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HOW STATES CAN TAKE THE LEAD ON A 100 BILLION TON CLIMATE PROBLEM

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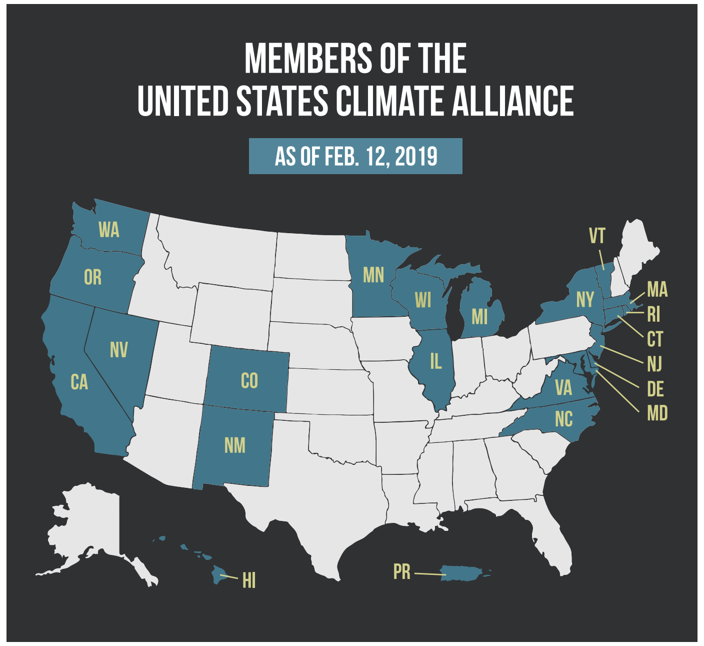
CFCs, HCFCs, and HFCs, potent greenhouse gases used as refrigerants, are commonly stored in pressurized color-coded cylinders. Proper management, reuse, and destruction of refrigerants could mitigate 96.5 gigatons, or nearly 100 billion metric tons, of CO_2 equivalent emissions globally between 2020 and 2050.

Introduction

The recent United Nation's Intergovernmental Panel on Climate Change (IPCC) report on limiting global temperature rise to within 1.5 degrees Celsius reveals the urgent need for near term, high impact strategies to reduce emissions of all climate pollutants. Fast action to reduce emissions of short-lived climate pollutants, including fluorinated greenhouse gases, or "F-gases" such as hydrofluorocarbons (HFCs), can avoid over half a degree of warming by 2050 and significantly reduce the likelihood of reaching dangerous climate tipping points.[1] Indeed, the projected reductions of fluorinated gases required by 2050 under 1.5°C-consistent pathways are deeper than published estimates of what a full implementation of the Montreal Protocol including its Kigali Amendment would achieve.[2] Mitigation of banks of fluorinated gases, or "F-gas banks" represents the most impactful near term strategy to achieve deeper mitigation of F-gases consistent with limiting warming to within a 1.5°C pathway.



> ...the projected reductions of fluorinated gases required by 2050 under 1.5°C-consistent pathways are deeper than published estimates of what a full implementation of the Montreal Protocol including its Kigali Amendment would achieve.

"F-gas banks" are the total quantity of fluorinated gases that have been or are to be produced and will be emitted into the atmosphere unless sustainably managed and disposed.[3] The F-Gas bank exists primarily in the form of refrigerants, and in smaller quantities in foams. Addressing the refrigerant bank, through minimizing leaks and increasing end-of-life recovery, reclamation, and destruction, has been identified as the single largest opportunity for emissions reductions in terms of carbon dioxide equivalent. These approaches have the potential to avoid up to 96.5 Gigatons of CO_2 equivalent ($GtCO_2e$) globally between 2020 and 2050.[4] In the U.S., an estimated 75 million metric tons CO_2 equivalent ($MTCO_2e$) emissions annually can be avoided in 2020 through collection and destruction of F-gas banks at end of life.[5]

F-gas banks consist of ozone depleting substances (ODS): chlorofluorocarbons (CFCs), and hydrochlorofluorocarbons (HCFCs), and their replacements hydrofluorocarbons (HFCs), which do not deplete the ozone layer, but have global warming potentials thousands of times that of carbon dioxide. While ODS banks are now declining following a global phase out of CFCs and HCFCs, the HFC bank is still rapidly growing.[6] Without further acceleration of the phase-down schedule under the Kigali Amendment, the global HFC bank alone is anticipated to reach approximately 64 $GtCO_2e$ in 2050.[7]

The U.S. Climate Alliance roadmap for states on decreasing short-lived climate pollutants to support meeting the goals of the Paris Agreement identified refrigerant management and end-of-life strategies as key elements of an overall approach to reducing HFC emissions.[8] A number of U.S. states are already taking steps to reduce HFCs by backstopping the previously established federal regulations under the EPA's Significant New Alternatives Policy (SNAP) Program.[9] While this step supports a transition away from high-global warming potential (GWP) HFCs in new equipment, a significant gap remains to address lifecycle emissions of existing banks, with no global policy framework nor an effective federal policy in the United States. U.S. states have the opportunity to take a more comprehensive approach to addressing HFC emissions through a range of available policy approaches to account for and reduce emissions from refrigerant banks.

Immediate steps can be taken by states to address emissions of refrigerant banks from both leaks and at end of life. California's refrigerant management program represents one approach to minimizing leaks that has potential to be replicated and expanded in other states. End-of-life emissions can also be tackled through programs to increase recovery, reclamation, and destruction. A host of examples of end-of-life programs in other countries provide demonstrated successful approaches. Several examples of such programs are provided herein, alongside specific recommendations for U.S. states. Finally, an assessment of costs and benefits of recovery and destruction demonstrates that there are significant climate benefits per ton of refrigerant recovered and destroyed, making end-of-life management a cost-effective approach.

Sources of Emissions from Refrigerant Banks

Inadvertent release or leakage of refrigerant can occur at many stages from the point of installation, during use and transport, to final disposal. The majority of recoverable F-gas banks take the form of refrigerant contained in existing refrigeration and air conditioning equipment or bulk inventories and stockpiles. Below are several key primary sources of emissions to be considered in developing policy approaches:

Leaks During Use and Transport

Refrigerants continually leak out of existing refrigeration and air conditioning equipment through compressors, seals and connections, often at high rates which can be reduced by encouraging improved practices for equipment maintenance, leak detection, and prompt repairs. The average supermarket refrigeration system leaks 25% of its total refrigerant charge annually, or 1,000 pounds.[10] For the average supermarket this could amount to 1,780 metric tons of CO_2e, or annual emissions of nearly 400 passenger cars.[11] These sources of significant greenhouse gas emissions often do not account for their carbon footprint under existing reporting systems.

Venting and Emissions at End of Life

The largest source of unaddressed emissions occurs when refrigerant is evacuated from equipment during maintenance and servicing or when equipment is retired. At end of life, without any incentives or regulations in place, refrigerants are often vented into the atmosphere or accumulated as stockpiles that contribute to further leaks and venting. End-of-life emissions from the refrigerant bank represent a very large quantity of avoidable emissions here in the United States in the near term. A 2018 study prepared for the EPA estimates the quantity of recoverable HCFCs and HFCs that could be collected and destroyed from equipment retired in a single year in the United States to be approximately 39,000 metric tons[12] in 2020, or roughly 75 million MTCO$_2$e annually.[13] This is equivalent to annual emissions from 16 million passenger vehicles or 19 coal-fired power plants.[14] According to EPA data, approximately 11 million pounds or approximately 8,600 metric tons of refrigerants were reclaimed in 2017, suggesting that current rates of reclamation of used refrigerant are around 22% of the recoverable amount forecast for 2020.[15] An assessment for the state of California estimated emissions avoidable for the state of over 10 million MTCO$_2$e in 2020 increasing to 15.5 million MTCO$_2$e annually in 2050.[16]

> …the quantity of recoverable HCFCs and HFCs that could be collected and destroyed from equipment retired in the United States [is] approximately 39,000 metric tons in 2020, or 75 million MTCO$_2$e annually.

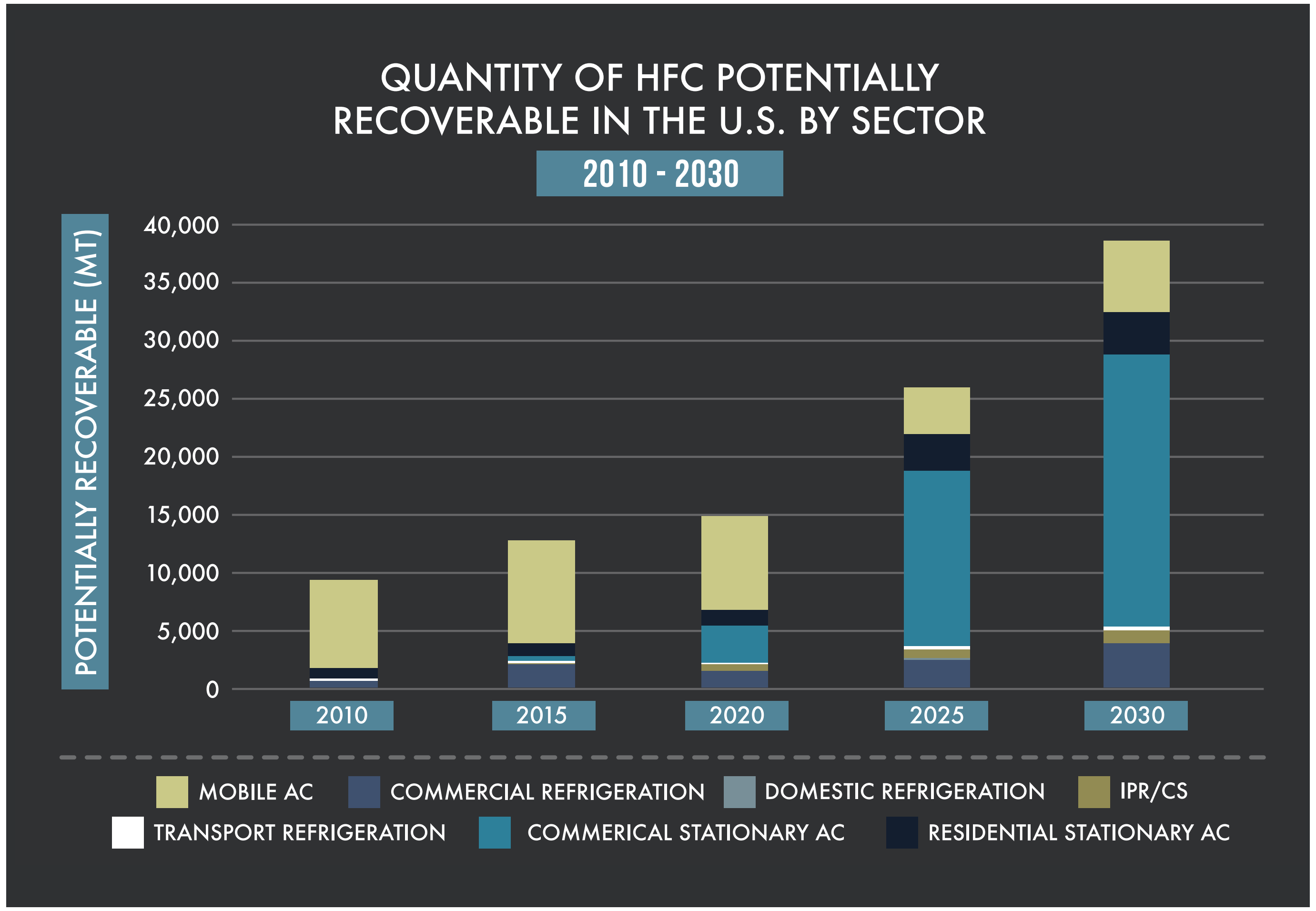


Figure 1: Quantity of HFCs potentially recoverable in the U.S. by sector
Source: ICF, 2018

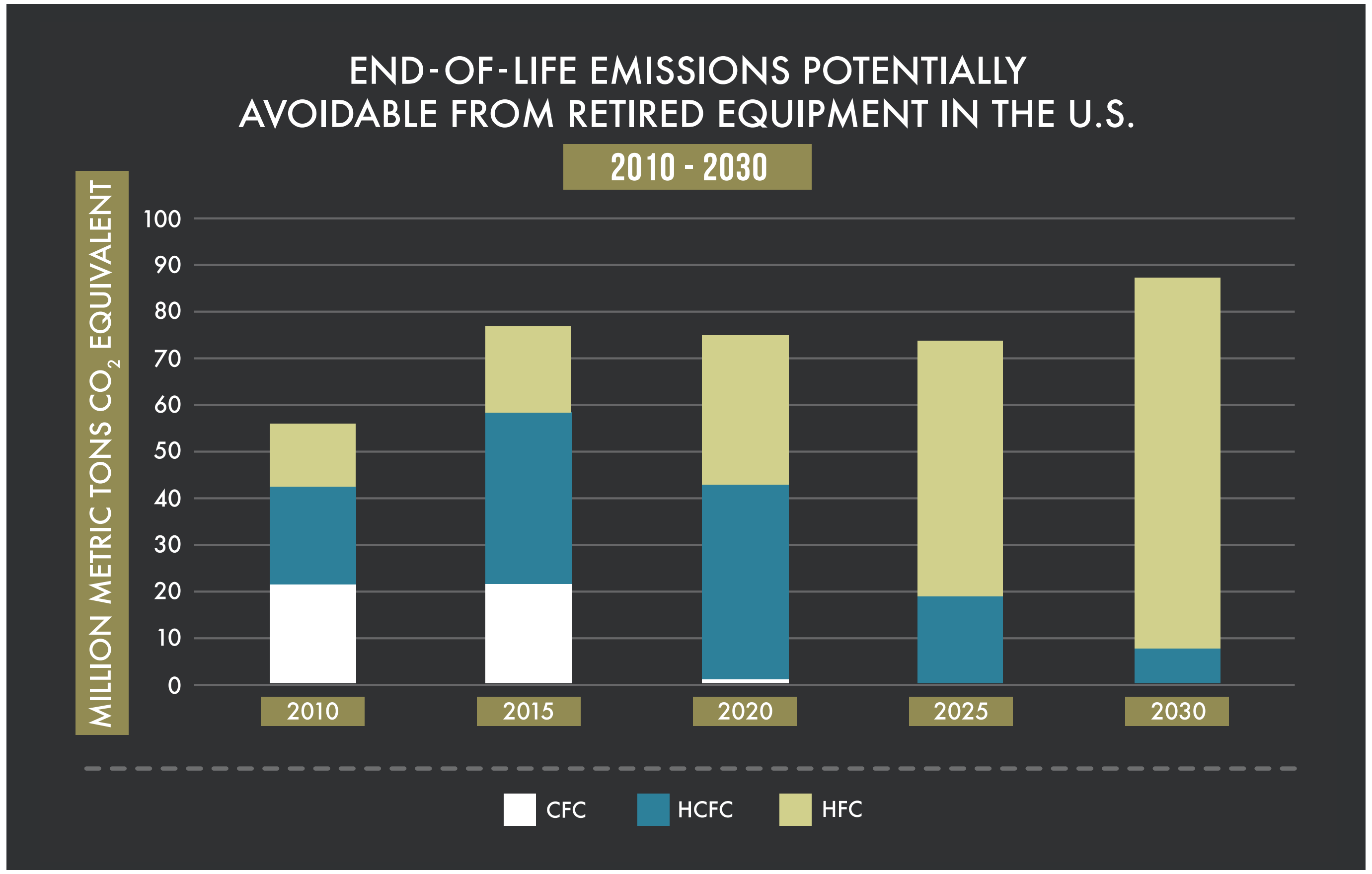


Figure 2: Annual emissions avoidable at end of life from retired equipment in the U.S.
Source: Derived from ICF, 2018

Bulk Inventories and Stockpiles

Finally, emissions occur from bulk inventories and stockpiles of refrigerants, which may accumulate after recovery from servicing and decommissioning of used equipment, or as virgin stockpiles that have been accumulated but not used. Bulk inventories and stockpiles in the U.S. are challenging to quantify given current lack of reporting requirements, but emissions of F-gases from these sources are likely considerable.

Overview of Refrigerant Lifecycle

In order to design effective policies, particularly for reducing end-of-life emissions, it is necessary to have a basic understanding of the full refrigerant lifecycle and best practices at each stage. As shown in Figure 3, the refrigerant lifecycle can be summarized in terms of five essential stages: 1) Use and Maintenance, 2) Recovery and Collection, 3) Consolidation, Storage, and Transport, 4) Reclamation or Destruction, and 5) Distribution and Reuse.

Use and Maintenance: Refrigerants are placed into refrigeration and air conditioning systems and appliances when they are first manufactured or installed and periodically added to 'top up' systems during regular servicing and maintenance.

Recovery and Collection: Refrigerants enter the waste stream when removed by technicians from existing refrigeration and air conditioning equipment during servicing, maintenance, and decommissioning. Recovery of refrigerants from commercial and industrial equipment can generally be performed on site using mobile recovery equipment, whereas recovery of refrigerants from household appliances is typically performed after transportation of the equipment to a waste facility upon decommissioning. Refrigerants may also be collected from stockpiles held at industrial facilities or other warehouses. Certification of technicians and servicing companies is essential to ensure proper handling and collection of waste refrigerants.

Consolidation, Storage and Transport: After refrigerant has been recovered and collected from domestic appliances, commercial equipment, and industrial facilities, it is

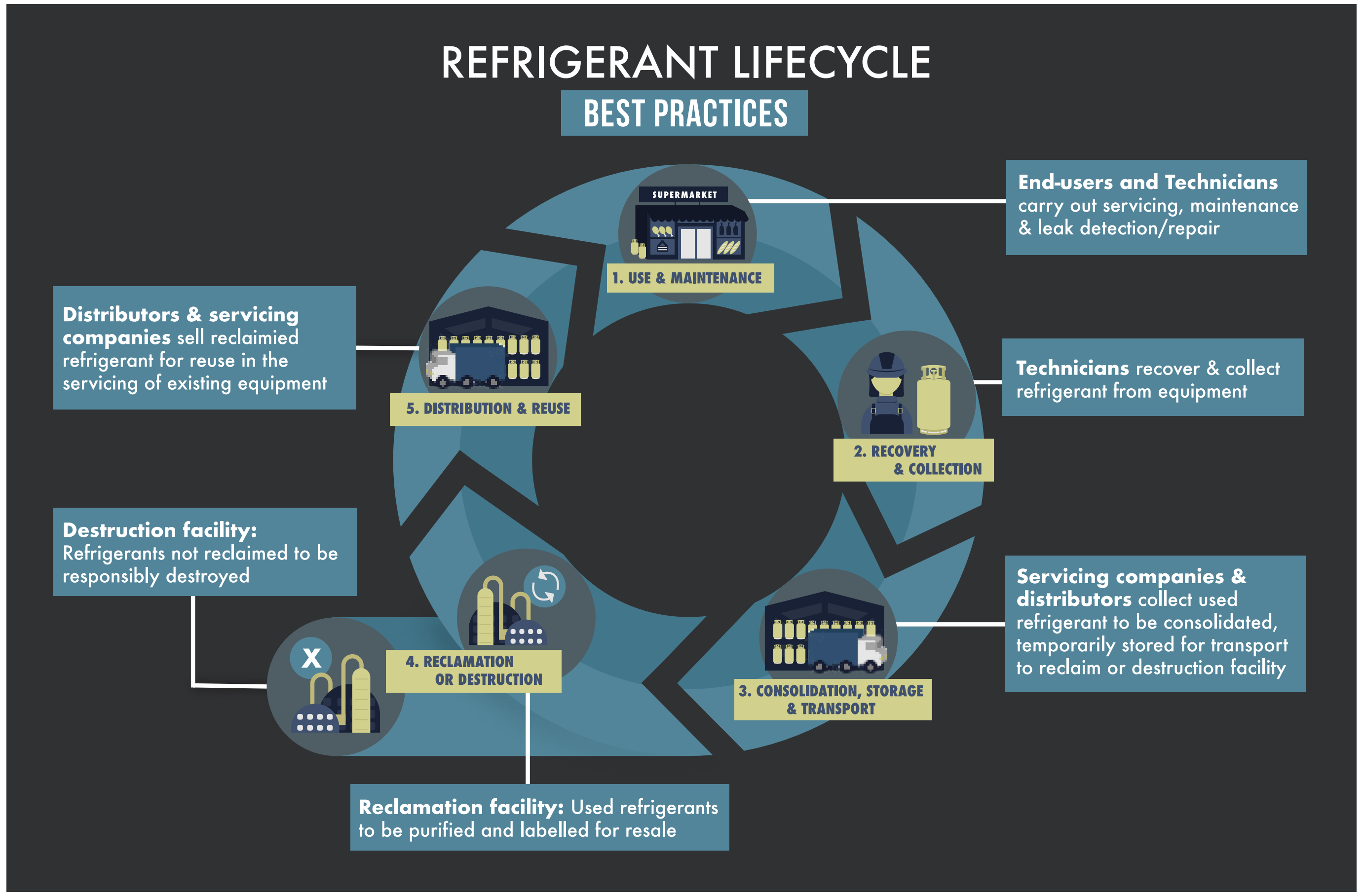


Figure 3: Best practices during different stages of the refrigerant lifecycle

typically consolidated into a storage tank, which should utilize best practices to minimize emissions during this process. Use of a closed loop system or dry break couplings can reduce emissions during transfer of refrigerant from a pressurized container to an unpressurized shipping vessel.[17] This step is undertaken in order to reduce transport costs and other issues faced in shipping larger quantities of smaller containers, such as inventory and recordkeeping complications, damage or loss during shipment. After sufficient refrigerant has been collected in a single location, it may be stored temporarily before being transported to a reclamation or destruction facility. Refrigerant must be labeled for transport according to waste codes under the Resource Conservation and Recovery Act (RCRA).[18]

Reclamation or Destruction: The end goal of refrigerant lifecycle management is that used refrigerants are destroyed using a process that results in their breakdown, or put through a reclamation process in order to be reused. Destruction is a process of permanently transforming or decomposing all or most of a refrigerant into one of more stable substances that are not fluorinated greenhouse gases. Technologies to destroy refrigerants include both thermal as well as other technologies such as plasma arc, or other non-incineration technologies.[19] According to global norms established under the Montreal Protocol for approval of specific destruction technologies, processes should achieve at least a 99.99% rate of destruction and removal efficiency.[20] Reclamation of refrigerants involves a process for removing impurities from used refrigerant and restoring them to a purity level that allows their safe reuse. In the U.S. reclaimed refrigerants are required to reach purity levels under the AHRI Standard 700, which has a purity requirement of 99.5% by mole.[21]

Distribution and Reuse: Refrigerants that have been reclaimed are then re-sold on to distributors and servicing companies for reuse in the servicing of existing equipment. In cases where policies have been put in place to limit or ban the sale of virgin ODS or HFCs, it is important to have a robust labeling and tracking system in place to verify the sale of reclaimed refrigerant, thereby ensuring that use of reclaimed refrigerant displaces the use and potential emissions of new virgin ODS or HFC refrigerants.

Available Policy Approaches

There are a number of regulatory, fiscal and non-regulatory approaches that can be undertaken to reduce emissions from refrigerant banks. Examples of regulatory measures include refrigerant management regulations, venting bans, refrigerant or product bans, or phase-down or phase-out as well as extended producer responsibility (EPR) schemes. Fiscal measures possible include GWP-weighted taxes on refrigerants, rebate systems, and financial incentives for end-users, while information campaigns, voluntary industry agreements, training and certification schemes as well as technical standards are types of non-regulatory measures.

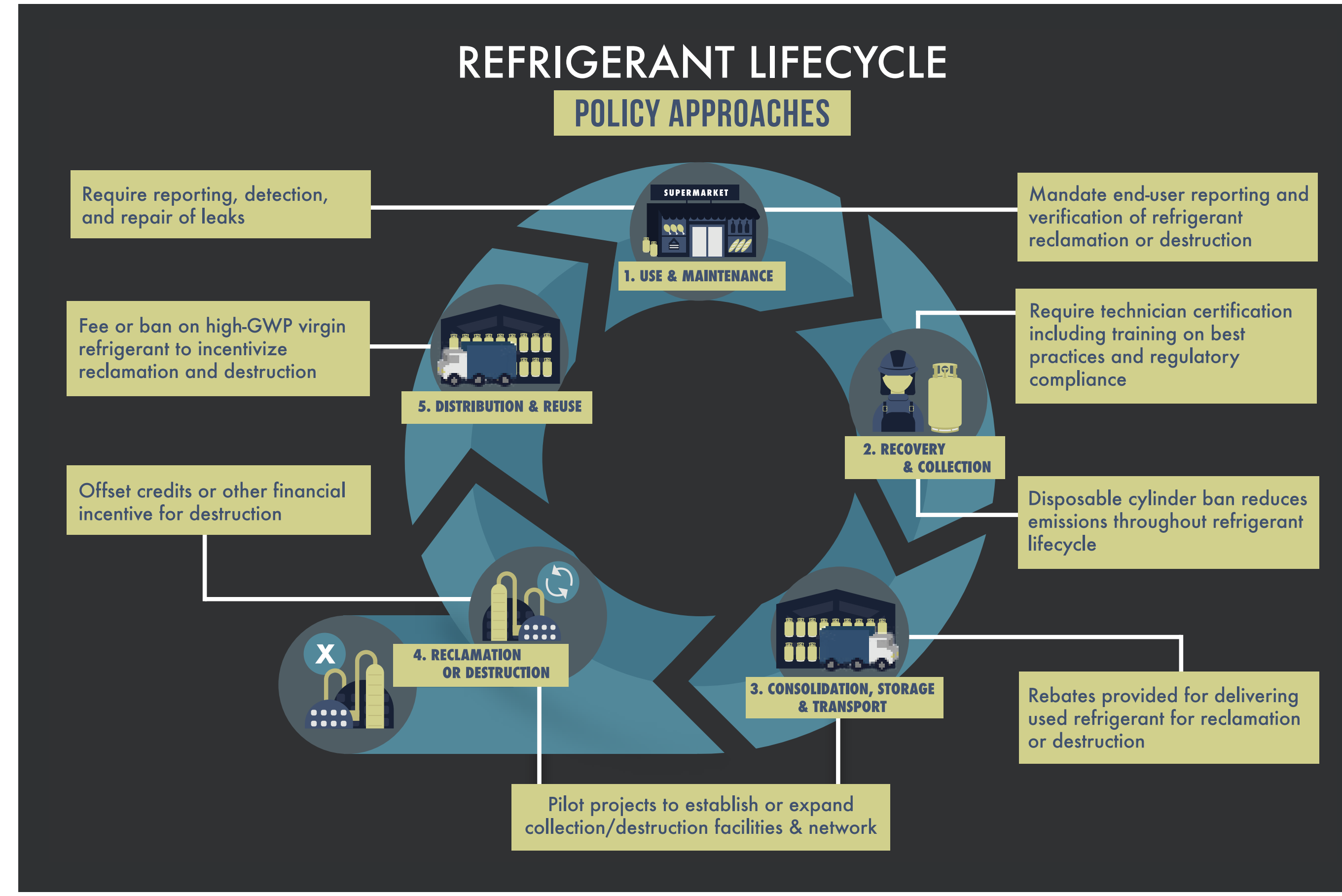


Figure 4: Potential policy approaches at different stages of refrigerant lifecycle

For the purposes of this report, the key potential policy approaches are broadly divided into two sets. The first set of policies deals with refrigerant management, which mainly targets reductions in leakage during use and transport, while the second set of policy approaches deal with avoiding emissions at end of life.

A. Reducing Leaks

Approaches to improving refrigerant management typically focus on incentivizing or requiring owners and operators of large refrigeration and air conditioning systems to report on and improve refrigerant management practices in order to reduce leaks from existing equipment and use.

1. Servicing Requirements, Leak Detection, and Repair

Owners and operators of large commercial and industrial refrigeration and air conditioning systems can be required or incentivized to employ refrigerant management practices that reduce refrigerant leaks from existing equipment. Most refrigerant management regulations focus on requiring periodic maintenance and leak inspections or installation of automatic leak detection equipment, calculation and reporting on leak rates, alongside requirements for prompt repair of leaks, and requirements to perform a more comprehensive retrofit or replacement of aging equipment with repeated leak events above a certain threshold.

2. Reporting, Recordkeeping, and Data Collection

Owners and operators of large commercial and industrial refrigeration and air conditioning equipment as well as refrigerant wholesalers and distributors can be required to submit information registering systems in a central database and reporting on key data such as amounts and types of refrigerant purchased and/or stockpiled, and types of servicing and maintenance events. This recordkeeping and data collection provides a useful source of information on refrigerant inventories, leaks, and amounts disposed. Such reporting is a complementary measure that can allow effective enforcement of other refrigerant management requirements and best practices. This has been successfully implemented in California, including through a central electronic reporting database.[22]

> Since disposable cylinders are difficult to trace, they are often the container of choice for illegal trade in counterfeit refrigerants, which can be both dangerous and contribute to emissions.

3. Banning Non-refillable/Disposable Refrigerant Cylinders

Non-refillable cylinders can be a significant source of unnecessary emissions and impair effective enforcement against illegal trade in banned F-gases. Disposable cylinders are specifically-manufactured 'one-way' containers charged with refrigerant, sold, used for servicing or commissioning equipment and then discarded. Aside from the additional waste management issues this brings, the cylinders result in a residual quantity of refrigerant, or 'heel', being emitted to the atmosphere as the cylinders must be cut or punctured before entering the waste stream. On average, 3-4% of gas remains in the most commonly used 30-pound disposable refrigerant cylinders,[23] while an additional liquid heel represents between 5 and 8%.[24]

> Policies that incentivize destruction of refrigerants at end of life have the added benefit of encouraging retirement of old energy-inefficient equipment containing ODS or HFCs, and therefore a more rapid transition to better refrigerants and more energy efficient systems.

Since disposable cylinders are difficult to trace, they are often the container of choice for illegal trade in counterfeit refrigerants, which can be both dangerous and contribute to emissions. The use of disposable cylinders has also facilitated low-price dumping of HFCs imported into the U.S. refrigerant market, which displaces environmentally friendly substitutes and alternative refrigerants. Banning disposable cylinders can therefore be an effective mechanism for counteracting illegal trade as well as reducing emissions. Disposable cylinders have been banned successfully in the EU, Australia, Canada, and India.[25]

4. Technician Certification Requirements and Training Programs

Technician training is essential to ensure persons recovering refrigerants from equipment or in bulk understand the environmental hazards and have the necessary technical skills to prevent their release to the environment. EPA requirements under Section 608 of the Clean Air Act require technicians to be certified in order to work with ODS, but may not require certification for working with equipment containing HFCs. California's RMP regulation requires technicians and contractors to be EPA certified to work with HFCs.[26] Policies to require enhanced technician certification for handing refrigerants that includes comprehensive training in proper recovery practices may be an effective approach to consider alongside other measures.

B. End-of-Life: Recovery, Reclamation, and Destruction

Policy measures to decrease venting and end-of-life emissions of refrigerants are aimed at increasing recovery, collection, and transport of used gas removed from equipment that is then delivered to a qualified facility for either reclamation and resale, or destruction.

Ensuring proper destruction of ODS and HFCs at end of life is essential for ensuring that these materials are properly handled and destroyed, rather than illegally or inadvertently vented to the atmosphere where they cause ozone depletion and global warming. Policies that incentivize destruction of refrigerants at end of life have the added benefit of encouraging retirement of old energy-inefficient equipment containing ODS or HFCs, and therefore a more rapid transition to alternative refrigerants and more energy efficient systems. Reclamation has the benefit of allowing the gradual, orderly phase-out of high-GWP refrigerants over time which minimizes the cost and disruption of a phase-out program and was an approach taken by the United States to implement the Montreal Protocol phase-out of ODS under the Clean Air Act.

There are a number of potential policies aimed at increasing rates of recovery, reclamation, and destruction of used refrigerant, all of which may be implemented individually or as a package of complementary measures:

1. Mandates for Reclamation, Destruction, and Take Back Obligations

Although a federal-level venting prohibition is in place, there is currently no requirement that refrigerant be reclaimed or destroyed, and no effective system for tracking and controlling refrigerants at end of life. States may consider passing a mandate requiring high-GWP ODS and HFC refrigerant recovered from equipment to be collected and certified as reclaimed or destroyed in certain subsectors where technically and economically feasible. Lessons from destruction efforts internationally have demonstrated that operational and well established recovery and recycling schemes are an essential prerequisite for the successful implementation of disposal activities.[27] States may also consider imposing a take back obligation requiring producers and distributors to 'take back' refrigerant from contractors at little or no cost. Examples of these programs are in place in France and Germany.[28] However, given existing experience with difficulty enforcing the mandate prohibiting venting of refrigerants and concerns about non-compliance, extended producer responsibility or other forms of incentives should be strongly considered to achieve the best results.

2. Servicing Ban on High-GWP Refrigerants

A ban on the sale or use of new/virgin bulk high-GWP HFC refrigerants after a certain date will require that the demand for refrigerant to service existing equipment be met by reclaimed refrigerants, thereby creating a market for scaling up recovery and reclamation of used refrigerant. The European Union has put such a ban in place beginning in 2020 for use of virgin HFC refrigerant with a GWP greater than 2500 for servicing certain equipment containing large amounts of high-GWP refrigerant.[29] The California Air Resources Board (ARB) has also proposed a future regulation to ban the sale of virgin refrigerants with a GWP greater than 1500, excluding HFC-410A.[30]

3. Extended Producer Responsibility Schemes and Other Incentives

The most commonly employed approach to promote sustainable end-of life management of refrigerants is to provide an incentive to offset costs associated with recovery, transport, storage, and destruction. These incentives are often financed under an extended producer responsibility (EPR) scheme, through a fee on imports and sales of virgin ODS/HFC refrigerant and/or pre-charged equipment. Typically, revenue from the fee is used to finance a rebate or other incentive provided to servicing companies and distributors for delivering used refrigerant to reclamation or destruction facilities. A number of countries including Australia, Norway, Denmark, Spain and Canada have implemented variations on this type of scheme, and have successfully increased recovery and destruction. By offsetting costs of recovery, collection, and transport, a rebate can increase the effectiveness of complimentary policies, such as a mandate for reclamation and destruction, or a ban on the sale of virgin high-GWP refrigerant.

Carbon credits for destruction of HCFCs and/or HFCs may offer another additional source of funding to offset costs and incentivize end-of-life destruction. Certified carbon credits for destruction of CFCs have also served in the past as an incentive for recovery and destruction under California's cap-and-trade legislation.[31]

4. Voluntary Programs and Pilot Projects

Voluntary programs and pilot projects offer other limited approaches for states to consider if not in a

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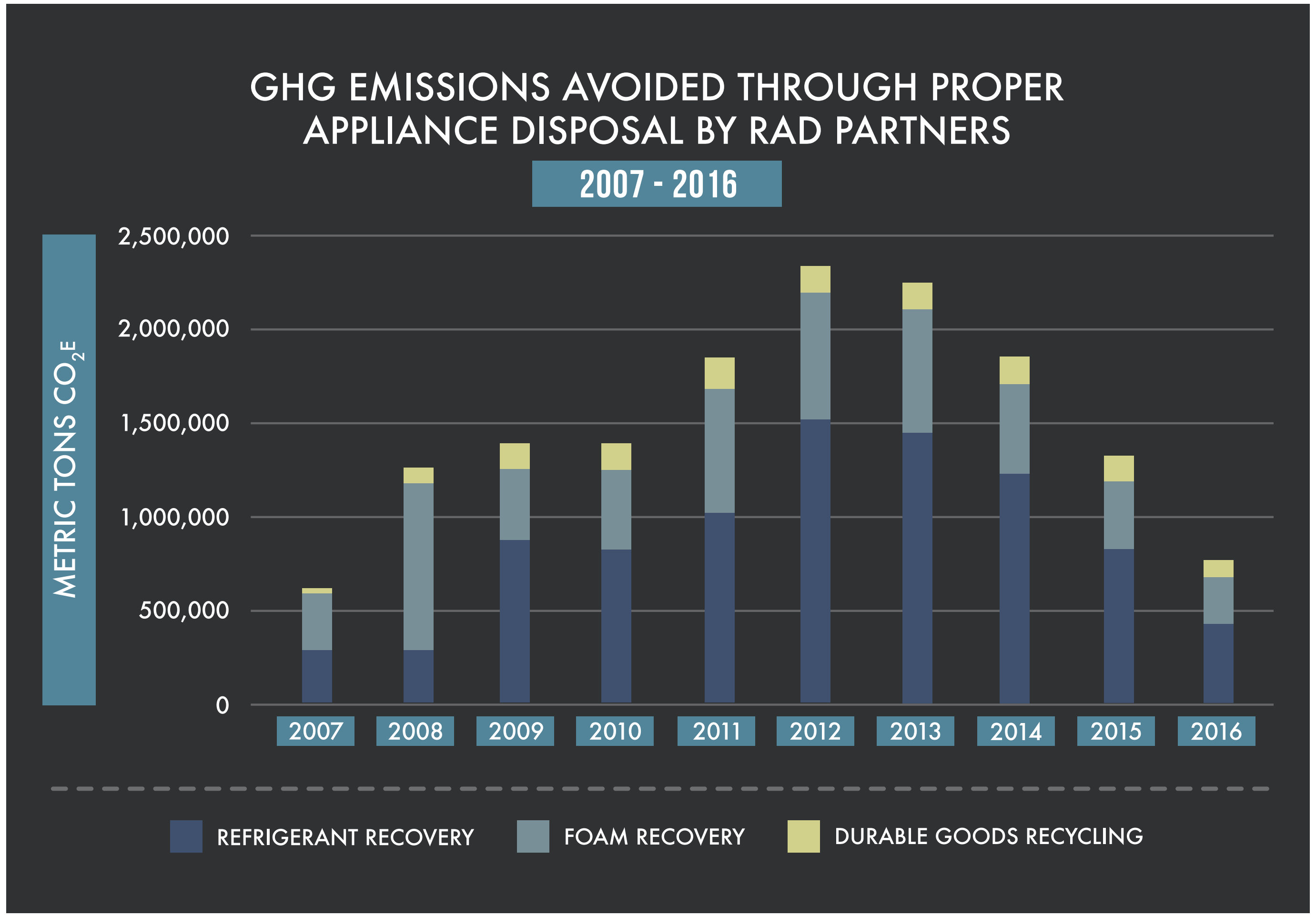

Figure 5: GHG emissions avoided through proper appliance disposal by RAD partners, 2007-2016 (MTCO$_2$eq.)
Source: https://www.epa.gov/rad/program-results

position to implement more comprehensive policies. Little information is available regarding the success of voluntary programs in the U.S., however programs in other countries have started as voluntary before being adopted into law under regulatory frameworks. Discussions with stakeholders familiar with these programs emphasize the benefits of mandatory programs due to free rider and other issues, however cooperative voluntary programs established with industry stakeholders to offer refrigerant buyback programs or other incentives for recovery may be explored in coordination with relevant industry stakeholders. Under a publicly financed pilot program, specific sources or subsectors of refrigerant banks or existing stockpiles may be targeted.

Current Policy Gaps in the U.S. and Globally

The global approach to mitigating F-gases under the Montreal Protocol has been a gradual phase-down in production and new use, which does not directly address emissions from leaks or end of life. The phase-down approach was first implemented globally for ODS and has now been expanded to HFCs under the landmark Kigali Amendment.[32] Under the Kigali Amendment, countries will gradually phase down HFCs by more than 80% over the next several decades, however, the agreement does not address banks and will allow substantial new production and consumption of HFCs over the next two decades that will add to the existing bank, with some remaining production permitted indefinitely.[33] To date, no comprehensive approach to manage ODS or HFC banks has been developed under the Montreal Protocol. However a limited number of demonstration projects related to ODS disposal and destruction have been funded through the Multilateral Fund that provide helpful context and lessons.[34]

To date, no comprehensive approach to manage ODS or HFC banks has been developed under the Montreal Protocol. However, a limited number of demonstration projects related to ODS disposal and destruction have been funded through the Multilateral Fund that provide helpful context and lessons.

Federally in the United States, regulations on refrigerant management and the installed base have been limited in scope, under-enforced, and face ongoing rollback in terms of their applicability to HFCs. Some controls have been put in place to encourage best practices for refrigerant management and leak control of systems and appliances containing ODS under Section 608 of the Clean Air Act (CAA).[35] The EPA Section 608 regulations prohibit intentionally venting ODS or HFCs into the atmosphere and place certain reporting, refrigerant management, and leak repair requirements on owners and operators of systems containing over 50 pounds of ODS.[36] However, to date EPA has found it administratively infeasible to enforce compliance with its intentional venting prohibition. Furthermore, the recent extension of requirements to cover equipment containing HFCs has been proposed for reversal and although the federal venting prohibition still applies to HFCs, it is unlikely that systems containing HFCs will be covered by the refrigerant management and leak repair provisions going forward.[37]

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While EPA administers a voluntary program for household appliances called the Responsible Appliance Disposal (RAD) Program, due to decreasing participation emissions reductions have declined from a height of 2.2 million $MTCO_2e$ in 2012 to just 0.7 million $MTCO_2e$ in 2016 of refrigerant emissions avoided.[38] The RAD Program is a voluntary partnership with private sector utilities and manufacturers and states to properly recover and dispose of refrigerant and foams contained in old household refrigerated appliances. Since being established in 2006, the RAD program has resulted in recovery of 14 million metric tons of CO_2e of refrigerants and foams. EPA estimates about 9 million refrigerators are thrown away each year.[39] At the height of its impact, the RAD Program was addressing about 9% of the household refrigeration sector, which declined to about 5.5% in 2016 and participation of states in the RAD program has been very limited.[40] The potential emissions reduction from this sector thus remains significantly high.

Given the logistical obstacles to enforcement of a "stick" in the form of a venting prohibition, states should consider adopting a "carrot," by providing a financial incentive for proper disposal of ODS and HFC banks in at least some sectors. Similar policies have been implemented in a number of other countries, such as Australia, Canada, and Norway among others. While F-gas destruction declined in the United States between 2010-2015, it has either remained steady or increased in other countries and regions where policies are in place.[41]

Examples of Policies and Programs in Other Countries

This section provides a number of examples of current policies and programs targeting emissions from refrigerant leaks or end-of-life management that could serve as potential model programs for states to consider. These are broadly categorized into three types of programs:

A) Refrigerant Management Programs
B) Extended Producer Responsibility Schemes
C) Pilot and Demonstration Projects

A. Refrigerant Management Programs

California Refrigerant Management Program

The California Air Resources Board (ARB) finalized a 2010 regulation to create a Refrigerant Management Program (RMP) for stationary sources, which was implemented beginning in 2012. The RMP applies certain requirements to owners and operators of stationary refrigeration systems containing 50 pounds or more of refrigerant with a GWP greater than 150 as well as refrigerant distributors, wholesalers, and reclaimers.[42] The program requires registration of refrigeration systems in a central reporting database[43] and implementation of best practice refrigerant management protocols for leak detection, periodic inspections, and prompt leak repairs. Owners and operators of large systems greater than 200 pounds are also required to report in the central database on all leaks detected during leak inspections, and on the type and amount of refrigerant purchased and used to service equipment. Refrigerant distributors, wholesalers, and reclaimers are also required to submit an annual report on amounts of refrigerant sold, reclaimed, or destroyed. RMP requirements are subject to enforcement measures, including fines for significant violations.[44]

Refrigerant Type	Full charge (Million Pounds)	Full charge ($MMTCO_2e$)
CFC	0.1	0.3
HCFC	7.9	6.7
HFC	8.6	12.4
HFO	0.1	0.05
Total	16.7	19.5

Table 1. Banked refrigerants by type as reported by California RMP covered facilities (2017)

HFC	Full Charge ($MMTCO_2e$)	%
R-404A	6.1	49%
R-507	3.6	29%
R-407A	1.4	12%
R-134a	0.69	6%
R-407F	0.22	2%
R-407C	0.16	1%
Total	12.4	

Table 2. HFC banks and common HFCs used by California RMP covered facilities (2017)

California RMP data provides a partial picture of the current bank in the state and trends over time. Data is self-reported by owners and operators of refrigeration and air conditioning systems containing more than 50 pounds of refrigerant and from distributors on annual refrigerant sales. Therefore, this data excludes equipment containing less than 50 pounds of refrigerant such as many household cooling appliances, and non-stationary systems such as motor vehicle air conditioning. As shown in Table 1 below, this data indicates that an existing bank of 16.7 million pounds of refrigerant, or 19.5 million $MTCO_2e$. Table 2 shows HFCs 404A and 507, with GWPs of around 4,000, are the most common HFCs used by California RMP covered facilities. Annual bulk sales of refrigerant in California from 2012 to 2017 varied between 10 and 12 million pounds, about 80% of which were HFCs as per Table 3 below.

Percentage of total pounds of refrigerant reported sold by distributors/wholesalers					
Refrigerant Type	2013	2014	2015	2016	2017
R-22	44%	42%	35%	28%	20%
R-404A	14%	17%	18%	16%	16%
R-507	5%	5%	7%	6%	6%
R-407A	4%	6%	7%	9%	8%
R-134a	9%	8%	7%	8%	8%
R-407F	1%	1%	1%	1%	1%
R-407C	3%	3%	4%	6%	9%
R-410A	12%	13%	15%	17%	20%

Table 3. Annual sales of refrigerants in California reported by distributors, which ranged from 10 to 12 million pounds

The California RMP currently reflects the highest standard for U.S. policy around refrigerant management requirements to control refrigerant leaks in the United States, and closely follows similar requirements in place in the European Union. However, the program is limited in scope as it does not cover air conditioning, and does not address end-of-life emissions or directly incentivize or mandate collection, reclamation, or destruction.

B. Extended Producer Responsibility Schemes

Australia: End-of-Life Recovery and Destruction by Refrigerant Reclaim Australia (RRA)

Australia has developed a robust program for managing end-of-life emissions through an EPR scheme that includes a mandatory levy on ODS and HFC refrigerants accompanied by an industry supported program to incentivize recovery and destruction.[45] The program has contributed to recovery of over 6,000 tons of refrigerant, and has achieved between a 50-70% rate of recovery.[46] As shown in Figure 6 below, between 0.6 and 1.1 million metric tons of refrigerant have been destroyed annually by the program since 2014. The majority of refrigerants destroyed under the program over the past several years have been HFCs, with a declining portion of ODS.

Refrigerant Reclaim Australia (RRA) is funded by a levy on sales of synthetic refrigerants to cover the costs of recovery and destruction.[47] The levy was initially voluntary, but became mandatory beginning in 2004. Each kilogram of synthetic refrigerant imported and sold in Australia, whether as bulk or in pre-charged equipment, is subject to a levy of AUD$2 per kilogram which has been adjusted over time. All funds are held in Trust, and can only be expended for recovery, reclamation, and destruction of synthetic refrigerants. Excess funds are invested to pay for recovery and destruction well into the future (2030 and beyond). In coordination with contractors and distributors, RRA plays an active role in recovery and processing. RRA operated as a non-profit governed by a Board of Directors that is comprised of associations representing importers, distributors, contractors, and end-users. The program depends on broad industry support with participation from more than 1000 companies.[48]

Key elements of Australia's RRA program and accompanying regulatory framework include:

- A mandatory levy on ozone depleting substances and synthetic greenhouse gas refrigerants including HFCs[49]
- A ban on disposable cylinders
- Mandatory certification license for buying, handling, possessing, or disposing of or handling ozone depleting substances or synthetic greenhouse gas refrigerants[50]
- Strong enforcement and compliance, including audits, investigations, and fines[51]
- Cooperative program with broad support from industry stakeholders

Canada: Refrigerant Management Canada (RMC) and Pollution Prevention Plan (P2 Plan)

Canada initiated a voluntary industry led program in 2000 called Refrigerant Management Canada (RMC).[52] RMC was designed to ensure proper lifecycle management of fluorinated refrigerants, through a six step process for collection, transportation, and storage and disposal of refrigerants.[53] In 2016 Environment Canada finalized the Pollution Prevention Plan for Halocarbons (P2 Plan),[54] making participation in RMC mandatory. [55] The P2 Plan also placed a levy on imported refrigerants of $1 per KG of HFCs and $4.50 per KG of HCFCs.[56] The funds collected from the levy are used to offset recovery and destruction costs. Canada also requires all HFCs to be imported in refillable containers, thereby effectively banning the use of disposable containers.[57]

Australia has developed a robust program for managing end-of-life emissions through an EPR scheme that includes a mandatory levy on ODS and HFC refrigerants accompanied by an industry supported program to incentivize recovery and destruction.

Denmark: Danish Refrigeration Installers Environmental Scheme

Denmark implemented a tax on HFCs in 2001, covering imports and production of bulk gases and servicing quantities, and the import or manufacture of pre-charged equipment.[58] Companies that import or manufacture HFCs in Denmark must register with the Danish Tax and Customs service and pay based on the GWP and quantity of substance being manufactured or imported.[59] A voluntary deposit-refund scheme was established in 1992, called the Danish Refrigeration Installers Environmental Scheme (KMO system). It includes a refund for service companies that return used refrigerants with the level of the refund depending on the purity of the recovered refrigerant.[60]

Norway: Tax and Refund Scheme

Norway has had a tax on HFCs in place since 2003 covering the import and production of both bulk gases and pre-charged equipment.[61] The tax is supplemented by a reimbursement scheme applied to all HFCs delivered for destruction.[62] The refund system utilizes tax revenues to refund the amount paid in taxes by a license holder that imported or manufactured the HFCs.[63]

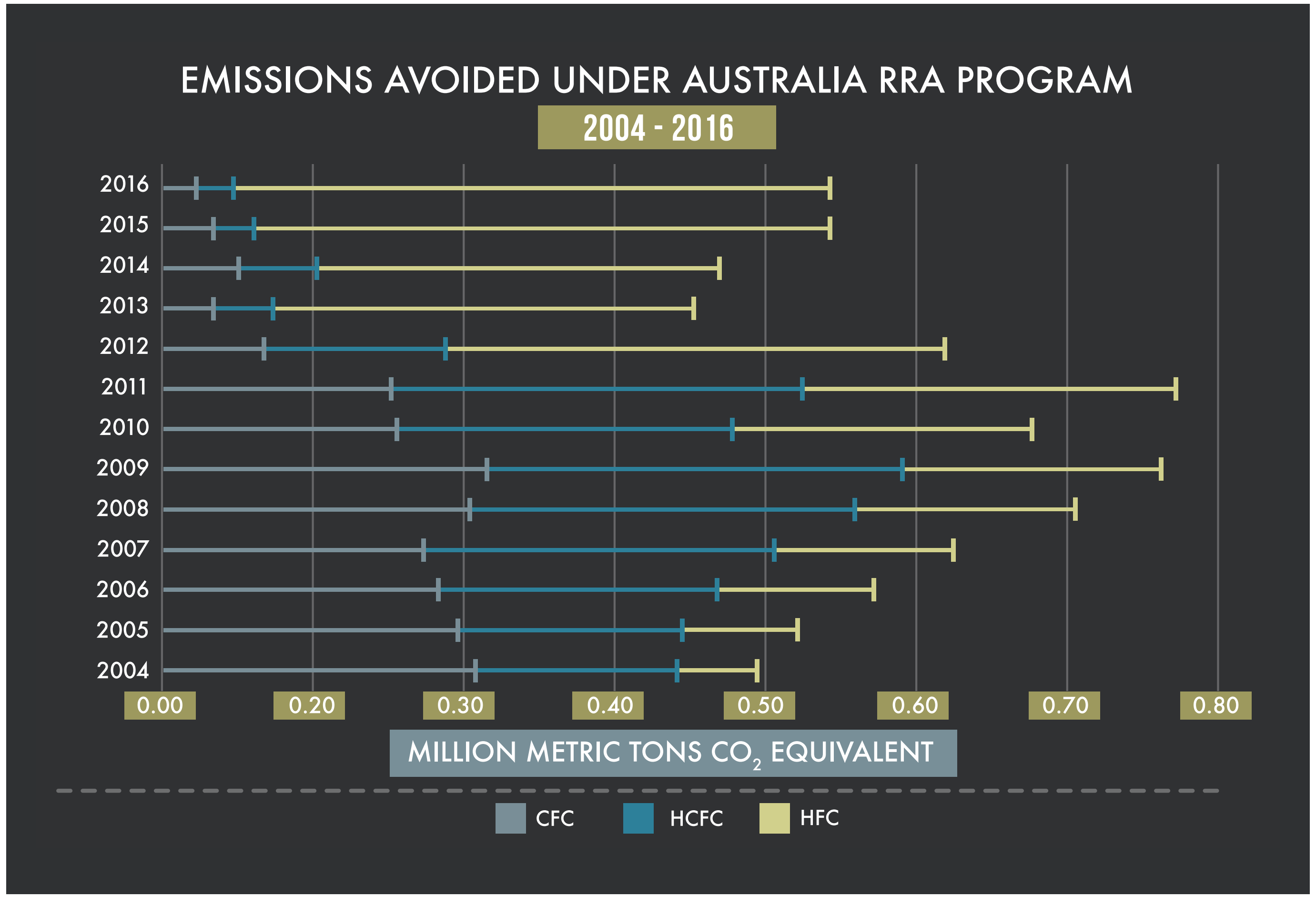

Figure 6: Emissions avoided under Australia RRA program[64]

C. Pilot and Demonstration Projects

Pilot and demonstration projects funded under the Montreal Protocol Multilateral Fund offer a point of comparison for states to consider more targeted approaches to initiating end-of-life programs, such as through offering incentives in a specific subsector or expansion of well-equipped collection, reclamation, and destruction facilities in a given geographic region.

Colombia

A demonstration project in Colombia lead to a sustainable EPR scheme following an industry-administered model supported by legislative and regulatory measures, which is now operational in five major cities.[65] A pilot demonstration project was undertaken to target recovery and destruction of ODS in the household refrigeration appliance sector by UNDP but was implemented within a broader national framework of an integrated approach to waste management, GHG management, and energy efficiency.[66] Colombia established a National Network for Recovery, Recycling and Reclaim of Refrigerant Gases (Red R&R&R).[67] As part of the national network, 18 collection centers and five reclaim centers were equipped. Funding from the Multilateral Fund of the Montreal Protocol was provided to cover initial recovery, transportation, and start-up destruction costs for 300,000 refrigerator units over three years (2013-2015). It also funded demonstration and testing of three existing industrial incineration facilities located in the country to ensure that these facilities met international TEAP standards for destruction. In order to monitor and verify destruction, an electronic database was also established to track refrigerants from consolidation, characterization, storage, transportation to destruction. Financial incentives related to tax (VAT) reductions and energy efficiency incentives applicable to equipment replacement further enabled this program to be successful. [68]

In addition to the Colombia project, ten other ODS management and destruction pilot and demonstration projects have been approved and implemented in a number of other countries including Ghana, Philippines, Nepal, Mexico, Brazil, and China. A recently published desk evaluation of these projects drew key lessons and factors affecting implementation of these projects. Among the key lessons learned regarding project design was that "Putting in place a cost-effective and sustainable EPR system based on an industry administered partnership is necessary to ensure a waste stream that will make destruction efforts profitable and sustainable."[69]

Assessing Cost-effectiveness of End-of-Life Management

Despite the various costs associated with end-of-life management, mitigation of refrigerant banks is a highly cost-effective approach to climate mitigation due to the high-GWPs of ODS and HFC refrigerants. The U.S. social cost of carbon (SCC), a conservative measure established by the U.S. EPA using a 3% discount rate, is calculated to be USD 46 per metric ton CO_2e in 2017 dollars.[70] The cost of preventing ODS and HFC emissions from banks depends on several factors, including the specific sector concerned, the geographic density of the area where the bank is located, and its proximity to a destruction facility. Cost effectiveness, i.e. the cost per metric ton CO_2e of emissions avoided, is also heavily dependent upon the GWP of the substance most commonly used in a given sector of refrigeration and air conditioning.

In 2009, the Montreal Protocol's Technical and Economic Assessment Panel (TEAP) estimated the costs of recovery, storage, transportation, and destruction of ODS banks in various sectors.[71] The TEAP report noted however the significant uncertainty in the cost data, particularly with regard to the commercial refrigeration and stationary air conditioning sectors. Table 4 below provides an analysis of the 2009 TEAP estimated costs for each sector translated into CO_2 equivalent cost per ton in 2017 USD. Certain sectors distinguish between "low" and "medium" effort banks representing differences between smaller and larger equipment and more or less densely populated areas, where level of effort and associated costs per unit differ. Costs of recovery and transport for large equipment in densely populated areas would represent the lowest effort and costs.

The estimated costs of abatement is lower than the US SCC of USD 46 for all sectors, except for medium effort commercial refrigeration, where it is approximately equivalent. The cost effectiveness of abatement are heavily dependent on the GWP of the chemical or chemicals used in a given sector. Therefore, abatement of CFCs is typically the most cost-effective, generally followed by HFCs which have the next highest GWPs. The notable exception to this rule is for mobile air conditioning where HFC-134a is used, which has a relatively lower GWP than HCFC-22 and HFCs more commonly used in other sectors. While this type of comparison would benefit from additional and more up-to-date sources of cost information applicable to the local policy setting in U.S. states, this provides a helpful contextual assessment for end-of-life management as a cost-effective mitigation strategy.

Sector	Chemical	Cost of Abatement per Metric Ton[72] (2017 USD)		Most common refrigerant(s) (GWP used)	Cost of Abatement per Metric Ton CO_2e (2017 USD)	
		Low Effort	Medium Effort		Low Effort	Medium Effort
Commercial Refrigeration	CFCs	59,000 – 77,000	65,000 – 83,000	R12[73] (10900)	5.5 – 7.2	6 – 7.7
	HCFCs			R22[74] (1810)	33.2 – 43.1	36.5 – 46.4
	HFCs			R404A/R134a[75] (2611)	22.6 – 29.5	24.9 – 32.5
Stationary AC	CFCs	13,000 – 20,000	18,000 – 29,000	R11/R12[76] (5284)	2.5 – 3.8	3.3 – 5.5
	HCFCs			R22[77] (1810)	7.3 – 11.3	9.9 – 16.5
	HFCs			R410A[78] (2088)	6.2 – 9.6	8.6 – 13.9
Mobile AC	CFCs	13,000 – 20,000	18,000 – 29,000	R12[79] (10900)	1.2 – 1.9	1.7 – 2.7
	HCFCs			R22[80] (1810)	7.3 – 11.3	9.9 – 16.5
	HFCs			R134a[81] (1300)	10 – 15.3	13.8 – 22.3
Industrial Refrigeration	CFCs	13,000 – 19,000		R12[82] (10900)	1.2 – 1.8	
	HCFCs			R22[83] (1810)	7.3 – 10.6	
	HFCs			R404A/R134a[84] (2611)	5–7.3	
Transport Refrigeration	CFCs	13,000 – 20,000		R12[85] (10900)	1.2 – 1.9	
	HCFCs			R22[86] (1810)	7.3 – 11.3	
	HFCs			R404A[87] (3922)	3.3 – 5.1	

Table 4. Cost of recovery, storage, transportation, and destruction of F-gas banks
Key: Green: \$/metric ton CO_2e is less than inflation adjusted US social cost of carbon at a 3% discount rate of \$46 in 2017

CONCLUSIONS AND RECOMMENDATIONS FOR U.S. STATES

Maintaining and accelerating emission reductions of ODS and HFCs is absolutely essential to ensuring that we remain on a pathway to limit global warming below 1.5 °C. States must lead on implementing policies and programs in the U.S. to reduce the future rate of emissions from the refrigerant bank, both from leakage and at end of life, which represent the single largest opportunity for climate mitigation. There are a number of potential approaches to tackling these emissions with many replicable models from around the world.

With respect to leaks, replicating and expanding on California's current RMP regulation would provide a consistent approach across states and counteract reversal of federal refrigerant management regulations. California's current RMP rule should also be expanded to cover large stationary air conditioning systems, which represent a rapidly growing portion of the HFC bank. Most importantly, policymakers must address end-of-life emissions by scaling up recovery, reclamation, and destruction. Recovering and destroying refrigerants represents a near-term, cost-effective mitigation opportunity that will have immediate and significant climate benefits.

Following are specific policy recommendations for states to consider:

1. Conduct state-level inventories to determine quantities and sectoral breakdown of ODS and HFC refrigerant banks.

2. Implement additional measures to increase recovery, reclamation, and destruction including:
   - Mandate reclamation or destruction at end of life and institute requirements for verification and reporting;
   - Impose a ban on sale of virgin high-GWP refrigerants for servicing with an exception for reclaimed refrigerants;
   - Incentivize recovery and collection through development of an extended producer responsibility scheme, including a fee/rebate system or other form of incentive.

3. Ban the use of non-refillable cylinders for recovery, transport, distribution, and sale of high-GWP ODS and HFC refrigerants.

4. Identify potential funding and opportunities for pilot projects on recovery and destruction of high-GWP ODS and HFC refrigerant banks in specific subsectors.

5. States other than California should implement key aspects of California's RMP Regulation:
   - Create registry and reporting requirements for large refrigeration and HVAC systems and refrigerant wholesalers and distributors to report on sales, stockpiles, and leaks;
   - Require improved refrigerant management practices for leak detection and repair;
   - Require technician certification and training for handling HFC refrigerants, including training on proper recovery and compliance with venting prohibition.

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