Yale Carbon Containment Lab
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Summary

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. The CC Lab is a part of the Yale School of the Environment and is a gift-funded non-profit.

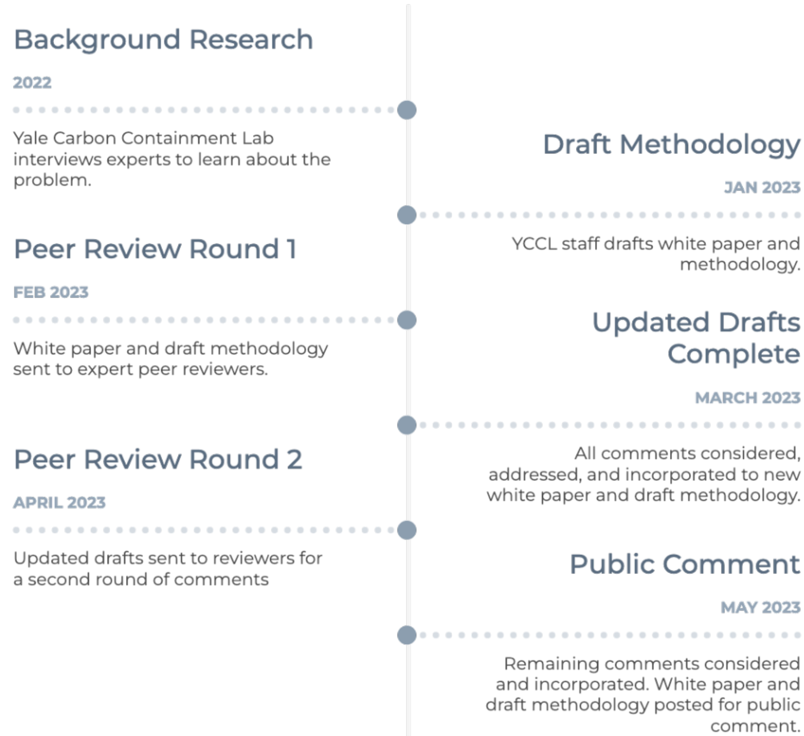
The CC Lab's Anthropogenic Program includes a project on refrigerant emissions, focusing on refrigerant recovery from servicing and end-of-life cooling equipment. As part of this work, the CC Lab Staff identified a gap in the available refrigerant methodologies available to project developers: HFC destruction in Article 5 countries. Drawing on several years of field research and interviews with technical experts, methodology writers, and project developers, we drafted a methodology and white paper to address this gap. We then solicited peer reviews on both documents, with a focus on the white paper and underpinning assumptions and arguments surrounding additionality and fraud prevention.

The ensuing document contains the following materials: 1) a description of the peer review process and timeline; 2) the first draft of the white paper; and 3) verbatim peer review comments and responses. The final version of the white paper and accompanying draft methodology—with all addressed comments included—will be published online alongside these documents.

The overall goal of this work is to provide project developers a pathway toward addressing this pool of refrigerant emissions, as well as to provide credit buyers with assurance of high-quality credits that should command a premium price. Towards this goal, we intend to publish all discourse on the topic and encourage further scrutiny and/or support from all who are interested.

Peer Review Process

The Yale Carbon Containment Lab Anthropogenic Team, led by Anastasia O'Rourke, PhD (Managing Director, CC Lab) and Charlie Mayhew (Analyst, CC Lab), pursued a peer review process for the draft methodology and white paper. We highlight the steps in this process in the below timeline:



As part of the peer review process, the CC Lab team identified a list of technical experts to review the drafts and outlined key questions for peer reviewers to consider, including:

- What are additional arguments in favor of (or against) the additionality of HFC recovery and destruction in A5 Group 1 countries?
- What are your opinions on including HFC stockpiles as an approved source, in line with the Climate Action Reserve's Mexico Halocarbon Protocol?
- Do you have concerns about including A5 Group 2 countries within this methodology?
- What modifications to our proposed methodology would enable HFC recovery and destruction in developed, non-A5 countries?
- We suggest an expanded project boundary to retain additionality in countries with growing refrigerant reclamation capacity. What flaws do you see in this approach?
- What are other ways to proxy reclamation capacity?
- What is the lifecycle impact of virgin HFC manufacturing relative to HFC reclamation?

After comments were submitted, the CC Lab team collated responses and coordinated the team's consideration, response, and incorporation of suggested changes. Verbatim comments and replies are contained at the end of this document.

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Table of Contents

Summary 1
Peer Review Process 2
Table of Contents 3
Draft White Paper 4
Peer Review Comments & Replies 20
  Reviewer #1: Anonymous 20
  Reviewer #2: Kristen Taddonio 25
Understanding Effects of Destruction on Baseline and Consumption 25
  Montreal Protocol & Baseline Calculations 25
  Destruction Effects on Baselines 26
  Destruction Effects on Stepdown Calculations 26
  Reviewer #3: Anonymous 32
  Reviewer #4: Christina Starr 35

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Methodology for Recovering and Destroying Hydrofluorocarbons in Article 5 Countries

Draft White Paper

February 9, 2023
New Haven, Connecticut

Prepared by the Yale Carbon Containment Lab

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White Paper Table of Contents

Table of Contents 5
Executive Summary 6
Background 7
Examining Existing Protocols 8
Past Protocol Failures: HFC-23 Destruction and the Clean Development Mechanism 9
Revising Existing Protocols Covering ODS 10
I. Additionality Case 10
II. Expanding Project Boundaries and Revisiting Project Emissions 12
III. Documenting Recoveries to Improve Credit Legitimacy 13
Conclusions 14
About the Yale Carbon Containment Lab 14
References 15
Appendix 1: Sizing the Emissions Reduction Opportunity 16
Appendix 2: Understanding Expanded Project Boundaries 17

Executive Summary

As climate change intensifies and global cooling demand increases, banks of hydrofluorocarbon (HFC) refrigerants will continue to grow substantially, even with full implementation of 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 HFCs will enter the market by 2100.[1]

Today, one of 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, often arising from underdeveloped or absent end markets for recovered refrigerant. 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, 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. 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 are likely to continue unabated.

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

In addition to modifying language in VM0016 to include HFCs, we propose three major revisions to the VM0016 methodology:

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

We welcome public comment 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).

Background

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.[3] 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 lays 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 first restrictions to production and consumption beginning near the end of the decade.[4] 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. By 2100, an estimated 67 gigatons CO_2e of HFCs will enter the market, quadrupling the amount of CO_2e of refrigerant currently in use.[5] This persistent and expanding HFC use poses a substantial refrigerant management challenge across the globe.

Refrigerants such as HFCs are emitted 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 because monitoring the millions of refrigerant-containing appliances in use is difficult and impractical. Further, technicians are rarely outfitted with proper equipment to capture the gas—leaving venting as the only possible course of action.

Our modeling suggests that more than 30 gigatons CO_2e of refrigerant will be vented to the atmosphere by 2050.[6] Venting is particularly rampant in A5 countries, which typically possess neither widespread reclamation and disposal infrastructure nor a legal end market for recovered refrigerant.[7] 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 25 million $MtCO_2$e emissions. Currently, however, this financing mechanism excludes HFCs, and methodologies in the pipeline fail to address HFC venting. 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 are likely to continue unabated.

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[3] IEA. (2018, May). *The Future of Cooling – Analysis*. The Future of Cooling (link).
[4] Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction (link).
[5] Theodoridi, C., *et al.*. (2022). The 90 Billion Ton Opportunity (link).
[6] See Appendix 1 for model parameters and methodology.
[7] 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 Theodoridi et al., 2022).

Examining Existing Protocols

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

Registry	Methodology Name	Approved Countries/Regions	Approved Activities	Assumptions About Recovery Rates	Notable Differences with Our Proposed Methodology
Verra	Recovery and Destruction of Ozone Depleting Substances (VM0016)[8]	Parties to the Montreal Protocol. Recovery can happen in the same or different country as destruction.	ODS destruction (recovered and stockpiled gas)	100% venting rates in the absence of regulatory prohibition	• Excludes HFCs • Has smaller project boundaries • Assumes venting only in the absence of regulatory prohibitions
Climate Action Reserve	U.S. and Article 5 Ozone Depleting Substances Project Protocol[9]	ODS source: USA or Article 5 countries ODS destruction: USA and its territories	ODS destruction (recovered and stockpiled gas)	100% venting rates from end-of-life equipment	• Excludes HFCs • Requires that ODS be imported to the USA for destruction • Has looser recordkeeping requirements for recovered gas
American Carbon Registry	The Destruction of Ozone Depleting Substances and High-GWP Foam[10]	ODS source: USA ODS destruction: USA	ODS destruction (recovered and stockpiled gas), high-GWP foams, aerosols, fire suppressants	Assumes 100% recovery rates for ODS (frames the destruction, rather than the recovery, as the driver for additionality)	• Limits sources and destruction to the USA • Excludes non-foam HFCs
American Carbon Registry	Destruction of Ozone Depleting Substances from International Sources	ODS source: outside USA and its territories ODS destruction: within or outside USA	ODS destruction (recovered and stockpiled gas)	Assumes 100% recovery rates for ODS (frames the destruction, rather than the recovery, as the driver for additionality)	• Excludes HFCs • Does not distinguish between end-of-life equipment, serviced equipment, and other refrigerant sources
Climate Action Reserve	Mexico Halocarbon Protocol[11]	Mexico	Destruction of select halocarbons (several common CFCs, HCFCs, and HFCs)	100% venting rates from end-of-life equipment	• Allows destruction from HFC stockpiles • Limits sources and destruction to Mexico • Limits eligible HFC species

[8] Lang, T., *et al.* (2021). *Mexican Halocarbon Protocol* (link).
[9] Climate Action Reserve. (2012). *Ozone Depleting Substances Project Protocol Article 5* (link).
[10] Winrock International. (2021). *The Destruction of Ozone Depleting Substances and High-GWP Foam* (link).
[11] Lang, T., *et al.* (2021). *Mexican Halocarbon Protocol* (link).

Past Protocol Failures: HFC-23 Destruction and the Clean Development Mechanism

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 is a greenhouse gas controlled by the Kyoto Protocol that 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.[12] HCFC-22 also continues to be used as feedstock for other chemicals.

Unfortunately, the CDM's use of carbon credits to reward HFC-23 destruction created a perverse incentive to produce HCFC-22 in excess. Fluorocarbon manufacturers exploited this crediting system, making windfall profits while increasing emissions harmful to the climate and ozone layer.[13] Stakeholders have frequently noted that this CDM failure is a primary reason why other HFC destruction methodologies have been slow to reach publication.

We believe that the crediting activity that we describe — recovering HFCs from *equipment* and then destroying them — is principally different from the CDM's, which worked with fluorocarbon manufacturers who themselves were credited for HFC-23 destruction. Although the CDM protocol and this proposed methodology both describe HFC destruction, we stress the importance of not conflating crediting activities. Nevertheless, we believe that this methodology should undergo rigorous vetting for perverse incentives, which we discuss in "Documenting Recoveries to Improve Credit Legitimacy" later in this note.

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[12] 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.
[13] Doniger, D. (2010, November 11). The Curious Case of HFC-23. Natural Resources Defense Council (link).

Revising Existing Protocols Covering ODS

Our proposed methodology builds upon VM0016 and draws 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. 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. The latter changes make three major contributions to VM0016:

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

I. Additionality Case

The additionality case for HFC recovery and destruction revolves around the following criteria:

1. Business-as-usual practices for refrigerant recovery in the host country; and
2. The effects of phasedown on future refrigerant recovery, reclaim, 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.

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 nominal refrigerant venting prohibitions. In practice, venting prohibitions are rarely enforced. Past methodologies, including the Climate Action Reserve Mexico Halocarbon Protocol, and industry stakeholders have similarly treated venting as the business-as-usual case in A5 countries. The prospect of generating a saleable carbon credit from HFC recovery and destruction creates an end market for recovered HFCs. The existence of an end market means that technicians can be compensated for responsibly recovering refrigerant, turning an activity that was previously a net cost into a net benefit.

In calculations for baseline emissions, we include terms that account for non-zero recovery, destruction, and compliance rates (Equation 1, Section 8.1 of draft methodology). Any of these terms being non-zero discounts credits accordingly. Although we assume that these rates are 0 percent today in A5 countries, future compliance or higher recovery rates (insofar as they maintain regulatory surplus) do not preclude additionality. This framework further suggests that HFC recovery and destruction may be considered additional in non-A5 countries with low HFC recovery rates.

We do not include non-A5 countries outright in this methodology for two reasons. First, refrigerant recovery is a more common practice in developed countries due to available recovery equipment, more mature refrigerant reclaim markets, 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.[14] Second, given that HFC phasedown is already underway and virgin HFCs are becoming scarcer in non-A5 countries, there exists a market incentive to recover HFCs. 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. We welcome feedback that could extend this methodology to non-A5 countries.

Effects of Phasedown on Future Practices

The Kigali Amendment assigns each signatory country to one of four possible HFC phasedown schedules, summarized in the table below.[15]

Article/Group HFC Phasedown Schedules Pursuant to Kigali Amendment			
Country Group	Countries Included	Baseline Calculation Years	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	2029
Article 5 (Group 2)	The Middle East (also includes India)	2024, 2025, 2026	2032

We foresee that one objection to HFC destruction is that early in phasedown (or prior to it), HFC can continue to be produced without restriction. Therefore, recovering and destroying HFCs — if the counterfactual is recovering and reclaiming them — could have the adverse effect of supporting demand and production of virgin HFCs. This effect would be particularly problematic in Article 5 Group 2 countries, in which future HFC destruction could conceivably *increase* baseline production and consumption numbers relative to a world in which HFCs are recovered and reclaimed instead. We share these concerns.

For now, we propose that this methodology apply to *all* A5 countries, whether or not baseline production and consumption levels have yet to be determined. Our perspective is that the current counterfactual to recovery and destruction is venting, rather than recovery and reclamation. Therefore, destruction in A5 Group 2 countries has little effect on baseline calculations because reclamation is currently a non-factor. We encourage feedback on this decision.

[14] Industry estimates, in combination with refrigerant reclaim data from EPA.
[15] Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction (link).

II. Expanding Project Boundaries and Revisiting Project Emissions

For decades, there has been a lively and ongoing debate among policymakers and industry stakeholders about the relative merits of reclamation and destruction. 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. Meanwhile, destruction has an immediate benefit of preventing HFC emissions. However, it has fewer climate benefits; i.e., destroyed HFC can simply be replaced by newly manufactured HFCs. Even worse, premature destruction – without proper safeguards – can encourage overproduction and illegal import of HFCs. In these cases, destroying refrigerant would deplete the stock that could otherwise be reclaimed—indirectly supporting demand for virgin gas.

We propose expanding project boundaries established in VM0016 to always include emissions from replacement gases for the HFCs recovered and destroyed (Figure 1). This change further safeguards additionality for HFC destruction while discounting credits generated from destruction as reclaim capacity grows. See Appendix 2 for the equation that achieves this goal and several scenarios highlighting how context will affect baseline calculations.

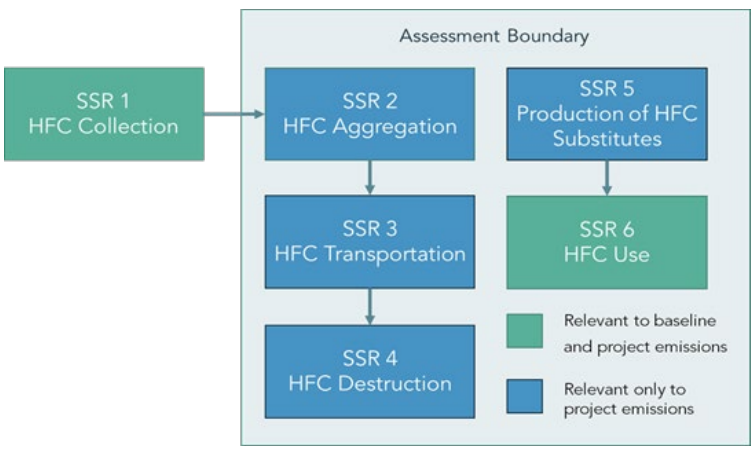

Figure 1. *Proposed project boundaries in the methodology update. Yale Carbon Containment Lab.*

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

We contend that the ideal solution requires a mixture of reclaim and destruction. Reclamation is an extremely important piece of a refrigerant recovery ecosystem, but building reclaim capacity in developing countries will be more expensive — especially given fractional distillation requirements for HFC blends — than building near-term destruction capacity. Furthermore, in the present case where reclamation is scarce, destruction is the preferable scenario compared with the counterfactual of refrigerant venting. Nonetheless, we included the possibility of reclamation in our equation for baseline emissions, in which higher refrigerant recovery rates translate to lower baseline emissions.

III. Documenting Recoveries to Improve Credit Legitimacy

One potential weakness in the legitimacy of HFC recovery and destruction projects is the prospect of fraud and perverse incentives. Since virgin HFC can still be produced and sold in most A5 countries and without any limitations, fraudulent projects could conceivably purchase virgin refrigerant and destroy it for carbon credits. We are similarly concerned about the destruction of HFC stockpiles early in or prior to HFC phasedown. These activities would not be additional, given that the virgin refrigerant had no likelihood of being vented, unless charged into operating equipment.

We strongly believe that a methodology approving HFC recovery and destruction should contain thoughtful and robust requirements for recovery documentation. This documentation should create a chain of custody that confirms that refrigerant bound for recovery 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/operator; date and approximate time of recovery; location of recovery; name of technician completing recovery
- **Equipment information**: photograph of the equipment's nameplate and unique identifying serial number; photograph of recovery equipment connected to the equipment; documentation of cylinder weight before and after recovery

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. Specific details about information collection during the transport, aggregation, and destruction phases are included in our methodology.

Though we did not explicitly require further anti-fraud 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 record-keeping around project finances, with attention paid to where perverse incentives might be present, would lend projects additional credibility.

Conclusions

We argue that developing an ecosystem for refrigerant recovery and destruction is critically important in maximizing the climate benefits of the Kigali Amendment. Currently, no methodology exists that approves HFC recovery and destruction as a project for voluntary credit markets. Our proposed methodology expands VM0016 (currently covering only ODS) to include HFCs, with several suggested modifications to defend additionality and safeguard credit legitimacy. We welcome public 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 (tCO_2e) contained by 2030, and 500 million tCO_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.

References

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 https://www.bitzer.de/shared_media/html/a-540/en-GB/158029963158036747.html

Clark, E., & Wagner, S. (n.d.). The Kigali Amendment to the Montreal Protocol: HFC Phase-down. OzonAction. https://multimedia.3m.com/mws/media/1365924O/unep-fact-sheet-kigali-amendment-to-mp.pdf

Climate Action Reserve. (2012). *Ozone Depleting Substances Project Protocol Article 5*. https://www.climateactionreserve.org/how/protocols/industrial/ozone-depleting-substances/

Doniger, D. (2010, November 11). The Curious Case of HFC-23. Natural Resources Defense Council. https://www.nrdc.org/experts/david-doniger/curious-case-hfc-23

Energy Changes Projekt Entwicklung GmbH, & USG Umweltservice GmbH. (2017). *VCS Methodology VM0016 Recovery and Destruction of Ozone-Depleting Substances*. https://verra.org/methodologies/vm0016-recovery-and-destruction-of-ozone-depleting-substances-ods-from-products-v1-1/

IEA. (2018, May). The Future of Cooling – Analysis. The Future of Cooling. https://www.iea.org/reports/the-future-of-cooling

Lang, T., Broekhoff, D., DuBuisson, M., Tornek, R., Kidman, T., & Findsen, J. (2021). *Mexican Halocarbon Protocol*. https://www.climateactionreserve.org/wp-content/uploads/2021/06/Mexico_Halocarbon_Protocol_V1.0_English.pdf

Theodoridi, C., Starr, Christina, Hillbrand, Alex, Mahapatra, Avipsa, & Taddonio, Kristen. (2022). The 90 Billion Ton Opportunity. https://us.eia.org/wp-content/uploads/2022/10/Refrigerant-Lifecycle-FullReport-6Spreads-PRINT.pdf

US EPA, O. (2015, August 5). Summary of Refrigerant Reclamation Trends [Data and Tools]. https://www.epa.gov/section608/summary-refrigerant-reclamation-trends

Winrock International. (2021). *The Destruction of Ozone Depleting Substances and High-GWP Foam*. https://americancarbonregistry.org/carbon-accounting/standards-methodologies/destruction-of-ozone-depleting-substances-and-high-gwp-foam

Appendix 1: Sizing the Emissions Reduction Opportunity

The Carbon Containment Lab 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.

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.

We encourage feedback on our modeling strategy and information about data sources that describe global air conditioning growth or other models that estimate refrigerant emissions from venting. Our model is available upon request.

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

Appendix 2: Understanding Expanded Project Boundaries

Expanded project boundaries 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 reclaim should not be discounted, because reclaim is not a viable alternative to destruction.

In the second case — which we view as a likely future scenario — recovery and reclaim 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 reclaim rate in the country of recovery, thereby discounting credits more when refrigerant reclaim 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 for 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 had they 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 for 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 an unlikely situation 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 should account for leakage in project emissions. 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 reclaim 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 gets 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. 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 Eq. 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 nonzero, we think that a life cycle assessment of virgin refrigerant manufacture 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 could be developed.)

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

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Peer Review Comments & Replies

Reviewer #1: Anonymous

Project Developer

Comment 1-1:

Lines 184-185: In calculations for baseline emissions, we include terms that account for non-zero recovery, destruction, and compliance rates (Equation 1, Section 8.1 of draft methodology).

Reviewer #1: I suggest removal of this concept. I understand the rationale but realistically, these values will be impossible to determine. Project developers will likely be left with conservative default deductions that are not representative of real world conditions as a result and this will make already difficult project economics more challenging. There are examples of extreme conservatism in ODS/F-Gas methodologies, such as CAR's use of a 1% emission rate for blowing agents contained in foam that is still in use in their program and ARB's (and was proven to be wildly inaccurate when we updated the foam method under ACR's domestic methodology in 2017). The assumption should be that the availability of a destruction credit drives recovery and in absence of that incentive, recovery and destruction would not occur.

Response: Thank you very much for this perspective. Considering other reviewer comments and our internal review, we have chosen to retain this concept in the methodology.

First, we note that our intentions in explicitly including baseline recovery, destruction, and compliance rates are to (1) 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. In the countries eligible under this methodology, we are confident that baseline recovery, destruction, and compliance rates are negligible. Thus, in the current text of the methodology, such baseline rates are assumed to be 0, and the project developer incurs no deduction.

Should baseline rates begin to increase due to increased enforcement of venting prohibitions or for any other reason, the methodology will be revised and further guidance will be provided on the calculation protocols.

Finally, as you note, terms for recovery, destruction, and compliance rates are commonly included in baseline equations for existing ODS destruction methodologies on major registries. While this can result in default rate deductions, the meaningful number of registered ODS projects suggests that, in practice, developers are able to estimate such terms without project activities becoming unprofitable.

Comment 1-2:

Lines 197-200: 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. We welcome feedback that could extend this methodology to non-A5 countries.

Reviewer #1: The clearest case for inclusion of HFC destruction in upcoming methodologies will come from the EU's F-Gas regulation which will include a blanket prohibition on virgin HFC production and import for gases with GWP over 2500. This prohibition may begin on Jan 1, 2024 but reclaimed gas over this GWP threshold can continue to be used until 2030. While limited in duration, this presents an opportunity to collect/destroy higher GWP HFCs in Europe. Rather than excluded from discussion, this should be promoted as an immediately eligible voluntary market HFC destruction opportunity in the white paper. New Zealand's "removal" credits are beyond scope as this is a project type under the NZ ETS so agree that it is not relevant to the concept.

Response: Thank you for this information. We agree that these cases are compelling and attractive for future methodologies. However, given the distinct situation leading to destruction additionality in the European Union, we believe that a separate methodology would be better suited for this geography. If you are interested in drafting such a methodology, we would be happy to speak further about how we may be able to get involved.

Comment 1-3:

Lines 224-228: However, it has fewer climate benefits; i.e., destroyed HFC can simply be replaced by newly manufactured HFCs. Even worse, premature destruction – without proper safeguards – can encourage overproduction and illegal import of HFCs. In these cases, destroying refrigerant would deplete the stock that could otherwise be reclaimed—indirectly supporting demand for virgin gas.

Reviewer #1: Suggest revision to wording here as it seems to run counter to what you are suggesting in the rest of the white paper. If the argument is that the baseline is venting, why would destruction yield less climate benefit? And, isn't this clause counter to the previous section, in general? Given that venting is the baseline scenario, why is overproduction an issue?

Response:

We absolutely agree. We have incorporated your comments and clarified our wording. Please see the updated wording pasted below.

"However, if the baseline is reclaim rather than venting, destroying refrigerant would deplete the stock that could 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 reclaim capacity, so credits generated from HFC destruction will be discounted accordingly."

Comment 1-4:

Lines 230-234: We propose expanding project boundaries established in VM0016 to always include emissions from replacement gases for the HFCs recovered and destroyed (Figure 1). This change further safeguards additionality for HFC destruction while discounting credits generated from destruction as reclaim capacity grows. See Appendix 2 for the equation that achieves this goal and several scenarios highlighting how context will affect baseline calculations.

Reviewer #1: This deduction is not necessary with an assumption that the baseline is venting. In A5 countries, that's a defensible assumption. Even in the example of Europe with high GWP HFC, a leakage deduction shouldn't necessarily apply. Given that no import/production would be allowed in that situation, reclamation has no impact on limiting eventual emissions...it only results in prolonging HFC use. From a climate perspective, destruction should be the preferred option there combined with an extended crediting period (over which all HFC would be emitted) to acknowledge that all HFC in circulation will be emitted if not destroyed.

Response: We agree that deductions are not necessary when the baseline is venting, which is reflected in Appendix 2. Our equation for project emissions from replacement gases is designed such that deductions only occur in the presence of reclaim infrastructure (and/or increased compliance).

In the case of Europe, there would be no deduction for emissions from replacement refrigerant leakage because the replacement HFC would have a lower GWP than the reclaimed HFC. However, since recovering and destroying the refrigerant reduces the amount of refrigerant that could otherwise have been reclaimed, we maintain that the project developer should be responsible for the emissions associated with the production of the replacement gas.

Comment 1-5:

Lines 257-260: We are similarly concerned about the destruction of HFC stockpiles early in or prior to HFC phasedown. These activities would not be additional, given that the virgin refrigerant had no likelihood of being vented, unless charged into operating equipment.

Reviewer #1: Agree, though one exception could be government seizures of illegal shipments. Where a government is willing to convey that gas to a project developer, those stockpiles could be eligible.

Response: Thank you for this comment. We agree that government seizures of illegal shipments of HFCs should be an approved source, insofar as governments turn seized refrigerants over to project developers for the purpose of destruction. We have modified documentation requirements accordingly to account for refrigerant coming from seized illegal shipments.

Comment 1-6:

Lines 262-271: We strongly believe that a methodology approving HFC recovery and destruction should contain thoughtful and robust requirements for recovery documentation. This documentation should create a chain of custody that confirms that refrigerant bound for recovery 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/operator; date and approximate time of recovery; location of recovery; name of technician completing recovery
- **Equipment information**: photograph of the equipment’s nameplate and unique identifying serial number; photograph of recovery equipment connected to the equipment; documentation of cylinder weight before and after recovery

Reviewer #1: In practice, completely impractical to implement, particularly without consideration of an acquisition size threshold. HFC sources are diffuse so applying these requirements to every recovery would be far too onerous. I'd suggest reviewing CAR's point or origin requirements from the Mexico Halocarbon Protocol (items 4-8 in table 6.1) and use those requirements or come up with similar. Even in that protocol, the documentation requirements on page 34 would need to be simplified. There has to be consideration that there will be some recoveries from large, engineered systems where the type of information that is proposed will be easily accessible such as decommissioned chillers but most of the time, HFC will be acquired in very small quantities and bulked up over time. One example: for appliance demanufacturing facilities/scrap centers, these will be fertile ground for HFC recovery that could be incentivized. A photograph of each piece of equipment and its serial number, while possible, would yield nothing meaningful from a project development perspective (a verifier can't trace this information anywhere nor can any other entity in the project development chain - the registry, ratings agencies, etc). This would only function to drive development costs much higher and disincentivize project development.

Response: We thank the reviewer for their perspective. Our aim with this methodology is to create positive outcomes and prevent fraud, and we believe that stringent recovery documentation is a necessary part of achieving this goal. The diffuse nature of HFC sources makes this a particularly important issue.

To address the challenges that may arise with verification, we plan to share this methodology with verifiers to ensure that chain of custody documentation is verifiable and to develop a plan for how verification will occur. We are aware of other standards which require spot checks to verify information gathered, and we expect the same to be true of this methodology. Furthermore, even if documentation is not checked on an individual basis, we believe that the collection of this information will increase credibility for individual projects, deter bad actors, and promote standards of transparency and rigor across the carbon credit market.

We acknowledge the concern that more stringent documentation requirements will raise costs for project developers. However, we also believe that credits generated with these requirements will ultimately be of a higher quality, conferring a higher degree of confidence that the emission reductions achieved by the project are truly additional. Thus, we believe that credits containing this information should command a higher price, which can offset the costs associated with documentation.

We are open to suggestions regarding alternative forms of documentation that would meet a similar level of stringency while keeping costs low. However, among the documentation methods we have considered, we believe that our proposal strikes a balance between feasibility for project developers and the need for fraud prevention and transparency.

Comment 1-6-2:

Reviewer #1: On flexibility with documentation requirements, I think one thing that could be added or acknowledged are end of life scenarios for recovery versus operational equipment. For instance, appliance demanufacturing centers will be important as a refrigerant source due to the number of small appliances they handle on a daily basis. In these situations, they are often handling a few ounces of refrigerant from an appliance and all of the appliances are being scrapped. In a situation like this, I think it's unreasonable to ask for photographs of every appliance, every recovery hook up, etc. The location where the recovery is occurring, in this example, only handles end of life equipment so I think that's a scenario that could be acknowledged in the methodology and would present a low risk.
One additional requirement that you could think about adding for rigor (potentially) would be an attestation by the recovery company or project developer regarding whether recovery has been conducted from a particular piece of equipment that is operational. Repeated recoveries from the same equipment should raise a red flag and could be tracked via attestation as well as a management system that contains equipment serial numbers.

Response: After further discussion, we agree that recoveries from appliance demanufacturing centers warrant alternative documentation requirements. We have revised the requirements accordingly.

We thank the reviewer for the suggestion of including a requirement for an attestation. It has been included.

Reviewer #2: Kristen Taddonio[18]

Comment 2-1:

What are additional arguments in favor of (or against) the additionality of HFC recovery and destruction in A5 Group 1 countries?

Reviewer #2: I think your argument and rationale is solid. We can cite plenty of evidence to back it up, but that may not even be necessary at this point.

Response: Thank you!

Comment 2-2:

Do you have concerns about including A5 Group 2 countries within this methodology?

Reviewer #2: I think there's potentially a solid argument that this is even more important in Group 2 countries because it could lower their baseline. Look closely at the Kigali baseline calculations. I think I recall there's a provision that says any refrigerant destroyed or exported (for destruction) gets subtracted for their baseline. So if you recover and destroy a bunch of HFC there during the baseline years, you're actually lowering their baseline. That doesn't just help the first year, it helps every subsequent year too. I invite you to look into that a bit more. Let me know what you calculate.

Response: We thank the reviewer for this comment. It led to a very informative deep dive into the specific definitions and boundaries of the Montreal Protocol. We summarize our learnings below. These details are now included as an Appendix to the white paper.

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

[18] Reviewing as an independent expert

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 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: $Baseline\ Consumption = CS_{Prod} - CS_{Dest} - CS_{Feedstock} + Imports - Exports$ 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: $Consumption\ Limit < Imports - Exports - CS_{Feedstock}$ If not, then the destruction enabled consumption above phasedown limits. In this case, the destruction credits should be discounted by the following amount: $Discount = (Imports - Exports - CS_{Feedstock}) - Consumption\ Limit$ If a country is not in compliance for >1 years, they are no longer eligible for methodology
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: $Consumption\ Limit < CS_{Prod} + Imports - Exports - CS_{Feedstock}$ If not, then the destruction enabled consumption above phasedown limits. In this case, the destruction credits should be discounted by the following amount: $Discount = (CS_{Prod} + Imports - Exports - CS_{Feedstock}) - Consumption\ Limit$ If a country is not in compliance for >1 years, they are no longer eligible for methodology

As a result of this comment and analysis, we have updated the methodology in the following ways:

- Inclusion of Article 5 Group 2 countries
- Inclusion of additionality check on a national level

We sincerely thank the reviewer for motivating this work!

Comment 2-3:

What are your opinions on including HFC stockpiles as an approved source, in line with the Climate Action Reserve's Mexico Halocarbon Protocol?

Reviewer #2: Yes

Response: Consistent with comment 2-3 and 1-5, we have included illegally imported HFCs as an approved source, contingent on the seized HFC being turned over to a project developer for the purpose of destruction. However, we chose not to include HFC stockpiles because of fraud risk. We believe that fraud risk is much higher for virgin refrigerant since it may come from overproduction (in a producing country) or unidentified illegal import (in an importing country). These risks vaguely resemble the circumstances that led to the Clean Development Mechanism HFC-23 destruction fiasco, which we aim to avoid.

Comment 2-4:

What modifications to our proposed methodology would enable HFC recovery and destruction in developed, non-A5 countries?

Reviewer #2: Initially: allow destruction credit for foam destruction and for destruction of contaminated refrigerant that can't be [feasibly/cost effectively] reclaimed. You may also want to allow credit for any refrigerant destroyed because it cannot be competitively reclaimed due to intellectual property restrictions. Eventually, expand to all HFCs.

Response: We appreciate these suggestions, and we will keep them in mind as we consider a future expansion of our methodology. We agree that destruction is additional in non-A5 countries for foams and refrigerants that cannot be reclaimed.

We thank the reviewer for bringing the issue of intellectual property to our attention. From our understanding, an overwhelming majority of the refrigerants currently being collected from end-of-life equipment are older-generation ODS and HFCs for which the patents have already expired, so there is no such limitation on reclaim in those cases. In the future, we will consider the question of how to deal with newer refrigerant blends for which intellectual property restrictions may still be in place.

Comment 2-5:

We suggest an expanded project boundary to retain additionality in countries with growing refrigerant reclamation capacity. What flaws do you see in this approach?

Reviewer #2: Curious what feedback you get from others on this. No opinion at the moment.

Response: Noted, thank you.

Comment 2-6:

What is the lifecycle impact of virgin HFC manufacturing relative to HFC reclamation?

Reviewer #2: Short answer: I don't know.
Longer answer: It will vary by HFC. Some are harder to make than others. Feedstocks vary, as do emissions associated with the production and use of those feedstocks. Energy consumption varies, as do emissions from that energy depending on where the manufacturing or reclamation is done. This could be a good thesis for someone.

Response: We thank the reviewer for noting the nuance and agree that this is a rich thesis to pursue. We do however note the existence of LCA literature comparing production, reclaim, and destruction in a subset of contexts (e.g., Yasaka et al. 2023, *Sustainability*, 15, 473, link; Wang et al. 2022, *Appl. Sci. 12*, 1, link; and citations within).

Reviewer #3: Anonymous

Comment 3-1:

General Comments: The details in this proposal are good in that they strengthen some of the existing protocol requirement (e.g., discounting based on expected reclamation rates). However, at a high level, I'm concerned about providing a carbon offset protocol for HFC destruction in A5 countries, especially the ones that have yet to ratify Kigali and/or set their production and consumption baselines which the proposal also recognizes as a concern. I've flagged that in the attached, as well as some additional minor comments.

There's also no discussion of destruction efficiencies and which destruction technologies would qualify for carbon offsets. I think that's important - particularly the need for near-complete destruction to avoid potential health impacts (esp. for those HFCs and HFOs that are PFAS). It feels improbable that destruction efficiencies, recovery rates, and other data can be reliably gathered in A5 countries and ensure a robust protocol.

Response: Thank you for this feedback!

Regarding the eligibility of countries yet to ratify the Kigali Amendment or set production and consumption baselines: While we believe that recovery and destruction from end-of-life equipment where otherwise venting would have occurred is an additional, creditable activity, we share your concern about incentivizing disposal in countries that have yet to ratify the Kigali Amendment. Ratifying should certainly be the first step in HFC lifecycle management policy, and nations that have yet to enter the agreement should not be eligible for this methodology. We have updated the requirements accordingly. Please see Table 1 in response to Comment 2-2 for additional boundaries.

Regarding destruction efficiency requirements: Although not mentioned in the draft white paper, the methodology as written requires that all destruction technologies comply with UNEP TEAP's approved destruction technology list and Code of Good Housekeeping. We have updated the language of the white paper to state this explicitly.

Regarding the availability of destruction and monitoring data: We are confident that destruction efficiencies and other data in accordance with UNEP TEAP's approved destruction technologies criteria can be gathered in A5 countries.

Regarding the availability of baseline recovery (or compliance) rate data: Existing evidence suggests that, in eligible regions, baseline recovery and compliance rates from end-of-life equipment are currently negligible. Should this change, we will update the methodology to provide clear guidance on the calculation of such rates.

Comment 3-2:

Line 129, American Carbon Registry, Notable Differences: Excludes non-foam HFCs

Reviewer #3: Reminder that the AIM Act specifically excludes recovery of foam blowing agent from EPA's authority on recovery and reclamation under subsection (h).

Response: Noted, thank you!

Comment 3-3:

Line 214-218: For now, we propose that this methodology apply to *all* A5 countries, whether or not baseline production and consumption levels have yet to be determined. Our perspective is that the current counterfactual to recovery and destruction is venting, rather than recovery and reclamation. Therefore, destruction in A5 Group 2 countries has little effect on baseline calculations because reclamation is currently a non-factor. We encourage feedback on this decision.

Reviewer #3: This is problematic. Why not include a requirement that the methodology apply to A5 countries once they ratify the Kigali amendment AND determine their production and construction levels?

Response: We have completed a full analysis of inclusion criteria and their upstream and downstream impacts. Please see Comment 2-2 (above) for the description of this work and the rationale behind the conclusions.

Comment 3-4:

Line 230-233: We propose expanding project boundaries established in VM0016 to always include emissions from replacement gases for the HFCs recovered and destroyed (Figure 1). This change further safeguards additionality for HFC destruction while discounting credits generated from destruction as reclaim capacity grows.

Reviewer #3: I think that's a good idea.

Response: Thank you!

Comment 3-5:

Lines 245-248: We contend that the ideal solution requires a mixture of reclaim and destruction. Reclamation is an extremely important piece of a refrigerant recovery ecosystem, but building reclaim capacity in developing countries will be more expensive — especially given fractional distillation requirements for HFC blends — than building near-term destruction capacity.

Reviewer #3: Are you envisioning the need for destruction capacity buildout? Many countries may rely on existing facilities like cement kilns to incinerate refrigerants (and many other wastes) instead of building out dedicated capacity.

Response: By “destruction capacity” we mean not only the approved destruction technology and infrastructure, but also the recovery, movement, and aggregation channels necessary for a meaningful refrigerant management ecosystem. Given the high capital costs required for reclamation, we think destruction credits are a better mechanism to finance the building of this entire recovery and disposal chain.

Reviewer #4: Christina Starr

Senior Policy Analyst, Environmental Investigation Agency

General Comments: It would be useful to mention other means of stimulating recovery and destruction such as through mandatory EPR schemes, and to consider how such voluntary offsets would apply in any country with such a scheme in place, as there are a few A5 countries that had pilot MLF projects. Having an EPR program in place would surely impact your counterfactual for additionality.

Response: Thank you for this feedback. We agree that extended producer responsibility (EPR) programs are the most desirable solution to improve refrigerant recovery rates.

Our methodology -- consistent with Verra and ACR ODS methodologies -- does not apply to countries with EPR programs that improve refrigerant recovery rates beyond 50 percent. However, we are aware of only a few countries that have reached this threshold, and, with long timelines and political uncertainty in establishing EPR, believe that voluntary carbon credits are an important bridging financing mechanism to improve recovery rates and develop refrigerant management infrastructure in the near term.

We look forward to further discussion about how the existence of voluntary carbon credits should not forestall the development and rollout of EPR programs and remain eager to discuss further about how credits can be complementary, rather than supplementary, to other policy efforts.

Comment 4-1:

Lines 52-55: 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 HFCs will enter the market by 2100.

Reviewer #4: Citing our report correctly: the $GtCO_2$e numbers footnote 1 is both ODS and HFCs, not just HFCs so it is not correct to refer to it that way.

Response: Thank you for the correction. We have modified the text to include ODS, in addition to HFCs. The 67 $GtCO_2$e figure is the difference in the installed refrigerant bank between today and 2100, rather than the 2050 61 $GtCO_2$e installed base to which we believe you are referring.

Comment 4-2:

Line 204:

	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

Reviewer #4: For your table and discussion on Kigali control measures in A5 countries, you might want to note the year that the countries freeze/cap HFC consumption which is sooner than the first stepdown years noted. In effect this will limit total HFC consumption sooner than the first stepdown year.

Response: We thank the reviewer for this suggestion, and we have updated the table accordingly (see blue text in table above).

Comment 4-3:

Lines 206-212: We foresee that one objection to HFC destruction is that early in phasedown (or prior to it), HFC can continue to be produced without restriction. Therefore, recovering and destroying HFCs — if the counterfactual is recovering and reclaiming them — could have the adverse effect of supporting demand and production of virgin HFCs. This effect would be particularly problematic in Article 5 Group 2 countries, in which future HFC destruction could conceivably *increase* baseline production and consumption numbers relative to a world in which HFCs are recovered and reclaimed instead. We share these concerns.

Reviewer #4: Does your methodology consider the extent to which refrigerants in A5 countries are being recycled/reused without being reclaimed? This may impact on your counterfactual discussion regarding doing this in A5 country before calculation of baselines, because reused/recycled refrigerant could be replaced with increased demand for virgin if the country has not yet set its baseline/entered its freeze in consumption. This would not be an issue if a country has begun its freeze. (which for Group 1 A5 countries, is in 2024, approaching quickly). Consider if you want to discuss this in your paper.

Response: We thank the reviewer for bringing up this point. It is challenging to precisely determine the rate of refrigerant recycling, since there is no centralized facility at which it occurs (as with destruction and reclaim). However, in Article 5 countries, technicians do not currently have access to the recovery equipment that would enable refrigerant recycling to take place. Therefore, we are confident that baseline rates of refrigerant recycling are negligible.

Regarding the relationship between incentivizing destruction and increasing demand for virgin gas production, we refer the reviewer to Response 2-2 above.