One Leak at a Time: Embedding Refrigerant Management in Building Electrification and Decarbonization Strategies

Ali White, Zoe Dawson, and Jake Marin, VEIC

ABSTRACT

Electrifying the building sector is typically considered a societal good and a positive step toward meeting a state's decarbonization goals. But refrigerant leaks in heating, ventilation, air conditioning, and refrigeration systems can hinder progress toward those goals. Hydrofluorocarbons, a family of refrigerants used across all markets, are greenhouse gases (GHG) thousands of times more potent than carbon dioxide. One effective method for meeting building sector decarbonization goals is to adopt strategies to address refrigerant leaks. Such a strategy also needs to recognize and articulate the necessary investments, training, and measurement and verification required to support this effort. If designed and implemented effectively, refrigerant management offers a path for utilities to expand their traditional efficiency offerings to include decarbonization initiatives recognized by, approved by, and accepted by regulators.

This paper shows how a Vermont efficiency program created the nation's first incentivized statewide refrigerant leak repair program, which contributed to the regulatory approval of a dedicated GHG performance metric for the state. The paper describes the GHG savings methods and how this approach supports energy efficiency performance metrics and state decarbonization goals. The authors compare Vermont's experience to that of subsequent refrigerant leak programs in New York and Washington, DC, demonstrating how DC's efficiency programs are using refrigerant management to support achievement of their own GHG goals, and how New York is driving market adoption of refrigerant management through the alignment of contractor training and education, supporting high-quality HVAC installation practices and decarbonization goals.

Finally, the paper suggests that refrigerant management, in addition to, or as a part of, broader efficiency programs, is a viable solution to help utilities meet their energy and GHG goals.

Introduction

The Emerging Role of Decarbonization Goals in State Climate Change Mitigation Planning

The United States has a long-term strategy to reduce greenhouse gas (GHG) emissions by 50 to 52 percent below 2005 levels, by 2030 (State Department 2021). Currently 24 states and the District of Columbia (C2ES 2022), along with many cities and businesses, have adopted GHG reduction targets as part of their economy-wide climate change mitigation strategies. Several have also created targets for carbon neutrality or net-zero emissions, to avoid the need for future removal of emissions. Further, as of December 4, 2021, 21 of the 30 largest U.S. electric and gas utilities are subject to mandated net-zero emission or equivalent targets to support or comply with statewide goals.

California experience: Sacramento and the concept of *avoided carbon.* In 2020, the Sacramento Municipal Utility Department (SMUD) became the first U.S. utility to change its program evaluation metric to *avoided carbon,* to help encourage investment in and measure broader adoption of electrification and decarbonization. Under SMUD's most recent integrated resource plan, the electrification of buildings and transportation comprises the primary strategy for achieving net-zero carbon emissions by 2040. Switching to electricity to support an avoided-carbon metric for investments has allowed SMUD to align its programs with these goals. SMUD has also created the Natural Refrigerant Incentive Program, made possible by the transition to an avoided carbon evaluation metric.

The rest of the state is in the process of shifting to a GHG metric for regulated efficiency programs, to be set by 2024 (CPUC 2021).

Massachusetts: Requirements for utilities. Similarly, under the Massachusetts Decarbonization Roadmap (Government of Massachusetts 2020), that state's government has asked utilities to decarbonize the building sector. Over the next 10 years, they will be responsible for annually installing 100,000 residential heat pumps. The state also aims to make a significant shift to electrifying heating for the commercial and industrial (C&I) sector. Massachusetts categorizes refrigerants and their management in the Roadmap's non-energy sector report; thus refrigerants fall outside the purview of utilities. Although there is no current pathway for utilities to directly incentivize refrigerant management in buildings if such actions result in GHG savings only, Massachusetts utilities are considering programs and measure recommendations with defensible estimates for specific technologies that can deliver both energy and GHG savings.

Although, as in the Massachusetts example, refrigerant management programs are not always the responsibility of a utility, a very profound need for them exists. That is, refrigerant management supports utility cost recovery strategies and aligns well with public policy goals. Further, leaving electrification up to the market is not likely to drive the pace of change that is needed to meet aggressive decarbonization goals.

New York: State decarbonization goals. In 2019 New York passed the Climate Action Leadership and Community Protection Act (CLCPA), the nation's most ambitious and comprehensive clean-energy legislation to date. It requires the state to reduce GHG emissions by 60 percent of 1990 levels by 2030, and 85 percent by 2050 (New York State 2022). These targets effectively place New York on a path to statewide carbon neutrality. The state's utilities, with the New York State Energy Research and Development Authority (NYSERDA), must demonstrate how they will meet these goals. Building electrification is a key strategy. Similar to Massachusetts' Roadmap, the NSYERDA New York Clean Heat Statewide Heat Pump Program plans to support 100,000+ heat pump systems in homes and business by 2025. However, if the systems are installed and maintained without addressing leaks, a conservative assumption of lifetime emissions associated with those systems' refrigerant leaks would total 264,000 metric tons of carbon dioxide equivalent (CO_2e) emissions.

The value of utility programs for ratepayers is often viewed narrowly from the perspective of energy savings, often through the lens of least cost acquisition. As regulated entities, utilities build programs to achieve metrics established through the regulatory process. The prudent use of ratepayer funds requires that utilities direct resources to meet mandated targets. However, the value of utility programs often goes well beyond energy savings. Other

benefits such as GHG reduction can be tracked; but unless they are required targets, they will not get the policy or program attention and resources required for success.

Adopting a GHG requirement makes it possible to shift the program design to optimize GHG reductions. The more comprehensive the GHG requirement, the more comprehensive programs can (and will) be designed to achieve the necessary savings. Standard practice uses CO_2e to account for GHG impacts. Using CO_2e enables a more comprehensive assessment of GHG, involving not only CO_2, but also methane, refrigerants, and lifecycle carbon. CO_2e is the common measure for describing the general impact of GHG reduction. It is typically expressed in metric tons, written as $MTCO_2e$.

A High-Value GHG Reduction Measure: Refrigerant Management

As jurisdictions begin to require GHG reductions and put programs in place for meeting targets, utilities must look beyond meeting requirements for electricity generation and providing services that relate primarily to site-based fossil fuel consumption.

Refrigerant management offers high-value GHG reduction that easily fits within a GHG reduction framework. Because the GHG impact of refrigerant management often correlates with energy savings, these measures can bridge traditional energy efficiency programs to new programs that reduce both the direct and indirect GHG emissions associated with a building's carbon footprint.

The Danger Is HFCs, and Refrigerant Management Is an Effective Response

Refrigerants are everywhere. We depend on refrigerant-based equipment and systems to keep our food cold and make our indoor air comfortable. Most refrigerant-based systems, however, contain hydrofluorocarbon (HFC) refrigerants, which have a very high global warming potential (GWP) relative to CO_2. When released into the atmosphere, these refrigerants have a GHG impact thousands of times greater than CO_2, pound for pound (Jaiswal and Ruehl 2017). Although HFC refrigerants are benign if they remain inside the pipe, nearly all refrigeration and air conditioning systems eventually leak. Some happen slowly over time, whereas others result from a catastrophic failure where most, if not all, of the refrigerant leaks out in a single event. Leaks not only degrade system performance, but they also have direct GHG consequences.

Properly managing refrigerants and refrigerant systems is one of the most important strategies for reducing GHG emissions (Hawken 2017). A single, medium-sized grocery store emits approximately 1,548 metric tons of CO_2e in direct refrigerant emissions each year (Morlino and White 2020). Heat pumps operate with refrigerants, too. From 2015 to 2020, the global stock of heat pumps increased nearly 10 percent per year (IEA 2021). Thus, higher numbers of installed heat pumps will lead to even higher emissions due to refrigerant leaks.

Existing Programs Can Integrate Refrigerant Management Initiatives

Utility efficiency programs often involve cost-effective opportunities for refrigerant management—but few have created specific programs for this strategy. Given appropriate regulatory guardrails, utilities have the customer relationships, administrative systems, and technical expertise to successfully deliver this expanded service to ratepayers.

Grocery stores, for example, rely heavily on refrigeration systems, and efficiency measures can dramatically reduce the electricity consumption associated with their operation.

Installing an additional measure—a permanent leak detection system—is one way to integrate cost-effective refrigerant management with other efficiency measures. Such systems can reduce leakage by more than half, saving kWh and reducing GHG from refrigerant emissions. New refrigeration rack systems[1] can incorporate low-GWP "natural" refrigerants, such as CO_2, thus saving energy and eliminating GHGs associated with refrigerant emissions.

Many utility programs support heat pump installation, which can displace fossil fuels for heating buildings. Incorporating "leak tight" installation best practices into heat pump programs can mitigate refrigerant leaks from the equipment. These best practices reduce refrigerant leaks, lower emissions, improve performance, and lead to greater customer satisfaction.

Three Case Studies

The following case studies describe three refrigerant management initiatives, demonstrating the impacts—beyond measured and verified energy savings—of next-generation measures in heating, ventilation, air conditioning, and refrigeration (HVACR) technology. They also demonstrate the success factors of each refrigerant management strategy.

Case Study 1: Efficiency Vermont

In 2021, Efficiency Vermont became the first efficiency utility nationwide to adopt GHG emissions as a contract performance metric. Efficiency Vermont's experience in tracking the GHG reductions associated with energy efficiency program activity, and in piloting refrigerant management initiatives, demonstrated the cost-effectiveness and feasibility of a GHG metric.

From its inception in 2000, Efficiency Vermont has tracked GHG reductions associated with program-related lowered electricity generation and site-based fossil fuel consumption. During the planning phase for the 2021-2023 performance period, these data proved the value of non-energy-related GHG emissions to Vermont ratepayers.

In addition, the Vermont General Assembly in 2020 passed legislation mandating GHG emissions reductions across all sectors. The Global Warming Solutions Act (Vermont General Assembly 2020) requires a 26 percent reduction over 2005 levels by 2025, a 40 percent reduction over 1990 levels by 2030, and an 80 percent reduction over 1990 levels by 2050. This is the state policy that supports Efficiency Vermont's GHG reduction metrics.

The GHG regulatory framework resulted in increased support for GHG reduction measures and accounting, well beyond what Efficiency Vermont had tracked historically. By setting non-energy GHG targets, Efficiency Vermont can expand measures such as refrigerant management that achieve large impact for an often minimal cost. This work initially applied to commercial refrigeration and has since expanded to address refrigerant management in HVAC and industrial process applications.

Before having the regulatory framework to account for the high impact of refrigerant management on GHG emissions reductions, Efficiency Vermont's regulatory reporting highlighted kWh savings from refrigerant management. However, although external reporting cited energy efficiency benefits, internal calculation methods and tracking systems showed the added value of these measures' direct emissions reductions. Thus, Efficiency Vermont effectively demonstrated the value stack of refrigerant management measures.

[1] Rack systems comprise several compressors, piped together, that connect more than one refrigerated case in a store.

In shifting to this new performance metric, Efficiency Vermont created a strategic framework for refrigerant management, clarifying its approach to this work and identifying three key strategies:

1. Reduce leaks in existing refrigerant-based systems
2. Replace high-GWP refrigerants with lower-GWP alternatives
3. Promote new systems with low-GWP refrigerants (for example, use natural refrigerants, and low-charge systems)

These three strategies can be applied across many system types and applications. In addition, Efficiency Vermont designed successful strategies for managing new and existing refrigerant-based equipment:

- **For existing systems.** Conduct a leak detection audit and repair any leaks or install a permanent leak detection system. Evaluate the system for refrigerant swap-out potential (often to low-GWP hydrofluoroolefin [HFO] or HFC / HFO blends). Consider early retirement if efficiency and GHG gains can be made.
- **For new or replacement systems**. Specify systems with low refrigerant charge and / or low-GWP refrigerants. Prioritize natural refrigerants (ammonia, CO_2, or propane) where possible.
    - Common equipment options are natural refrigerant racks, chillers, and self-contained reach-in units. CO_2 condensing units are on the very near horizon for customers with end-of-life equipment or new-construction plans.
    - Low-charge options use chillers over direct-expansion (DX) options, and air-to-water (or ground-source) heat pumps over variable refrigerant flow (VRF) systems. These systems have a fraction of the refrigerant found in systems that use the refrigerant as the transfer medium, dramatically cutting the total potential refrigerant emissions impact of the system.

Impact. Table 1 shows the emissions and consumption effects of the first year of Efficiency Vermont's operating under the new GHG metric. Cumulatively, the four measures resulted in approximately 8,500 metric tons (MT) of reduced CO_2e, 7,900 of which came from non-energy (refrigerant emissions) reductions. These efficiency measures also achieved over 1,200,000 kWh in energy savings. Some measures, such as refrigerators and freezers, produce the bulk of CO_2e reductions through electricity savings, whereas refrigerant leak repair and other measures produce most of the non-energy CO_2e savings.

Leak repair involved two initiatives. For large groceries, Efficiency Vermont incentivized the installation of permanent leak detection systems with individual refrigerant sensors installed throughout the store. These systems catch leaks as they occur and trigger a targeted service call. On at least two accounts, these warning measures prevented catastrophic failures of refrigerant systems. For small and medium businesses, Efficiency Vermont created an initiative to spot-check for leaks, using ultra-high-sensitivity leak detection equipment (1 ppm). This initiative established a contractor network trained and outfitted to conduct these leak detection and repair projects.

Table 1. Efficiency Vermont's 2021 refrigerant management measures and their corresponding GHG emissions ($MTCO_2e$) and energy savings (MWh)

Measure	Number of units	Energy, in $MTCO_2e$	Non-energy, in $MTCO_2e$	Total MTCO2e	Energy Savings (MWh)
Rack—natural refrigerant	1	106	162	268	240
Refrigerant leak repair	48	270	7,751	8,021	610
Commercial refrigerators and freezers—natural refrigerant	136	123	2	125	278
Residential refrigerators and freezers—natural refrigerant	1,222	39	4	43	88
2021 total	1,407	539	7,918	8,457	1,217

Source: Efficiency Vermont

What made it succeed. All measures in the Efficiency Vermont portfolio deliver measurable, real-world value to customers, ensuring optimal use of ratepayer funding to meet customer needs. For example, refrigerant loss from grocery rack systems can result in rising box / case temperatures and, in severe situations, reduced shelf life and product spoilage. Installing permanent leak detection systems helps grocery stores catch leaks before any severe effects occur. Regulatory oversight related to refrigerant management has traditionally been a major pain point for C&I customers using chillers and other refrigeration equipment. But shifting to natural refrigerants effectively removes this regulatory burden. Properly designed natural refrigerant systems also save enough energy to make them cost-effective investments.

Case Study 2: The District of Columbia Sustainable Energy Utility

The District of Columbia Sustainable Energy Utility (DCSEU) provides an alternate model for GHG program development. In the case of Efficiency Vermont, pilot projects undertaken within the framework of existing energy efficiency programs demonstrated the value of refrigerant management for ratepayers and helped support the establishment of a regulated GHG metric. By contrast, the DCSEU oversight body, the District Department of Energy & Environment (DOEE), under its new 5-year contract cycle with the DCSEU (FY 2022 - 2026), has adopted a program performance benchmark and set $MTCO_2e$ targets for reducing GHG. The DCSEU has tracked GHG reductions from its portfolio of energy efficiency and renewable energy programs and services since 2012. However, this new performance benchmark is the first time these reductions are to be accounted for, against a cumulative (5-year) emissions reduction target. In response, the DCSEU is not only reviewing its full portfolio of proven programs and customer / contractor engagement strategies, but also exploring new programs, services, and energy—and notably, GHG-only—savings measures that can help meet this goal.

One such strategy under consideration is the expansion of the DCSEU's current refrigeration campaign, launched in FY 2021. It offers retrofit opportunities for lower-GWP refrigerants, natural refrigerant systems, and refrigerant management and leak detection in new and existing grocery stores. It also supports adoption of such measures beyond just the grocery

market. Just as important, staff will evaluate and screen any new measure that meets the DCSEU's required performance benchmarks—particularly those that offer high GHG savings, but low (or zero) MWh savings—for cost effectiveness in the DCSEU portfolio.

The DCSEU plans to target both its existing energy-saving measures and new GHG-only measures under its Refrigeration Campaign for C&I customers[2] (which targets grocery and hospitality markets). But it recognizes an opportunity exists to evaluate measures applicable to other commercial customers and the residential market. In addition, the DCSEU expects to expand its contractor training and outreach to include general refrigeration efficiency and refrigerant management awareness, and hands-on skill development in refrigerant leak detection and mitigation. The objective for this strategy is to ensure that future grocery customer site assessments can be paired with a refrigerant leak audit.

Impact. The DCSEU is assessing market effects of new refrigerant management initiatives and establishing clear methods for calculating the energy and GHG savings potential of existing and expanded Refrigeration Campaign measures and services. The DCSEU has begun a detailed market characterization and an assessment of potential impact from proposed refrigeration / refrigerant management measures:

- C&I – Grocery store leak detection / mitigation (retrofit)
- C&I – Commercial kitchen equipment (self-contained) - freezer / refrigerator (end-of-life replacement)
- C&I – Commercial natural refrigerant rack system (retrofit)
- C&I – Conversion to lower-GWP refrigerant in existing equipment (retrofit)
- Residential – Refrigerator – natural refrigerant (market opportunity)

This market impact assessment draws on work in Vermont and will help the DCSEU determine the best measures to implement for DC's customers as well as equipment type, savings (energy / GHG per measure), quantity to be installed, overall market adoption strategy (most measures will likely be bundled), and overall impact on the DCSEU's ability to meet these GHG targets.

Following the successful adoption of commercial refrigerant management initiatives, the DCSEU also plans to assess refrigerant management for building heating and cooling systems across the District. Finally, it will evaluate the adoption of new and expansion of defensible program opportunities that align with their GHG performance benchmark goal. Such initiatives might involve a prescriptive offering for commercial small businesses and / or take advantage of the DCSEU's trade ally network with the following measures:

- **Commercial.** Preventative maintenance (contractor training)
- **Residential window air conditioner recycling program**. Support the model for reclaiming refrigerants with appliance recycling, and pair with positive midstream incentives / market awareness
- **Commercial and residential heat pump installation and leak mitigation.** Contractor training)

[2] The District has deemed *C&I* to mean *commercial and institutional,* because the presence of heavy industry is minimal.

What will make it successful. Several success factors pertain to the DCSEU strategy. The high-level program scaling / impact assessment of these measures, in terms of MWh saved or $MTCO_2e$ reduced for the residential and C&I markets (beyond the grocery initiative), will support the DCSEU's achievement of GHG reductions from refrigerant management. However, it will also be important to drive adoption of energy- and GHG-saving opportunities with District customers and contractors. This is a performance matter, as much as it relates to regulatory compliance.

The DCSEU expects that District contractors might have knowledge and experience gaps for many of the new, energy-efficient and supportive technologies that will be promoted across the 5-year contract—particularly with regard to refrigerant management, natural refrigerants, and advanced heat pumps. The DCSEU therefore plans to use its well-recognized Workforce Development Program and the Train Green Sustainable Energy Infrastructure and Capacity Building Pipeline (Train Green SEICBP) program to address these gaps. It will also engage trade allies via the Refrigeration Campaign and new pilots, and work with distributors and manufacturers to train contractors in refrigerant management best practices. This strategy will support the promotion of equipment and natural refrigerant systems that can help to meet the DCSEU's decarbonization targets.

The DCSEU also expects customers to show moderate to high levels of risk aversion to adopting new technologies, given the associated cost, knowledge gaps, and / or lack of clear value propositions or benefit to them. Again, taking advantage of experience in Vermont, the DCSEU plans to use the results of its market impact assessment to make program design recommendations for each measure, to improve the chances of successful adoption in the market. This approach will require the active engagement of the DCSEU's customer account management and engineering consultant teams, and of the DCSEU's commercial refrigeration customers and their contractors. Together, input from these groups will help ensure effective design of pilot programs, market education, and engagement strategies and incentives. For example, pilot programs that provide high incentives for early adopters of natural refrigerant technology, rather than other strategies, might drive optimal success.

Separately, it is important to note the District Building Energy Performance Standard (BEPS) is measured in terms of energy use intensity (that is, in MMBTU / EUI factor; EPA 2022), per the Clean Energy Omnibus Amendment Act of 2018 (CEDC Act; DOEE 2022). No one has yet determined if BEPS should switch to a GHG reduction instead of an EUI metric. However, if fugitive refrigerant emissions, are included in a future BEPS compliance GHG calculation, added support for research, development, and adoption of refrigeration leak detection and natural refrigerant technologies would be warranted.

Case Study 3: NYSERDA

VEIC′s work with NYSERDA shows how a market-based approach can advance refrigerant management initiatives even in the absence of a GHG performance framework for utilities.

The potential for high-GWP refrigerant leaks in existing and new HVACR systems can diminish the benefits of building electrification, both through decreased system efficiency and the GWP of the refrigerant itself. NYSERDA sought innovative solutions to accelerate the mitigation and phase-out of high-GWP refrigerants through refrigerant monitoring and leak detection, novel compressors, in-field leak repair, and low-GWP refrigerants. NYSERDA has contracted with VEIC to test a scalable strategy for uniform, effective market resources for the

prevention, detection, and repair of refrigerant leaks in new and existing field-installed HVAC systems. The project, which began in January 2022, will be completed in two phases—development and demonstration—across 36 months.

New York can significantly benefit from investments in refrigerant leak prevention, detection, and monitoring tools, in tandem with contractor training. This combination will effectively mitigate the climate impact of high-GWP refrigerants in field-installed HVAC systems and refrigeration equipment, and in new systems. Further, as low-GWP refrigerants come onto the market, health and safety issues from leaked flammable or caustic refrigerant can be addressed.

The distribution of new diagnostic Leak-Tight Toolkits, combined with deep training of HVACR contractors, provide a commercially viable, readily scalable solution to the problem of refrigerant leaks. The Toolkits support proper installation, handling, and servicing of refrigerant-based equipment. In conjunction with Toolkits and training, this project will also evaluate field-installed metering for predictive leak monitoring, offering reliable data on the environmental impacts of non-energy CO_2e savings. The project will create a pathway for a clean heating and cooling supply chain and avoid large environmental and economic costs from HVAC leaks.

Impact. HVACR accounts for 54 percent of energy use in the U.S. commercial sector; 44 percent comes from electricity use, and 10 percent from refrigeration (EIA 2012). For New York, this equates to approximately 40,500 million kWh / year. The energy efficiency impact of leaks varies by system type and configuration, but a low refrigerant charge typically results in more electricity use. For example, a residential heat pump undercharged by 40 percent reduces the relative coefficient of performance by approximately 45 percent while heating, and approximately 24 percent while cooling. For HVACR systems under 5 HP, VEIC analysis show that leaks can result in excess energy costs between $500 and $3,000 per system year (or 5,500 to 20,500 kWh / year). If 3.6 percent of 100,000 heat pump systems in New York experience catastrophic leaks, it could result in an additional 46,800 MWh annually by 2025. If VEIC's solution prevents or addresses leaks in just 10 percent of those systems, the benefit to electricity ratepayers will be 4,680 MWh / annually.

The New York Clean Heat Statewide Heat Pump Program plans to support 100,000+ heat pump systems in homes and businesses by 2025. If these systems are installed and maintained without Leak-Tight Toolkit foundations, a conservative assumption of lifetime emissions associated with refrigerant leaks in those systems would total 264,000 metric tons of CO_2e, as shown in Table 2.

Table 2. Estimated total lifetime CO_2e emissions from two types of refrigerant used in heat pump systems, absent Leak-tight Toolkit remediation, under the New York statewide program.

Refrigerant	GWP	Charge size (pounds)	System lifetime (years)	Annual leak rate	Market share by 2025	Total lifetime emissions ($MTCO_2e$)
R410a (non-ozone-depleting)	2088	5	20	3.6%	70%	228,887
Low-GWP	750	5	20	3.6%	30%	35,235
						264,122

VEIC's multiform approach cannot mitigate all projected emissions, but it will make a significant impact. For example, an estimated 10 to 25 percent market adoption rate of these strategies by 2025, ensuring through verification that HVACR systems are leak-tight when installed and serviced with non-invasive tools throughout the equipment lifetime, will reduce projected emissions by 26,000 to 66,000 $MTCO_2e$ from heat pumps alone.

As climate change creates more cooling demand, components of the VEIC solution can be easily translated to other vapor compression-cycle, field-installed systems, greatly expanding the potential for New York's GHG saving goals. By encouraging strong private-sector relationships and targeting training to HVAC contractors with businesses, operators of HVACR systems, and maintenance staff, this project supports statewide workforce development. This can inspire a new generation of digital- and tech-savvy graduates who want to be recognized for their role in championing environmental stewardship.

What will make it successful. The Leak-Tight Toolkit for HVAC contractors supports training that builds qualifications in minimizing leaks in new and existing systems. The Toolkit contains digital pressure gauges for faster and more accurate pressure readings, saving contractors time and allowing testing at lower pressures. The training also shows contractors how to use remote diagnostic equipment (for example, smartphones) to eliminate the need for invasive testing in at least half of all service calls. Current troubleshooting practice, for example, involves physically cutting into the system, inevitably leaking refrigerant.

Predictive monitoring, the second success factor, enables contractors to act quickly when there is a leak. Building on experience with real-time predictive monitoring of commercial refrigeration systems in Vermont, VEIC will be installing metering equipment on HVAC systems at several New York locations. Collecting and analyzing data (operating pressures and compressor starts / stops) along the way, VEIC will use modeling simulation to demonstrate when a refrigerant leak is likely to occur, allowing business owners and contractors time to make repairs. Commercially, customers and their contractors could use the system metering and predictive monitoring—as could unions, trade groups, and manufacturers.

Together, investments in scalable Toolkits (with accompanying HVAC contractor training) and in predictive monitoring will help mitigate the climate impact of high-GWP refrigerants in field-installed HVAC systems and refrigeration equipment, and in new systems. These tools also offer benefits related to equipment reliability, product and system quality, compliance, operation and maintenance (O&M) cost reductions, and marketing and environmental stewardship benefits. Monitoring creates a "thumbprint" of an HVAC system, helping identify energy efficiency opportunities and alerting staff to O&M needs before an equipment failure occurs.

The effective delivery of both the training and toolkit components of this project will help guide considerations of how to accelerate full-scale adoption of leak prevention and detection across New York. For example, they may inform certification programming to build a more inclusive clean-energy workforce trained in refrigerant management, or utility support and incentives for contractors interested in investing in a Leak-Tight Toolkit. Separately, the in-depth review of the quantified data on the economic, energy, and HFC emissions effects of leak prevention and detection for commercial HVAC systems can support (1) statewide savings potential estimates, (2) recommended updates to New York's Technical Reference Manual, and (3) guidance on advancing regulatory assurance toward investments in statewide strategies that address benefits beyond saved MWh and therms (MMBtu).

What the Case Studies Say about the Next Generation of Efficiency Programs

These case studies show how recognition of currently unaccounted-for GHGs can support the creation of a GHG performance metric in customer-facing programs. They also demonstrate how utilities with GHG metrics can use the energy and GHG savings impact of refrigerant management to meet their goals. The case studies describe ways to ensure that market adoption or even market awareness can be realized—especially in the context of going beyond incentivizing a refrigerant management measure and providing a meaningful and cost-effective value proposition for customers and contractors. Each case study demonstrates that states with carbon goals must (1) recognize the direct link between building electrification and the state's decarbonization goals; (2) address any misalignment or missed opportunity in statewide utility cost recovery strategies and public policy goals; and (3) consider the incentivization and market adoption of refrigerant management strategies as critical next steps in realizing the full environmental benefits of decarbonization goals.

Utilities need to make long-term plans for deep decarbonization and are under pressure to position themselves and their investments in a manner that will achieve climate goals. Although many utilities have set aggressive targets, many, too, are counting on innovative technologies to achieve their goals. As valuable as technology can be, the human element (training in and action on front-line refrigerant management, at a minimum) is essential.

Utilities will also need to respond to the increase in residential and commercial building electrification from heat pumps and other refrigeration systems—especially if this electrification occurs without leak monitoring or leak-free installation protocols. Otherwise, utilities will be unable to drive effective market adoption of these technologies, and states will face having to reconcile how they allow the electrification market to grow at the expense of making progress toward meeting their decarbonization goals.

References

CPUC (California Public Utilities Commission). 2021. "CPUC Better Aligns Energy Efficiency Programs to Reduce GHG Emissions, Support Equity, and Increase Grid Stability." docs.cpuc.ca.gov/PublishedDocs/Published/G000/M385/K242/385242131.PDF.

C2ES (Center for Climate and Energy Solutions). 2022. "U.S. State Greenhouse Gas Emissions Targets." www.c2es.org/document/greenhouse-gas-emissions-targets/.

DOEE (District Department of Energy & Environment). 2022. "Clean Energy DC Act." District of Columbia Government. doee.dc.gov/service/clean-energy-dc-act#:~:text=The%20Clean%20Energy%20Omnibus%20Amendment,the%20fight%20against%20climate%20change.

EIA (U.S. Energy Information Administration). 2012. *Commercial Buildings Energy Consumption Survey.* Washington, DC: EIA. www.eia.gov/consumption/commercial/data/2012/.

EPA (U.S. Environmental Protection Agency). 2022. "What Is Energy Use Intensity (EUI)?" Washington, DC: ENERGY STAR®. www.energystar.gov/buildings/benchmark/understand_metrics/what_eui.

Government of Massachusetts. 2020. "MA 2050 Decarbonization Roadmap." Boston: Executive Office of Energy and Environmental Affairs. www.mass.gov/info-details/ma-decarbonization-roadmap.

Hawken, P., ed. 2017. *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. New York: Penguin Books. drawdown.org/solutions/refrigerant-management.

IEA (International Energy Agency). 2021. "Heat Pumps." www.iea.org/reports/heat-pumps.

Morlino, L., and A. White. 2020. "Appendix 5: Study of GHG Emissions from In-Use Natural Refrigerants." *2019 Greenhouse Gas Taskforce Efficiency Vermont Report.* Updated March 10. Burlington, VT: Efficiency Vermont. www.efficiencyvermont.com/Media/Default/docs/white-papers/2019_RD_GHG_taskforce.pdf.

Jaiswal, Anjali, and H. Ruehl. 2017. "Climate Action: Global Transition Away from HFCs." Washington, DC: Natural Resources Defense Council (NRDC). www.nrdc.org/experts/anjali-jaiswal/climate-action-global-transition-away-hfcs-moving-forw.

New York State. 2022. "Our Climate Act: Climate Leadership and Community Protection Act." Albany: Climate Action Council. climate.ny.gov/Our-Climate-Act.

State Department (U.S. Department of State). 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050.* www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

Vermont General Assembly. 2020. "An act relating to addressing climate change." 10 V.S.A. § 578. (passed September 9). legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT153/ACT153%20As%20Enacted.pdf.

White, Ali. 2021. "Direct Expert Testimony Regarding Refrigerant Management Programs." Before the New York State Public Service Commission. Testimony on behalf of New Yorkers for Cool Refrigerant Management. Case 21-E-0074. May 28. documents.dps.ny.gov/search/Home/ViewDoc/Find?id=%7B0950F2C9-D50B-4AEA-B934-2CDEEA48D159%7D&ext=pdf.