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Recovery and Destruction of Hydrofluorocarbon Refrigerant Gases in Article 5 Countries

Summary, Context, and Justification for Draft Methodology

WHITE PAPER

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Executive Summary

As global cooling demand increases and temperatures rise across the world, banks of hydrofluorocarbon (HFC) refrigerants will continue to grow substantially, even with the reductions to HFC production and consumption mandated by the Kigali Amendment to the Montreal Protocol. In addition to the 24 gigatons CO_2e of high Global Warming Potential (GWP) refrigerant already in use, an estimated 67 gigatons CO_2e of refrigerant will enter the market by 2100.[1] This is a major and growing source of greenhouse gas emissions which requires urgent attention and action.

Today, one of the largest sources of HFC emissions is venting, or release, of gases from equipment during servicing or end-of-life activities. Venting occurs because there are insufficient incentives for refrigerant recovery. Prohibitions on venting exist in many countries, but governments struggle to monitor technicians who manage HFCs and, as a result, fail to penalize non-compliance.

Voluntary carbon markets can play an important role in incentivizing proper refrigerant recovery and destruction, as evidenced by the many successful projects that recover Ozone Depleting Substances (ODS) refrigerants for carbon credits. Currently, however, this financing mechanism excludes HFCs, which are ineligible under major registry protocols. In the absence of reliable incentives for recovery and disposal, HFC emissions from venting are likely to continue unabated.

In this white paper, we present and discuss proposed revisions to the existing Verra Methodology "VM0016 Recovery and Destruction of Ozone-Depleting Substances (ODS) from Products'' (hereafter VM0016), last revised in 2017.[2] We intend for these proposed revisions to contribute to the expansion or development of a major registry methodology for the recovery and destruction of HFC refrigerants in Kigali Amendment Article 5 countries.[3] This white paper and the associated Draft Methodology revisions draw on several years of field research in Article 5 countries and interviews undertaken by the authors with technical experts, methodology writers, and project developers, among other stakeholders.

In addition to expanding VM0016 to include certain HFC refrigerants, we propose the following three major revisions:

I. Outlining the additionality case for HFC recovery and destruction in Article 5 countries;
II. Adjusting project boundaries to account for non-zero refrigerant recovery levels, while retaining additionality for HFC destruction; and
III. Clarifying documentation requirements to ensure legitimacy and traceability of generated credits.

We welcome comments on this white paper and the accompanying Draft Methodology.

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[1] Theodoridi, C., *et al.*. (2022). The 90 Billion Ton Opportunity (link).
[2] Energy Changes Projekt Entwicklung GmbH, & USG Umweltservice GmbH. (2017). *VCS Methodology VM0016 Recovery and Destruction of Ozone-Depleting Substances* (link).
[3] We chose to base our methodology on VM0016 because of Verra's existing approval of projects in international contexts. Our methodology revisions are broadly applicable to existing methodologies from all registries.

1. Motivation

As climate change intensifies, the world will increasingly rely upon air conditioning to cope with extreme heat. Today, over two billion air conditioners supply global cooling needs. This number is expected to triple by 2030.[4] Almost every air conditioner in operation today — as well as the majority of heat pumps and refrigerators — use synthetic refrigerant gases to function. Most equipment uses hydrofluorocarbons (HFCs), which replaced previous generation, ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). While HFCs are ozone-friendly, they are also GHGs with thousands of times the Global Warming Potential (GWP) of CO_2.

The 2016 Kigali Amendment to the Montreal Protocol on Substances That Deplete the Ozone Layer (hereafter "Montreal Protocol") laid the groundwork to phase down the production and consumption of HFCs globally. The Kigali Amendment assigns every country to one of four phasedown schedules. Developed countries, referred to as "non-Article 5" (non-A5), follow the fastest phasedown schedules, which have already commenced. Developing countries, referred to as "Article 5" (A5), follow slower phasedown schedules, with restrictions to production and consumption beginning near the end of the decade.[5] Given the nature of HFC phasedown and the slower phasedown schedules in A5 countries, HFCs will continue to enter the market for the foreseeable future. This persistent and expanding HFC use poses a substantial refrigerant management challenge across the globe.

Refrigerants such as HFCs are emitted from cooling equipment via two primary pathways: *leakage* during equipment operating lifetime or *venting* during routine maintenance or at equipment end-of-life. Venting prohibitions are common in national environmental regulations. However, these prohibitions are seldom enforced, for three main reasons:

I. Monitoring the millions of refrigerant-containing appliances in use is difficult and impractical.
II. Technicians are rarely outfitted with proper equipment to capture the gas, leaving venting as the only possible course of action.
III. In many countries, the infrastructure does not yet exist to reclaim or destroy refrigerants at scale.

Our modeling suggests that more than 30 gigatons CO_2e of refrigerant will be vented to the atmosphere by 2050 (See Appendix 1). Venting is particularly rampant in A5 countries, which typically possess neither widespread reclamation and disposal infrastructure nor a legal end market for recovered refrigerant.[6]

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[4] IEA. (2018, May). *The Future of Cooling – Analysis*. The Future of Cooling (link).
[5] Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction (link).
[6] As a result, baseline scenarios in existing protocols approving the destruction of ozone-depleting substances (ODS) assume 100 percent venting of refrigerant in A5 countries (see Section II, Examining Existing Protocols).

Voluntary carbon markets can play an important role in incentivizing proper refrigerant recovery, as evidenced by the many successful projects that recover ozone depleting substances (ODS). To date, projects that recover and destroy ODS have prevented over 30 million $MTCO_2e$ emissions.[7] Currently, however, this financing mechanism excludes HFCs. Without a methodology, project developers seeking to recover and destroy HFCs cannot easily credit and sell the consequent emissions reductions. In the absence of reliable incentives, HFC emissions from venting will continue unabated, and the infrastructure to gather, recover, and destroy HFCs will not be built.[8]

While we believe HFC recovery and disposal has the potential to be a verifiable and creditable activity in all countries that have ratified the Kigali Amendment, we limit the geographic scope of our proposed revisions to A5 countries, where the case for additionality is strongest.

[7] COPA Technical Working Group Financial Mechanism Meeting 2, March 30, 2023.
[8] We view voluntary carbon credits as a strong near-term contributor to improving recovery rates. But we acknowledge that a long-term solution may look beyond carbon markets, toward regulatory programs such as Extended Producer Responsibility. We support the development of effective mandates for refrigerant recovery, while addressing the near-term financing gap that this methodology seeks to fill.

2. Examining Existing Protocols

Several published methodologies cover destruction of ODS and HFCs. None of these methodologies, however, enables recovery and destruction of HFCs from equipment at meaningful scale. In Table 1, we provide a short review of existing methodologies on which we have based our revisions.

Table 1. *Review of Existing Methodologies*

Registry	Methodology Name	Approved Countries/Regions	Eligible Activities	Baseline Assumptions	Notable Differences with Our Proposed Methodology
American Carbon Registry	Destruction of Ozone Depleting Substances and High-GWP Foam, last revised 2023 (link).	For sourcing material: U.S. or Canada For destruction: No geographic restrictions	Destruction of select ODS refrigerants, high-GWP foam blowing agents, and high-GWP insulation foam. Substances may be sourced from equipment or stockpiles.	100% baseline emission rate for all eligible sources (frames the destruction, rather than the recovery, as the driver for additionality).	• Limits sources to the U.S. • Excludes non-foam HFCs • Project emissions do not include replacement gases for destroyed refrigerants
American Carbon Registry	Destruction of Ozone Depleting Substances from International Sources, last revised 2021 (link).	For sourcing material: Outside the U.S. For destruction: No geographic restrictions	Destruction of select ODS refrigerants from equipment or stockpiles.	Ten-year baseline emission rates range from 61% to 95%, depending on species.	• Excludes HFCs • Does not distinguish between end-of-life equipment, serviced equipment, and other refrigerant sources
Climate Action Reserve	U.S. Ozone Depleting Substances Project Protocol, last revised 2012 (link).	For sourcing material: U.S. For destruction: U.S.	Destruction of select ODS refrigerants from equipment or stockpiles. Destruction of foam from appliances or building panels.	100% baseline reclamation rate for refrigerant recovered from equipment. Ten-year baseline emission rates for stockpiled gas range from 61% to 95%, depending on species.	• Excludes HFCs • Limits sources and destruction to the U.S.
Climate Action Reserve	Article 5 Ozone Depleting Substances, last revised 2012 (link).	For sourcing material: Article 5 countries For destruction: U.S.	Destruction of select ODS refrigerants from equipment or stockpiles. Sourced gas must be phased out in source country.	100% baseline emission rate for recovered refrigerant. Ten-year baseline emission rate for stockpiled gas is 94%.	• Excludes HFCs • Limits destruction to the U.S.
Climate Action Reserve	Mexico Halocarbon Protocol, last revised 2021 (link).	For sourcing material: Mexico For destruction: Mexico	Destruction of select halocarbons (several common CFCs, HCFCs, and HFCs)	100% baseline emission rate for refrigerant recovered from equipment.	• Limits projects to Mexico • Limits eligible HFC species
Verra	Recovery and Destruction of Ozone Depleting Substances (VM0016), last revised 2017 (link).	For sourcing material: Parties to the Montreal Protocol For destruction: Parties to the Montreal Protocol	Destruction of ODS refrigerants and blowing agents. Refrigerants may be recovered or stockpiled gas.	In Article 5 countries, 100% baseline emission rate at equipment end-of-life. Otherwise, uses Climate Action Reserve Protocol's default rates (see above). Ten-year baseline emission rate for stockpiled gas is 65%.	• Excludes HFCs • Assumes venting only in the absence of regulatory prohibitions

3. Past Protocol Failures: HFC-23 Destruction

Until 2014, the Kyoto Protocol's Clean Development Mechanism (CDM) credited the destruction of HFC-23. To our knowledge, this CDM protocol and the Climate Action Reserve's Mexico Halocarbon Protocol are the only other published non-foam HFC destruction methodologies to date.

HFC-23, a greenhouse gas controlled by the Kyoto Protocol, is an unwanted byproduct of HCFC-22 production. HCFC-22 is now phased out in the developed world but continues to be produced and consumed in limited quantities in A5 countries.[9] HCFC-22 also continues to be used as feedstock for some synthetic polymers.

The CDM protocol intended to incentivize fluorocarbon manufacturers to capture HFC-23 from their existing production of HCFC-22. Unfortunately, certain manufacturers responded by increasing HCFC-22 production, for the sole purpose of generating carbon credits from HFC-23 destruction. These fraudulent projects made windfall profits while increasing emissions harmful to the climate and ozone layer.[10]

Stakeholders have frequently cited this failure as a primary reason why other HFC destruction methodologies have been slow to reach publication. However, the refrigerant sources eligible under our Draft Methodology — used cooling equipment or seized government stockpiles — are entirely different from the industrial process that was covered by the CDM protocol. As such, the baseline calculations, additionality arguments, and verification requirements within this methodology share little with those utilized by the CDM protocol. Although both protocols describe HFC destruction, the two should not be conflated.

Nevertheless, we believe that our Draft Methodology should undergo rigorous vetting for perverse incentives, as discussed in Section 4.III, "Documenting Recoveries to Improve Credit Legitimacy."

[9] Bitzer. (n.d.). HCFC (R22) phase-out according to the Montreal Protocol—HCFC (R22) phase-out according to the Montreal Protocol. Timing for Prohibitions. Retrieved January 27, 2023, from link.
[10] Doniger, D. (2010, November 11). The Curious Case of HFC-23. Natural Resources Defense Council (link).

4. Revising Existing Protocols to Cover HFCs

Our proposed methodology revisions build upon VM0016 and draw from the Climate Action Reserve and American Carbon Registry. The suggestions we make in this white paper are broadly applicable to methodologies on all three registries. Our proposed revisions fall into two categories: 1) language extending coverage to include HFCs, and 2) conceptual revisions enabling HFC recovery and destruction in A5 countries, including:

I. Revising additionality tests for HFC recovery and destruction in A5 countries;
II. Adjusting project boundaries to account for non-zero refrigerant recovery rates, while retaining additionality for HFC destruction; and
III. Clarifying documentation requirements to ensure legitimacy and traceability of generated credits.

I. Additionality Case

Carbon credit projects are deemed *additional* when they effectuate a reduction in emissions that would not have occurred in the absence of project activity. Additionality is essential for both individual carbon credit projects and broader methodologies. Additionality tests often consider regulation and regulatory compliance, project economics, barriers to project activities, and common practice (sometimes called "business-as-usual").

The case for issuance of carbon credits for HFC destruction requires that project activity is demonstrably additional relative to both of the following cases:

1. Current business-as-usual practices for refrigerant recovery in the host country; and
2. The effects of phasedown on future refrigerant recovery, reclamation, and destruction practices.

Our interviews with project developers, industry participants, and technical experts, as well as field research in the United States and A5 countries, have provided the foundational evidence for the additionality case presented below.[11]

Examining Business-As-Usual for A5 Countries

In the business-as-usual case in A5 countries, refrigerant venting occurs consistently during both equipment servicing and end-of-life disposal, even in the presence of legal prohibitions. The difficulty of regulatory enforcement, the inaccessibility of recovery equipment, and the absence of incentives together make venting the norm. NGOs, policymakers, and project developers consulted in our drafting process, as well as existing methodologies (including the Climate Action Reserve Mexico Halocarbon Protocol), all attest to this practical reality.

[11] We continue to research current refrigerant management practices in A5 countries, and we intend to share ongoing findings from this work. We welcome comments from all stakeholders with knowledge of or a perspective on the practical realities of refrigerant management.

A carbon credit methodology for HFC recovery and destruction alters the business-as-usual case by creating an end market for recovered HFCs. Project developers can be compensated for recovering refrigerant, turning an activity that was previously a net cost into a net benefit.

We limit the eligibility of this methodology to A5 countries for two reasons. First, refrigerant recovery is more common practice in non-A5 countries due to available recovery equipment, more mature markets for reclaimed refrigerant, and higher levels of environmental consciousness and education. Nonetheless, we estimate that refrigerant recovery rates in the U.S. hover between 8 and 20 percent.[12] Second, given that HFC phasedown is already underway and that virgin HFCs are becoming scarcer in non-A5 countries, a market incentive to recover HFCs may exist.[13]

We follow VM0016 by including business-as-usual destruction and reclamation rates in the calculation of baseline emissions. As in VM0016, however, we set both of these terms to zero. We chose to carry over this convention for two reasons:

1. To indicate that these activities are theoretically possible in the absence of a carbon credit incentive; and
2. To make the methodology resilient to a future scenario in which such activities are meaningfully carried out as part of business-as-usual (see Equation 1, Section 8.1 of Draft Methodology).

If baseline rates begin to increase due to increased enforcement (or for any other reason), the methodology will be revised, and further guidance will be provided on the calculation protocols.

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12 Industry estimates, in combination with refrigerant reclamation data from EPA.

13 We are also aware of arguments supporting additionality for HFC destruction in New Zealand and the European Union, although these cases arise from particulars in domestic policy. In the interest of developing a streamlined methodology for the A5 scenario, we do not extend the methodology to incorporate these idiosyncratic scenarios. We are, however, supportive of new methodologies addressing this gap.

Effects of Phasedown on Future Practices

The Kigali Amendment to the Montreal Protocol assigns each signatory country to one of four possible HFC phasedown schedules, summarized in the table below.[14]

Table 2. *HFC Phasedown Schedules*

	Article/Group HFC Phasedown Schedules Pursuant to Kigali Amendment			
Country Group	**Countries Included**	**Baseline Calculation Years**	**Freeze Year**	**First Stepdown Year**
Non-Article 5 (Main)	Most of the developed world	2011, 2012, 2013	--	2019
Non-Article 5 (Other)	Belarus, Russia, Kazakhstan, Turkmenistan, Uzbekistan	2011, 2012, 2013	--	2020
Article 5 (Group 1)	Most of the developing world (includes China)	2020, 2021, 2022	2024	2029
Article 5 (Group 2)	The Middle East (also includes India)	2024, 2025, 2026	2028	2032

The Kigali Amendment to the Montreal Protocol requires the determination of baseline production and consumption, from which HFC phasedown schedules are calculated:

$$Production = CS_{Produced} - CS_{Destroyed} - CS_{Feedstock} \qquad \text{(Equation 1)}$$

$$Consumption = Production + Imports - Exports \qquad \text{(Equation 2)}$$

where CS or "controlled substance" refers to a substance in Annex A, B, C, E or F to the Montreal Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance.

Substituting Equation 1 into Equation 2 yields the following equation for consumption:

$$Consumption = CS_{Produced} - \boldsymbol{CS_{Destroyed}} - CS_{Feedstock} + Imports - Exports \qquad \text{(Equation 3)}$$

The interaction between the Montreal Protocol and carbon crediting for HFC destruction depends on a country's phasedown stage because destroyed refrigerant ($\boldsymbol{CS_{Destroyed}}$, Equation 3) is subtracted from both the baseline and stepdown consumption values.

Specifically, if destruction occurs during baseline setting years, it will decrease the baseline consumption calculation and all subsequent stepdown year values will follow. As a result, we argue that destruction in Article 5 Group 2 countries should be a priority in 2024-2026, while their baseline is being calculated (Table 2).

[14] Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction (link).

When a country is already in phasedown, however, subtracting destroyed refrigerant ($\boldsymbol{CS_{Destroyed}}$) from the calculated consumption level could in theory increase allowable production and/or imports. After thorough investigation, our research demonstrated that, in reality, such manipulations would be highly improbable and have never been exploited (despite the existence of destruction credits for controlled substances such as ODS). Nevertheless, to safeguard against this issue and ensure additionality, we have suggested eligibility requirements such that countries which use destruction to comply with their consumption limits may no longer be eligible for this methodology. See Appendix 3 for more details regarding inclusion criteria, effects of destruction on consumption and production levels, additional analyses from the Ozone Secretariat's Office, and our proposed additionality check.

With these safeguards in place, we propose that this methodology apply to all A5 countries that have ratified the Kigali Amendment.

II. Expanding Project Boundaries and Revisiting Project Emissions

For decades, policymakers and industry stakeholders have debated the relative merits of reclamation and destruction.[15] While reclamation reduces demand for virgin refrigerant and creates an opportunity to accelerate phasedown, it can prolong the use of HFCs and defer, rather than prevent, emissions. Destruction, on the other hand, has an immediate benefit of preventing HFC emissions. However, if the base case is reclamation rather than venting, destroying refrigerant depletes the stock that can otherwise be reclaimed—indirectly supporting demand for virgin gas.

Though we maintain that venting is the current baseline scenario in A5 countries, we propose an expansion of project boundaries to account for the future possibility of increased reclamation capacity, as shown in Figure 1. Expanding project boundaries further safeguards additionality for HFC destruction while discounting credits generated from destruction as reclamation capacity grows. See Appendix 2 for the equation that achieves this goal and several scenarios highlighting how context will affect baseline calculations.

The ideal solution should motivate both reclamation and destruction. However, building reclamation capacity in developing countries may be more expensive—especially given fractional distillation requirements for HFC blends—than building near-term destruction capacity. Where reclamation is scarce, destruction is the preferable scenario compared with the counterfactual of refrigerant venting.

[15] This topic, while less explored in published literature, is frequently discussed in policy meetings at the state, national, and international level. We encountered these discussions in meetings with the Climate and Ozone Protection Alliance (COPA), with NGO experts, and with refrigerant reclaimers, who frequently must decide whether to reclaim or destroy ODS, largely dependent on the unit economics of each activity.

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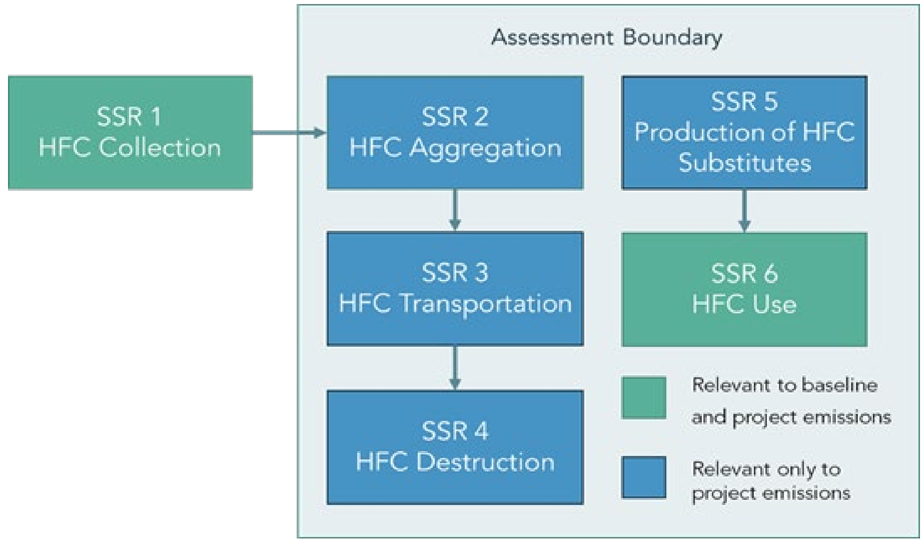
Figure 1. *Proposed revisions to project boundaries in the methodology. Yale Carbon Containment Lab, 2023.*



SSR 1 HFC Collection	Fossil fuel emissions from collection of HFCs; Excluded; No difference from baseline
SSR 2 HFC Aggregation	HFC and fossil fuel emissions from recovery of HFC at servicing or end of life; Included; Venting assumed 100% in baseline, complete capture assumed in project scenario
SSR 3 HFC Transportation	Fossil fuel emissions associated with transport of HFC from collection to aggregation and from aggregation to destruction facility; Included; Estimated based on distance and weight
SSR 4 HFC Destruction	Emissions of incomplete HFC destruction, emissions from oxidation of carbon contained in destroyed HFC, fossil fuel emissions from destruction facility operation, indirect emissions from use of grid- delivered electricity; Included; Based on HFC destroyed or included in default deduction
SSR 5 Production of HFC Substitutes	Fossil fuel and substitute refrigerant emissions from production of substitute refrigerant; Included; Based on reclamation rate in project location; expected to be negligible in Article 5 countries
SSR 6 HFC Use	HFC or substitute gas emissions from leaks resulting from continued operation; Included; Project emissions based on market-weighted emission rates and reclamation rates

III. Documenting Recoveries to Improve Credit Legitimacy

An HFC destruction methodology, like any protocol for the generation of carbon credits, must have protections in place to ensure the quality of credits generated. Since virgin HFC can still be produced and sold in most A5 countries, a methodology lacking sufficient anti-fraud protections could conceivably enable the acquisition and destruction of virgin refrigerant for carbon credits. These activities would not be additional, given that virgin refrigerant is not likely to be vented unless charged into operating equipment.

Any methodology approving HFC recovery and destruction should contain thoughtful and robust requirements for recovery documentation. This documentation should create a chain of custody confirming that refrigerant bound for destruction came from operating or end-of-life equipment. We propose that project developers be required to collect the following information at the point of recovery:

- **General information**: confirmation of recovery from equipment owner or operator; date and approximate time of recovery; location of recovery; name of technician completing recovery; documentation of cylinder weights before and after recovery
- **Source-specific information**:
    - If from an appliance aggregation or de-manufacturing facility: facility name, address, and primary contact; attestation that recovery occurred solely from end-of-life equipment
    - If directly from onsite equipment: photograph of the equipment's nameplate and unique identifying serial number; photograph of recovery equipment connected to the equipment; attestation that recovery occurred during equipment end-of-life or necessary servicing

Project developers should also record where, when, and how they aggregate recovered refrigerant into larger cylinders and how they transport refrigerant from recovery site to destruction facility. We also require that all destruction technologies comply with UNEP TEAP's approved destruction technology and Code of Good Housekeeping. The Draft Methodology includes specific details about information collection during the transport, aggregation, and destruction phases.

We allow for one case where HFCs are not collected from operating or end-of-life equipment, namely government seizures of illegal shipments. Insofar as governments turn seized refrigerants over to project developers for the purpose of destruction, this is an approved source. In this case, the documentation requirements outlined in the Code of Good Housekeeping are sufficient.

Though we do not explicitly require further measures within the methodology project monitoring plan, we encourage project developers to pre-empt and mitigate any other opportunities for fraud arising at the individual project level. Careful and transparent record-keeping around project finances, with attention paid to where perverse incentives might be present, will lend additional credibility.

5. Conclusions

Refrigerant recovery and destruction ecosystems are critically important to maximize the climate benefits of the Kigali Amendment. Creating a market for recovered and destroyed HFCs is a near-term and effective way to incentivize the necessary management of installed banks. Currently, no carbon credit methodology exists that approves HFC recovery and destruction, slowing progress. Our proposed Draft Methodology builds upon VM0016 (currently covering only ODS) to include HFCs, strengthen additionality tests, and safeguard credit legitimacy.

We welcome comment on this white paper and the accompanying Draft Methodology.

About the Yale Carbon Containment Lab

Part of the Yale School of the Environment, the Yale Carbon Containment Lab (CC Lab) researches, develops, implements, and teaches low-cost, safe, and scalable approaches to carbon removal and containment. The CC Lab works with academic advisors, students, technical experts, and other collaborators to pursue concrete quantitative goals: 30 million metric tons of carbon dioxide equivalent ($MTCO_2e$) contained by 2030, and 500 million $MTCO_2e$ by 2050. The CC Lab's Anthropogenic Program includes a project on refrigerant emissions, focusing on refrigerant recovery from end-of-life cooling equipment. The CC Lab is a gift-funded non-profit.

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Appendix 1: Sizing the Emissions Reduction Opportunity

The Carbon Containment Lab built and maintains a refrigerant emissions model to estimate the climate benefits of improving refrigerant recovery rates. This model uses air conditioner stock data from IEA and estimates expected emissions from refrigerant venting from air conditioners through 2050.[16] The model excludes refrigerant emissions from refrigerators, foams, and aerosols.

Our model first estimates the amount of refrigerant in use in air conditioners at any given time. We calculate these figures based on estimates for global residential and commercial air conditioning stocks. We assume a baseline GWP of 2088 — reflecting the potency of R-410A, the most common air conditioning refrigerant — but reduce GWP over time in line with Kigali Amendment phasedown schedules and the entry of climate-friendlier refrigerants such as R-32. We do not model cases where ultra-low-GWP refrigerants such as R-290 penetrate the air conditioning market, given that scaling this technology in the next several decades would go above and beyond what phasedown schedules require in Article 5 countries. We are working to build scenarios into this model to understand how different technology adoption pathways affect expected venting emissions.

Next, we estimate how much of this refrigerant in use is contained in equipment that will reach end-of-life in any given year. We derive this proportion based on expected equipment lifetimes. This value represents potential emissions from venting in CO_2e.

[16] IEA. (2018, May). The Future of Cooling – Analysis. The Future of Cooling (link).

Appendix 2: Understanding Expanded Project Boundaries

Expanding project boundaries to include the production and leakage of replacement gas will change the way that project developers account for project emissions, particularly in cases where recovery or reclamation rates are non-zero. The following equation, described in detail in Section 8.3 of our proposed methodology (Equation 13), is the backbone of this suggested change.

$$LE_{Total} = \sum_{i=1}^{n} RR_{HFC,i} \times (PE_{Sub,i} + \left(M_{DESTR,HFC,i,y} \times TLR\right) \times \max\left[0, \left(GWP_{Sub,i} - GWP_{HFC,i}\right)\right])$$

Where:

LE_{Total}	=	Total leakage emissions by the project activity over project crediting period [tCO_2e]
$RR_{HFC,i}$	=	Rate of HFC refrigerant i which would be used, reused or remain in storage in the baseline [0-1]
$PE_{Sub,i}$	=	Emissions associated with production of substitute refrigerant for HFC refrigerant i [tCO_2e]
$M_{DESTR,HFC,i,y}$	=	Quantity of HFC refrigerant i which is sent to destruction by the project activity in year y [$tHFC_i$]
$GWP_{HFC,i}$	=	Global warming potential of destroyed HFC refrigerant i [$tCO_2e/tHFC_i$]
$GWP_{Sub,i}$	=	Global warming potential of substitute refrigerant for HFC refrigerant i [tCO_2e/tSubstitute]

To examine how the calculation works in practice, we consider two cases: the first in which reclamation capacity is low (near or at zero); and the second in which reclamation capacity is non-zero but low enough to maintain regulatory surplus.

In the first case – which we view as the business-as-usual case today – refrigerant venting occurs both during servicing and at equipment end-of-life. Furthermore, we assume that there is no legal end market for recovered refrigerant. This suggests that the $RR_{HFC,i}$ term in the equation is zero, driving project emissions from replacement gases to zero. This finding is important because it suggests that credits generated from HFC destruction in a country without scaled refrigerant reclamation should not be discounted, because reclamation is not a viable alternative to destruction.

In the second case – which we view as a likely future scenario – recovery and reclamation levels are non-zero ($RR_{HFC,i} > 0$) but low enough to maintain regulatory surplus. In this case, recovering and destroying refrigerant reduces the amount of refrigerant that could have otherwise been recovered and reclaimed. In this case, we believe that project developers should now account for emissions associated with the virgin or reclaimed HFCs that *replace* the HFCs that the developer destroyed. These emissions fall into two categories: emissions from replacement refrigerant production, and emissions from leakage over the project lifetime. These emissions are weighted by $RR_{HFC,i}$, the reclamation rate in the country of recovery, thereby discounting credits more when refrigerant reclamation is a more significant market alternative to destruction.

The attentive reader may notice that the term that accounts for leakage of replacement gases over the project lifetime is zero in almost all cases, except when the replacement gas is *higher* GWP than the gas that the project developer recovered.

Why should this be the case? First, we imagine a situation where technicians recover gas during servicing and send that recovered gas to destruction. They then recharge the system with the same species of virgin or reclaimed gas. In these cases, project developers hold some responsibility for the emissions required to acquire the replacement refrigerant, since if they had not destroyed the refrigerant in the system, it could have been recycled or reclaimed. But project developers should not be accountable for leakage since their intervention has no effect on expected leak rates.

Second, we imagine a situation where technicians recover gas from end-of-life equipment and send that recovered gas to destruction. The equipment owner then buys a new piece of equipment with a lower-GWP refrigerant. Again, the project developer should be responsible for emissions required to acquire the refrigerant from the new system (whether from reclaimed or virgin sources). To be conservative, project developers should not be *positively* credited with the adoption of low-GWP equipment *in addition to* the credits they generate from recovery and destruction. (In fact, there are already carbon credit methodologies, such as ACR's Advanced Refrigeration Systems, for certain kinds of refrigerant replacement or system retrofitting. In the event this class of protocols expands into A5 countries, ensuring refrigerant destroyers are not credited for subsequent low-GWP equipment adoption would be essential to avoiding double-counting). Thus, project emissions from leakage of the replacement gas are zero.

Third, we imagine a situation, albeit unlikely, in which technicians recover gas during servicing or at end-of-life, and for some reason, the replacement gas is *higher* GWP than the recovered gas. To be conservative, we assume that the project developer's intervention had some role in increasing the GWP of the replacement gas – had they recovered and reclaimed it, perhaps the lower GWP gas could still be used – and therefore project emissions should account for this leakage. In this case, project emissions from leakage are positive.

One may argue that, just as emissions associated with reclaimed gas leakage should be factored into a baseline calculation, there are emissions associated with reclaimed gas "production" (i.e., cleaning and processing) that should also be considered. To be conservative and err on the side of under-crediting, however, we elected not to include this term in the baseline.

Expanded project boundaries are easy to introduce in theory, but they pose major practical questions. How do policymakers and project developers measure countrywide reclamation capacity? How do we gain conviction that these rates are accurate? How should the GWP and production emissions of replacement gas be estimated? Should these vary with country or region?

The United States provides one example of how policymakers might assess reclamation capacity. Each year, the Environmental Protection Agency publishes a summary of refrigerant reclamation trends, which collects data on the amount of ODS and HFC reclaimed across the United States.[17] Refrigerant reclaimers report these data. Combined with a vintaging model that estimates how much refrigerant gas should be available for recovery each year, policymakers would reasonably be able to estimate a refrigerant reclamation rate – the proportion of refrigerant available for recovery that is actually recovered and reclaimed each year. Estimated rates need not be precise, but they should be accurate – an outcome that we believe is possible with existing models and modes of data collection. These methods should be transferable to the developing world. We welcome comments on how to better calculate these rates. At this time, if country-level reclamation data do not exist, we consider it safe to assume legal reclamation is not occurring at a meaningful rate.

Estimating the characteristics of replacement gas, represented in Equation 13 by the variables $PE_{Sub,i}$ and $GWP_{Sub,i}$ (denoting production emissions and estimated GWP, respectively) is a similarly challenging problem. In the future, when business-as-usual recovery rates are non-zero, we think that a life cycle assessment of virgin refrigerant manufacturing and an industry-wide breakdown of refrigerant consumption by species could provide guidance on the quantification of these factors. Should these not currently exist to a suitable level of rigor, we may attempt them in a future revision. We welcome comments on such resources, either as they are now or on how they could be developed.

[17] US EPA, O. (2015, August 5). *Summary of Refrigerant Reclamation Trends* [Data and Tools] (link).

Appendix 3: Understanding Effects of Destruction on Baseline and Consumption

Montreal Protocol & Baseline Calculations

The Kigali Amendment to the Montreal Protocol requires countries to report baseline production and consumption, from which HFC phasedown limits are calculated.

$$Production = CS_{Produced} - CS_{Destroyed} - CS_{Feedstock} \quad \text{(Equation 1)}$$

$$Consumption = Production + Imports - Exports \quad \text{(Equation 2)}$$

where CS or "controlled substance" refers to a substance in Annex A, B, C, E or F to the Montreal Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance.

Substituting equation (1) into equation (2) yields the following consumption equation:

$$Consumption = CS_{Produced} - CS_{Destroyed} - CS_{Feedstock} + Imports - Exports$$

(Equation 3)

Because destruction is subtracted from production in both baseline and stepdown calculations, there are two questions of relevance:

1. Does destruction in countries within their baseline years effectuate a lower baseline consumption allowance?
2. Does destruction of refrigerants in countries already in phasedown effectuate an equal magnitude of increase in production (or imports)?

Destruction Effects on Baselines

To assess the first question, we began by investigating the definition of a controlled substance, particularly the reasoning behind the clause in the Montreal Protocol that excludes from the definition "any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance." We initially interpreted this to mean that the baseline calculation of production or destruction ceases once the controlled substance is charged into equipment and begins its lifetime of use (i.e., since the destruction deduction ($CS_{Destroyed}$) applies only to refrigerant classified as a controlled substance, destruction of refrigerant after its lifetime of use should not be included as part of the baseline or stepdown calculations).

However, in conversations with the Ozone Secretariat, we learned that once recovered, non-virgin gas is again considered a controlled substance and its destruction can be subtracted from the calculation of consumption in baseline or stepdown years. The clause in the definition was included to allow for movement of charged equipment across country borders without necessitating the detailed accounting that this would represent.

Thus, the answer to the first question above is *yes*: any reported destruction during baseline years decreases the baseline consumption. This suggests that collection and destruction in Article 5 Group 2 countries should be a priority in their baseline years of 2024-2026.

Destruction Effects on Stepdown Calculations

In countries that have already set their baselines and are in phasedown, however, these definitions of production, consumption, and controlled substance could create problematic consequences for the phasedown process, especially in countries with large-scale recovery and destruction. For example, consider the following scenarios:

I. *Producing Country A*

- Imagine the baseline consumption level for Country A has already been set to 100 $MTCO_2e$
- In the first stepdown period, Country A is required to reduce their consumption by 15%, so their allowable consumption in the first stepdown period is 85 $MTCO_2e$
- They can achieve this stepdown by reducing the amount of HFC produced by 15 $MTCO_2e$ (desired result), **or** they can destroy an existing 15 $MTCO_2e$ of HFC that is recovered from equipment
- In this case, destroying 15 $MTCO_2e$ increases the allowable production amount from 85 $MTCO_2e$ (in the absence of destruction) to 100 $MTCO_2e$

II. *Importing Country B*

- Assume Country B has no production or exports and follows the same phasedown schedule as Country A
- Country B can similarly achieve stepdown by reducing the amount of HFC imported by 15 $MTCO_2e$ (desired result), **or** they can destroy an existing 15 $MTCO_2e$ of HFC that is recovered from equipment
- If the imported HFC comes from Country C which has not yet set its baseline (e.g., India or other HFC-producing Article 5 Group 2 country), Country C could increase its production to supply the additional imports permitted by the destruction in Country B
- In this case, Country B's increased import (15 $MTCO_2e$) can effectuate an increase in the baseline of Country C, which affects the Country C's production not just in the baseline year but for all subsequent stepdowns

Both scenarios lead to increased production of refrigerants that would otherwise not have been permitted in the absence of destruction. Given that the GWP of the virgin gas is comparable (or identical) to that of the destroyed gas, this effect substantially reduces the impact and desired outcome of the methodology.

As such, we again sought clarification from the Ozone Secretariat on whether these scenarios were realistic. The Secretariat provided clarity and a pathway for safeguarding against the above scenarios. First, the Secretariat outlined scenarios that could feasibly lead to negative outcomes: production quotas are set for manufacturers at the country level, so a country could, in theory, estimate and/or keep track of destruction throughout the year and continuously increase the quotas of national manufacturers to mirror the volumes of destruction occurring.

However, the Secretariat noted that such a scheme would require an improbable deal of oversight, planning, and motivation to increase production. Further, they knew of neither any instances in which a country anticipated destruction or adjusted quotas in the allocation of allowances, nor any in which a country would have exceeded its allowance cap but for destroyed refrigerant in a given year. To test this hypothesis, the Secretariat analyzed past reported data to see if destruction was the basis for compliance by any Article 5 party for the years 1986 to 2022, inclusive of all controlled substances. They found the following:

1. *One A5 country with regular annual by-production of CTC, all of which gets destroyed within the year. This happens in a similar fashion for NON-Article 5 parties and would not count as using destruction to boost production.*
2. *One A5 country with one year in which a small amount of destruction of Halon helped the country be in compliance. The amount destroyed is considered small because it is about 0.1% of the total production reported by that country in that year.*

The Secretariat concluded that "*as per my indication during our teleconference, we do not seem to have cases of countries using destruction to boost their annual production or consumption*" (Mr. Gerald Mutisya; March 28, 2023).

Therefore, we are confident this methodology will incentivize the collection of gas that would otherwise be vented, without affecting production or consumption phasedowns. However, Ozone Secretariat data can be monitored in the future to ensure that destruction as outlined in this methodology is not enabling a country to exceed its consumption cap. If a country does increase its production or imports due to destruction, pathways for addressing this could include discounting total credits (by the excess over the cap) or removing them from the list of eligible countries (Table A3-1).

Moreover, production and consumption allowances reset annually, so there is no risk of a previous year's destruction affecting the following year's production. Thus, one alternative approach to safeguard against increasing quotas would be to destroy all recovered refrigerant at end of year or to simply report substances destroyed on an annual basis (provided this is compliant with local or host country regulation).

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Table A3-1. Proposed criteria for inclusion and exclusion

Scenario	Kigali Ratified	Baseline Set	Producer	Result	Who does this apply to?	Key considerations
I	No			Exclude	Any Article 5 country yet to ratify the Kigali Amendment (e.g., Qatar)	N/A
II	Yes	No		Include	Article 5 Group 2 (with Kigali Amendment ratified; e.g., India)	Destruction can be included in baseline calculation: $\boldsymbol{Baseline\ Consumption = CS_{Prod} - CS_{Dest} - CS_{Feedstock} + Imports - Exports}$ Given effect on baseline calculation, all efforts to raise awareness and promote inclusion should be a priority
III	Yes	Yes	No	Include, with check	Article 5 Group 1 countries with zero production (e.g., Indonesia)	It is essential that destruction does not enable production above set stepdown limits. A country is eligible if the following is true: $\boldsymbol{Consumption\ Limit \geq Imports - Exports - CS_{Feedstock}}$ If not, then the destruction enabled consumption that would have otherwise been above phasedown limits. Courses of action can include assigning discounts to generated credits, [e.g., $\boldsymbol{Discount = (Imports - Exports - CS_{Feedstock}) - Consumption\ Limit}$], or amending inclusion criteria if non-compliance continues for >1 year.
IV	Yes	Yes	Yes	Include, with check	Article 5 Group 1 countries with non-zero production (e.g., China)	It is essential that destruction does not enable production above set stepdown limits. A country is eligible if the following is true: $\boldsymbol{Consumption\ Limit \geq CS_{Prod} + Imports - Exports - CS_{Feedstock}}$ If not, then the destruction enabled consumption that would have otherwise been above phasedown limits. Courses of action can include assigning discounts to generated credits, [e.g., $\boldsymbol{Discount = (Imports - Exports - CS_{Feedstock}) - Consumption\ Limit}$], or amending inclusion criteria if non-compliance continues for >1 year.