# Refrigerant Cylinders: Analysis of Use, Disposal, and Distribution of Refrigerants

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# Acronyms and Abbreviations

| | |
|---|---|
| AHRI | Air-Conditioning, Heating, and Refrigeration Institute |
| BAU | Business-As-Usual |
| CARB | California Air Resources Board |
| DOT | Department of Transportation |
| EPA | Environmental Protection Agency |
| GWP | Global warming potential |
| HCFC | Hydrochlorofluorocarbon |
| HFC | Hydrofluorocarbon |
| HFO | Hydrofluoroolefin |
| $MMTCO_2e$ | Million metric tons of carbon dioxide equivalent |
| MVAC | Motor vehicle air conditioning |
| ODS | Ozone-depleting substances |
| OMB | Office of Management and Budget |
| psi | pound-force per square inch |
| PV | Present Value |

## 1. Introduction

Most hydrofluorocarbons (HFCs), including those used as refrigerants, are gases at room temperature and are typically transported and stored as compressed liquids in pressurized metal containers called cylinders. "30-pound" metal cylinders are used primarily in the stationary air-conditioning and refrigeration system servicing industry, and to a lesser extent in the motor vehicle air-conditioning (MVAC) sector.

There are two primary types of cylinders. Disposable (also known as non-refillable) cylinders are used once before disposal, and refillable cylinders can be used multiple times throughout the cylinder lifetime. Refrigerants can be emitted from non-refillable and refillable cylinders due to several conditions, including overfilling and subsequent exposure to excessive heat or blunt contact; mechanical damage to valves; valve defects; cylinder corrosion; and human error. However, non-refillable cylinders are typically discarded with amounts of refrigerants still in the cylinders that will be emitted over time including from amounts commonly referred to as heels (i.e., small amounts of refrigerant that remain in an "empty" cylinder).

The remainder of the report is organized as follows:

- **Section 2** provides an overview of non-refillable cylinders in the United States;
- **Section 3** provides estimates of disposal emissions from cylinders resulting from heels, and provides emissions savings estimates associated with refrigerant heel removal from non-refillable cylinders prior to disposal;
- **Section 4** analyzes the costs associated with refrigerant heel removal from non-refillable cylinders prior to disposal;
- **Section 5** provides conclusions;
- **Appendix A** provides the methodology used to calculate emissions from heels in non-refillable cylinders; and
- **Appendix B** estimates of annual emission changes from heel recovery from non-refillable cylinders.

## 2. Cylinders in the United States

The so-called "30-pound" cylinder[1] is the most commonly used cylinder for air-conditioning and refrigerant servicing and is the focus of this report. Both virgin and reclaimed refrigerant[2] can be transported and stored in refillable and non-refillable 30-pound cylinders. Based on input from industry sources[3], it is estimated that there are approximately four to five million 30-pound

[1] The actual amount of refrigerant in a full "30-pound" cylinder varies by gas. Some typical values are 30 pounds (e.g., HFC-134a), 25 pounds (e.g., R-410A), and 24 pounds (e.g., R-404A).
[2] Refrigerant that is removed from equipment, however, is transported and stored in special recovery cylinders that are designed differently from non-refillable and refillable cylinders. Recovery cylinders are outside the scope of this analysis.
[3] This input was provided in communications between EPA and representatives of A-Gas on February 24, 2021, EPA and representatives of Fluorofusion on March 26, 2021, and ICF and representatives of National Refrigerants on February 19, 2021.

cylinders used to charge and service stationary air-conditioning and refrigeration systems annually in the United States, including both non-refillable and refillable cylinders[4] , although estimates vary considerably. For the purposes of this report, it is assumed that 4.5 million cylinders will be sold in the United States in 2025. Industry estimates that refillable cylinders currently account for between less than 1 percent and 10 percent of all 30-pound cylinders used, with a general assumption that the quantity of refillable cylinders as a percentage of all 30-pound cylinders used is closer to 1 percent as of 2020 .[5] Of the 4.5 million cylinders assumed in use each year, this report specifically considers the proportion of cylinders sold containing HFCs and blends containing HFCs versus other non-regulated substances such as hydrofluoroolefins (HFOs), as provided in Table 1. These estimates are based on HFC refrigerant demand for servicing and charging equipment estimated by the Environmental Protection Agency's (EPA) Vintaging Model (EPA, 2023).[6]

**Table 1. Assumed Refrigerant Mix in Non-refillable Cylinders (2025-2050)**

| Year | Percentage of Cylinders containing HFC and HFC blends |
|---|---|
| 2025 | 79% |
| 2026 | 78% |
| 2027 | 77% |
| 2028 | 76% |
| 2029 | 75% |
| 2030 | 73% |
| 2031 | 72% |
| 2032 | 71% |
| 2033 | 70% |
| 2034 | 69% |
| 2035 | 69% |
| 2036 | 68% |
| 2037 | 67% |
| 2038 | 67% |
| 2039 | 66% |

[4] This is based on input provided in communications between EPA and representatives of A-Gas on February 24, 2021, and EPA and representatives of Fluorofusion on March 26, 2021.
[5] This is based on input provided in communications between EPA and representatives of A-Gas on February 24, 2021, EPA and representatives of Fluorofusion on March 26, 2021, and ICF and representatives of National Refrigerants on February 19, 2021.
[6] As explained in the RIA to the Allocation Framework Rule and associated addenda to that RIA, the Vintaging Model estimates the consumption and emissions from end-uses that traditionally relied on ozone-depleting substances (ODS) and are transitioning to HFCs and other alternatives. The EPA 2023 version of the model (VM IO file_v4.4_02.04.16_Final TT Rule 2023 High Addition.xls) incorporates the transitions and practices anticipated to occur under the 2023 Technology Transitions RIA Addendum Base Case, which in turn incorporates provisions of that rule and other actions anticipated under the 2024 Allocation Rule not otherwise adjusted based on the 2023 Technology Transitions Rule.

| Year | Percentage of Cylinders containing HFC and HFC blends |
|---|---|
| 2040 | 66% |
| 2041 | 66% |
| 2042 | 65% |
| 2043 | 65% |
| 2044 | 65% |
| 2045 | 65% |
| 2046 | 65% |
| 2047 | 65% |
| 2048 | 64% |
| 2049 | 64% |
| 2050 | 64% |

Non-refillable cylinders are specifically manufactured to be single-use. These cylinders are charged with refrigerant, sold for use to fill or service equipment, and disposed (EIA, 2018). Many stationary air-conditioning and refrigeration systems are serviced using refrigerants transported in non-refillable cylinders that receive classification from the U.S. Department of Transportation (DOT) as DOT-39 cylinders. These cylinders come in several sizes, including 15-pound, 30-pound, and 50-pound varieties, with the 30-pound cylinder being the most commonly used in the stationary air-conditioning and refrigeration system servicing industry.

DOT-39 cylinders have a single one-way valve, and DOT prohibits the refilling of cylinders due to safety concerns.[7] They must be disposed of after use, either by recycling as scrap metal or disposed of as solid waste in a landfill. Non-refillable cylinder valves come with a rupture disk pressure relief device that allows the contents to be released when the pressure limits are exceeded. Once activated, this type of relief device ruptures and cannot reseal. If cylinders are disposed of improperly (i.e., without removing all refrigerant remaining in the cylinder), the residual refrigerant is emitted to the atmosphere. Table 2 summarizes the specifications for DOT-39 non-refillable cylinders.

[7] 49 CFR 178.65(i). DOT-39 cylinders are not designed to withstand repeated pressurization cycles, unlike reusable cylinders.

**Table 2. Specifications of "30-pound" DOT-39 non-refillable cylinder**

| | 30-lb | | |
|---|---|---|---|
| Service Pressure (psi)[a] | 260 | 300 | 400 |
| Test Pressure (psi) | 325 | 400 | 500 |
| Water Capacity (lb.) | 29.7 | 29.7 | 29.7 |
| Height (in)[b] | 16.4 | 16.4 | 16.4 |
| Diameter (in)[b] | 9.5 | 9.5 | 9.5 |
| Construction Standards | DOT39 TC39M | DOT39 TC39M | DOT39 TC39M |

Source: Worthington n.d., 49 CFR 178,65 (i)
[a] Recommended service pressure is dependent on gas type
[b] Dimensions are assumed to be interior

As discussed above, for purposes of this analysis it is assumed that the vast majority of refrigerant cylinders sold annually in the United States (i.e., 99 percent) are non-refillable, or approximately 4.455 million cylinders. The remaining 45,000 cylinders (i.e., 1 percent) are assumed to be refillable.

## 3. Disposal Emissions from Cylinders

Emissions from all refrigerant cylinders can occur under various conditions. Refrigerant remaining in non-refillable cylinders, including amounts commonly referred to as refrigerant heels, are also emitted during disposal by leaking over time, once the cylinder breaks down, or when the cylinders are crushed. Service technicians will generally stop using a cylinder once all the liquid-phase fluid has been extracted while the vapor-phase gas remains as a heel. When a refillable cylinder is disposed, either from reaching end-of-life or due to damage to the cylinder, the heel would be emitted to the atmosphere unless it is removed.

### 3.1. Disposal of Non-refillable Cylinders

Non-refillable cylinders are not designed to be reused and are prohibited from refilling under DOT regulations for safety concerns, and therefore they must be disposed of after they are used. If cylinders are disposed of without removing all remaining refrigerant including refrigerant heels, that refrigerant would be emitted to the atmosphere.

There is substantial uncertainty regarding the volume of refrigerant that remains in non-refillable cylinders at the point they are discarded, including the amount in the heels. To better assess the emissions from non-refillable cylinders, it is necessary to estimate emissions associated with the common practice of disposing of cylinders with refrigerant heels (i.e., deemed to be "empty") by service technicians. A study by Stratus (2012) involved collecting empirical data on refrigerant remaining in cylinders collected after use in the field by service technicians for charging stationary refrigeration and air-conditioning systems. Based on the average heel amount found in the theoretical and empirical studies, an analysis of potential emissions from non-refillable cylinders under various recovery scenarios was also conducted (Stratus 2012).

#### 3.1.1. Empirical study of heels

Stratus (2010) collected data from a refrigerant technician company measuring quantities of refrigerant remaining in non-refillable cylinders after being used to service stationary air-conditioning and refrigeration equipment in the field. In this empirical study, the average amount of refrigerant remaining across all refrigerant types and applications was 1.08 pounds, with a range of 0.28 pounds to 3.69 pounds Stratus (2010) indicated one reason why the amounts in the empirical study exceed theoretical estimates could be that often, a service technician will decline to take a cylinder "into the field" if he/she determines, simply by lifting the cylinder, that there is not enough refrigerant remaining in the cylinder to make transporting it worthwhile. Service technicians would prefer to have their service vehicle loaded with full cylinders at the beginning of the day to minimize the number of trips back to the vehicle that would be necessary when charging systems in the field.

### 3.1.2. Comparison of results to other studies

A comparison of the empirical studies by Stratus (2010) shows that the results of this analysis are comparable to the results of other studies (see 3) and comments from industry stakeholders. A comparison of the empirical studies by Stratus (2010) shows that the results of this analysis are comparable to the results of other studies (see Table 3) and comments from industry stakeholders. In a previous study of 30-pound non-refillable cylinders commissioned by EPA, the estimated heel amount after recovery to 29 psi was approximately 0.56 pounds (EPA 2007). Another study of amounts of refrigerant remaining in non-refillable cylinders conducted by a private company indicates an average amount of 0.59 pounds (approximately 2 percent) for 128 cylinders. In this study, cylinders containing HCFC-22 accounted for nearly 70 percent of all cylinders and had an average amount of 0.66 pounds. Cylinders containing R-404A, which accounted for approximately 25 percent of all cylinders, contained an average amount of 0.39 pounds. The Air Conditioning, Heating, and Refrigeration Institute (AHRI) estimated that heel amounts in cylinders at system suction pressure (i.e., following use of cylinder for charging in the field) range from approximately 0.45 pounds (about 1.5 percent) to roughly 0.90 pounds (about 3 percent). These estimates were based on AHRI calculations (AHRI 2000). The amounts of refrigerant remaining in these studies is smaller than estimates from a 1998 study on heel amounts in 30-pound non-refillable cylinders conducted for Airgas Inc., which estimated heel amounts of approximately 1.65 pound (about 5.5 percent) across the industry (Airgas, 1998).

**Table 3. Comparison of amount of refrigerant remaining from different sources**

| Source | Average Amount[a] | Amount by sector or use |
|---|---|---|
| Empirical study | 1.08 lbs. (3.6 - 4.5%) | Appliance Servicing: 0.64 lbs.<br>Residential AC: 1.02 lbs.<br>Commercial AC: 1.13 lbs.<br>Chillers: 1.15 lbs. |
| Private study[b] | 0.59 lbs. (2.0 - 2.5%) | HCFC-22: 0.66 lbs.<br>R-404A: 0.39 lbs. |
| EPA, 2007 | 0.56 lbs. (1.9 - 2.4%) | NA |
| Airgas, 1998 | 1.65 lbs. (5.5 - 6.9%) | NA |
| AHRI, 2000 | 0.45 lbs. (2%) - 0.90 lbs. (3%) | NA |
| Worthington, 2023 | 0.288 - 0.35 lbs. (1.2%) | |
| CARB and HARDI as cited by Worthington, 2023 | 0.444 - 0.555 lbs. (1.85%) | |
| Chemours, cited by Worthington, 2023 | 0.552 – 0.69 lbs. (2.3%)[c] | |

| Source | Average Amount[a] | Amount by sector or use |
|---|---|---|
| National Refrigerants, cited by Worthington, 2023 | 0 - ≥0.5 lbs. (0 - 0.167%)[d] | |

[a] Ranges are based on a 24-to-30 pound cylinder.
[b] Summary of study provided in Stratus (2010)
[c] Cited as 0.2 percent to 4.4 percent; average used above.
[d] Cited as 60 percent with no discernible heel, 90 percent with 0.5 pounds or less; information on the remaining 10 percent not provided

Stratus (2010) indicated potential causes for variation between the results of the different studies could be due to differing baseline assumptions and whether the study was theoretical or empirical. The results of an empirical study can vary depending on assumptions about operating conditions and the size of the sample. Theoretical studies can also produce varying results depending on assumptions about operating conditions (e.g., whether there are any assumed inefficiencies in the cylinder-to-system connection).

As shown in Table 3, estimates of the amount of refrigerant remaining in cylinders at the time of their disposal vary. Industry sources contacted by Stratus (2010) confirmed the fact that there is uncertainty as to how much refrigerant remains in cylinders when they are determined to be "empty" and additional comment from industry stakeholders likewise show a variability in estimates of the heel. To determine a central estimate, we examine the complete records (i.e., all but the National Refrigerants information) cited above and find the average between the highest percentage heel (6.9 percent) and lowest percentage heel (1.2 percent) to be 4.05 percent. For mathematical simplicity and to be conservative, we use as a central estimate a 4 percent heel. Also being conservative, we assume cylinders are nominally 24 pounds. Hence, as a central estimate, we use a heel of 0.96 pounds.

Recent industry outreach, not used for the calculation above, estimates heels larger than the central estimate presented above. One such source indicated non-refillable cylinders contain approximately 1 to 1.25 pounds of residual heel and another source estimated the typical heel in a non-refillable cylinder is approximately 1.5 pounds .[8]

### 3.1.3. Avoided Emissions Under Different Refrigerant Removal Assumptions

Disposal emissions can be reduced by employing refrigerant recovery practices to minimize the heel. How service technicians dispose of used non-refillable cylinders will determine whether refrigerant that remains in the cylinder is released to the atmosphere or removed for reuse. To understand whether refrigerant remaining in cylinders is emitted to the atmosphere, it is important to know:

- When service technicians make the decision to switch to fresh cylinders;
- Whether service technicians remove the refrigerant remaining in the cylinders before they dispose of them;

[8] This is based on input provided in communications between EPA and representatives of A-Gas on February 24, 2021, and EPA and representatives of Fluorofusion on March 26, 2021.

- How (and to whom) service technicians dispose of the cylinders; and
- Whether there are downstream opportunities for refrigerant recovery after cylinders are no longer in the service technician's possession.

Disposal of non-refillable cylinders could present opportunities for downstream recovery (i.e., after the cylinder leaves the hands of the service technician). These practices have implications for avoiding the potential release of refrigerant remaining in the cylinders.

The prevalence of the different disposal practices is difficult to estimate. Input from industry sources varied considerably, and the majority of sources noted that there is no conclusive evidence about how service technicians dispose of cylinders. Several sources indicated that service technicians are aware of appropriate disposal methods (i.e., following AHRI guidelines for evacuating cylinders and opening their valves before having them recycled), but there seems to be less certainty on the issue of whether service technicians remove all refrigerant before recycling cylinders, or whether they allow the refrigerant to vent.

In the central scenario where the typical amount of refrigerant remaining is 0.96 pounds, estimated annual emissions can amount to between 0.27 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) and 2.7 $MMTCO_2e$, depending upon the percentage of cylinders vented (see Appendix B of this report). The assumed baseline for a central scenario is that 0.96 pounds of refrigerant remain in the cylinder that is vented unless recovered, and that 100 percent of all cylinders are vented .[9] Therefore, the assumed annual emissions in 2025 are 2.7 $MMTCO_2e$ and 0.9 $MMTCO_2e$ in 2050, based on the changing proportion of cylinders sold containing HFC and blends containing HFCs and mix of HFC refrigerants.

## 3.2. Emission Reductions from Heel Removal from Cylinders

To understand the potential amount of emissions avoided from heel recovery from non-refillable cylinders prior to disposal, the calculations were run using the assumption that 4.455 million 30-pound non-refillable cylinders are in use each year. Emissions from cylinder disposal were estimated assuming 0.96 pounds of refrigerant are remaining in the cylinders. The proportion of cylinders sold containing HFCs and blends containing HFCs versus other non-regulated substances is assumed to change over time (see Table 1). In addition, it is assumed that the mixture of HFCs and blends containing HFCs also changes over time with the transitions and practices anticipated to occur under the 2024 Allocation Rule and the 2023 Technology Transitions Rule (EPA 2023). The assumed HFC refrigerant mix in 2025 is shown in Table 4.

[9] This is based on input provided in communications between EPA and representatives of A-Gas on February 24, 2021, and EPA and representatives of Fluorofusion on March 26, 2021.

**Table 4. HFC Refrigerants in Cylinders, 2025**

| Refrigerant | Distribution of Cylinders |
|---|---|
| R-410A | 32% |
| R-454B | 21% |
| HFC-134a | 11% |
| R-404A | 11% |
| HFC-32 | 8% |
| R-407A | 8% |
| R-450A/R-513A | 3% |
| R-452B | 3% |
| R-507 | 2% |
| R-452A | 1% |
| R-407C | 1% |
| R-448A/R-449A | 0% |
| **Total** | **100%** |

Source: EPA (2023)

This analysis also considers a low and high scenario under which cylinders are assumed to contain a refrigerant heel within the range of average heels as shown above in Table 3. The estimates therein lead us to a low scenario with an average heel of 0.288 pounds (1.2 percent of a 24-pound cylinder) and a high scenario with an average heel of 1.65 pounds (6.875 percent of a 24-pound cylinder).

The difference in emissions between the business-as-usual (BAU) scenario, where the heel is released upon disposal of non-refillable cylinders, and a scenario where all heels are removed before non-refillable cylinders are disposed is shown in Table 5. If heels were removed from non-refillable cylinders prior to disposal in the United States, 38.5 $MMTCO_2e$ in HFC emissions[10] would be avoided from 2025 through 2050. Annual emission reductions and the low and high scenario are presented in Appendix B of this report.

**Table 5. Estimated Total Avoided Emissions from Heel Recovery from Non-refillable Cylinders (2025-2050)**

| Scenario | Assumed Heel Amount Recovered (lbs.) | Pounds emitted | Metric tons emitted | $MMTCO_2e$ |
|---|---|---|---|---|
| Low | 0.288 | 26,433,000 | 11,990 | 11.5 |
| **Central** | **0.96** | 76,620,000 | 34,800 | 38.5 |
| High | 1.65 | 131,690,000 | 59,700 | 66.2 |

[10] This estimate includes HFCs and blends containing HFCs and hydrofluoroolefins (HFOs).

## 4. Cost Analysis of Heel Removal from Non-refillable Cylinders

Heel removal from non-refillable cylinders could have other implications for businesses in addition to emissions savings. Estimating the economic impacts of heel removal from non-refillable cylinders must account for the costs associated with the change in procedure handling of cylinders (i.e., returning the cylinders to have their heels removed) and the potential savings from avoided refrigerant loss from heel emissions.

For the purposes of quantifying direct costs for this analysis, it was assumed that reclaimers, wholesalers, and distributors of refrigerant cylinders currently primarily sell refrigerant in non-refillable cylinders.

**Cost of transport.** In the BAU scenario, non-refillable cylinders are assumed to travel from gas producer/filler to the wholesale distributor; wholesale distributor to end user/technician; and end user/technician to a disposal facility (e.g., landfill or steel recycler).

Transportation costs were updated to account for the distance traveled for each trip and the use of company fleets to transport cylinder based on a California Air Resources Board (CARB,2011) analysis. It is assumed that companies already own or lease the proper vehicle fleet to transport cylinders.

Table 6 summarizes estimated distances per shipment for non-refillable cylinders. Based on the location of chemical production facilities around the United States, located primarily along the East Coast, Midwest, Southern United States, and California, it is assumed that a cylinder would travel an average of 1,000 miles from producer to the wholesale distributor. As assumed in CARB (2011), the distance between wholesale distributor and end-user/technician is assumed to be 25 miles. Other distances—75 miles from an end-user or wholesaler to a steel recycler and 50 miles from a distributor to a reclaimer—were also based on CARB (2011).

In the heel removal scenario, it was assumed that non-refillable cylinders would take one of three potential transportation scenarios in equal shares: 1) cylinders would be returned directly to a reclaimer for heel removal; 2) cylinders would be returned to the distributor and then to a disposal facility for heel removal; or 3) cylinders would be sent directly to a disposal facility for heel removal. Upon removal of the heel, the disposal facility would store recovered refrigerant heels until the facility has accumulated enough refrigerant to send to a reclaimer. Based on a central estimate of a heel of 0.96 pounds, it is assumed that a disposal facility would remove refrigerant from 25 cylinders in order to accumulate enough to fill one 30-pound cylinder (i.e., 24 pounds of refrigerant).

**Table 6. Travel Distances for Non-refillable Cylinders Before Disposal**

| Trip | BAU | Recovery Scenario | | | | |
|---|---|---|---|---|---|---|
| | | Non-refillable-1[a] | Non-refillable-2[a] | | Non-refillable-3[a] | |
| | | End-user to Reclaimer to Disposal Facility | End-user to Distributor to Disposal | Disposal Facility to Reclaimer | End-user to Disposal Facility | Disposal Facility to Reclaimer |
| Gas producer/filler to wholesale distributor | 1,000 | 1,000 | 1,000 | NA | 1,000 | NA |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wholesale distributor to end user/technician | 25 | 25 | 25 | NA | 25 | NA |
| End user/technician to disposal facility | 75 | NA | NA | NA | 75 | NA |
| End user/technician to reclaimer | NA | 50 | NA | NA | NA | NA |
| End user/technician to distributor | NA | NA | 25 | NA | NA | NA |
| Wholesale distributor or reclaimer to disposal facility | NA | 75 | 75 | NA | NA | NA |
| Disposal facility to Reclaimer | NA | NA | NA | 75[b] | NA | 75[b] |
| **Total Miles** | **1,100** | **1,150** | **1,125** | **75** | **1,110** | **75** |

[a] Assumed for one-third of shipped HFC cylinders.
[b] Disposal facilities are assumed to recover refrigerant from 25 cylinders before sending one 30-pound cylinder (containing 24 pounds of refrigerant) to a reclaimer based on a 0.96-pound heel.

Table 7 provides additional assumptions related to fuel use and labor associated with transporting cylinders.

**Table 7. Additional Transportation Assumptions**

| Parameter | Assumption |
|---|---|
| Average Fuel Efficiency | 6.1 miles per gallon[a] |
| Diesel Fuel Cost | $4.034/gallon[b] |
| Average Truck Speed | 50 miles per hour[c] |
| Labor Rate (Truck Transport) | $53.59[d] |

[a] Geotab (2024)
[b] Energy Information Agency (2024)
[c] CARB (2011)
[d] Labor rate for Heavy and Tractor-Trailer Truck Drivers from Bureau of Labor Statistic's Employer Costs for Employee Compensation – May 2022. Median hourly wages rates were multiplied by a factor of 2.1 to reflect the estimated additional costs for overhead (BLS 2024).

This analysis estimates transportation costs on a per cylinder basis assuming a truck could fit approximately 1,120 non-refillable cylinders (CARB 2011). Table 8 summarizes the transport cost per cylinder based on the assumptions presented above in Table 7. Transportation costs are assumed to be the same under both the low and high scenarios.

**Table 8. Transportation Assumptions before Disposal per Cylinder[a]**

| Scenario | | Fuel Costs | Labor | Total |
|---|---|---|---|---|
| BAU | Non-refillable | $0.65 | $1.05 | $1.70 |
| Recovery Scenario | Non-refillable-1 [b] | $0.68 | $1.10 | $1.78 |
| | Non-refillable-2[b] | $0.66 | $1.08 | $1.75 |
| | Non-refillable-2 (Disposal Facility) | $0.002 | $0.003 | $0.005 |

| | | | | |
|---|---|---|---|---|
| | Non-refillable-3[b] | $0.65 | $1.05 | $1.71 |
| | Non-refillable-3 (Disposal Facility) | $0.002 | $0.003 | $0.005 |

[a] Costs are based on a recovered heel amount of 0.96 pounds and assumes disposal facilities recover refrigerant from 25 cylinders before sending one 30-pound cylinder (containing 24 pounds of refrigerant) to a reclaimer.
[b] Assumed for one-third of HFC cylinders sold per year.

**Removed heel.** Under the recovery scenario**,** non-refillable cylinders are eventually returned to a reclaimer prior to disposal containing a refrigerant heel that is removed and sold back into the market. It was assumed that cylinders contain a heel of 0.96 pounds as described previously in this section. Removed refrigerant is assumed to be resold at $4 per pound based on average refrigerant costs applied in EPA (2021a).

Under the low scenario, cylinders are assumed to contain a refrigerant heel of 0.288 pounds (1.2 percent) and under the high scenario, cylinders are assumed to contain a refrigerant heel of 1.675 pounds (6.875 percent).

Table 9 summarizes the cost assumptions associated with refrigerant heel removal from non-refillable cylinders prior to disposal. Because the proportion of non-refillable cylinders changes per year as equipment is assumed to transition towards lower-global warming potential (GWP) substitutes, estimates are shown for 2025 for which the highest proportion of HFC cylinders are assumed in circulation, as shown in Table 1 (i.e., 79 percent); however costs are estimated throughout the 2025 to 2050 time period.

**Table 9. Cost Assumptions for BAU and Central Estimate plus Low and High Scenario from Cylinder Heel Recovery, 2025**

| Assumption | BAU | Central Estimate | Low Scenario | High Scenario |
|---|---|---|---|---|
| Number of Cylinders Disposed | 3,530,028 | 3,530,028 | 3,530,028 | 3,530,028 |
| Average Transport Cost per Cylinder | $1.70 | $1.74 | $1.74 | $1.75 |
| Cylinder Heel Amount (lbs.) and Percent of Cylinder | 0.96 (4%) or 0.288(1.2%) or 1.65 (6.875%) | 0.96 (4%) | 0.288 (1.2%) | 1.65 (6.875%) |
| Average Refrigerant Price ($/lbs.) | $4 | $4 | $4 | $4 |

Using the methodology and additional assumptions described previously in this section, Table 10 presents estimates of the present value (PV) of incremental costs associated with cylinder heel removal under the central scenario over the 26-year period from 2025 to 2050, in addition to the low and high scenario assumptions. Annual incremental costs were discounted to 2024 at 2 percent, 3 percent and 7 percent discount rates, as directed by the Office of Management and Budget's (OMB) Circular A-4. Using a 3 percent discount rate, total savings across affected businesses are estimated to be $205 million.

**Table 10. Summary of Incremental PV Costs of Cylinder Heel Recovery for 2025-2050 (Millions of 2022$, Discounted to 2024)**

| Discount Rate | Central | Low | High |
|---|---|---|---|
| **2%** | **-$232** | **-$68** | **-$401** |
| **3%** | **-$205** | **-$60** | **-$354** |
| 7% | -$133 | -$39 | -$230 |

Table 11 presents detailed cost estimates for each scenario using a 3 percent discount rate.

**Table 11. Detailed Incremental PV Costs of Cylinder Heel Recovery for 2025-2050 (millions of 2022$, discounted to 2024, 3 percent)**

| Cost | Central | Low | High |
|---|---|---|---|
| Transportation | $2.26 | $2.14 | $2.37 |
| Recovered Refrigerant Heel | -$208 | -$62 | -$357 |

## 5. Conclusion

Refrigerant losses can occur from non-refillable cylinders during disposal if unrecovered refrigerant is released. The amount of refrigerant heel remaining in cylinders can vary by refrigerant type and recovery practices by servicing technicians but is estimated to be approximately 0.96 pounds of refrigerant per cylinder. Disposal emissions from non-refillable cylinders can therefore equal 2,660,000 $MTCO_2e$ in 2025, assuming the heel is completely released from 100 percent of the cylinders. This amount would be expected to decrease as refrigerant transitions take place. The removal of refrigerant heels in non-refillable cylinders prior to their disposal in the United States would therefore be estimated to save approximately 38,500,000 $MTCO_2e$ from 2025 through 2050 in emissions.

There are other implications associated with the removal of refrigerant heels, including potentially higher costs associated with transporting cylinders back to reclaimers for refrigerant removal; however, there are also cost savings associated with removing and reselling the refrigerant heel.

## References

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# Appendix A. Estimate of Emissions from Heels in Non-refillable Cylinders

Stratus (2010) collected data by measuring quantities of refrigerant remaining in non-refillable cylinders after being used to service stationary air-conditioning and refrigeration equipment in the field. A refrigerant recovery, measurement, and recording framework was designed to facilitate collection and analysis of the data obtained with a Phoenix, Arizona refrigerant distributor. This section describes the methodology employed for collecting the data and the results produced.

## *Methodology*

A sample of 30-pound non-refillable cylinders was collected by the Phoenix distribution company from service technicians who used the cylinders for various applications (i.e., servicing of residential air conditioners, appliances, commercial refrigeration systems, and chillers). The amounts of refrigerant remaining in the cylinders were measured, recorded, and analyzed. The cylinders were subjected to a recording and testing process that involved identifying the application for which the cylinder was used and the type of refrigerant it contained and measuring the amounts of refrigerant remaining by weighing the cylinders when they were obtained after use in the field.

## *Results*

For this study, 110 30-pound non-refillable cylinders were collected and evaluated over a two-month period. As they were collected, the cylinders were identified as having been used to service stationary equipment in four categories of applications:

- Residential air-conditioning (e.g., standard home roof/split systems);
- Chillers (e.g., industrial and mechanical uses);
- Appliances (e.g., refrigerators and air conditioners); and
- Commercial refrigeration (e.g., supermarket refrigeration systems).

Many service technicians might service systems in only one of these applications, but some might service systems across multiple applications. The term “refrigerant remaining” is used in this section of the report. Due to the constraints of the cylinder collection component of the empirical study, it was not possible to determine whether the refrigerant remaining in the cylinder meets the regulatory definition of a heel (as defined in 40 CFR 82.3).

The cylinders collected for this study contained the following refrigerants: HCFC-22, R-404A, R-408A, R-410A, and R-507. Table A-1 provides the distribution of the cylinders by refrigerant type and application.

**Table A- 1. Summary of cylinders collected by refrigerant and application**

| Application | HCFC-22 | R-404A | R-408A | R-410A | R-507 | Total |
|---|---|---|---|---|---|---|
| | 30 lb cylinder | 24 lb cylinder | 24 lb cylinder | 25 lb cylinder | 25 lb cylinder | |
| Appliance servicing | 2 | 0 | 0 | 0 | 0 | 2 |
| Residential A/C | 32 | 0 | 0 | 0 | 0 | 32 |
| Commercial refrigeration | 24 | 12 | 0 | 2 | 5 | 43 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Chillers | 26 | 5 | 2 | 0 | 0 | 33 |
| **Total** | **84** | **17** | **2** | **2** | **5** | **110** |

Source: Stratus (2010)

For each cylinder collected, an initial pressure gauge reading was taken, and the cylinder's weight recorded. Refrigerant recovery equipment was then used to extract the refrigerant remaining in the cylinder by pulling a vacuum. For 47 (or 43 percent) of the 110 cylinders collected, there was no pressure in the cylinder, either because the cylinder valve was opened and the refrigerant remaining in the cylinder was vented or because the refrigerant had already been recovered. Of these 47 cylinders:

- The refrigerant remaining in the cylinder was recovered by the source for 16 cylinders (all contained HCFC-22);
- Twelve cylinders had no pressure, but the valves had been closed; and
- Nineteen cylinders had no pressure and the valves were open.

Of the latter two types, it is unknown whether refrigerant was recovered by the source or if the refrigerant was vented. Of the 63 cylinders that remained under pressure (i.e., had measurable amounts of refrigerant remaining), most contained HCFC-22 and came from the residential air-conditioning sector. Table A-2 provides a summary of cylinders with pressure by refrigerant and source.

**Table A- 2. Summary of cylinders collected with pressure by refrigerant and application**

| Application | HCFC-22 | R-404A | R-408A | R-410A | R-507 | Total |
|---|---|---|---|---|---|---|
| | 30 lb cylinder | 24 lb cylinder | 24 lb cylinder | 25 lb cylinder | 25 lb cylinder | |
| Appliance servicing | 1 | 0 | 0 | 0 | 0 | 1 |
| Residential A/C | 28 | 0 | 0 | 0 | 0 | 28 |
| Commercial refrigeration | 7 | 8 | 0 | 2 | 2 | 19 |
| Chillers | 11 | 4 | 0 | 0 | 0 | 15 |
| **Total** | **47** | **12** | **0** | **2** | **2** | **63** |

Of the cylinders that remained under pressure, the amounts of refrigerant remaining varied, with a mean of 1.08 pounds. Table A-3 and Table A-4 provide summary statistics of the amounts by refrigerant and application.

**Table A- 3. Mean and median amounts of refrigerant remaining pounds), by refrigerant**

| Refrigerant | Number of cylinders | Mean amount | Median amount | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| HCFC-22 | 47 | 1.02 | 0.68 | 0.78 | 0.28 | 3.69 |
| R-404A | 12 | 1.40 | 0.96 | 0.91 | 0.42 | 2.91 |
| R-408A | 0 | N/A | N/A | N/A | N/A | N/A |
| R-410A | 2 | 0.96 | 0.96 | 0.09 | 0.89 | 1.02 |
| R-507 | 2 | 0.53 | 0.53 | 0.03 | 0.51 | 0.55 |
| **Total** | **63** | **1.08** | **0.70** | **0.79** | **0.28** | **3.69** |

**Table A- 4. Mean and median amounts of refrigerant remaining pounds, by application**

| Application | Number of cylinders | Mean amount | Median amount | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Appliance servicing | 1 | 0.64 | 0.64 | N/A | N/A | N/A |
| Residential A/C | 28 | 1.02 | 0.68 | 0.80 | 0.28 | 3.69 |
| Commercial refrigeration | 19 | 1.13 | 0.87 | 0.78 | 0.33 | 2.91 |
| Chillers | 15 | 1.15 | 0.68 | 0.84 | 0.47 | 3.26 |
| **Total** | **63** | **1.08** | **0.70** | **0.79** | **0.28** | **3.69** |

## Appendix B. Estimation of Annual Emission Changes from Heel Removal from Disposable Cylinders

The annual emission changes between the BAU scenario without heel removal from non-refillable cylinders prior to disposal and the central, low, and high scenarios with heel removal assuming cylinders contain a 0.96, 0.288, or 1.65-pound heel and the average refrigerant GWP applied reflecting the change in mixture of HFCs and HFC blends resulting from mitigation options applied in EPA (2023) are shown in Table B-1.

**Table B- 1. Estimated Annual Emission Changes Compared to BAU, 2025-2050**

| Year | Average HFC GWP | Emission Changes Relative to BAU ($MMTCO_2e$) | | |
|---|---|---|---|---|
| | | Central | Low | High |
| 2025 | 1,732 | -2.66 | -1.25 | -4.58 |
| 2026 | 1,652 | -2.49 | -1.17 | -4.28 |
| 2027 | 1,598 | -2.38 | -1.12 | -4.09 |
| 2028 | 1,547 | -2.27 | -1.06 | -3.90 |
| 2029 | 1,498 | -2.17 | -1.02 | -3.73 |
| 2030 | 1,445 | -2.06 | -0.97 | -3.54 |
| 2031 | 1,390 | -1.95 | -0.91 | -3.35 |
| 2032 | 1,332 | -1.84 | -0.86 | -3.17 |
| 2033 | 1,274 | -1.74 | -0.81 | -2.99 |
| 2034 | 1,210 | -1.63 | -0.76 | -2.80 |
| 2035 | 1,142 | -1.52 | -0.71 | -2.61 |
| 2036 | 1,071 | -1.41 | -0.66 | -2.42 |
| 2037 | 1,002 | -1.31 | -0.61 | -2.25 |
| 2038 | 945 | -1.22 | -0.57 | -2.10 |
| 2039 | 900 | -1.16 | -0.54 | -1.99 |
| 2040 | 872 | -1.12 | -0.52 | -1.92 |
| 2041 | 843 | -1.07 | -0.50 | -1.84 |
| 2042 | 814 | -1.03 | -0.48 | -1.77 |
| 2043 | 788 | -0.99 | -0.47 | -1.71 |
| 2044 | 769 | -0.97 | -0.45 | -1.66 |
| 2045 | 753 | -0.94 | -0.44 | -1.62 |
| 2046 | 742 | -0.93 | -0.44 | -1.60 |
| 2047 | 733 | -0.92 | -0.43 | -1.58 |
| 2048 | 726 | -0.91 | -0.43 | -1.56 |
| 2049 | 720 | -0.90 | -0.42 | -1.55 |
| 2050 | 717 | -0.90 | -0.42 | -1.54 |
| **Total** | | **-38.5** | **-18.0** | **-66.2** |