unaddressed emissions occurs when the refrigerant is evacuated from equipment during servicing or end-of-life (EOL) decommissioning" (Environmental Investigation Agency, 2019).

As most heat pumps installed in Vermont are still within their usable lifespans, only systems from early adopters and legacy AC systems are approaching the end of their lifecycles. There is an

---

[2] Efficiency Vermont and the DC Sustainable Energy Utility are both jurisdiction-wide energy efficiency utilities administered by VEIC, operating independently under separate regulatory and funding structures.

opportunity to implement market levers that ensure refrigerant recovery as replacements occur in the near future.

To capitalize on this opportunity, Vermont could adopt a more hands-on approach to heat pumps and implement a Quality Installation and Applicable Decommissioning Incentive Program that ensures new HVAC installations meet efficiency standards and comply with refrigerant recovery requirements. The bundling of energy efficiency and refrigerant recovery measures would embed best practices into both installation and end-of-life processes, reducing leaks, improving system performance, and preventing emissions.

Key components of this comprehensive LRM program include:

- Contractor-documented refrigerant recovery during equipment replacement or repairs that require removing refrigerant.
- Statewide adoption of a standardized checklist or list of data collection points, codeveloped with local contractors, distributors, and subject matter experts, to guide installation, refrigerant recovery practices, and documentation. (Several survey respondents noted inconsistencies in record-keeping and documentation, especially when multiple service providers are involved.)
- Contractor adoption of smart tools for commissioning (e.g., FM Hero, MeasureQuick), hosted by Efficiency Vermont training and lunch-and-learn sessions.
- Efficiency Vermont program integration with national efforts like the Northwest Energy Efficiency Alliance (NEEA) original equipment manufacturer commissioning reporting initiative, to gain access to and leverage for verifying equipment-generated data.

By tying incentives to quality installation and recovery practices, Vermont can raise the bar for residential HVAC outcomes, protect climate investments, and build consumer confidence in heat pump technology.

Learning from the DCSEU's National Leadership in LRM

The DCSEU launched the nation's first Refrigerant Recovery and Reclamation Pilot, offering a model Vermont can learn from as it considers LRM strategies. While the program delivers no direct energy savings, it demonstrates how targeted incentives can reduce GHG emissions by compensating contractors for properly recovering and returning high-GWP refrigerants. By creating a clear economic signal to prioritize recovery and prevent venting during servicing or decommissioning of equipment, the DCSEU pilot demonstrates that climate-focused programs can succeed even when they fall outside traditional energy efficiency frameworks. Vermont could look to this model as a benchmark when considering a Quality Installation and Applicable Decommissioning Incentive, ensuring that refrigerant recovery becomes a standard practice alongside efficiency goals.

Heat Pump Service and Repair Incentive

Vermont's market actors could collaborate to launch a Heat Pump Service and Repair Incentive Program. Refrigerant leaks during system operation contribute to GHG emissions and efficiency losses. Undercharged systems deliver less heating and cooling capacity, resulting in longer run times, increased energy consumption, and premature equipment failure. Maintaining the correct refrigerant charge is essential for optimal performance, customer affordability, and equipment longevity. When the charge drops, heat pumps consume more electricity to maintain comfort, especially during peak grid periods, which raises energy bills and stresses components. Research from Rocky Mountain Institute (RMI) shows that even modest charge loss (around 10%) can noticeably decrease efficiency, while larger losses (30–40% and above) can lead to significant performance decline, with efficiency reductions exceeding 30% depending on system design and ambient conditions. Although the exact impact varies by equipment and operating conditions, the overall trend is consistent: properly charged systems perform better, last longer, and emit fewer greenhouse gases (Vennamaneni, Muralidharan, & Ankit, 2025). If leaks are not repaired, repeated failures increase long-term costs, and the rising price of refrigerants under phasedown rules will amplify these impacts (Vennamaneni, Muralidharan, & Ankit, 2025).

Vermont could draw on elements of California's approach to quantify electric savings and reduce refrigerant emissions. California's electronic Technical Reference Manual (eTRM) measure "Lifecycle Refrigerant Management, Residential" (California Technical Forum, 2025) demonstrates that leak detection and repair can deliver peak load reductions and climate benefits. Core implementation criteria for this eTRM measure include:

- Contractors detecting system refrigerant leaks using non-invasive tools
- Program-supported technician training on leak prevention and repair
- Contractor-installed specialty locking valve caps to prevent venting and tampering
- Contractors performing charge correction when undercharge thresholds are met

Annual equipment service visits also offer contractors key opportunities to clean coils, monitor performance, replace valves, and repair leaks—actions that compound efficiency gains and extend the equipment's lifespan. Compared with legacy systems like oil boilers, heat pumps require more routine cleaning and servicing. Vermonters need clear information, access to qualified contractors, and financial support to help normalize these practices.

Efficiency Vermont has experience in this space, having pioneered a refrigerant leak detection and repair program for commercial systems. However, this program does not currently extend to residential-sized systems due to multiple factors, including funding constraints that require prioritizing the most energy- and GHG-intensive outcomes in the commercial market. For residential heat pumps, a leak detection and repair incentive would need to be part of a comprehensive heat pump program or suite of programs to ensure alignment with Vermont's climate goals and available resources. Vermont's limited pool of residential heat pump service providers poses another challenge for scaling leak detection and maintenance programs. To overcome this, Efficiency Vermont can leverage its experience growing the contractor base by pairing financial incentives with targeted workforce development and training.

Workforce and Cultural Foundations

The survey feedback reflects cultural gaps within the HVAC industry. Some contractors are frustrated by the poor workmanship of others they see, such as faulty line set connections that lead to refrigerant leaks or contractors failing to properly service the heat pumps they install. This quality-of-service gap underscores the need for targeted workforce development and cultural transformation to cultivate a skilled workforce in Vermont. As in any industry, company culture drives accountability and quality. In the HVAC industry, a primary mechanism for skill development is on-the-job training. Habits, good or poor, are routinely passed along during ride-alongs and shadowing senior technicians. Without intervention, practices such as topping off leaks or skipping recovery under time pressure can become normalized, even among technicians who are aware of the legal requirements. Structured quality checks, refresher courses, and training on new refrigerant technologies are critical to keeping skills current and maintaining best practices throughout the workforce.

Vermont could provide the following engagement activities to encourage contractor participation in LRM training and best practice service delivery.

- Recurring training to foster a culture of quality and compliance.
    - Efficiency Vermont could expand Efficiency Excellence Network (EEN) trainings to include LRM best practices, such as non-invasive testing, troubleshooting, service, and proper refrigerant recovery procedures, as well as advanced topics such as handling next-generation refrigerants and holistic best practices beyond EPA Section 608 certification.
- Recognition and promotion to help consumers identify professionals committed to climate stewardship
    - Highlight high-performing contractors with strong customer communication through case studies and public recognition.
    - Create an industry award or designation for contractors demonstrating strong refrigerant management practices.
- Encouraging businesses to use refrigerant as a revenue source
    - Host informational sessions on payment opportunities from reclaimers and distributors.
    - Explain the importance of refrigerant separation and purity for resale value, especially as phasedown regulations tighten.
    - Facilitate partnerships with reclaimers and distributors through familiar formats such as lunch-and-learns and webinars on “How to Get Signed Up.”

Incentives for Necessary Tools

Coupled with growing the heat pump service provider network, increasing contractor access to refrigerant recovery tools is a key step. The cost of refrigerant recovery equipment and leak avoidance tools emerged as a major barrier in contractor surveys, distributor interviews, and the literature review. To address this, a trade ally incentive program could help contractors purchase essential equipment for proper refrigerant recovery.

As new refrigerant technology adoption evolves, contractors will need tools compatible with both legacy and next-generation refrigerants, including updated recovery machines, scales, and gauges. Access to better tools can speed recovery and address one of the most persistent barriers. Suggested approaches to making refrigerant recovery tools available to contractors include:

- Tool and equipment purchasing support for EEN HVAC contractors to improve the quality and quantity of refrigerant recovery.
- Pay-for-performance stipends tied to proof of refrigerant recovery for an agreed-upon number of projects or pounds of refrigerant.
- Starter packs of empty refrigerant cylinders or stipends to reduce the upfront costs of obtaining containers for recovered refrigerant.
- Efficiency Vermont could add refrigerant recovery equipment to the existing Tool Library, allowing contractors to borrow and test the equipment before purchasing.

However, tools alone do not change practices. To ensure proper use, the incentive should be paired with a training requirement that reinforces EPA Section 608 standards, the federal baseline for refrigerant handling, and builds practical skills beyond certification. Strong training programs already exist through organizations such as NATE, ESCO, and ACCA; Efficiency Vermont can host these courses through the EEN and make participation a condition of receiving the tool incentive. This approach could include refresher training on leak prevention and repair, recovery best practices, and compliance documentation, while also covering advanced topics such as proper evacuation procedures and handling next-generation refrigerants. Linking tool access to verified training ensures contractors and technicians apply best practices consistently and helps companies that lack internal training capacity meet legal requirements.

A refrigerant trade ally incentive program should be anchored in durable business practices, such as internal recovery policies, contracts with reclaimers or distributors, and standardized documentation, and could be modeled after the DCSEU program. By linking tool access to training and compliance, this approach can foster a culture of quality and accountability while supporting contractors in adopting LRM practices that improve customer experience and business profitability.

Public Education

Consumers increasingly ask Efficiency Vermont questions about refrigerants, signaling a shift in public interest toward understanding refrigerant technologies. Customer interest in refrigerants presents Vermont with an opportunity to build foundational consumer knowledge, empowering people to make informed choices that reduce emissions and protect valuable service gases. Refrigerant stewardship is not just a technical issue; it is a mindset that spans equipment selection, installation, maintenance, and end-of-life recovery.

A targeted consumer refrigerant awareness campaign could:

- Emphasize that refrigerant recovery is a legal requirement and a critical climate action, especially for existing, high-GWP systems nearing replacement.
- Illustrate the full lifecycle of HVAC systems, focusing on proper installation for leak prevention, maintenance, and responsible recovery at end-of-life.
- Highlight the CO_2e impact of refrigerant releases, helping consumers understand why managing what is already in the field matters more than ever.

Efficiency Vermont can draw inspiration from international efforts, such as Australia's homeowner-friendly refrigerant guides and New Zealand's Cool Safe campaign, which have run successful public education campaigns on refrigerant issues.

Efficiency Vermont's LRM Capabilities

Efficiency Vermont can integrate LRM work into existing programs. Current infrastructure supports rapid implementation through:

- Contractor Access: The Efficiency Excellence Network (EEN) connects directly with HVAC professionals, who are the key actors for refrigerant recovery and stewardship.
- Program Infrastructure: Established systems are in place to deliver financial incentives at scale, a proven lever for behavior change.
- Market Relationships and Technical Expertise: Strong ties exist with contractors, distributors, and building owners, supported by in-house HVAC and refrigerant expertise.
- Operational Experience: Efficiency Vermont has a history of adapting programs to meet evolving priorities, such as refrigerant management for commercial systems and EV adoption programs.

LRM represents a necessary evolution of current metrics, and Efficiency Vermont has the technical expertise, relationships, and infrastructure to implement it.

Conclusions

Vermont is at a pivotal moment. The state's installed base of heat pumps—and an untold number of legacy air conditioners—contains a large inventory of high-GWP refrigerants. Over the coming years, that refrigerant will either be emitted through operational leaks and end-of-life venting or recovered and managed responsibly. Lifecycle refrigerant management, paired with comprehensive heat pump programs, is the right intervention at the right time.

Contractor interviews and survey data reveal systemic barriers: time pressures, equipment costs, and entrenched norms. Consumers need clear guidance to maximize fossil fuel displacement, and contractors need practical tools, training, and incentives to make recovery and leak prevention routine. Acting now to address legacy refrigerants and optimize heat pump use will protect Vermont's climate investments and set a national example for pairing electrification with refrigerant stewardship.

References

California Technical Forum. (2025). Lifecycle Refrigerant Management, Residential (SWSV014). Retrieved from https://www.caetrm.com/measure/SWSV014/05/

DNV. (2024, June). *Forward Looking Low-GWP Refrigerant Transition Study.* Retrieved from www.dnv.com

Efficiency Vermont. (2025). *Vermont Heat Pump Market Assessment.* Retrieved from https://www.efficiencyvermont.com/Media/Default/docs/white-papers/vermont-heat-pump-market-assessment.pdf

Energy Action Network. (2024). *Vermont Energy Dashboard*. Retrieved from Pace of Adoption Cold-Climate Heat Pumps: https://eanvt.org/vermont-energy-dashboard/

Environmental Investigation Agency. (2019). *Search, Reuse, and Destroy: How States Can Take the Lead on a 100 Billion Ton Climate Problem.* Retrieved 2025, from https://eia.org/report/20190214-search-reuse-destroy/

EPA. (2025). *Stationary Refrigeration Leak Repair Requirements*. Retrieved from General Leak Repair Requirements: https://www.epa.gov/section608/stationary-refrigeration-leak-repair-requirements

Mayhew, C., Chao, T., & O'Rourke, A. (2023). *Lifecycle Refrigerant Management: Maximizing the Atmospheric and Economic Benefits of the Montreal Protocol.* Yale Carbon Containment Lab. Retrieved from https://carboncontainmentlab.org/documents/yale-cc-lab-lrm-background-paper-(updated-for-mop-35)-1704231604.pdf

Muralidharan, R., Westler, G., Sheeraz, H., Y. L., McGavisk, I., & Kalanki, a. A. (2024). *Refrigerant Reclamation: Assessing Potential Emissions Impacts of R-410A Refrigerant Reclamation in the United States' Residential HVAC Sector.* RMI. Retrieved February 2025, from https://rmi.org/insight/refrigerant-reclamation

Northeast Energy Efficiency Partnership. (2025). *Northeast High-Performance HVAC Market Assessment.* Retrieved from https://neep.org/sites/default/files/media-files/neep_ne_high_performance_hvac_market_assessment_final__0.pdf

Quach, K. (2024, September 16). *2023 ISO-NE Electric Generator Air Emissions Results.* ISO New England. Retrieved 2025, from https://www.iso-ne.com/static-assets/documents/100015/2024-09-16-2023-generator-emissions-results.pdf

Theodoridi, C., Hillbrand, A., Starr, C., Mahapatra, A., & Taddonio, K. (2022). *The 90 Billion Ton Opportunity: Lifecycle Refrigerant Management.* Environmental Investigation Agency, the Institute for Governance & Sustainable Development, and the Natural Resources Defense Council. Retrieved from https://eia.org/report/20221020-the-90-billion-ton-opportunity/

United Nations Environment Programme Technology and Economic Assessment Panel. (2024). *Decision XXXV/11: TEAP 2024 Task Force Report on Life Cycle Refrigerant Management*. Ozone Secretariat. Montreal Protocol on Substances that Deplete the Ozone Layer.

United States Environmental Protection Agency. (n.d.). *Reducing HFCs*. Retrieved from Background on HFCs and the AIM Act: https://www.epa.gov/climate-hfcs-reduction/background-hfcs-and-aim-act

Vennamaneni, L., Muralidharan, R., & Ankit, K. (n.d.). *Why Refrigerant Matters More Than You Think for AC (or Heat Pump) Efficiency*. (RMI, Editor) Retrieved from https://rmi.org/why-refrigerant-matters-more-than-you-think /?utm_medium=email&utm_source=spark&utm_campaign=2025-10-02&utm_content=spark&jobid=73439&sfmc_id=94738789

Walke, P. (2025, October 6). Part 1-#25-1094-INV & #25-0443-INV - 10/6/25 In Person Workshop re EEU and RES Tier III Programs. Montpelier, VT: Vermont Public Utility Commission. Retrieved from https://www.youtube.com/watch?v=GZqHr2URQok