Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020

May 2026

EPA Document Number: 430R26001

Executive Summary

ES.1 Purpose

This document provides an assessment of the economic and environmental impacts for the final rule, "Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020" (hereafter referred to as the "Technology Transitions Reconsideration Rule"). This analysis is intended to provide the public with information on the relevant costs and environmental impacts of this rule and to fulfill analytical guidance with respect to Executive Order 12866. Results presented in this analysis are for informational purposes and are separate from the rationale the U.S. Environmental Protection Agency (EPA) relied on to inform specific policy decisions included in the final rule. For more information on the EPA's rationale in determining these decisions, please see the final rule preamble.

ES.2 Background/Introduction

The Technology Transitions Reconsideration Rule addresses petitions and other requests from companies and trade associations concerning a 2023 final rule codified at Title 40 of the Code of Federal Regulations (CFR) part 84, subpart B (88 FR 73098, hereafter referred to as the "2023 Final Rule") and includes amendments to certain requirements. The regulations codified at 40 CFR part 84, subpart B, place restrictions on the use of certain hydrofluorocarbons (HFCs) above specified global warming potential (GWP) limits (hereafter "limits") in specific sectors and subsectors in which HFCs are used.

After the finalization of the 2023 Final Rule, the EPA received petitions and other requests from companies and trade associations which included information indicating a discrete set of regulated entities would face barriers and/or economic burden associated with meeting the final requirements. These barriers are based on unique industry circumstances and include concerns regarding safety and the lack of readily available or economically viable alternatives able to meet specific technical requirements. As discussed in the rule preamble, the EPA is making adjustments to specific requirements codified at 40 CFR part 84, subpart B, in order to provide a smoother path to transition for affected entities.

This final rule is inherently deregulatory in that the compliance deadlines (after which newly manufactured or installed equipment must meet requirements) have been extended and, in some cases, limits have increased, or compliance requirements are relaxed. As noted above, after publication of the 2023 Final Rule and prior to the proposed rulemaking to the current action, certain stakeholders requested that the EPA make changes to certain requirements citing difficulties with meeting the compliance requirements due to a variety of reasons, including lack of availability of technically achievable alternatives, or other barriers, such as building codes. Entities requesting changes to the restrictions finalized in 2023 provided new information to support their requests. Through the notice-and-comment rulemaking, the EPA is making the following changes under the final Technology Transitions Reconsideration Rule, as summarized in **Error! Reference source not found.** below.

Table ES - 1: Summary of Changes to Restrictions Under the Final Technology Transitions Reconsideration Rule

Equipment Category Impacted	***Changes Implemented in the Final Technology Transitions Reconsideration Rule***
Retail Food – Supermarkets	Raised the limit from 150/300 starting in 2027 to 1,400 starting in 2027, followed by a limit of 150/300 starting in 2032.[1,2] Established that an increase in cooling capacity of a supermarket system of up to 15 percent would not be considered a new installation.
Retail Food – Remote Condensing Units	Raised the limit from 150/300 starting in 2026 to 1,400 upon the effective date of the rule, followed by a limit of 150/300 starting in 2032.
Cold Storage Warehouses	Raised the limit from 150/300 starting in 2026 to 700 upon the effective date of the rule, followed by a limit of 150/300 starting in 2032.
Industrial Process Refrigeration (IPR) – Chillers and IPR Equipment Used in Semiconductor Manufacturing	Extended compliance dates for IPR equipment, with a refrigerant charge capacity of 100 pounds or less, used as chillers or temperature control units for process equipment used in the manufacture of semiconductors from 2026/2028 to 2030.[3]
Industrial Process Refrigeration – Refrigerated Centrifuges and Laboratory Shakers	Extended compliance dates for refrigerated centrifuges and laboratory shakers from 2026 to 2028.
Refrigerated Transport – Intermodal Containers	Exempted certain intermodal containers by adjusting the temperature threshold at which restrictions do not apply from -50 °C (-58 °F) to -35

[1] Where used in this document, "150/300" refers to limits for a particular subsector that depend on the charge size and configuration of the equipment, as explained in the preamble to this rule.
[2] Unless stated otherwise, all compliance dates stated in this document begin January 1st of the given year.
[3] Where used in this document, "2026/2028" refers to compliance dates based on the operating conditions (*e.g.,* fluid exiting temperature) of the equipment.

	°C (-31 °F). Changed the location where the temperature is measured to the box temperature.[4]
Residential and Light Commercial Air Conditioning and Heat Pump Systems	Removed the 2026 installation compliance date for equipment manufactured or imported before January 1, 2025.

ES.3 Economic Impacts Evaluated

The anticipated economic impacts of this rule can be categorized as follows:

1. **Direct engineering costs/savings for equipment owners** – The final rule provides additional compliance flexibility for certain subsectors and equipment. The EPA estimates that the additional flexibility provided by this rule will, in some cases, result in avoided costs for stakeholders that are end-users of HFC-containing equipment.
2. **Indirect effects on HFC supply and prices** – By providing additional flexibility, the EPA anticipates that the restrictions as amended will result in additional demand (in Exchange Value Equivalent, or EVe) for HFCs relative to a baseline[5] scenario where the regulations codified at 40 CFR part 84 subpart B were left unchanged. Since overall supply of HFCs is constrained by the statutory HFC phasedown caps contained in subsection (e) of the AIM Act, an increase in demand may result in tighter supply and higher HFC prices for downstream consumers, including users of HFCs in subsectors outside the scope of this rulemaking. Note that an increase in demand for HFCs would also result in less demand for alternatives that would have been utilized instead, such as hydrocarbons, carbon dioxide (CO_2 or R-744), and ammonia (NH_3 or R-717). However, because there is no production or consumption cap with respect to these non-HFC refrigerants, and because usage as a refrigerant represents a relatively small share of total market demand for many of these substances, any market impact would likely be minimal.
3. **Reliance interests and sunk costs** – Domestic equipment manufacturers have, in most cases, made significant investments in anticipation of the limits and dates in the 2023 Final Rule. Changes to these restrictions may therefore result in difficulty recouping these investments or other adverse effects due to market uncertainty. In addition to this uncertainty, those who had prepared for the restrictions codified in the 2023 Final Rule will face additional competition from foreign manufacturers and any others who did not invest in preparation for the previous restrictions.

[4] Previously, the temperature was that of the refrigerant entering the evaporator (for direct heat exchange systems) or of the exiting fluid (for chillers).
[5] This term as used here should not be confused with the "baseline" as defined in the AIM Act, which refers to a specific calculation of exchange value equivalents based on past consumption or production.

This analysis provides quantitative estimates for the first factor in the list above, engineering cost savings for equipment owners in affected subsectors, and mostly qualitative discussion of the other two factors.[6] In aggregate, indirect effects on HFC supply and prices and impacts on equipment manufacturers are expected to partially offset estimated engineering cost savings and emissions changes. The EPA further notes there may be additional cost savings that may result from this rule which we have not quantified in this analysis, including productivity losses and stranded inventory costs that may have otherwise occurred (see Section 6 for more details and discussion).

The EPA also recognizes that the different types of impacts described above illustrate potentially significant cost/benefit tradeoffs. On the one hand, the rulemaking aims to provide economic relief for stakeholders facing compliance burden. On the other hand, this additional flexibility may exacerbate the already tight supply of HFCs anticipated as the phasedown continues and/or create market uncertainty for equipment manufacturers and supply chains. Since, given the limited data at hand, we are not able to quantify all of these tradeoffs in this document, the estimates provided are not totally representative of the net effects of this rulemaking.

Finally, the EPA notes uncertainties related to the monetization of carbon dioxide (CO_2)-related domestic and global climate benefits. There are significant uncertainties related to the monetization of greenhouse gases (GHGs), such as HFCs, that include, but are not limited to: the magnitude of the change in climate due to a change in GHG emissions; the relationship between changes in the climate and the economy and, therefore, the resulting economic impacts; future economic and population growth which are important for estimating vulnerability, willingness to pay to avoid impacts, and the ability to adapt to future changes; future technological advancements that would reduce vulnerability and impacts; the share of impacts from GHG emissions that affect citizens and residents of the U.S.; and the appropriate discount rates to use when discounting in an intergenerational context. For purposes of this analysis, the EPA did not monetize these impacts, and notes that monetizing these impacts could result in potentially flawed decision-making due to overreliance on highly uncertain social cost of carbon values.

ES.4 Data updates following proposed rulemaking

In the draft version of this economic memo included with the proposed rule, the EPA noted that it did not have sufficient data to serve as a basis for quantifying certain economic impacts and provided a detailed

[6] The EPA is not, at this time, able to quantify all of these effects due to limitations in available data and existing Agency models, but has provided a qualitative discussion.

summary of data gaps where additional information was needed.[7] Following the publication of the proposed rule, a large number of commenters provided the EPA with additional quantitative and qualitative information regarding possible impacts of the rule. The EPA has also further supplemented this with additional publicly available information and data identified after the publication of the proposed rule.

Based on this, the EPA has incorporated updated information related to technology adoption and characteristics into the analysis presented in this document to both: 1) update the status quo policy baseline scenario; and 2) estimate engineering cost savings that result from the final rule. More details on information received that the EPA relied on for this analysis and resulting updated assumptions can be found in Section 1and Section 2 of this document.

The EPA further notes that some information provided by stakeholders was not directly incorporated into our analysis of direct economic impacts but nonetheless describes effects of the rulemaking that are anticipated to be likely outcomes of the restrictions as amended. In particular, the EPA received several comments containing qualitative information and/or analysis regarding impacts on HFC supply and prices, as well as sunk costs and reliance interests of stakeholders that have already made investments based on the regulations that the EPA is amending.

ES.5 Summary of economic impacts

As noted above, the EPA has combined several important economic impacts associated with this rulemaking. Table ES - 2 below provides a summary of both monetized and non-monetized impacts. Monetized impacts include estimated engineering cost savings for equipment owners in affected subsectors. These cost savings arise from cases where additional flexibility provided by the rule allows for the use of refrigerant-containing equipment with lower capital and/or operating costs than equipment that would otherwise be likely chosen without additional flexibility. The analysis period used in this memo is 2026 to 2050. This period was chosen because it captures the vast majority of changes in HFC demand from the flexibility provisions in the final rule.[8] As part of fulfilling analytical guidance with

---

[7] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

[8] The final rule includes flexibility provisions for equipment installed between 2026 and 2032. Because the underlying modeling assumes equipment lifetimes of no more than 18 years for equipment in the supermarkets and remote condensing units subsectors, all equipment subject to flexibilities of this rule have reached end of life by 2050. Impacts to intermodal containers extend beyond the analysis period.

respect to Executive Order 12866, the EPA presents estimates of the present value (PV) of the benefits and costs over the full time series included in this analysis (2026-2050). To calculate the PV of the cost savings of the rule, annual savings are discounted to 2025 at three percent and seven percent discount rates as directed by OMB's Circular A-4. The EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year in the time series, would yield a sum equivalent to the PV, discounted at three percent and seven percent. In aggregate, indirect effects on HFC supply and prices and impacts on equipment manufacturers are expected to partially offset estimated engineering cost savings. The EPA further notes that additional cost savings will result from this rule which we have not quantified in this analysis, including productivity losses and stranded inventory costs that may have otherwise occurred (see Section 6 for more details and discussion).

Table ES - 2: Summary of Monetized and Non-Monetized Economic Impacts, 2026-2050 (millions of 2024$)

Monetized Impacts				
Engineering Cost Savings in Affected Subsectors[9]	***3 Percent Discount Rate***		***7 Percent Discount Rate***	
	PV	EAV	PV	EAV
	$976	$56	$653	$56
Non-Monetized Impacts				
Benefits and Cost Savings: • Avoided loss of ability to produce semiconductor wafers within the United States • National security benefits Costs and Forgone Benefits: • Indirect costs via HFC market impacts • Costs to equipment manufacturers and suppliers related to incremental investments required • Forgone benefits from potential increased emissions of HFCs				

Note: Monetized impacts are expressed in 2024 constant dollars. Present values are discounted to 2025. PV and EAV are calculated over the analysis period of 2026 to 2050.

Table ES - 3 below provides a breakdown of the above aggregate cost savings by affected subsector. The EPA notes that engineering cost savings for three subsectors in particular—Supermarkets, Remote Condensing Units, and Refrigerated Transport—have been quantified. For the remaining subsectors being

[9] Does not include engineering cost savings due to final rule provision establishing that an increase in cooling capacity of a supermarket system of up to 15 percent would not be considered a new installation. See section 1.3 for further discussion of this limitation.

granted compliance flexibility under this rule, the EPA could not quantify engineering cost savings due to data limitations and other technical factors (*see* detailed methodology descriptions in section 1 of this document).

Table ES - 3: Total Engineering Cost Savings by Subsector, Over 2026 to 2050, Discounted to 2025 (millions of 2024$)

	3 Percent Discount Rate		***7 Percent Discount Rate***	
Subsector	***PV***	***EAV***	***PV***	***EAV***
Retail Food – Supermarkets	$835	$48	$560	$48
Retail Food – Remote Condensing Units	$133	$8	$88	$8
Cold Storage Warehouses	*	*	*	*
Industrial Process Refrigeration – Chillers and IPR Equipment Used in Semiconductor Manufacturing, Refrigerated Centrifuges, and Lab Shakers	**	**	**	**
Refrigerated Transport – Intermodal Containers	$9	$0.5	$5	$0.4
Total	$976	$56	$653	$56

Note: Dollar values are presented in 2024 constant dollars. Present values are discounted to 2025. PV and EAV values are calculated over the analysis period of 2026 to 2050.
* The EPA has insufficient data on technology costs to estimate cost savings and did not receive additional, sufficiently quantitative data related to compliance costs in this subsector following publication of the proposed rule to quantify cost savings. We expect the effects to be small compared to the other subsectors, given that 91% of the cold storage market already uses R-717 (ammonia), while 5% uses R-744 (CO_2), and hence comply with the original restrictions.
** For some facilities the technology transition schedules in the 2023 Final Rule were technically infeasible to meet, according to certain stakeholders, and therefore the required transition would not have taken place. For this reason, changes in costs between the baseline and policy scenario cannot be calculated for this subsector.

The EPA did not estimate cost savings associated with cold storage warehouses, industrial process refrigeration, or the provision to prevent stranded inventory of residential and light commercial air conditioning and heat pump equipment. The EPA expects the total impact on HFC demand related to these provisions to be small. However, there are economic effects with potentially significant consequences related to these provisions, particularly for affected facilities or entities. For example, under the baseline requirements semiconductor facilities using IPR equipment faced technically infeasible requirements. Such facilities would have been forced to delay operations or invest in costly pre-commercial technologies. To the extent productivity may have been impacted, the costs could have been significantly larger than the costs of refrigeration equipment.[10] Regarding the provision related to stranded inventory, to the extent that existing inventory could not have been installed or used to repair existing systems, that could have caused a costly loss of capital equipment for distributors or installers holding that inventory. See Section 6 for further discussion.

As supermarkets operate with extremely thin margins (1 – 2%), supermarkets are not able to internalize costs much and externalize those costs on customers, thereby driving up costs of food and other goods. Therefore, we expect that almost all, if not all, of the cost savings for supermarkets will be passed onto customers, thus reducing the burden of AIM Act implementation under subsection (i) on consumers in the form of increased prices for food and other goods.

Table ES - 4 provides estimated cost savings across all affected subsectors for which they are quantified by year. Cost savings reflect incremental capital and operating cost savings that are annualized over equipment lifetimes. Therefore, annual savings ramp up during the additional flexibility window provided by this rulemaking before eventually leveling out and finally falling to zero as equipment reach end of life.

The EPA notes that cost savings results presented in this document are highly sensitive to factors such as incremental capital and operating costs of alternative refrigerant technologies, and that information on these factors—as provided by multiple stakeholders and identified in the literature—varies widely. We have therefore developed a sensitivity analysis with an upper- and lower-bound estimates of cost savings resulting from this rule in addition to a central scenario estimate shown in Table ES - 4. Details on these scenarios and corresponding upper- and lower-bound results can be found in Section 5 of this document.

[10] Comment from SEMI: "The economic costs of downtime in semiconductor production are extraordinary. A modern fabrication plant can lose millions of dollars per day in halted output."

Table ES - 4: Total Estimated Engineering Cost Savings for Equipment Owners in Affected Subsectors, 2026-2050 (Undiscounted millions of 2024$)

Year	*Annual Savings (Central Policy Scenario, millions)**	
2026	$3	
2027	$34	
2028	$67	
2029	$48	
2030	$60	
2031	$72	
2032	$72	
2033	$72	
2034	$72	
2035	$72	
2036	$72	
2037	$73	
2038	$73	
2039	$73	
2040	$73	
2041	$73	
2042	$73	
2043	$73	
2044	$73	
2045	$58	
2046	$41	
2047	$28	
2048	$16	
2049	$4	
2050	$2	
Discount rate	**3%**	**7%**
PV	$976	$653
EAV	$56	$56

* The PV and EAV presented in this table are based on a 25-year analysis period, expressed in 2024 constant dollars, discounted to 2025, and using beginning-of-period discounting. For E.O. 14192 regulatory accounting purposes, the EPA has prepared an alternative analysis that estimates costs in perpetuity. This requires the EPA to extrapolate costs beyond the analysis period. For this rule, the EPA projects that impacts to supermarkets and remote condensing units are fully captured in the analysis period, while impacts to intermodal containers continue indefinitely. Based on this approach, estimated present value and annualized value of the cost savings of this rule are $576 million and $40 million, respectively (7% discount rate, 2024$, 2024 present value year, perpetuity time horizon).

ES.6 Summary of demand and emissions changes

Table ES - 5 below shows total estimated demand for virgin HFCs (in metric tons of exchange value equivalent (MTEVe)) in the baseline and central policy scenarios as well as the net increase.[11] Increases in demand for virgin HFCs are anticipated to occur due to the increased flexibility provided by the rule, which will in some cases allow for greater demand on an EVe basis. These results reflect increases in demand based on the restrictions as amended, without accounting for additional and potentially offsetting measures that may occur in order to keep import and production of virgin HFCs below the statutory caps.

Table ES - 5: Total Demand for Virgin HFCs, 2026-2050 (MMTEVe)

Year	*Demand for Virgin HFCs – Baseline*	*Demand for Virgin HFCs – Final Rule Central Scenario*	*Increase from Baseline*
2026	154.9	155.8	0.8
2027	130.0	135.4	5.3
2028	115.3	121.6	6.3
2029	107.1	112.5	5.4
2030	97.1	103.2	6.1
2031	88.3	95.0	6.7
2032	79.2	82.9	3.6
2033	74.7	78.3	3.6
2034	66.7	70.3	3.6
2035	61.2	64.9	3.6
2036	59.7	63.3	3.6
2037	57.0	60.6	3.6
2038	53.8	57.5	3.6
2039	51.2	54.9	3.6
2040	48.4	52.0	3.6
2041	48.4	51.6	3.2
2042	48.4	51.1	2.8
2043	48.4	50.7	2.3
2044	48.4	50.4	1.9
2045	48.3	48.6	0.3
2046	48.5	48.5	0.0
2047	48.7	48.7	0.0
2048	49.0	49.0	0.0
2049	49.2	49.2	0.0
2050	49.8	49.9	0.1

[11] The model used in this analysis already incorporates high levels of recovery and reuse (*e.g.*, through reclamation) of refrigerants in the subsectors subject to this rule. Because it does not include information on stockpiled materials and no assumptions are made here for additional reclamation beyond that included in the model, we refer to the remaining demand as "virgin" HFCs.

Increases in HFC demand are also anticipated to result in increased emissions of HFCs over time over the course of equipment lifetimes. Projected incremental increases in HFC emissions are shown in Table ES - 6 below. Specifically, the EPA estimates increases in emissions for HFC-32, HFC-125, HFC-134a, and HFC-143a, which are constituent gases in the refrigerant blends that the rule's increased flexibility allows for (*e.g.,* R-448A, R-449A, and R-513A). See Appendix A for annual emissions by gas.

As discussed in section ES.7 below, given the backdrop of the statutory HFC phasedown limits, incremental increases in demand and resulting emissions in the subsectors affected by this rule as shown in the tables above may be offset by reductions in demand and emissions in other subsectors. The EPA has not endeavored in this analysis to evaluate specific end-uses where additional offsetting measures would be undertaken, but notes that this is a likely outcome given finite supply and a binding cap.

Table ES - 6: Incremental Increases in HFC Emissions Relative to Baseline, 2026-2050 (MMTEVe)

Year	*Total Emissions – Baseline Scenario*	*Total Emissions – Final Rule Central Scenario*	*Increase from Baseline*
2026	215.4	215.5	0.1
2027	212.9	213.9	1.0
2028	204.3	206.2	1.9
2029	195.3	197.8	2.5
2030	187.0	190.1	3.1
2031	177.9	181.5	3.6
2032	167.0	170.7	3.6
2033	156.1	159.7	3.6
2034	144.7	148.4	3.6
2035	133.1	136.8	3.6
2036	121.9	125.5	3.6
2037	108.1	111.7	3.6
2038	94.9	98.5	3.6
2039	83.6	87.2	3.6
2040	73.2	76.9	3.6
2041	70.2	73.8	3.6
2042	66.9	70.6	3.6
2043	63.7	67.4	3.6
2044	60.7	64.4	3.6
2045	58.3	61.5	3.2
2046	57.1	59.4	2.4
2047	56.1	57.8	1.7
2048	55.3	56.4	1.1
2049	54.7	55.2	0.5
2050	54.4	54.6	0.2

ES.7 Indirect HFC market impacts

In the scenarios described above, baseline and policy results are focused on the engineering cost and emissions changes that result from stakeholders in the affected subsectors utilizing additional flexibility provided by the Technology Transitions Reconsideration Rule. The EPA expects that greater demand for HFCs in the affected subsectors will have indirect effects on HFC prices and usage, including for other subsectors not directly affected by this rulemaking. The reason for this is the finite and decreasing amount of HFC production and import which is governed by the AIM Act phasedown schedule provided in subsection (e); thus, the supply of HFCs is relatively inelastic. To the extent that projected total HFC demand exceeds the statutory cap levels HFC prices are expected to rise significantly, leading to higher costs and increased incentives to reduce HFC usage across all subsectors. For example, uses that are not restricted fully, partially, or on a graduated schedule under subsection (i) of the AIM Act, such as fire suppression, or uses where alternatives are known and flexibility is being provided, such as cold storage warehouses, could react to the higher prices by transitioning to alternatives.

The baseline and policy scenarios used for this analysis represent projections of HFC quantity demanded based on the restrictions of the Technology Transitions regulations alone (with baseline representing the limits as originally codified and policy representing the limits as amended by this rulemaking). In other words, these scenarios represent demand based on these restrictions without accounting for additional measures that may be needed in order to keep import and production of virgin HFCs below the statutory caps. Demand for virgin HFCs in these scenarios that is over-and-above the cap therefore represents demand that may need to be offset through other measures, although as noted below there is significant uncertainty with these projections related to equipment leak rates, rates of recovery and re-use, and other factors. [12] Any demand for virgin HFCs in these scenarios that is over-and-above the cap therefore represents demand that must be offset through other measures. The EPA further notes that due to long equipment lifetimes, a significant share of HFC demand may be "locked in" for many years to come based on the installed base of equipment in preceding years. For example, this rulemaking allows for additional installation of R-448A and R-449A-based systems on the part of supermarkets until 2032, which will require HFCs for servicing as leaks occur through the end of the equipment's useful life, well past 2032. While the EPA understands that retrofits, if acceptable under the EPA's Significant New Alternatives Policy (SNAP) program, are possible, equipment owners and operators often find that the

[12] The EPA's projections also do not account for the share of demand that may be met in the form of "pre-charged" equipment (*i.e.*, equipment charged oversees and then exported to the United States) which would not count against the United States' statutory phasedown caps. Projections instead simply represent total demand for virgin HFCs, agnostic of where equipment is charged.

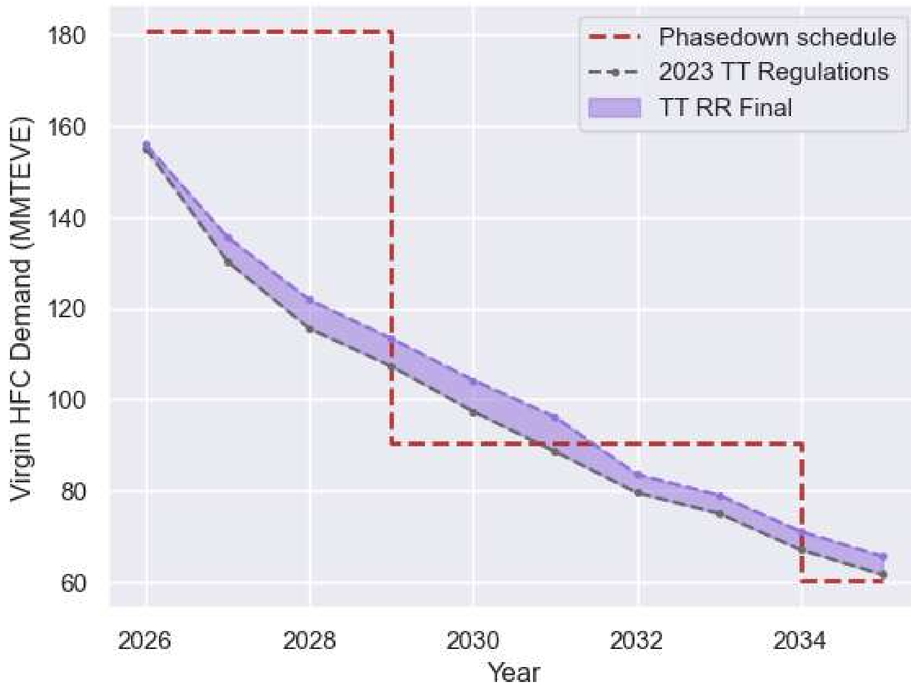
best performance is achieved when using the specific refrigerant with unique thermophysical properties for which a particular refrigeration system is designed, and will choose to continue to operate with that refrigerant to protect the significant up-front investment made for the system.

Figure ES - 1 shows projected HFC demand based on the status quo restrictions prior to this rulemaking overlaid with additional demand that is expected to result from the Technology Transitions Reconsideration Rule. In both baseline and policy scenarios, total virgin HFC demand is expected to approach or exceed consumption cap levels around the 2029 statutory step-down. The increases in demand depicted in the figure are from the subsectors directly affected by this rulemaking. Potential increases are represented as a sensitivity bound, with the top sensitivity line representing our central scenario estimate of incremental demand for virgin HFCs based on the revised deadlines contained in the final rule.

On an exchange-value-weighted basis, total economy-wide HFC quantity demanded increases by up to 8.9% from baseline through 2031 and by 5% to 8% from 2032-2044 due to additional "locked in" servicing demand following the deadline. The EPA anticipates that these increases in quantity demanded are of a sufficient magnitude to increase overall HFC prices. Based on a simple elasticity method, the EPA estimates potential HFC price increases in 2029 relative to the policy scenario of 12 to 24 percent. More discussion of the potential price increases and other indirect market effects is in section 4 of this document.

Finally, for all years where projected demand exceeds the statutory caps, the market is expected to undertake additional measures, such as conversions to alternatives in subsectors not covered by the current regulations, use of lower EVe alternatives than those chosen for compliance with current or future restrictions, reliance on stockpiled bulk HFCs produced before 2029, additional recovery and re-use, improved leak detection and repair practices, and/or forgoing or delaying the repair and recharging of existing HFC systems. The EPA has not evaluated these additional measures or their costs in this analysis. In aggregate, these market responses are expected to result in added costs and reduced emissions, such that engineering cost savings and emissions increases are partially offset by the indirect market effects.

*Figure ES - 1: Virgin HFC Demand in 2023 Final Rule and Technology Transitions Reconsideration Rule Scenarios**



*Upper-end of the projection shown in this figure represents the EPA's central scenario estimate of increased demand. However, we note that there is uncertainty regarding transition rates and technology choices for subsectors being granted compliance flexibility under this rule. Figure does not represent all sensitivities potentially impacting demand, and overall demand for virgin HFCs may be higher or lower than shown in this figure based on additional factors not evaluated here (*e.g.,* lower or higher recovery-reuse rates, lower or higher leak rates, earlier or later transitions in subsectors not affected by this rulemaking). The EPA further notes that a share of the projected demand in this figure may be met in the form of pre-charged equipment imported to the United States and thus would not count toward the United States' production and consumption limits, although we have not quantified this share for purposes of this analysis.

ES.8 Comparison of Alternative Scenarios

In addition to the amendments to requirements finalized in the Technology Transitions Reconsideration Rule, the EPA considered an alternative policy option under which limits for supermarkets and cold storage warehouses would be implemented in 2029 and limits for remote condensing units would be implemented in 2027, as opposed to in 2032 as in the final requirements. Under this alternative scenario, the engineering cost savings to affected subsectors would be smaller than realized in the final Technology Transitions Reconsideration Rule scenario, while incremental HFC demand, emissions, and potential HFC price changes in 2029 would have been smaller. Table ES-7 summarizes incremental cost savings, HFC consumption, and emissions changes over the analysis period of 2026 to 2050 for the alternative policy option and the selected Technology Transitions Reconsideration Rule central scenario.

Table ES - 7: Estimated Incremental Cost Savings, HFC Consumption, and Emissions Changes, 2026-2050

	Alternative Scenario (2029)	***Final Rule Central Scenario***
Engineering Cost Savings in Affected Subsectors		
3 Percent Discount Rated		
Present Value (million 2024$)	$522	$976
Equivalent Annualized Value (million 2024$)	$30	$56
7 Percent Discount Rate		
Present Value (million 2024$)	$369	$653
Equivalent Annualized Value (million 2024$)	$32	$56
Incremental Virgin HFC Demand (Total MTEVe, 2026-2050)	39	74
Incremental HFC Emissions (Total MTEVe, 2026-2050)	35	68
Potential HFC Price Increases from Baseline in 2029 (%)	4% - 8%	12% - 24%

An additional policy option not evaluated in this document relates to the treatment of new condensing units in the residential and light commercial AC/HP subsector. As discussed in the rule preamble, the EPA is not making any changes to the treatment of new condensing units in this subsector. Stakeholders had requested that the EPA change the treatment of new condensing units that use regulated substances above the 700 limit in order to effectively disallow continued replacement of such units in existing systems. The EPA anticipates that the requested change would have potentially imposed compliance costs by limiting flexibility in repairing existing equipment because installing a new system is generally more costly than replacing a component, particularly if the existing equipment is relatively new and/or under warranty. The EPA also anticipates that the requested change would have resulted in additional avoided emissions of and reduced demand for HFCs (on an EVe-weighted basis). The EPA did not quantify costs or environmental impacts for this policy alternative that was not selected.

Section 1. Methods and Approach

1.1 Background

The Technology Transitions Reconsideration Rule addresses petitions and other requests from companies and trade associations concerning a 2023 final rule codified at Title 40 of the Code of Federal Regulations (CFR) part 84, subpart B (88 FR 73098, also referred to as the “2023 Final Rule”) and includes amendments to certain requirements. The regulations codified at 40 CFR part 84, subpart B, place restrictions on the use of certain HFCs above specified limits in specific sectors and subsectors in which HFCs are used.

After the finalization of the 2023 Final Rule, the EPA received petitions and other requests from companies and trade associations which included information indicating a discrete set of regulated entities would face barriers to meeting the final requirements. These petitions and requests claimed barriers existed based on unique industry circumstances including concerns regarding safety and the lack of readily available alternatives able to meet specific technical requirements. As discussed in the final rule preamble, the EPA is therefore making adjustments to specific requirements codified at 40 CFR part 84, subpart B, in order to provide a smoother path to transition for affected entities.

The changes under the Technology Transitions Reconsideration Rule are summarized in Table 1-1 below:

Table 1-1: Summary of Changes to Restrictions in the 2023 Final Rule

Equipment Category Impacted	***Change Implemented***
Retail Food – Supermarkets	Raised the limit from 150/300 starting in 2027 to 1,400 starting in 2027, followed by a limit of 150/300 starting in 2032. Established that an increase in cooling capacity of a supermarket system of up to 15 percent would not be considered a new installation.
Retail Food – Remote Condensing Units	Raised the limit from 150/300 starting in 2026 to 1,400 upon the effective date of the rule, followed by a limit of 150/300 starting in 2032.
Cold Storage Warehouses	Raised the limit from 150/300 starting in 2026 to 700 upon the effective date of the rule, followed by a limit of 150/300 starting in 2032.
Industrial Process Refrigeration (IPR) – Chillers and IPR Equipment Used in Semiconductor Manufacturing	Extended compliance dates for IPR equipment, with a refrigerant charge capacity of 100 pounds or less, used as chillers or temperature control units for process equipment used in the manufacture of semiconductors from 2026/2028 to 2030.
Industrial Process Refrigeration – Refrigerated Centrifuges and Laboratory Shakers	Extended compliance dates for refrigerated centrifuges and laboratory shakers from 2026 to 2028.
Refrigerated Transport – Intermodal Containers	Exempted certain intermodal containers by adjusting the temperature threshold at which restrictions do not apply from -50 ºC (-58 F) to -35 ºC (-31 ºF). Changed the location where the temperature is measured to the box temperature.
Residential and Light Commercial Air Conditioning and Heat Pump Systems	Removed the 2026 installation compliance date for equipment manufactured or imported before January 1, 2025.

1.2 Description of baseline and policy scenarios

The effects of this rule are estimated as the difference between two scenarios, namely:

Baseline scenario. This reflects the EPA's updated understanding of the HFC market and includes changes from that presented in the 2023 Final Rule Regulatory Impact Analysis (RIA) Addendum based on new data and information identified in literature and comments regarding certain subsectors. In particular, based on newly available data, the EPA updated its assumptions regarding historic rates of technology adoption for subsectors affected by this rule as well as technologies that would be adopted to comply with the originally codified restrictions (*i.e.*, without the changes finalized in this rulemaking). This provides a more accurate starting point from which to evaluate the effects of policy that is reflective of the latest market data. Details on this updated baseline scenario and specific changes made can be found in section 1.3.

Policy Scenario. The policy scenario assumes transitions occur in the various subsectors to meet the requirements, as amended by this rule, in 40 CFR part 84 subpart B. For subsectors that are not addressed in this rule, the analysis uses the same transition assumptions provided in the 2023 Final Rule RIA

Addendum. For the subsectors where requirements are amended by this rule, the analysis assumes conforming updates in the policy scenario.

In some cases, the final rule uses a graduated schedule which allows for additional technology options such that—for the time period up until the amended deadline in the final rule—market actors have a choice between technology that is compliant with the originally codified limits versus additional options that the revised, more flexible limits in the graduated schedule allow. The EPA notes that there is inherent uncertainty regarding the share of market actors that will choose various options, and that such decisions are dependent on a combination of short- and long-term costs, availability, technology preference, and other factors. We note that the transitions assumed in this analysis are based on engineering judgement as informed through the additional data and information gathered. While these assumed transitions would meet the revised regulations, they are not prescriptive, and the market may choose other options that would be allowed and would yield different environmental and economic effects as estimated in the EPA's analysis. More details are available in the sections below.

1.3 Vintaging Model

The EPA used the Vintaging Model (VM) to forecast HFC consumption and resulting emissions that would occur in both the baseline and policy scenarios described in this document.

The model tracks the use and emissions of each of the regulated substances separately for each successive generation or "vintage" of equipment across all major end-use sectors.[13] The VM is used to produce various rule analyses and reports related to the use of ozone-depleting substances and their substitutes, including HFCs, and is updated and enhanced annually.

The peer-reviewed VM utilizes detailed information concerning end-uses across the five major industrial sectors that previously relied on ODS and have more recently used HFCs (*i.e.*, Foams, Aerosols, Solvents, Fire Suppression, and Refrigeration, Air Conditioning, and Heat Pumps (RACHP)).[14, 15] Each end-use is modeled differently based on its characteristics such as pieces of equipment in operation, the number added or removed annually, the average amount of HFC used and emitted over time from each item,

---

[13] The VM version used for this analysis includes 65 unique end-uses across the refrigeration/air-conditioning, foams, aerosols, fire suppression, and solvents sectors. The specific end-uses affected by this rulemaking include supermarket systems, remote condensing units used in retail food, cold storage warehouses, refrigerated transport, and niche segments of industrial process refrigeration (*e.g.*, lab equipment).

[14] U.S. Environmental Protection Agency. (2018b). EPA's Vintaging Model of ODS Substitutes. EPA Report EPA-400-F-18-001. Available at https://www.epa.gov/sites/default/files/2018-09/documents/epas-vintaging-model-of-ods-substitutes-peer-review-factsheet.pdf

[15] More details on EPA's Vintaging Model can also be found in section 3 of the Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs). U.S. Environmental Protection Agency (EPA). 2021. Available at https://www.regulations.gov/document/EPA-HQ-OAR-2021-0044-0227 (attachment 1)

typical lifetime of operation, and growth/decline rate in the U.S. market. As each end-use transitions from an ODS to one or more HFC(s) and possibly other alternatives—such as those analyzed here as options to reduce HFC consumption—the model tracks annual vintages and calculates the amount of each chemical in use, emitted, and the amount needed to both support new products and service existing products (*e.g.*, to "top-off" leaks from air conditioners).

The VM estimates the use and emissions of ODS substitutes—including HFCs and other substitutes— by taking the following steps:

1. **Gather historical data.** The VM is populated with information on each end-use, taken from published and confidential sources and industry experts.
2. **Simulate the implementation of new, non-ODS and HFC replacement technologies.** The VM uses detailed characterizations of the historical and current uses of HFCs to simulate the implementation of new technologies. This step can be expanded to include secondary transitions from HFCs to other technologies as a means to comply with regulations under 40 CFR part 84 and estimate the HFC reductions achievable with such actions.
3. **Estimate emissions of the ODS substitutes and HFC substitutes.** Chemical use is estimated based on amounts that are required each year for the manufacture, installation, use, or servicing of products or systems. The emissions are estimated from the emission profile for each vintage of equipment or product in each end-use category. By aggregating the emissions from each vintage, a time series of emissions from each end-use is developed.

To project into the future, each end-use is assigned a growth rate based on various factors including the overall growth seen from the past several years as well as regulatory requirements. In some cases, other data are used to estimate growth rates; for instance, the U.S. Energy Information Administration's Annual Energy Outlook projections for automobile sales and new single-family housing starts are used to estimate future growth in the motor vehicle air conditioner and residential split system air conditioning end-uses, respectively.[16,17]

A limitation relevant to this final rule is that the Vintaging Model tracks equipment brought online in a given year based on demand for new units as well as demand for replacement of legacy equipment

---

[16] U.S. Energy Information Administration (EIA). 2024a. Annual Energy Outlook 2025: Table 4: Residential: Key Indicators: Households. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=4-AEO2025&cases=ref2023&sourcekey=0.
[17] U.S. Energy Information Administration (EIA). 2024b. Annual Energy Outlook 2025: Table 38: Light-Duty Vehicle Sales by Technology Type. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=48-AEO2025&cases=ref2025&sourcekey=0.

reaching end of useful life but does not explicitly track capacity additions to existing equipment. For example, supermarket refrigeration systems are modeled as having an average lifetime of 18 years, and while additional demand for refrigerant is modeled over the course of equipment lifetime based on typical operational losses, increases in demand due to system capacity expansions are not modeled. Due to this, the impact of the provision in this final rule which allows for cooling capacity additions up to 15% to not be considered new installations is not captured in our analysis. However, we anticipate these effects to be much smaller in comparison to impacts of the adjusted limits and deadlines for new installations, which this analysis does explicitly account for.

1.4 Updates to modeling from proposal

The EPA has made significant updates to its analytic approach and underlying data sources since the proposed rule, based on additional information identified in stakeholder comments as well as through supplementary literature review.

During the proposed rulemaking process, the EPA noted that we did not have sufficient quantitative information to compute relevant costs and savings associated with this deregulatory rulemaking. To fill these data gaps, we requested comments on the potential cost savings in subsectors affected by the proposed amendments, the rates of adoption of various technology options, and other factors related to the effects of the proposed rule. In addition to this request for additional information, the EPA also conducted a supplementary literature review following the publication of the proposed rule.

The EPA has explored approaches to best consider the data and information that we received and has attempted to account for these factors in this analysis, taking into account both information received in comments as well as supplementary information identified through literature review. We reiterate that relevant quantitative information provided by commenters has been included in our analyses, while acknowledging that some of the information provided was more qualitative in nature and/or not directly applicable to our modeling approach. However, in some cases, this information has still been used to inform assumptions and general discussion in subsequent sections of this document.

A summary of specific information gaps identified at proposal and relevant information received from commenters is provided in section 7.3 (Appendix C). The EPA notes that commenters in some cases provided widely divergent quantitative data on the same or similar factors, some of which are significant drivers of the estimated economic impacts of this rule such as capital costs of supermarket systems and comparative energy efficiency of different supermarket systems. To the extent practical, the EPA has validated information received through verification of sources, supplementary literature review, and stakeholder outreach to determine suitable ranges to use for central estimates and sensitivity ranges described in the sections below.

The EPA also updated HFC prices based on publicly available data. For a discussion of the cost of refrigerants used in this analysis, see Appendix D.

Sections 1.5 and 1.6 below detail specific updates made and approaches used to develop updated technology adoption assumptions for the "no action" baseline scenario from which policy impacts are evaluated along with the updated policy scenario reflecting likely market responses to the final rule as amended. Section 2 provides details on specific data sources used to develop central estimates of engineering costs for relevant technologies.

1.5 Baseline Updates and Technology Adoption Assumptions

The updated baseline scenario includes revised rates of transition and technology adoption based on new information received and identified by the EPA, as well as some additional costs not previously quantified by the EPA but which have been raised as barriers to compliance by stakeholders.[18] While the EPA was unable to incorporate sunk costs already invested in technologies compliant with the restrictions at 40 CFR part 84, subpart B, as finalized in 2023, we provide a summary of these costs in Section 3 and acknowledge that these are a significant economic aspect to this rulemaking that are not monetized for this analysis. In addition, in some cases the EPA received information that compliant technologies were not yet commercially available or otherwise technically achievable. Such transitions were removed from the status quo baseline to the extent they were previously modeled. The regulatory changes contained in the rule were then evaluated relative to this updated baseline scenario.

Significant changes to the EPA's baseline technology adoption assumptions are summarized in Table 1-2 below.

Table 1-2: Baseline Assumption Updates

Subsector	***Previous Baseline***	***Revised Baseline***
Retail Food – Supermarkets	• CO_2 refrigeration system make up 33% of new units in 2017 and 100% by 2027 compliance date	• New transitions for R-448A, R-449A, and CO_2 beginning in 2017 • CO_2 systems are assumed to gradually increase share to 17.5% of new systems by 2024. Beginning in 2027, all new systems transition to CO_2

[18] For detailed information on revised engineering cost estimates used in this analysis, see Section 2. The EPA is also including a table of cost assumptions that were used in order to evaluate incremental costs and savings resulting from some of the changes contained in the rule (see Appendix B).

Retail Food – Remote Condensing Units	• Starting in 2018 and prior to 2026, remote condensing units use either R-407A or HFC-134a	• Starting in 2018 and prior to 2026, remote condensing units use either R-404A, R-507, R-407A, R-448A, or R-449A, with increasing use of A2Ls[19] (R-454A, R-454C, and R-455A) between 2025-2026
Cold Storage Warehouses	• 80% of cold storage warehouses – all using ammonia – not accounted for due to no prior use of ODS • Transition from R-404A/R-507A to 100% R-407F by 2023 • Average stock growth rate of 2.5% annually	• Updated split of new cold storage warehouses using ammonia vs. those that would use fluorinated refrigerants before 2025. • Transition from R-404A/R-407A to ammonia (66%), CO_2 (29%), and R-407F (5%)[20] • Average annual growth rate of 2.3% for new cold storage warehouse systems from 2024 through 2030 • Smaller rate of growth (0.8%) in new units continues from 2031 through 2050
IPR: Refrigerated Centrifuges	• Transition to CO_2/ammonia (as part of the broader IPR subsector) by 2026	• Not assumed to transition to CO_2/ammonia until the modified compliance date of 2028
IPR: Laboratory Shakers	• Transition to CO_2/ammonia (as part of the broader IPR subsector) by 2026	• Not assumed to transition to CO_2/ammonia until the modified compliance date of 2028
IPR: Semiconductors	• Transition to CO_2/ammonia (as part of the broader IPR subsector) by 2026	• Not assumed to transition to CO_2/ammonia until the modified compliance date of 2030
Refrigerated Transport – Intermodal Containers	• Transition from R-404A and HFC-134a to R-450A and R-513A by 2025 compliance date	• No revision

In total, these updates result in greater projected virgin demand for HFCs in 2026 through 2032 in the updated baseline than had been estimated in the previous baseline. Table 1-3 shows total demand for virgin HFCs (in MMTEVe) in the previous and updated baseline scenarios.

[19] The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 34 provides safety group classifications where "A" and "B" refer to lower and higher toxicity, respectively, and 1, 2L, 2, and 3 refer to as no flame propagation, lower flammability, flammable, and higher flammability, respectively.
[20] Technology uptake percentages are only for share of the market that that had previously used R-404A/R-407A, rather than the full cold storage warehouses market, which is assumed to have an overall market share already using ammonia higher than 66%.

Table 1-3: Incremental Change in Total Demand for Virgin HFCs from Baseline Updates, 2026-2050 (MMTEVe)

Year	*Previous Baseline*	*Revised Baseline*	*Incremental Change from Baseline Updates*
2026	147.2	154.9	7.7
2027	124.4	130.0	5.6
2028	110.3	115.3	5.0
2029	102.4	107.1	4.7
2030	93.3	97.1	3.8
2031	86.1	88.3	2.2
2032	78.4	79.2	0.8
2033	76.1	74.7	-1.5
2034	69.7	66.7	-3.0
2035	63.9	61.2	-2.7
2036	61.9	59.7	-2.2
2037	58.4	57.0	-1.4
2038	54.5	53.8	-0.7
2039	51.3	51.2	-0.1
2040	48.3	48.4	0.2
2041	48.5	48.4	-0.1
2042	48.5	48.4	-0.1
2043	48.5	48.4	-0.1
2044	48.5	48.4	-0.1
2045	48.4	48.3	-0.1
2046	48.6	48.5	-0.2
2047	48.9	48.7	-0.2
2048	49.2	49.0	-0.2
2049	49.4	49.2	-0.2
2050	50.0	49.8	-0.2
Total (2026-2050)			17.1

Note: Demand is based on the amount of HFCs needed to produce new equipment and products plus the amount to maintain/service existing systems, less the amount recovered and reused from equipment disposed. The baseline and policy scenarios used for this analysis represent projections of HFC quantity demanded based on the restrictions of the Technology Transitions regulations alone (with baseline representing the limits as originally codified and policy representing the limits as amended by this rulemaking). In other words, these scenarios represent demand based on these restrictions without accounting for additional measures that may be needed in order to keep import and production of virgin HFCs below the statutory caps.

The following sections provide additional details on data sources relied on by the EPA that served as a basis for these baseline assumptions of technology adoption rates.

Supermarkets

The baseline scenario previously used by the EPA assumed an early market transition from R-404A and R-407A to CO_2, starting in 2015, with CO_2 refrigeration systems reaching a market share of 33% of new units in 2017 and 100% by the 2027 compliance date.

The EPA has since reviewed data from its GreenChill partnership program, recent industry announcements and product information, and recently passed state regulations regarding use of alternatives and technology types in supermarket systems and determined that updates could be made to assumptions regarding historic refrigerant transitions.

GreenChill[21] and industry data and announcements[22,23,24,25,26,27] indicate that the refrigerant landscape is more diverse than previously modeled. According to 2024 GreenChill data, the most commonly used refrigerants among participating stores include R-404A, R-407A, R-448A, R-449A, and HCFC-22, with R-404A still representing the largest share. While adoption of blends such as R-448A and R-449A is accelerating, with R-448A stock increasing by 163% between 2020 and 2024 in GreenChill stores, other refrigerants that exceed the interim 1,400 limit, such as R-404A, R-407A and R-507, still represent a considerable share of installed stock according to the industry-wide store analysis. To reflect this shift, the EPA adjusted baseline transition assumptions in the VM such that:

- R-448A, R-449A, and CO_2 are slowly introduced beginning in 2017. R-448A and R-449A are assumed to initially make up 12% of new systems, increasing to a market share of 30% of new systems by 2021 in compliance with certain state regulations and the industry-wide refrigerant

---

[21] GreenChill. (2025). GreenChill Partnership Raw Data. Prepared by the EPA on August 5, 2025.
[22] TriplePundit. (2024). *How Aldi is Tackling Extremely Potent Greenhouse Gases.* https://triplepundit.com/2024/aldi-hfcs-natural-refrigerants/#:~:text=To%20date%2C%20more%20than%20700%20Aldi%20stores,are%20currently%20considered%20the%20most%20climate%2Dfriendly%20alternative
[23] Refindustry. (n.d.). *Leader of the Rack*. https://refindustry.com/news/market-news/leader-of-the-rack/#:~:text=More%20than%2010%20projects%20so,based%20ALDI%20South%20(S%C3%BCd)
[24] EIA. (2024). *ALDI becomes first U.S. food retailer to commit to natural refrigerants across all stores.* Available online at: https://eia.org/blog/aldi-becomes-first-u-s-food-retailer-to-commit-to-natural-refrigerants-across-all-stores/
[25] Albertsons Companies (2024). Albertsons Companies. 2024. Albertsons Companies Releases 2023 ESG Report. Available online at: https://www.albertsonscompanies.com/newsroom/press-releases/news-details/2023/Albertsons-Companies-Releases-2023-ESG-Report/
[26] Globe Newswire (2023). Food Lion's Ongoing Sustainability Efforts Recognized by the EPA's GreenChill Program. Available online at: https://www.globenewswire.com/news-release/2023/10/04/2754918/0/en/Food-Lion-s-Ongoing-Sustainability-Efforts-Recognized-by-EPA-s-GreenChill-Program.html.
[27] Whole Foods Market. (2024). *Retail Innovation for Climate Impact.* https://impact.wholefoods.com/retail-innovation.html

analysis. CO_2 systems are assumed to gradually increase market share to 17.5% of new systems (and 5% of the installed base) by 2024.

- Beginning in 2027, all new systems will transition to CO_2 in response to the restrictions established in the 2023 Final Rule.

This timeline captures both early adoption among GreenChill partners and slower uptake among non-partner chains, while also assuming compliance with state HFC regulations (*i.e.*, California, Washington, New York) and the 2023 Final Rule, recognizing that a portion of GreenChill stores and other supermarkets that have announced refrigerant transitions are likely located in states with existing HFC regulations. These updates are also consistent with comments received by the EPA as a part of the proposed rulemaking process, which indicated increasing adoption of R-448A and R-449A as well as more muted historic adoption of CO_2 than previously assumed by the EPA.[28,29,30]

Remote Condensing Units

The baseline scenario previously used by the EPA assumed that, starting in 2018 and prior to 2026, new remote condensing units use either R-407A or HFC-134a. CO_2-based equipment was then assumed to be the primary compliance option from 2026 onward. The EPA has since updated its baseline based on additional data and research. Growing adoption of alternatives below the interim 1,400 limit (*e.g.*, R-448A/R-449A) and alternatives below the final 150/300 limit (*e.g.*, A2Ls) in remote condensing units is evidenced by product availability, state regulations, and industry insight. The EPA therefore revised its assumptions to reflect more widespread adoption of a more diverse set of technology options.

Several U.S. OEMs released A2L-compatible systems in 2024 and 2025, and A2L product introductions are expected to continue.[31,32,33,34] State-level restrictions discussed with regard to supermarkets are also expected to influence refrigerant choice in remote condensing units. The NASRC's 2020 Food Retailer Survey Report showed that the majority of retailers surveyed have indicated interest in CO_2-based

---

[28] Public comment from The Chemours Company FC, LLC. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0132.
[29] Public comment from Solstice. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0134.
[30] Public comment from H-E-B, LP. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0122.
[31] Heatcraft Refrigeration Products. (2024). *A2L Product Selection Guidelines*. https://www.meiersupply.com/customer/images/resources/A2L%20Product%20Selection%20Guidelines.pdf.
[32] Tecumseh. (2024). *Condensing Units*. https://www.tecumseh.com/ProductFamily/SILENSYS/Catalog/product-type/condensing-units?attributeValueIds=f425844b-e369-448d-b42a-aff100a9dca5%2Cafaf3b3d-d067-4460-87d7-aff100a9de19&isInitialLoad=false&IncludeSubcategories=true
[33] American Walk-In Coolers. (2025). *Regulatory Landscape and New Products*. https://www.americanwalkincoolers.com/wp-content/uploads/2025/01/AWIC-A2L-Presentation-2025.pdf.
[34] Air Conditioning, Heating, and Refrigeration NEWS (ACHR News). (2025). *A2L Commercial Refrigeration Equipment Hits the Market*. https://www.achrnews.com/articles/165195-a2l-commercial-refrigeration-equipment-hits-the-market.

condensing units,[35] although the EPA understands based on stakeholder discussions that CO_2 systems currently have significantly lower market uptake relative to A2L or A1 options.[36] Many manufacturers continue to market alternatives such as R-448A and R-449A,[37,38] and some manufacturers have recently indicated preference for A2L refrigerant blends that can meet the limits of the 2023 Final Rule (*e.g.*, R-454A, R-454C, and R-455A) over CO_2 for their relative affordability and energy efficiency performance.[39,40,41]

The EPA amended its baseline assumptions in this subsector to account for these findings such that A2L blends will begin entering the market in 2025, and all new systems will transition to CO_2 or A2L refrigerant blends in response to the 2023 Final Rule restrictions.

These updates are also consistent with public comments received by the EPA, which suggest that A2Ls do not face significant building code challenges or other restrictions, they are already commercially viable and marketed, interest in CO_2 remains strong, and R-448A and R-449A are reliable market alternatives until the compliance date.[42,43,44]

Cold Storage Warehouses

The baseline scenario previously used by the EPA assumed that, between 2020 and 2026, the share of the market using HFCs would fully transition from R-404A/R-407A to ammonia and CO_2. The EPA has revised this assumption to account for the industry response to SNAP Status Change Rules. The updated

---

[35] Air Conditioning, Heating, and Refrigeration NEWS (ACHR News). (2021). *Food Retailers Interested in Natural Refrigerants*. https://www.achrnews.com/articles/144720-food-retailers-interested-in-natural-refrigerants.
[36] EPA meeting with NASRC members on March 18, 2026. EPA meeting with Lennox on February 6, 2026. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.
[37] Hussmann. (2025). HE H-Series Condensing Units (High Efficiency). https://www.hussmann.com/products/refrigeration-systems/condensing-units/hseries-condensing-units-high-efficiency.
[38] Ice Machines Plus. (2025). Ice-O-Matic RC106C49 Remote Condenser R449 Refrigerant for Model CIM0636R. https://icemachinesplus.com/products/ice-o-matic-rc106c49-remote-condenser-r449-refrigerant-for-model-cim0636r.
[39] Heatcraft Refrigeration Products. (2025). https://www.heatcraftrpd.com/resources/news/next-gen-refrigerants-making-sense-of-changing-regulations.
[40] Enns. (2025). *CO2 vs A2L Refrigerants: The Future of Refrigeration*. https://www.gaenns.com/blog/co2-vs-a2l-refrigerants.
[41] Air Conditioning, Heating, and Refrigeration NEWS (ACHR News). (2025). *A2L Commercial Refrigeration Equipment Hits the Market*. https://www.achrnews.com/articles/165195-a2l-commercial-refrigeration-equipment-hits-the-market.
[42] Public comment from Solstice. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0134.
[43] Public comment from Lennox International Inc. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0129.
[44] Public comment from The Chemours Company FC, LLC. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0132.

baseline reflects that 66% of pre-2026 new systems use ammonia, 29% use CO_2, and 5% use R-407F. The EPA notes that these estimates generally conform with industry survey data on refrigerant usage across facilities as of 2023.[45]

Additionally, historic stock data and growth rates for the cold storage warehouse subsector were updated based on USDA's biennial *Capacity of Refrigerated Warehouses Summary* report, which offers data on the number of refrigerated warehouses by type and size group, as well as gross and usable refrigerated storage capacity. Previously, the VM used data from prior versions of this report for 1985-1992, then assumed an average stock growth rate of 2.5% annually from those starting values. The EPA identified that the VM projected growth of total cold storage space was overestimated compared to actual estimates (*i.e.*, average annual growth rate of VM estimated cold storage capacity is 3.9% from 1985-2023 compared to 2.9% growth in USDA[46] estimated cold storage capacity). As a result, the EPA updated the VM to reflect an average growth of 16% for new cold storage warehouse systems from 2024 through 2030. From 2031 to 2050, the model assumes new units will continue to grow at an average 0.8% growth rate, which mimics population increases.

Because the VM was designed at its inception to track transitions away from ODS, which only an estimated 20% of the cold storage warehouse market utilized, it by design excludes a substantial share (about 80%) of the cold storage warehouse market that historically used non-ODS refrigerants (*e.g.*, ammonia). As a part of this update, the EPA further revised historic transitions in the cold storage warehouse subsector to reflect greater utilization of ammonia than previously assumed.

IPR - Refrigerated Centrifuges and Laboratory Shakers

The baseline scenario previously used by the EPA assumed that the entire IPR subsector, including refrigerated centrifuges and laboratory shakers, would transition to CO_2/ammonia by 2026. In response to comments from industry stakeholders, the EPA now assumes in its baseline that these subsectors do not transition to CO_2/ammonia until the modified compliance date (2028).

Beyond this, the EPA has not received or identified sufficient quantitative information to modify its assumptions regarding equipment market share and refrigerant usage. The EPA therefore relied on

---

[45] IARW. (2023). *Productivity and Benchmarking Survey.* Global Cold Chain Alliance. https://www.gcca.org/resource/iarw-productivity-and-benchmarking-tool-and-executive-summary/

[46] U.S. Department of Agriculture (USDA). (2024). Publication – *Capacity of Refrigerated Warehouses*. Latest release January 31, 2024. https://usda.library.cornell.edu/concern/publications/x059c7329.

information and assumptions consistent with its analysis provided in the proposed rule economic impacts memo,[47] as summarized below.

Refrigerated centrifuges and laboratory shakers are considered part of the IPR subsector. As such, they are subject to the IPR subsector restrictions, which are based on temperature, charge size, and whether it is a cascade system. In the 2023 Final Rule, the limits for this subsector were set at 150, 300, and 700, with compliance dates ranging from 2026 to 2028, depending on the above factors. No restrictions were placed on IPR systems operating at temperatures below -50 ºC.

Prior analyses of the 2023 Final Rule did not subdivide refrigerated centrifuges refrigerated IPR subsectors. To determine the share of the market represented by these subsectors, the EPA reviewed available data and consulted with industry representatives.[48,49] Based on data provided as well as additional analysis regarding the U.S. market, estimated annual production, equipment charge sizes, and the EVe of the relevant gases used, the EPA estimates that refrigerated centrifuges and laboratory shakers account for approximately 0.034% and 0.00267% of annual IPR demand, respectively.

As indicated by stakeholders and discussed in the preamble to this rule, the original transition schedule from the 2023 Final Rule was determined to be infeasible for these subsectors. Given this, we have updated our baseline scenario to assume that the share of the market represented by refrigerated centrifuges and laboratory shakers does not transition to alternatives below the limit by the 2026 date in the original 2023 Final Rule and instead transitions by the amended date of 2028.

IPR – Equipment used in semiconductor manufacturing

The baseline scenario previously used by the EPA assumed that the entire IPR subsector, including equipment used in semiconductor manufacturing, would transition to CO_2/ammonia by 2026. In response to comments from industry stakeholders, the EPA now assumes in its baseline that these subsectors do not transition to CO_2/ammonia until the modified compliance dates.

Beyond this, the EPA has not received or identified sufficient quantitative information to modify its assumptions regarding equipment market share and refrigerant usage. The EPA therefore relied on

---

[47] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

[48] The EPA met with industry representatives on January 22, 2025. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Notice of Proposed Rulemaking, April 18, 2025, in the docket for this action.

[49] The EPA met with industry representatives on April 8, 2025. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Notice of Proposed Rulemaking, April 18, 2025, in the docket for this action.

information and assumptions consistent with its analysis provided in the proposed rule economic impacts memo,[50] as summarized below.

Equipment used in semiconductor manufacturing is considered to fall within the IPR and Chillers for IPR subsectors. As such, these types of equipment are subject to the IPR and Chillers for IPR subsector restrictions, which are based on temperature, charge size, and whether it is a cascade system. In the 2023 Final Rule, the limits for this subsector were set at 150, 300, and 700, with compliance dates ranging from 2026 to 2028, depending on the above factors. No restrictions were placed on IPR or Chillers for IPR systems operating at temperatures below -50 ºC (-58 ºF).

Prior analyses of the 2023 Final Rule did not subdivide cooling equipment used in semiconductor manufacturing from the Chillers for IPR and IPR subsectors. For the current analysis, we model refrigeration equipment used to cool processes in semiconductor manufacturing as a portion of the IPR end-use in the EPA's Vintaging Model (which encompasses both Chillers for IPR and IPR equipment), with the portion of equipment used for semiconductor manufacturing derived from industry data.

To determine the market share represented by process refrigeration equipment used for semiconductor manufacturing, the EPA reviewed available data, including data provided by SEMI, its members, and suppliers.[51] Based on this information and meeting discussions, the EPA developed an estimate of the current stock of equipment and associated charge size, compared that to the total IPR market, and identified an amount of cooling equipment used for semiconductor manufacturing as separate from other IPR equipment. Based on this, we assumed the installed refrigerant in semiconductor IPR cooling equipment to be 150,000 kg. To calculate the IPR market share that semiconductor equipment comprises, we divide this figure by the total estimated refrigerant charge for all IPR uses.

As indicated by stakeholders and discussed in the preamble to this rule, the original transition schedule from the 2023 Final Rule was determined to be infeasible for this subsector. Given this, we have updated our baseline scenario to assume that the share of the market represented by semiconductor cooling equipment does not transition to alternatives below the limit by the 2026 and 2028 dates in the original 2023 Final Rule and instead transitions by the amended date of 2030.

---

[50] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

[51] The EPA had a series of meetings with SEMI in 2024 and 2025 during which data and assumptions regarding the relative size of the market and types of equipment used for cooling in semiconductor manufacturing were discussed. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Notice of Proposed Rulemaking, April 18, 2025, in the docket for this action.

Refrigerated Transport - Intermodal Containers

In the prior baseline, the EPA assumed that based on the 700 limit, all intermodal containers transition from R-404A and HFC-134a to R-450A and/or R-513A by the 2025 compliance date. Based on research and industry literature, we found that more than half are now manufactured with R-513A and about one-third is using CO_2, HFO-1234yf are also used.[52,53,54] The EPA did not receive or identify additional information to update baseline estimates in this subsector.

1.6 Policy Scenario Technology Adoption Assumptions

Modeling Compliant Technology Transition Options

Technology transition options evaluated in this analysis were compiled partly from subsector-specific literature and studies referenced in the methodology documentation that accompanies the Non-CO_2 Greenhouse Gas Emission Projections & Mitigation reports[55,56] and explained in section 3.2.2. of the original HFC Phasedown RIA (EPA-HQ-OAR-2021-0044-0227). Assumptions were then further updated based on sources identified in the subsector-specific sections of this document. Because this rule, like the 2023 Final Rule, does not restrict the use of existing equipment, the model assumes that existing HFC equipment continues to be used for its typical lifetime; *i.e.*, there is no pre-retirement of equipment. Market penetration of newer technologies complying with the regulations at 40 CFR part 84 is based on expert judgment and would apply as older HFC-using vintages reach their end of life and adopt the new technologies within the deadlines as set forth in the regulations.

The EPA's modeling approach assumes new, compliant equipment are brought online based on new demand as well as demand for replacement of legacy equipment reaching end of useful life in a given year, with the effect that the existing stock of equipment predominantly used in the past (*e.g.* R-404A and R-407A in supermarket systems) is gradually replaced over time. For the policy scenario, the EPA evaluated options that would comply with the limits and deadlines as amended by this rule. For example,

---

52 Carrier. (2025). NaturaLINE Container Refrigeration Unit. https://www.carrier.com/container-refrigeration/en/worldwide/products/Container-Units/naturaline/

53 Maersk Container Industry (MCI) Containers. (2024). New US Regulations on Refrigerants: Implications for Intermodal Containers. https://www.mcicontainers.com/stories/new-us-regulations-on-refrigerants-implications-for-intermodal-containers/

54 Cooling Post. (2024). Maersk adopts R1234yf for reefers. https://www.coolingpost.com/products/maersk-adopts-r1234yf-for-reefers/.

55 U.S. Environmental Protection Agency. (2019a). *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. EPA Report EPA-430-R-19-012. https://www.epa.gov/sites/production/files/201909/documents/nonco2_methodology_report.pdf.

56 U.S. Environmental Protection Agency. (2019b). *Global Mitigation of Non-CO2 Greenhouse Gases: 2010–2030*. EPA Report EPA-430-R-13-011. https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgs-report-20102030.

for supermarket systems during the period of 2027 until 2032, all new equipment is assumed to be to either CO_2, R-448A, or R-449A. From 2032 onward, all new systems are then assumed to transition to the same option assumed in the analysis for the 2023 Final Rule (*i.e.*, CO_2 in supermarket systems).

Where data allow the EPA based technology uptake assumptions on comparative costs of various technology options within subsectors directly affected by this rulemaking. In some cases, these costs are assumed to vary for different shares of the market, as described in more detail in the sections below. Comparative technology costs are further assumed to vary over time, based on assumed increased HFC prices in 2029.[57] This results in increased cost competitiveness of non-HFC options vis-a-vis HFC-based technology options and thus increased market shares for non-HFC options (namely CO_2) over time, as shown in Table 1-4.

As discussed in section ES.7, the binding HFC phasedown cap requires a broad mix of technology transitions and other measures (such as HFC re-use and leak mitigation) in order to keep demand for virgin HFCs below supply limits. The EPA has not at this time conducted an updated, comprehensive assessment of the comparative cost-effectiveness of all known mitigation options across subsectors (including those not directly affected by this rule) and in turn a hypothetical optimal set of compliance options that would maximize market efficiency. Technology uptake assumptions used to develop the policy scenario as detailed in this section reflect likely market outcomes based largely on the comparative engineering costs of competing compliance options within a given subsector (*e.g.*, R-448A and R-449A versus CO_2 for supermarket refrigeration systems). Thus, a limitation of this approach is that specific technology uptake assumptions below are not necessarily representative of optimal market behavior when considering the HFC phasedown limits across all subsectors.

Finally, it is important to note that while the EPA assumes a discrete set of technology options for purposes of modeling compliance, these are not prescriptive, and many other options exist for the markets to explore.

Table 1-4 below summarizes technology adoption assumptions in both baseline and policy scenarios. The remainder of this section goes on to describe subsector-specific assumptions in more detail.

---

[57] This year was chosen as an inflection point in HFC prices for modeling purposes, as it is the next year in which a significant step-down in HFC consumption and production limits will occur per the statutory phasedown schedule. For purposes of this analysis, the EPA assumes a baseline HFC price increase of approximately 55% in 2029. We note that there is significant uncertainty regarding potential price increases, depending on actual demand vis-a-vis supply as well as the assumed price elasticity of demand for HFCs. We further note that in reality price changes will likely occur both before and after the inflection year of 2029, which would result in potentially higher or lower rates of technology adoption and resulting cost savings than those estimated for purposes of this analysis. For more details and discussion, see Section 4 of this analysis.

Table 1-4: Summary of Technology Adoption Assumptions in Baseline and Central Policy Scenario [a]

Subsector [b]	***Baseline***	***Policy***
Retail Food – Supermarkets	100% market penetration of CO2 in new equipment starting in 2027	A share of the new equipment market (20%) opts to transition to CO_2 during the compliance period of 2027-2028, while the remainder (80%) opts for R-448A or R-449A. CO_2 market share rises to approximately 50% in 2029, and then 100% from 2032 onward.
Retail Food – Remote Condensing Units	100% market penetration of CO_2 in new equipment starting in 2026.	New equipment market share for CO_2 and A2Ls, respectively, are 16% and 34% during the compliance period of 2026-2028, while the remainder (50%) opts for R-448A or R-449A. CO_2 market share rises to approximately 34% in 2029. The market then transitions fully to 43% CO_2 and 57% A2Ls from 2032 onward.
Cold Storage Warehouses	100% market penetration of ammonia in new equipment starting in 2026.	A share of the market (5%) opts to transition to an interim refrigerant (R-513A) during the compliance period of [2026-2028], during which the limit is set at 700, and then transitions to ammonia/CO_2 to meet the limit by 2032. Remainder of the market transitions to ammonia as previously assumed.
IPR: Refrigerated Centrifuges*	The share of the market represented by refrigerated centrifuges (0.034%) does not transition to CO_2 until 2028, given present limits on technical achievability.	No change from updated baseline assumptions.
IPR: Laboratory Shakers*	The share of the market represented by laboratory shakers (0.003%) does not transition to CO_2 until 2028, given present limits on technical achievability.	No change from updated baseline assumptions.
IPR: Semiconductors*	The share of the market represented by semiconductor manufacturing (0.118%) does not transition to CO_2 until 2030 given present limits on technical achievability	No change from updated baseline assumptions.
Intermodal Containers*	100% market penetration of R-513A, CO_2, and HFO-1234yf in new equipment starting in 2025.	The share of the market operating at temperatures as described in this rule (about 6.07%) transitions to R-452A equipment instead of R-513A equipment. Remainder of market transitions to R-513A, CO_2, or HFO-1234yf consistent with updated baseline assumptions.

[a] Vintaging Model market penetration assumptions are based on new demand as well as demand for replacement of legacy equipment reaching end of useful life. Thus, market penetration and installation rates included in this table are representative of demand in both new facilities as well as at existing facilities.
[b] Note that an asterisk (*) indicates there has been no change in adoption rate assumption from proposal.

Supermarkets

For this subsector, the EPA modeled uptake of compliant technologies in the policy scenario based on review of market data and information received by stakeholders on available technologies. In cases where EPA lacks information on the precise mix of competing technologies that will be adopted, an underlying assumption was made that a model facility will choose the most cost-effective technology available. It was further assumed that the most cost-effective option varies from one model facility to the next, based on information reviewed by the EPA.

As discussed in sections 1.4, 1.5, and 7.3, the EPA has received and identified a number of information sources indicating that R-448A, R-449A, and, to a lesser degree, CO_2 are increasingly widely adopted technology options for supermarket systems and will be the most commercially prominent options available to supermarkets during the compliance period of 2027-2031 (when the limit for the subsector will be 1,400, based on the amendments in this rule). The EPA notes that the relative market penetrations of these two alternatives during this period is uncertain but assumes that a majority of firms are likely to act primarily based on the comparative cost effectiveness of each option. However, as indicated by information received by the EPA, there are a wide range of estimates regarding the comparative cost effectiveness of CO_2 systems in particular. Based on additional literature review and consultation with stakeholders, our understanding is that the cost effectiveness of CO_2 systems depends in large part on energy efficiency (which is dependent in part on outdoor ambient temperature and system design features) as well as the availability of skilled labor and expertise in the management of the higher operating pressures inherent in these systems, which may vary by region.[58]

To best represent this variation, rather than modeling CO_2 system costs as a single point estimate, the EPA developed a distribution of the potential incremental costs of adopting CO_2 technology. Given the lack of robust observed data related to system performance, we modeled a Beta-PERT (Program Evaluation and Review Technique) distribution, which requires only minimum, maximum, and most likely values. The resulting distribution is assumed to be representative of the spread of cost-effectiveness likely to be seen in the actual market, with the bottom quartile generally representing the share of the market for which CO_2 is more cost effective (*e.g.*, lower ambient temperature, higher prevalence of technical expertise to

[58] EPA meeting with NASRC members on March 18, 2026. EPA meeting with Copeland on January 20th, 2026. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.

optimize performance) and the upper quartile representing the share of the market for which CO_2 is more cost prohibitive. The exact share of actors assumed to choose CO_2 is then assumed to be the share where incremental costs are below zero (*i.e.*, a net savings) relative to the competing option.

To account for increased cost-effectiveness of CO_2 as HFC prices increase over time, the EPA modeled incremental costs for two time periods: one with HFC prices at today's levels, which was used to determine market shares for the 2027-2028 compliance period; and one with elevated HFC prices, which was used to determine market shares for the 2029-2031 period and results in increased cost-effectiveness of CO_2 starting in 2029.[59] For both periods, an assumption is made that firms are rational economic actors with profit maximizing motives. Thus, the share of the market for which the relative cost of a CO_2 system is negative (provides net savings) will opt to adopt CO_2 technology despite the flexibility offered in the final rule, while those for which the incremental cost is positive will choose R-448A or R-449A technology.

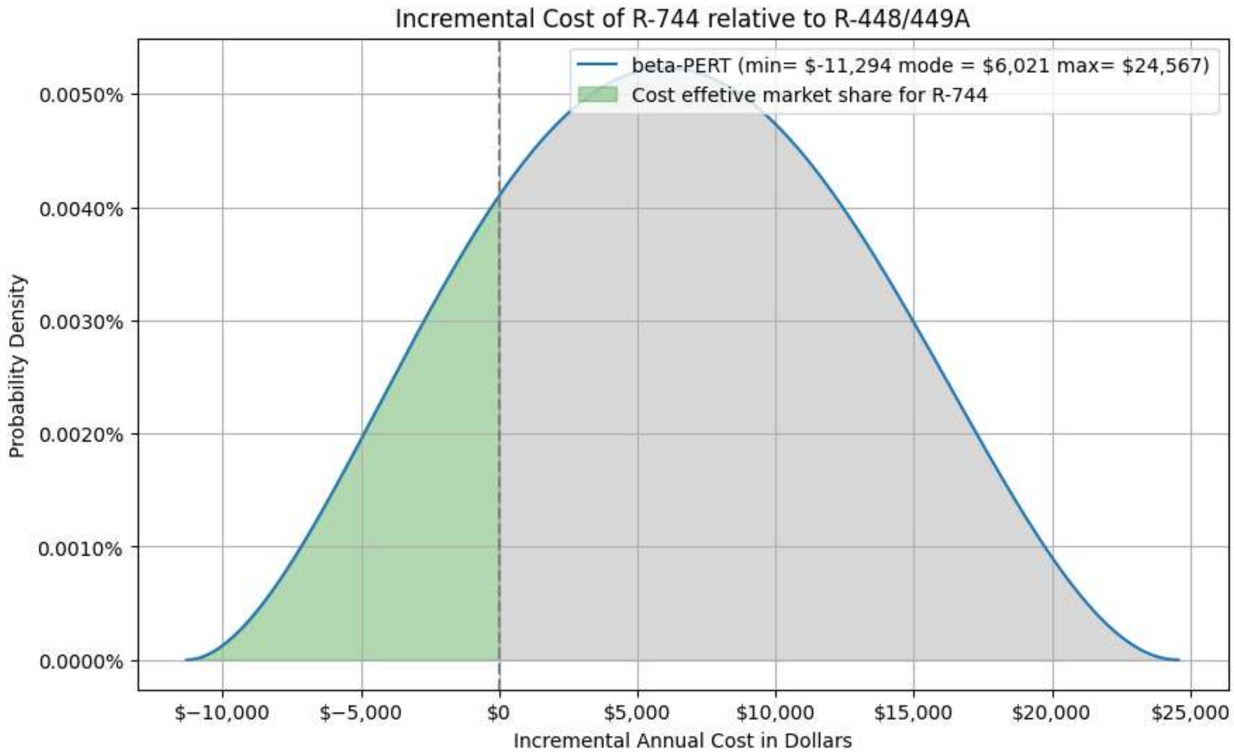
Figure 1 below shows the resulting distributions based on our assumptions of the comparative costs of these technologies, and Table 1-5 details the key input parameters used to simulate the distributions. Taking the example of the 2027-2028 period, based on the EPA's assumptions CO_2 would yield incremental cost savings (relative to the alternative R-448A or R-449A) for approximately 20% of model supermarket facilities, while for the remainder it would result in incremental costs. Thus, 20% of demand for new supermarket systems is assumed to be met by CO_2 technology during this compliance period (despite the flexibility provided by this rule) while the remainder of the market (approximately 80%) will opt for R-448A or R-449A. The market share for CO_2 then increases to approximately 50% during the 2029-2031 period. These market shares were used as direct inputs to the VM to examine the effects of this rule in terms of total HFC demand changes relative to baseline.[60] The EPA further notes that these

[59] See section 2 of this document for specific HFC prices assumed for the pre-2029 modeling period. As described earlier in this document, for the post 2029 modeling period EPA assumed a price increase of approximately 55%. We note that there is significant uncertainty regarding potential price increases, depending on actual demand vis-a-vis supply as well as the assumed price elasticity of demand for HFCs. We further note that in reality price changes will likely occur both before and after the inflection year of 2029, which would result in potentially higher or lower rates of technology adoption and resulting cost savings than those estimated for purposes of this analysis. For more details and discussion, see Section 4 of this analysis.

[60] Market share or "market penetration" is an input parameter in the Vintaging Model determining the share of new units met by a given equipment or technology type. Market shares and resulting new units by equipment or technology type are calculated annually. See section 1.3 for additional discussion of the Vintaging Model.

resulting market shares are generally consistent with information the EPA has received from stakeholders and identified in literature on the relative rates of adoption of these competing technologies.[61,62,63,64]

Figure 1: Distributions of Incremental Annual Costs for Model Supermarket Facilities for 2027-2028 and 2029-2031 Compliance Periods



[61] EPA. (2026b). Technical Memorandum: Summary of Recent Data for the Large Retail Food End Use and Proposed Vintaging Model Updates

[62] ATMO. (2025). 2024 North American Food Industry: Economic Outlook. https://atmosphere.cool/wp-content/uploads/2025/02/2024_ATMO_Marketreport_03_NorthAmerica.pdf

[63] Butsch, J. (2025). Public comment from Copeland. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0112.

[64] Rosenberg, E. (2025). Public comment from The Chemours Company, FC LLC. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0132.

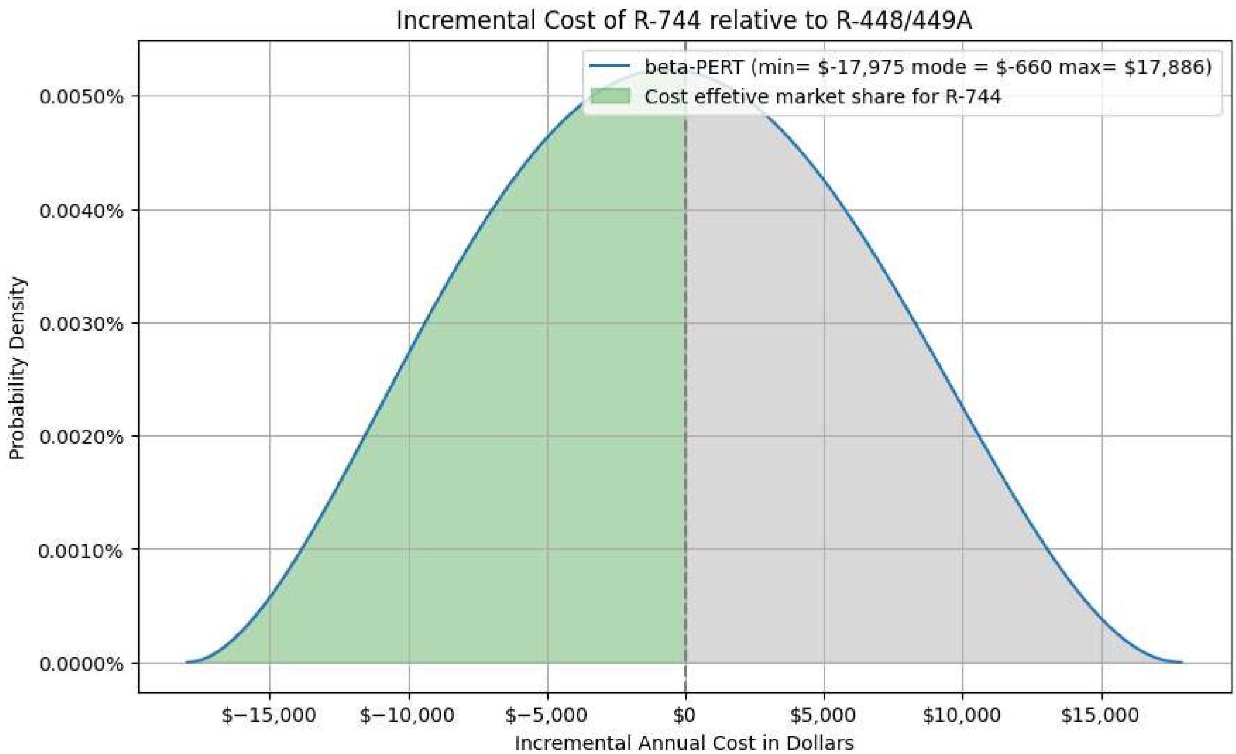


Table 1-5: Cost Distribution Parameters

Parameter	**Value (2027-2028 period)**	**Value (2029-2031 period)**
N (number model facilities with new installations per year)	3,865[a]	3,865[a]
18-year annualized incremental CO2 system cost (most likely/mean energy performance)[b]	$6,021	-$660
18-year annualized incremental CO2 system cost (worst-case energy performance)[b]	$24,567	$17,886
18-year annualized incremental CO2 system cost (best-case energy performance)[b]	-$11,294	-$17,975

[a]Estimated number of new installations in 2027 based on the Vintaging Model. For purposes of developing distributions representing the range of comparative technology cost effectiveness as described in this section, this value was used for both compliance periods.
[b]Mean/most likely values of incremental costs estimated using engineering costs data as described in section 2.1. Worst-case and best-case estimates are based on high- and low-end values of incremental energy performance, which are assumed to range from losses of 9% to gains of 27% based on sources reviewed and summarized in section 2.1.

Remote Condensing Units

As with supermarkets above, for this subsector, the EPA modeled uptake of compliant technologies in the policy scenario based on review of market data and information received by stakeholders on available technologies. In cases where the EPA lacks information on the precise mix of competing technologies that will be adopted, an assumption was made that a model facility will choose the most cost-effective technology available. It was further assumed that the most cost-effective option varies from one model facility to the next, based on information reviewed by the EPA.

Review of market data and information provided by stakeholders indicates that the leading technology options available as compliance options for this subsector include A1 refrigerants (R-448A and R-449A), A2Ls (R-454A, R-454C, and R-455A) and to a lesser degree CO_2. Based on the limits and compliance dates as amended by this rule, units that use A1 refrigerants are available as a compliant technology option through 2031, while from 2032 onward, A2Ls and CO_2 are expected to be the primary compliant technologies available. As discussed in section 1.5, the EPA has updated its baseline assumptions of historic rates of adoption of these technologies based on market data through 2025. For 2026, information received by the EPA from stakeholders indicated that R-448A and R-449A units will make up approximately 50% of sales for the year, with A2Ls and CO_2 making up the remainder.[65]

EPA's general approach was to assume that A1 HFC-based and A2L compliance options will make up the majority of new equipment, with A1 HFC options in particular making up 50% of the market during the interim period. CO_2 market shares are assumed to rise over time with increased HFC prices and with the fact that most A1 HFC options are above the lower limit, they are not assumed here as a compliance option starting in 2032. However, a majority of the market is still assumed to opt for either A1 HFC-based or A2L options during the interim period or for A2L options from 2032 onward, as these options have on average lower incremental costs. To determine the specific market share for CO_2 over time, as with above the EPA used probabilistic distribution curves of incremental costs. The approach is based partly on the EPA's understanding that—as with supermarket CO_2 systems—the cost competitiveness of CO_2 equipment can vary significantly depending on factors such as regional temperature, operating conditions, and availability of skilled labor.

As with the approach described above, we used a Beta-PERT distribution to model market shares. The resulting distribution is assumed to be representative of the spread of cost-effectiveness likely to be seen in the actual market, with the bottom quartile generally representing the share of the market for which CO_2 is more cost effective (*e.g.*, lower ambient temperature, higher prevalence of technical expertise to optimize performance) and the upper quartile representing the share of the market for which CO_2 is more cost prohibitive. The exact share of actors assumed to choose CO_2 is then assumed to be the share where incremental costs are below zero (*i.e.*, a net savings) relative to the competing option.

---

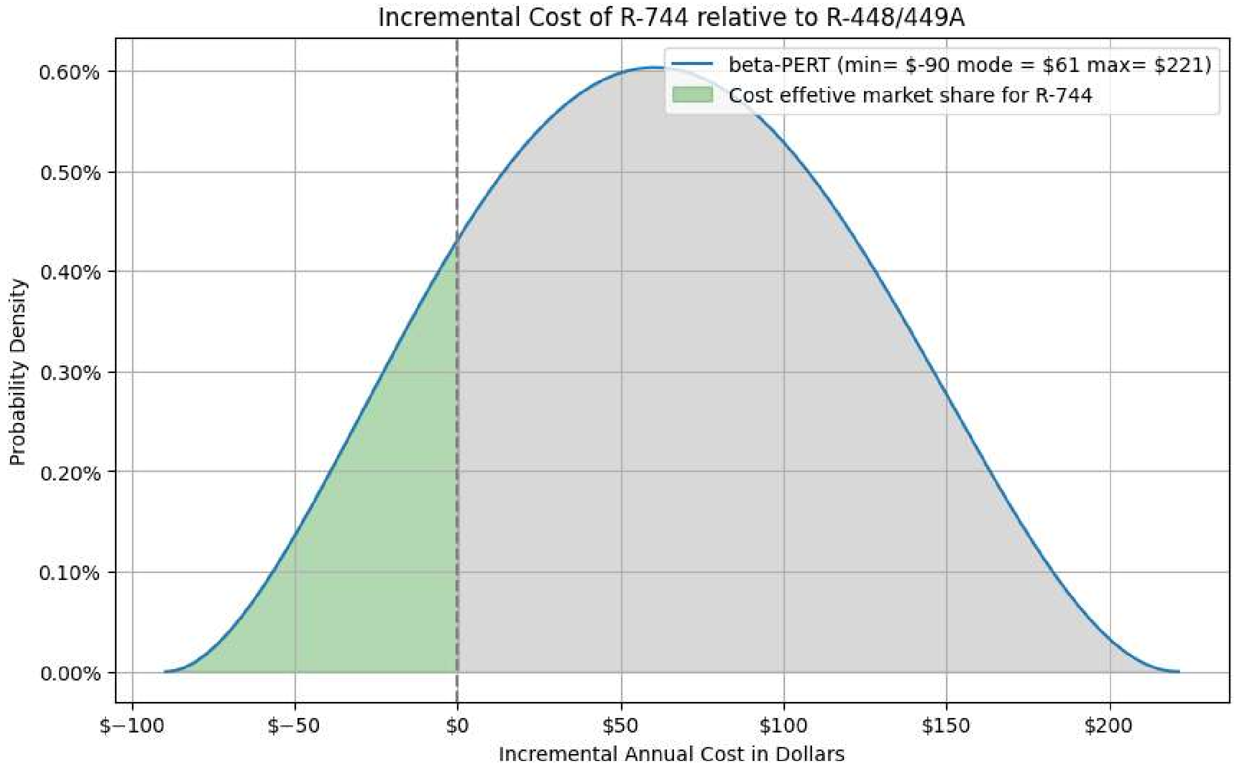
[65] *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.

To account for increased cost-effectiveness of CO_2 with an assumed increase in HFC prices in 2029, the EPA modeled incremental costs for two time periods: one with HFC prices at today's levels, which was used to determine market shares for the 2026-2028 compliance period; and one with elevated HFC prices, which was used to determine market shares for the 2029-2031 period and results in increased cost-effectiveness of CO_2 starting in 2029.[66] For both periods, an assumption is made that firms are rational economic actors with profit maximizing motives. Thus, the share of the market for which the relative cost of a CO_2 system is negative (provides net savings) will opt to adopt CO_2 technology, while the remaining share will adopt A2L or A1 technology.

Figure 2 below shows the resulting distributions based on our assumptions of the comparative costs of these technologies, and Table 1-6 details the key input parameters used to simulate the distributions. Taking the example of the 2026-2028 period, based on the EPA's approach CO_2 would yield incremental cost savings for approximately 16% of model facilities. Thus, 16% of demand for new equipment is assumed to be met by CO_2 technology during this compliance period. It is then assumed that 50% of demand is met by A1 options as described above while the remaining 34% opts for A2L equipment. These market shares were used as direct inputs to the VM to examine the effects of this rule in terms of total HFC demand changes relative to baseline.

[66] See section 2 of this document for specific HFC prices assumed for the pre-2029 modeling period. As described earlier in this document, for the post 2029 modeling period EPA assumed a price increase of approximately 55%. We note that there is significant uncertainty regarding potential price increases, depending on actual demand vis-a-vis supply as well as the assumed price elasticity of demand for HFCs. We further note that in reality price changes will likely occur both before and after the inflection year of 2029, which would result in potentially higher or lower rates of technology adoption and resulting cost savings than those estimated for purposes of this analysis. For more details and discussion, see Section 4 of this analysis.

Figure 2: Distribution of Incremental Annual Costs for Model Facilities using Remote Condensing Units for 2026-2028 and 2029-2031 Compliance Periods



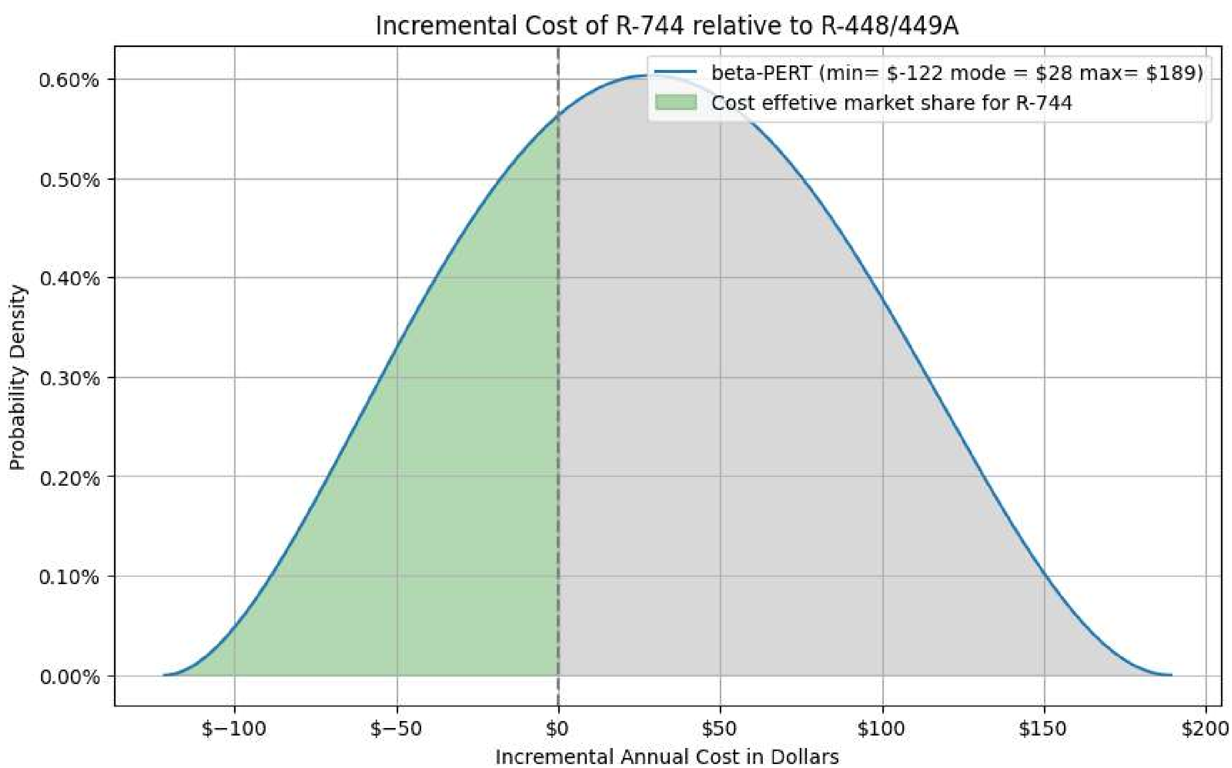


Table 1-6: Cost Distribution Parameters

Parameter	Value (2026-2028 period)	Value (2029-2031 period)
N (number new units per year)	152,534[a]	152,534[a]
20-year annualized incremental CO2 system cost (most likely/mean energy performance)[b]	$61	$28
20-year annualized incremental CO2 system cost (worst-case energy performance)[b]	$221	$189
20-year annualized incremental CO2 system cost (best-case energy performance)[b]	-$90	-$122

[a]Estimated number of new installations in 2026 based on the Vintaging Model. For purposes of developing distributions representing the range of comparative technology cost effectiveness as described in this section, this value was used for both compliance periods.
[b] Mean/most likely values of incremental costs estimated using engineering costs data as described in section 2.1 and 2.2. Worst-case and best-case estimates are based on high- and low-end values of incremental energy performance, which are assumed to range from losses of 9% to gains of 27% based on sources reviewed and summarized in section 2.1 and 2.2.

Finally, for the compliance period from 2032 onward when A1 refrigerants will no longer be available as compliance options, the EPA assumes that the new equipment market will comprise only CO_2 and A2Ls. For this period, we again used a probabilistic distribution curve to determine the mix of technology uptake. A2L options are assumed to have modest cost premium relative to A1 options, but still on average have lower costs than CO_2 equipment. As a result, CO_2's market share rises during this period, but a majority of the market is still assumed to opt for A2Ls. **Figure 3** below shows the resulting distribution and Table 1-7 details the key input parameters used to simulate the distributions.

Figure 3: Distribution of Incremental Annual Costs for Model Facilities using Remote Condensing Units for 2032-2050 Compliance Period

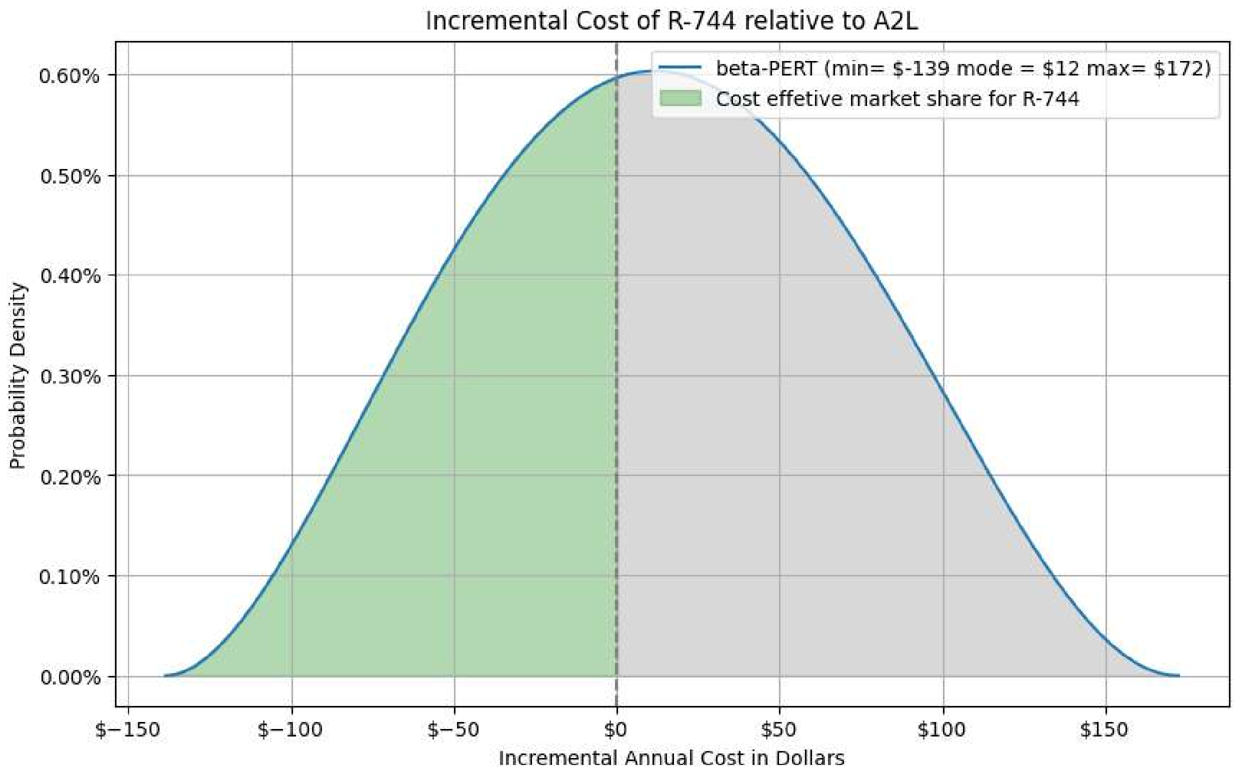


Table 1-7: Cost Distribution Parameters

Parameter	Value (2032-2050 period)
N (number new units per year)	152,534
20-year annualized incremental CO2 system cost (most likely/mean energy performance)	$12
20-year annualized incremental CO2 system cost (worst-case energy performance)	$172
20-year annualized incremental CO2 system cost (best-case energy performance)	-$139

Cold Storage Warehouses

For this subsector, the EPA did not receive from stakeholders or independently identify sufficient information on the relative costs of competing technologies to use as a basis for adoption assumptions. Instead, the EPA modeled uptake of compliant technologies in the policy scenario based on review of market data and information received by stakeholders on the most prominent technologies used.

The EPA has identified literature and market reports indicating that there has already been large industry movement towards low-charge ammonia systems.[67] According to data from the International Association of Refrigerated Warehouses FY2020 survey, about 90% of the cold storage warehouse market already uses ammonia systems.[68] This is likely in part, as literature suggests, due to the fact that while ammonia is more expensive than HFC systems in terms of capital expenditures,[69] the energy and annual costs savings are often much larger than that of HFC systems.[70,71,72,73,74]

Review of information provided by stakeholders indicates that preferences of some market actors may be determined by factors other than comparative system performance and capital costs. As discussed in several comments, some firms may prefer a non-toxic refrigerant, particularly in smaller warehouses or distribution facilities closer to higher-density population centers, and/or have concerns about ammonia's toxicity risk to employees.[75,76] The extent to which these factors play into firms' decision making is uncertain, but the EPA reiterates that market data suggest the vast majority of facilities rely on ammonia as a refrigerant, while a modest share will opt to use newer $CO2_2$ -based technologies or opt to rely on HFCs.

As discussed in section 1.5, the EPA has updated its baseline assumptions of technology adoption in this subsector based on available market data, with the assumption that 5% of the market currently still uses HFC-based refrigerants. In the policy scenario, it is assumed that this same market segment will opt for R-513A until the revised compliance deadline of 2032, after which point all new system installations will go to either ammonia or CO_2.

---

[67] ATMOsphere. (2023). *Natural Refrigerants: State of the Industry. Commercial and Industrial Refrigeration in North America, Europe, and Japan*. 2022 Edition. https://atmosphere.cool/marketreport-2022/

[68] IARW. (2023). *Productivity and Benchmarking Survey.* Global Cold Chain Alliance. https://www.gcca.org/resource/iarw-productivity-and-benchmarking-tool-and-executive-summary/

[69] IRPros. (2025). *Ammonia vs. CO2 vs. HFC: Choosing the Right Refrigerant for Your Industrial Facility*. https://irpros.com/ammonia-vs-co2-vs-hfc-choosing-the-right-refrigerant-for-your-industrial-facility/

[70] Jensen, S. (2013). *Ammonia in the Traditional HFC Territory: How Does It Compare?* IIAR Technical Paper #2.

[71] Scott, D. (2016). *Comparing Evaporative and Air-Cooled Condensing in Ammonia and HFC-507 Refrigeration Systems.* IIAR.

[72] Herzog C & Lepschat. (2025). *Operating Cost Comparison Between Transcritical CO2 and Ammonia Recirculation Systems in a Cold Storage Warehouse*. *IIAR.*

[73] Jensen, S. (2017). *Energy Performance of Low Charge, Central Type, Dual Stage NH3 Refrigeration Systems in Practice.* IIAR.

[74] IRPros. (2025). *Ammonia vs. CO2 vs. HFC: Choosing the Right Refrigerant for Your Industrial Facility*. https://irpros.com/ammonia-vs-co2-vs-hfc-choosing-the-right-refrigerant-for-your-industrial-facility/

[75] Public comment from ALTA Refrigeration. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0147.

[76] Public comment from New England Cold. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0057.

Refrigerated Transport - Intermodal Containers

EPA's general approach for modeling market transitions in the policy scenario was to isolate the market segment exempted under the final rule and assume this segment transitions instead to R-452A-based units instead of R-513A-based units that would have been necessary to comply with the original restrictions. Cost savings relative to baseline then accrue to the extent that R-452A-based units are a more cost-effective option relative to R-513A-based units (for details on these cost assumptions, see section 2.5). The EPA did not identify additional information through comments received or literature regarding the share of the intermodal containers market that is exempted under the amendments contained. Thus our approach for estimating this market segment remains as it was in the proposed rule economic impacts memo and is summarized below.[77]

The 2023 Final Rule established restrictions on the use of HFCs in the refrigerated transport - intermodal containers subsector starting January 1, 2025. This limit for this subsector is set at 700. The original restrictions applied to equipment where the temperature of the refrigerant entering the evaporator (for direct heat exchange systems) or the temperature of the fluid exiting (for chillers) is -50 °C or higher, but exempted units where temperatures are below -50 °C. This rulemaking further amends these restrictions such that the regulations to not apply where temperature ranges are below -35°C.

To account for the additional market share that is exempted under this rule. Our analyses further subdivides the refrigerated transport – intermodal containers subsector market size by box temperature achieved by refrigeration equipment in intermodal containers. Specifically, we break out this subsector to determine the share of affected equipment and systems that are designed to achieve a box temperature between -35 ºC and -50 ºC.[78]

To determine the share of the intermodal refrigerated transport container market represented by equipment designed to achieve this box temperature, the EPA reviewed available data and consulted with industry experts. Based on the EPA discussion with Trane Technologies ("Trane") on December 18, 2024, the EPA obtained the following information and performed the calculations shown Table 1-8 below.

Table 1-8: Data and Estimates on Market Size of Intermodal Containers in the United States and Globally

Intermodal Containers Data	***Data provided by Trane***

[77] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

[78] The regulations at 40 CFR part 84 subpart B exempt equipment operating at temperatures below -50 ºC.

Intermodal containers manufactured globally each year	140,000	
Intermodal containers manufactured globally with refrigeration equipment designed to achieve temperatures between -35 ºC and -50 ºC	5,000 - 12,000	
Intermodal containers with refrigeration equipment designed to achieve temperatures between -35 ºC and -50 ºC entering the United States each year	200	
Assumption: the U.S. share of the global market for refrigeration equipment in intermodal containers designed to achieve temperatures between -35 ºC and -50 ºC is proportional to the U.S. share of the global market for intermodal containers operating at all temperatures		
Domestic market share of intermodal containers with refrigeration equipment designed to achieve temperatures between -35 ºC and -50 ºC (relative to equipment operating at all temperatures)	**Low**	**High**
	3.57%	8.57%

Research from Abt Global[79] further corroborated the estimated market share range indicated in the table above. They found only one model with refrigeration equipment designed to achieve temperatures in the -35 ºC to -50 ºC range out of 19 identified models. In the absence of more detailed industry data, one could assume equal market share for each of these models, which would result in a market share of 1/19 (5.26%), which sits within the range estimated in the table above.

For this analysis, we assume the U.S. share of the global market for intermodal units with refrigeration equipment designed to achieve temperatures between -35 ºC and -50 ºC is proportional to the U.S. share of the global market for refrigerated intermodal units operating at all temperatures. We thus estimate a domestic market size between 2,333 and 5,600 units, and a resulting estimated average domestic market share for intermodal units with refrigeration equipment designed to achieve temperatures between -35 ºC and -50 ºC of 6.07%. Because the EPA proposed and is finalizing to adjust the temperature threshold at which restrictions in the refrigerated transport – intermodal containers subsector apply, this analysis assumes the costs and consumption/emission reductions from this subsector are reduced as compared to those previously presented.

In addition to revising its prior analysis to reflect the exemption of the share of affected equipment and systems that are designed to achieve a box temperature between -35 ºC and -50 ºC as described above, the EPA has also updated its assumptions regarding the refrigerant used by this market segment. Information from the industry indicates that manufacturers of intermodal containers with box temperatures between -35 ºC and -50 ºC are transitioning to utilize R-452A, a refrigerant with an EVe of 2,140. The EPA

[79] See research memo from Abt Global included in the docket for this action.

therefore assumes that a transition to this blend for new equipment in the affected market segment has been achieved as of 2025.

Section 2. Engineering Costs

As discussed earlier in this document, the EPA has relied on a combination of new data sources in order to update its estimate of engineering costs associated with transitioning to compliant equipment. In addition to the information provided by stakeholders as discussed in sections 1.4 and 7.3, the EPA has collected additional data through literature review and stakeholder engagement. Engineering cost analyses for all subsectors include annual average refrigerant prices (per pound) as of Q4 2025 collected from several sources.[80]

The updated data and cost factors discussed in this section are limited to that which was ultimately incorporated into the EPA's revised analysis. The EPA identified several data points through comments and literature that were ultimately excluded from analysis. This determination varied on a case-by-case basis, but was guided by:

- Recency of the datapoint – we relied on data published within the past 10 years, except in cases where no other verifiable data was available
- Comparability to other sources – we excluded outliers that were orders of magnitude larger/smaller than other data points from different sources, substantially impacted the mean, and/or was credibly disputed by industry stakeholders

For each technology transition option, the EPA used data received from comments, literature, and technical expertise to estimate:

- capital cost (*e.g.*, the cost premium of a CO_2 system relative to an HFC system)
- annual revenue (*e.g.,* savings from transition to a cheaper chemical or increased energy efficiency)
- annual costs (*e.g.*, costs from transition to a more expensive chemical or lower energy efficiency)
- net HFC consumption avoided/incurred for a given facility after transition to new chemical

[80] The EPA regularly tracks and updates information on refrigerant prices by collecting and averaging data points across websites of manufacturers, wholesale retailers, and related organizations, including Halotron, United Refrigeration Inc., Royal Refrigerants, eRefrigerants, Fluorofusion, Refrigerant Depot, and J&J A/C Supply Inc.

To calculate a compliance option's break-even price for a given year, the relevant equipment lifetime assumed in the EPA's VM was used to calculate annualized costs using an assumed opportunity cost of capital of 7%. This method develops annualized incremental cost per model facility over the course of anticipated equipment lifetime. Applying these cost factors across new units added, in operation, and phased out per year by equipment type from the VM, we calculate total engineering costs as well as consumption and emission changes over time. A summary of the technology transition options analyzed, and the incremental cost of each transition option, is shown in Appendix B.

2.1 Supermarkets:

Capital Costs/Savings Data

Comments and literature converge on CO_2 capital cost premiums (relative to HFC systems) ranging between 10% and 20%,[81,82,83,84] with a few outlier data points,[85,86] the most extreme of which was excluded based on its high divergence from other data. Literature and comments indicate that the capital investment (including system, cases, and installation including first fill of refrigerant) of an HFC rack system for an average sized supermarket is around \$1.9 million. Thus, accounting for a capital cost premium of about 15% (average across several comment and literature sources), the EPA estimates the total capital cost for a CO_2 system to be about \$2.2 million.

The majority of the data reviewed by the EPA were not explicit about whether or not an adiabatic cooler or other additional technology was used in tandem with a CO_2 system. However, some data provided by stakeholders distinguished between costs for adiabatic versus non adiabatic CO_2 systems. Based on discussions with industry stakeholders, the EPA assumes that a majority of new domestic CO_2 systems are

---

[81] Hillphoenix. (2019). *DeCO2ded - Understanding the ROI on CO2 Refrigeration Systems*. Hillphoenix. https://www.hillphoenix.com/wp-content/uploads/2018/02/Advansor-White-Paper-RS-DeCO2ded-Understanding-ROI-on-CO2-Systems-Final-.pdf
[82] M&M Carnot & SubZero Constructors. (2023). *A Case Study for CO2 Condensing Units in Various Climates.* ATMO Summit. https://mmcarnot.com/wp-content/uploads/2023/02/2_FINAL_Andrews-Gilliland_MM-Carnot-SubZero.pdf
[83] Public comment from Copeland. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0112.
[84] North American Sustainable Refrigeration Council (NASRC). (2024). *CO2 Case Study: Grocery Outlet.* NASRC. https://nasrc.org/wp-content/uploads/2024/08/NASRC_GroceryOutletCaseStudy_Final.pdf
[85] Gibbons, C and Meakin C. (2025). *HFC Transition in The Grocery Industry, An Updated Assessment (Prepared for FMI – The Food Industry Association).* Available in the docket for this action at EPA-HQ-OAR-2025-0005-0511.
[86] Public comment from Houchens Food Group. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0015.

accompanied by an adiabatic cooler. [87] Thus, for cases where data clearly designated costs for use of an adiabatic cooler versus no add on, the EPA relied on the former.

Annual Costs/Savings Data

The EPA was able to identify very limited data surrounding annual operating and maintenance (O&M), costs associated with transitioning from legacy supermarket systems to CO_2 systems.

One commenter suggested there is little to no difference in operating cost, but their comment also acknowledges significant investment in technician training and potentially higher labor costs as a result are possible, especially in the early stages of CO_2 adoption.[88] Another commenter stated that there is a cost due to a shortage of technicians with skills on transcritical CO_2 systems, and stated that the availability of such technicians varies with location. They suggested this fact is expected to increase labor costs, maintenance expenses, and store downtime.[89]

Additional maintenance costs for CO_2-based systems using an adiabatic cooler exist. As the cooler is used, the pads in the cooler can become fouled, for instance from calcification of the water used in the cooler. The frequency of how often the pads need to be replaced would vary on factors such as the amount of time it is in use and the hardness of the water, which also varies regionally.

Another commenter provided data suggesting that there are modest incremental annual operating costs for CO_2-based systems relative to HFC systems.

Based on the stakeholder input and the literature reviewed, the EPA estimates that incremental O&M costs for a CO_2-based system would on the high end be approximately 10% higher than those of a legacy HFC system, while on the low end there would be no incremental costs. A midpoint between these two bounds was used as a basis for estimating incremental annual O&M costs.

Energy Costs/Savings Data

Information collected during the comment period indicate a wide range of potential gains or losses in energy efficiency associated with transitioning from legacy supermarket systems (*i.e.*, R-404A, R-407A)

---

[87] Industry stakeholders confirmed that this is common practice in modern installs of CO_2 systems regardless of geographic location or climate. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.

[88] Public comment from Hillphoenix. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0015

[89] Gibbons, C and Meakin C. (2025). *HFC Transition in The Grocery Industry, An Updated Assessment (Prepared for FMI – The Food Industry Association).* Available in the docket for this action at EPA-HQ-OAR-2025-0005-0511.

to CO_2, ranging from 45% less efficient[90] to 32% more efficient.[91] Many commenters articulated the greatest challenge to achieving efficiency gains would be in warm climates where CO_2 systems would operate longer hours in a transcritical state. One common method employed to pre-cool the CO_2 before entering the gas cooler is to use add-on equipment such as adiabatic boosters, which also require the use of water. Additional research on the EPA's part and supplementary stakeholder engagement to clarify comments received indicated that on average CO_2 systems yield energy efficiency gains over HFC systems, but that overall energy efficiency performance could range from net losses to gains of as much as 27%.[92, 93,94] Not all estimates reviewed by the EPA provided details on facility location and/or average outdoor temperature or whether the system uses add-on equipment that improves efficiency such as an adiabatic booster. However, where noted, energy efficiency of CO_2 systems relative to HFC systems seems to be lower in warmer climate, but this issue is at least somewhat mitigated with installation of an adiabatic cooler. This gives credence to the hypothesis that energy efficiency gains are more difficult to achieve in warmer climates, though still achievable depending on system design, add-on equipment used, and optimized O&M strategies. As noted above, some data that were identified in comments and literature were excluded on the basis that they were significant outliers among the other data identified and their validity could not be corroborated through other sources. Balancing all these factors and the data received, the EPA assumes the increase in energy efficiency for CO_2 relative to R-448A, R-449A and R-404A is variable, with an average improvement of about 9.5%, a minimum of -9% (*i.e.*, a loss) and a maximum of 27%.

Water Usage

The EPA collected several data points regarding water usage associated with CO_2 systems in supermarkets when paired with an adiabatic cooler. While one commenter claimed that one CO_2 system (with adiabatic cooler) requires 500,000 gallons of water annually,[95] literature identified by the EPA as well as additional estimates provided by stakeholders suggest on average smaller quantities depending on

---

[90] Public comment from H-E-B, LP. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0122.
[91] Shecco. (2020). *World Guide to Transcritical CO2 Refrigeration.* Shecco Market Development. https://atmosphere.cool/fact_sheets/world-guide-to-transcritical-co2-refrigeration/
[92] North American Sustainable Refrigeration Council. (2024). *CO2 Case Study: Grocery Outlet.* NASRC. https://nasrc.org/wp-content/uploads/2024/08/NASRC_GroceryOutletCaseStudy_Final.pdf
[93] Public comment from Copeland. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0112.

[94] Some of the information included in the EPA's review of comparative system costs and performance also came in the form of additional supplementary data that is considered proprietary. The EPA incorporated this data into our review, but has not included the specific sources in the public docket given their confidential nature.
[95] Public comment from the Food Industry Association (FMI). Available in the docket for this action at EPA-HQ-OAR-2025-0005-0511.

location and design.[96] Averaging this information together, the EPA assumes that approximately 260,000 gallons on average are consumed annually by CO_2 systems using an adiabatic cooler. For commercial users, like supermarkets, water costs vary widely with an average cost of $6.13 per thousand gallons.[97,98]

The literature also points to an advantage a CO_2 transcritical system has compared to an HFC system to provide heating, for either space heating and/or potable water heating.[99] The need for space heating varies widely based on local temperatures, as well as system design. Likewise, the need for hot potable water would vary based on the activity of a supermarket. For instance, a store that provides food products mainly packaged off-site might have minimal needs for additional hot water, making such an investment not likely, while a store that offers on-site sized, cooked, and/or packaged foods would see the hot water as an advantage for cleaning. The EPA received little data on the costs and benefits of heat reclaim; therefore, we do not include these savings in our calculation, although they may be an important consideration for some supermarkets.

Central Estimate for Engineering Costs

Based on industry research, we assume the average supermarket is between 40,000-45,000 square feet.[100,101] All estimates presented in Table 2-1 below have been scaled, where appropriate, to reflect this average store size. All dollar values are presented in terms of 2024 dollars.

Table 2-1: Central Estimate Factors for Supermarkets

Variable	***Value***	***Unit***
Model Facility (same across all technologies)		
45,000 sq. ft. Store Average Charge Size	1,111	kg
Annual Leak Rate	15%	
Equipment Lifetime	18	years
Capital Costs		
DX System Cost (R-404A, R-407A, R-448A, or R-449A)	$1,924,000	

[96] M&M Carnot & SubZero Constructors. (2023). *A Case Study for CO2 Condensing Units in Various Climates.* ATMO Summit. https://mmcarnot.com/wp-content/uploads/2023/02/2_FINAL_Andrews-Gilliland_MM-Carnot-SubZero.pdf
[97] Ibid.
[98] U.S. Environmental Protection Agency. (2026a). Data and Information Used by WaterSense. https://www.epa.gov/watersense/data-and-information-used-watersense#Cost%20of%20Water (for 2024).
[99] Danfoss. (2015). *Discover the opportunities of transcritical CO_2 with heat reclaim*. https://assets.danfoss.com/documents/latest/57233/BE181286422948en-000101.pdf
[100] FMI. (2026). *Food Industry Facts.* The Food Industry Association. https://www.fmi.org/our-research/food-industry-facts
[101] *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.

Capital (equipment + installation) Cost Premium for CO_2	14.79%	
O&M Costs		
Incremental Maintenance Cost of CO_2 (annually)	5%	
Energy Usage		
Energy Consumption	913,900	kWh/year
Increase EE for CO_2 vs HFC system (*e.g.*, R-407A, R-404A, R-448A, R-449A)	9.62%	
Energy Cost	$0.13	$/kWh
Water Usage		
Average annual water usage of CO_2 system w/adiabatic cooler	258,400	Gallons
Cost of Water	$6.13	$/1000 gallons
Refrigerant Costs[a]		
Cost for R-404A, R-507A, R-407A	$51.17	per kg
Cost for R-448A/R-449A	$51.17	per kg
Cost for CO2	$6.36	per kg

[a] As discussed earlier in section 2 and in Appendix D, refrigerant costs presented here are averaged across several tracked sources and are recent as of Q4 2025. See section 4.2 for analysis of potential HFC price increases.

2.2 Remote Condensing Units

Capital Costs/Savings Data

The EPA did not identify sufficient information through comments received on relative costs of competing technologies to update capital cost premiums for remote condensing units. While some information presented in comment was broad enough that it could arguably pertain to all retail food subsectors addressed by the rule (both supermarkets and remote condensing units), no data specific to remote condensing units was provided. Discussions with industry stakeholders did, however, illuminate some useful data points, described below.

Discussions with industry stakeholders also revealed that systems can be equipped with technology which allows users to easily transition between legacy HFCs (*i.e.*, R-404A, R-407F, R-407A, R-507A), R-448A, R-449A, and A2Ls without a complete overhaul of the system.

The EPA was able to identify the following general trends regarding the comparative costs of different remote condensing unit technology options:

Legacy HFCs vs. CO_2

A 3-horsepower (2.2 kW, 0.64 TR) medium temperature remote condensing unit using R-404A costs, on average, $4,136 (system only, no installation or initial charge costs, in 2024 dollars).[102,103,104] The initial cost of CO_2 is 1.5 times that of R-404A.[105]

Legacy HFCs vs. R-448A/R-449A

The EPA did not identify sufficient information through comments received or literature review on relative costs of legacy HFCs and R-448A/R-449A to update capital cost premiums for remote condensing units.

R-448A/R-449A vs. CO_2

Based on conversations with industry stakeholders, the EPA determined that the capital cost premium of CO2 systems relative to legacy HFCs and R-448A/R-449A is around 50%.[106]

Annual Costs/Savings Data

The EPA did not identify sufficient information through comments received or literature review on relative costs of legacy HFCs or R-448A/R-449A and CO_2 to serves as a basis for estimating comparative annual O&M costs. Given this, the EPA relied the above-described incremental maintenance costs for supermarket CO_2 systems and used them as a proxy for estimating incremental maintenance costs for CO_2-based remote condensing units as well. This approach results in higher incremental maintenance costs for CO_2-based remote condensing units relative to legacy HFC or R-448A/R-449A-based systems, although CO_2 systems are assumed to have lower refrigerant costs.

---

[102] Coldparts. (2026). *A1C907 – 3 HP Refrigeration Condensing Unit – Medium Temp – R-404A.* https://coldparts.com/shop/refrigeration-application/condensing-units/r-404a-refrigeration-condensing-units/r-404a-230v-1ph-medium-temperature-condensing-units/a1c907-medium-temp-r-404a-3-hp-refrigeration-condensing-unit/
[103] Barr Refrigeration. (2026). *3 HP Heatcraft Surplus Medium Temp System w/ electric defrost (1 ph 208/230v).* https://www.barrinc.com/product/5719/
[104] Chef's Deal Restaurant Equipment. (2026). *Turbo Air TS030MR404A3-T 3 HP Medium Temp Remote Refrigeration Unit with Scroll Compressor, 208-230V/3Ph/60Hz. https://www.chefsdeal.com/p/remote-refrigeration-units/turbo-air-ts030mr404a3-t?gad_source=4&gad_campaignid=20165435414&gbraid=0AAAAAD064AYV7Rx0HRl02YAHZqckOdEBN&gclid=Cj0KCQiAy6vMBhDCARIsAK8rOgnOYJlNXB7aiB864uW4gpIiounmPVj2xFEbufqdzSCBvInRHGQyGGkaAnwAEALw_wcB*
[105] United Nations Environment Program. (2016). *Lower-GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO2, ammonia and HFO case studies.* Climate & Clean Air Coalition. https://www.ccacoalition.org/sites/default/files/resources/Lower%20GWP%20Alternatives%20in%20Commercial%20and%20Transport%20Refrigeration.pdf
[106] EPA meeting with Lennox on February 6, 2026. *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.

Energy Costs/Savings Data

Market literature[107] indicate that the leading A2L options that are commercially available for use in this subsector (R-454C, R-454A, and R-455A) have varying levels of comparative performance and capacity gains or losses relative to legacy A1 HFC-bases systems. However, the EPA did not identify sufficient empirical data on the comparative performance of these options to make assumptions about efficiency gains or losses, and the EPA's understanding based on stakeholder consultation is that A2L systems are designed to have capacity and energy performance characteristics that are on-par with or better than A1 systems, and furthermore that all systems (whether A1 or A2L) will generally need to meet updated building code and efficiency standard, thus minimizing any meaningful difference in performance from an end-user perspective.

By contrast, review of available data and supplementary stakeholder consultation indicate that CO_2-based remote condensing units can provide significant energy efficiency gains (or in some cases losses) relative to both A1 and A2L systems, and that these differences are likely to occur even after considering efficiency standards due to the unique properties of CO_2-based systems. In cases where CO_2-based systems result in energy efficiency losses, additional engineering techniques may be required to meet updated efficiency standards or goals.

The EPA was able to identify the following general trends regarding the comparative energy performance of different remote condensing unit technology options:

<u>R-404A vs. CO_2</u>

Through literature review, the EPA found that CO_2 offers about 20% energy savings[108] over legacy HFCs (specifically R-404A), though that varies based on temperature range (25.4% for freezing mode, 16.2% for refrigeration mode).[109] Because the EPA received no other estimates specific to this subsector, we instead relied on the average energy efficiency gain of 9.62% used to model supermarkets.

<u>R-404A vs. R-448A/R-449A</u>

---

[107] Turpin, J. (2025). *A2L Commercial Refrigeration Equipment Hits the Market.* ACHR News. https://www.achrnews.com/articles/165195-a2l-commercial-refrigeration-equipment-hits-the-market

[108] United Nations Environment Program. (2016). *Lower-GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO2, ammonia and HFO case studies.* Climate & Clean Air Coalition.

[109] EPEE. (2020). *Sustainable cooling solutions: Emission Reduction in Food Factory with Panasonic CO2 Commercial Refrigeration*. European Partnership for Energy and the Environment. https://countoncooling.eu/wp-content/uploads/2020/06/Sustainable-cooling-cases-Panasonic-CO2-Refrigeration.pdf

The EPA did not identify sufficient information through comments received or literature review on relative costs of legacy HFCs and R-448A/R-449A to update energy cost/savings data for remote condensing units.

R-448A/R-449A vs. CO_2

The EPA did not identify information through comments received or literature review specific to energy costs/savings for remote condensing units using these technologies and therefore adopted the same energy efficiency gains as modeled in supermarkets (9.62%).

Water Usage

The EPA did not identify any information specific to remote condensing unit water consumption through either comments received or literature review and used the same incremental water consumption assumptions as described for supermarkets, scaled down to remote condensing units based on average charge size.

Central Estimate for Engineering Costs

All estimates presented in Table 2-2 below are presented in terms of 2024 dollars.

Table 2-2: Central Estimate Factors for Remote Condensing Units

Variable	***Value***	***Unit***
Model Facility (same across all technologies)		
Total Charge Size	7.66	kg
Equipment Lifetime	20	years
Annual Leak Rate	8%	
Capital Costs		
Cost of R-404A/R-407A Unit	$4,136	
Cost Premium of A2L Compatible Unit (*e.g.*, R-454A) Relative to A1	10%	
Cost Premium of CO2 systems vs R-404A/R-407A/R-448A/R-449A	50%	
O&M Costs		
Incremental Maintenance Cost of CO2 (annually)	5%	
Incremental water cost of CO2 (annually)	$12.34	
Energy Usage		
Energy Consumption	7,926	kWh/year
Increase EE for CO2 vs. R-404A	9.62%	
Increase EE for CO2 vs R-448A/R-449A	9.62%	
Energy Cost	$0.13	

Refrigerant Costs[a]		
Cost for R-404A, R-507A, R-407A	$51.17	per kg
Cost for R-448A/R-449A	$51.17	per kg
Cost for A2Ls (R-454A, R-454C, or R-455A)	$51.17	per kg
Cost for CO2	$6.36	per kg

[a] As discussed earlier in section 2 and in Appendix D, refrigerant costs presented here are averaged across several tracked sources and are recent as of Q4 2025. See section 4.2 for analysis of potential HFC price increases.

2.3 Cold Storage Warehouses

The EPA does not have sufficient data to reliably model incremental cost savings associated with the amendments in this rulemaking for the cold storage warehouses subsector. As indicated by some stakeholders, incremental permitting, maintenance, and/or added health and safety protocols are factors which may lead to higher costs of ownership and operation for ammonia- or CO_2- based refrigeration systems vis-a-vis fluorinated options such as R-513A in the cold storage warehouses subsector. The EPA did not receive sufficient quantitative information on such costs but recognizes that for some facilities such costs may be significant and therefore make R-513A a more cost-effective option.

While a share of the market is therefore anticipated to experience cost savings associated with the flexibility provided by this rule, the EPA notes that—as indicated by commenters and literature discussed in more detail below as well as the sources discussed in sections 1.5 and 1.6 above— the vast majority of the cold storage warehouses subsector already uses refrigeration systems that are compliant with the limits set forth in the original rule and are likely to continue using these technology options regardless of this rulemaking. We further note that—as discussed in more detail below—a number of sources point to ammonia and to a lesser degree CO_2 as cost-effective and long-established technology options.

The EPA therefore anticipates that there will be relatively small cost savings associated with a subset of stakeholders resulting from the flexibility provided by this rulemaking, but is unable to quantify these savings due to: 1) the relatively small share of market for which savings would apply, and 2) the lack of sufficient data available with which to reliably estimate savings these savings.

While the EPA was not ultimately able to collect enough data to quantitively evaluate incremental costs or savings resulting from this rulemaking for this subsector, comments and literature review did illuminate some valuable and relevant information discussed below.

Capital Costs/Savings Data

The EPA did not identify sufficient information through comments received or literature review on relative costs of competing technologies to update capital cost premiums. Literature review did, however, indicate that ammonia systems tend to have higher capital costs than both CO_2 (5-10%) and legacy HFC systems (15-25%).[110]

Annual Costs/Savings Data

The EPA did not identify sufficient information through comments received or literature review on relative costs of competing technologies to update annual cost premiums. We did, however, identify qualitative literature which implies that facilities using ammonia likely face annual costs not faced by those using other refrigerants. Specifically, ammonia facilities have unique compliance requirements, such as Process Safety Management (PSM) and Risk Management Programs (RMP) required by OSHA and the EPA, respectively.[111,112] The permitting process for ammonia use is especially rigorous and expensive due to the use of a hazardous refrigerant.[113] The hazardous nature of ammonia also requires careful system design, regular maintenance and inspections, leak detection systems, emergency response plans, and specialized training of technicians.[114,115,116] The EPA is not at this time able to quantify these incremental annual costs relative to legacy HFCs (*i.e.*, R-404A, R-407C, R-507A, HFC-134a) or R-513A, but note that they are likely nonzero.

Energy Costs/Savings Data

The EPA did not identify sufficient quantitative information through comments received regarding relative energy efficiency of ammonia or CO_2 relative to legacy HFCs that could serve as a basis for modeling the comparative performance of one technology versus another. However, the EPA did identify a number of sources in the technical literature review indicating that ammonia systems have comparatively superior energy efficiency, ranging between 15% and 38% in annual energy costs over

---

[110] IRPros. (2025). *Ammonia vs. CO2 vs. HFC: Choosing the Right Refrigerant for Your Industrial Facility*. https://irpros.com/ammonia-vs-co2-vs-hfc-choosing-the-right-refrigerant-for-your-industrial-facility/

[111] Herzog C & Lepschat. (2025). *Operating Cost Comparison Between Transcritical CO2 and Ammonia Recirculation Systems in a Cold Storage Warehouse*. IIAR. https://iiarcondenser.org/operating-cost-comparison-between-transcritical-co2-and-ammonia-recirculation-systems-in-a-cold-storage-warehouse/

[112] IIAR. *IIAR Certificate Course PSM RMP*. IIAR. https://www.iiar.org/IIAR/iiar/education/iiar_certificate_course_psm_rmp.aspx

[113] Herzog C & Lepschat. (2025). *Operating Cost Comparison Between Transcritical CO2 and Ammonia Recirculation Systems in a Cold Storage Warehouse*. IIAR. https://iiarcondenser.org/operating-cost-comparison-between-transcritical-co2-and-ammonia-recirculation-systems-in-a-cold-storage-warehouse/

[114] Refindustry. (2024). *Understanding Ammonia Refrigeration Systems: Key Benefits and Applications*. https://refindustry.com/articles/techguides/a-concise-overview-of-ammonia-refrigeration-technology/

[115] ACE Refrigeration and Air Conditioning. (2026). *Why Choose Ammonia Refrigeration for Industrial Cold Storage: Benefits and Long-Term ROI.* https://acerefrigeration.ca/why-choose-ammonia-refrigeration-for-industrial-cold-storage-benefits-and-long-term-roi/

[116] U.S. Environmental Protection Agency. (2018a). *Ammonia Refrigeration List of Key Safety Measurements*. https://www.epa.gov/sites/default/files/2018-05/documents/listofkeymeasurements.pdf

legacy HFCs.[117,118,119] A prominent equipment manufacturer also notes that there has been significant uptake of CO_2 systems despite higher initial costs due to lower energy costs leading to a lower total cost of ownership. [120]

Comments received by the EPA offered somewhat contradicting evidence regarding the energy costs/savings associated with ammonia or CO_2 versus fluorinated refrigerant options such as R-513A.. We note that one commenter stated that using R-513A resulted in savings of 40% on energy bills relative to ammonia systems.[121] By contrast, a prominent industry association stated that ammonia is between 19% and 32% more energy efficient than R-513A.[122]

One commenter also discussed concerns over the intense water requirements for ammonia and CO_2 systems (over 6 million gallons per year) as a limitation R-513A systems do not face. [123] One example identified in literature reviewed by the EPA indicated that water usage for ammonia may be around 2 million gallons per year[124] and for CO_2 systems between 350,000 and 1.35 million gallons annually.[125,126] Another source indicated that a system using R-448A and an evaporative condenser annually consumes 5.76 million gallons of water.[127] Industry stakeholders have noted that R-513A, ammonia, and CO_2 systems can all use air-cooled rather than water-cooled condensers to reduce water consumption,[128] and thus it is unclear whether there is an inherent water cost premium in using ammonia or CO_2.

---

[117] Jensen, S. (2013). *Ammonia in the Traditional HFC Territory: How Does It Compare?* IIAR Technical Paper #2.
[118] Gordon Brothers Industries. (2026). *Low Charge Ammonia NH3: A New Era of Industrial Refrigeration*. https://gordonbrothers.com.au/lowcharge-ammonia/
[119] Hillphoenix. (2025) *Ammonia (R-717) Refrigerant for Industrial Applications.* Hillphoenix Industrial. https://hillphoenixindustrial.com/ammonia-r-717-refrigerant/#:~:text=An%20ammonia%2Dbased%20system%20requires%20less%20electricity%2C%20resulting,to%20other%20refrigerants%2C%20ammonia%20also%20performs%20favorably.
[120] Hillphoenix. (2022). *Which Refrigerants are Typically Used in Industrial Cold Storage Applications?* https://hillphoenixindustrial.com/which-refrigerants-are-typically-used-in-industrial-cold-storage-applications/
[121] Public comment from New England Cold Storage, LLC. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0057
[122] *See* Memorandum - EPA Meetings Related to the Technology Transitions Reconsideration Final Rulemaking, 2026, in the docket for this action.
[123] Public comment from ALTA Refrigeration, Inc. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0147.
[124] Herzog C & Lepschat. (2025). *Operating Cost Comparison Between Transcritical CO2 and Ammonia Recirculation Systems in a Cold Storage Warehouse*. IIAR. https://iiarcondenser.org/operating-cost-comparison-between-transcritical-co2-and-ammonia-recirculation-systems-in-a-cold-storage-warehouse/
[125] ibid.
[126] Herrar & Obrien. (2025). *Sustainable Solutions for Agricultural Cold Storage: A Case Study. https://iiarcondenser.org/2025-technical-paper-14/*
[127] ibid.
[128] Environmental Investigation Agency and International Institute of Ammonia Refrigeration. (2020). *Letter to California Air Resources Board.* https://eia.org/wp-content/uploads/2020/12/EIA_and_IIAR_Letter_to_CARB_Proposed_HFC_Regulation_Ice_Rinks_150_GWP_Full_List_of_Signatories.pdf

2.4 IPR – Refrigerated Centrifuges, Laboratory Shakers, Semiconductors

As discussed in the rule preamble, the technology transition schedules in the 2023 Final Rule were technically infeasible to meet, according to certain stakeholders, for facilities using refrigerant in laboratory shakers, refrigerated centrifuges, and equipment used in semiconductor manufacturing. In light of the technical feasibility issues raised by stakeholders, the EPA recognizes that there is significant uncertainty with regards to what measures facilities in these subsectors may have undertaken were the original transition schedules left unamended. For example, facilities may have chosen to continue to install legacy HFC equipment (possibly receiving fines or other issues), undertaken transitions to costly, not-yet-commercial solutions, attempted to prolong the life of existing legacy HFC equipment via retrofits, and/or experienced new facility delays.

In the proposed rule economic impacts memo,[129] the EPA noted that we were soliciting additional information on costs that would be faced by affected industries if compliant technology is not yet available or commercially mature by the original deadline. The EPA did not receive sufficient quantitative information related to such costs for refrigerated centrifuges, laboratory shakers, or semiconductor manufacturing. Since the EPA did not identify additional information through comments received or literature review, and given the significant uncertainties discussed above, changes in costs between the baseline and policy scenario could not be calculated for this subsector. However, as discussed in sections 0 and 0, the EPA has updated its baseline and policy scenario assumptions regarding transitions in these subsectors and resulting HFC demand and emissions for purposes of overall modeling.

2.5 Intermodal containers

The EPA did not identify additional information through comments received or literature regarding intermodal containers in order update the analysis of costs of this subsector, and thus, the methodology remains as it was in the proposed rule economic impacts memo.[130]

Specific assumptions on costs are detailed in Table 2-3 below, presented in 2025 dollars. As with previous estimates, the EPA does not assume that R-513A units have incremental capital or O&M costs relative to legacy R-404A or HFC-134a units. We similarly do not assume that R-513A units have incremental

---

[129] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

[130] See Draft Memorandum: Analysis of Economic and Environmental Impacts – Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020 available in the docket for this action at EPA-HQ-OAR-2025-0005-0008.

capital or O&M costs relative to newer R-452A units that the now-exempt share of the market (per the amendments in this rule) is assumed to transition to in our policy scenario. However, we do assume that R-513A refrigerant has higher costs per pound relative to R-404A, HFC-134a, or R-452A. Thus—all else being equal—R-513A units are assumed to have higher costs.

Table 2-3: Central Estimate Factors for Intermodal Containers

Variable	***Value***	***Unit***
Model Facility (same across all technologies)		
Charge Size	5	kg
Equipment Lifetime	12	years
Annual Leak Rate	33%	
Capital Costs		
System Cost Premium	$0	
O&M Costs		
Incremental Maintenance Costs	$0	
Energy Usage		
Increased Energy Efficiency	0%	
Refrigerant Costs[a]		
Cost HFC-134a	$31.43	per kg
Cost of R-404A	$50.13	per kg
Cost of R-513A	$58.24	per kg

[a] As discussed earlier in section 2 and in Appendix D, refrigerant costs presented here are averaged across several tracked sources and are recent as of Q4 2025. See section 4.2 for analysis of potential HFC price increases.

Section 3. Sensitivity: Reliance Interests

Many OEMs and trade associations commented that the domestic industry has already retooled, certified new product platforms, and trained workforces to meet the existing limits and dates (*e.g.,* AHRI/Alliance, Business Council for Sustainable Energy, CARB, Chemours, Copeland, EIA, HARDI, Hill Phoenix, Lennox, NRDC, Solstice, Walgreens). Lennox, a manufacturer of supermarket systems, remote condensing units, and cold storage systems, commented that proposing to change restrictions has already led to market confusion. They ceased hiring production workers in their Georgia factory, attritted approximately 10% of their hourly workforce, and shut down operations for the last two weeks of 2025.

They noted they have tens of millions of dollars invested in raw materials on hand and millions more on order to support the current compliance date. Copeland also noted they have committed tens of millions of dollars in engineering, project development, and capital investment to transition refrigeration market sectors. While prior manufacturer investments are sunk costs and therefore are not impacts of this action, they do provide some information regarding future revenue losses or additional investments that may be required for manufacturers to adjust to the changes in this action.

Under the final amendments, in addition to these sunk costs, American manufacturers who have by and large already prepared for these transitions would face additional competition from those who only offer products with refrigerants above the limits set in 2023. Some larger companies may have a separate production line operating in another country, so one way they could respond is to increase production there and direct a portion of the products to the U.S. market. Smaller companies who may only have one production line might need to temporarily revert to prior technologies so that they could compete against such imports; however, they would then need to modify their production technology again when the final limits take effect (2032 in the proposal), adding to the costs they would experience as a result of this rule.

As noted above, there are additional costs incurred and not recouped based on this final rule. We have not incorporated such costs or losses into the engineering costs, shown above, that are associated with end-user transitions as compared to those assumed for the 2023 Final Rule. Based on data from multiple OEMs (including both system and component providers) based in the United States, it is apparent that the costs to prepare for transitions has been significant. As pointed out by Lennox, the changes promulgated in this rule can have indirect effects as well, such as lower employment especially amongst those skilled in and trained for the emerging technologies that were created for the expected transitions. As a comparison, not including the many other manufacturers who may have likewise already made changes to comply with the 2023 Final Rule, the very low-end of the two commenters estimates (tens of millions of dollars each) would be $20 million in comparison to the engineering cost estimates presented above of approximately $650 million (at 7 percent discount rate).

Section 4. Sensitivity: Indirect HFC Market Impacts

In the scenarios described above, baseline and policy results are focused on the engineering cost and emissions changes that result from stakeholders in the affected subsectors utilizing additional flexibility provided by the Technology Transitions Reconsideration Rule. The EPA expects that greater demand for HFCs in the affected subsectors will have indirect effects on HFC prices and usage, including for other subsectors not directly affected by this rulemaking. The reason for this is the finite and decreasing amount of HFC production and import which is governed by the AIM Act phasedown schedule provide in subsection (e); thus, the supply of HFCs is relatively inelastic. To the extent that projected total HFC demand exceeds the statutory cap levels, HFC prices are expected to rise significantly, leading to higher costs and increased incentives to reduce HFC usage across all subsectors. For example, uses that are not restricted fully, partially, or on a graduated schedule under subsection (i) of the AIM Act, such as fire suppression, or uses where alternatives are known and flexibility is being provided, such as cold storage warehouses, could react to the higher prices by transitioning to alternatives.

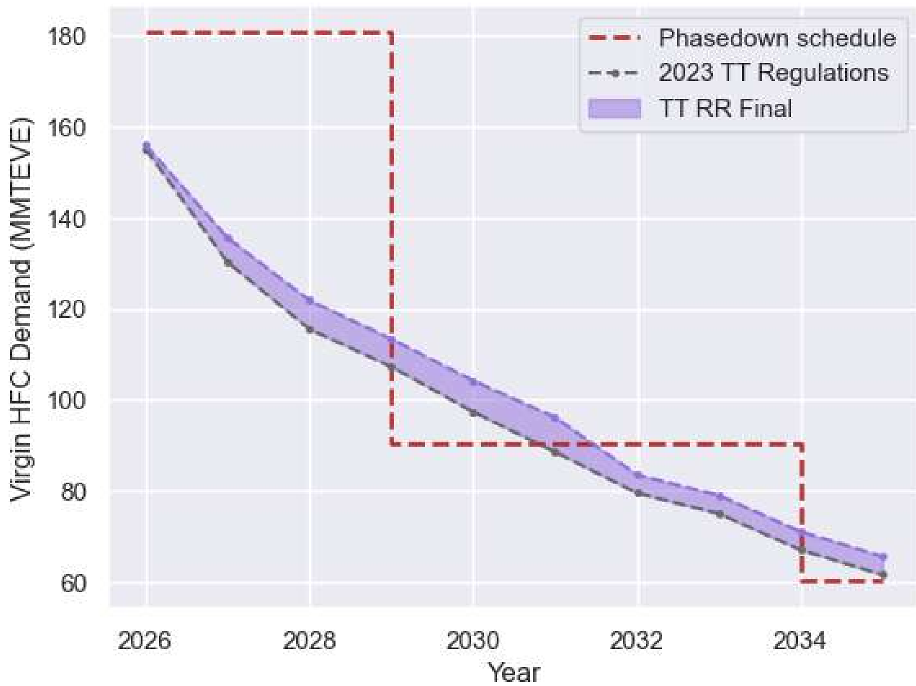
The baseline and policy scenarios used for this analysis represent projections of HFC demanded based on the restrictions of the Technology Transitions regulations alone (with baseline representing the limits as originally codified and policy representing the limits as amended by this rulemaking). In other words, these scenarios represent demand based on these restrictions without accounting for additional measures that may be needed in order to keep import and production of virgin HFCs below the statutory caps. Any demand for virgin HFCs in these scenarios that is over-and-above the cap therefore represents demand that must be offset through other measures. The EPA further notes that due to long equipment lifetimes, a significant share of HFC demand may be "locked in" for many years to come based on the installed base of equipment in preceding years. For example, this rulemaking allows for additional installation of R-448A and R-449A-based systems on the part of supermarkets until 2032, which will require HFCs for servicing as leaks occur through the end of the equipment's useful life, well past 2029. While the EPA understands that retrofits, if acceptable under the EPA's SNAP program, are possible, equipment owners and operators often find that the best performance is achieved when using the specific refrigerant with unique thermophysical properties for which a particular refrigeration system is designed, and will choose to continue to operate with that refrigerant to protect the significant up-front investment made for the system.

4.1 Increased HFC Demand Resulting from Rule

Figure 4 shows projected HFC demand based on the status quo restrictions prior to this rulemaking overlaid with additional demand that is expected to result from the Technology Transitions Reconsideration Rule. The black lines and shaded region represent projections of HFC demand, while the dashed red lines represent statutory limits on HFC production and consumption. In both baseline and policy scenarios, total virgin HFC demand is expected to exceed cap levels around the 2029 statutory step-down. The increases in demand depicted in the figure are driven by the subsectors directly affected by this rulemaking. Potential increases are represented as a sensitivity bound, with the top sensitivity line representing our central scenario estimate incremental demand for virgin HFCs assuming the revised deadlines contained in the final rule.

On an exchange-value-weighted basis, total economy-wide HFC quantity demanded increases by up to 8.9% from baseline through 2031 and by 5% to 8% from 2032-2044 due to additional "locked in" servicing demand following the deadline. The EPA anticipates that these increases in quantity demanded are of a sufficient magnitude to increase overall HFC prices.

Figure 4: Virgin HFC Demand in 2023 Final Rule and Technology Transitions Reconsideration Rule Scenarios*



*Upper-end of the projection shown in this figure represents the EPA's central scenario estimate of increased demand. However, we note that there is uncertainty regarding transition rates and technology choices for subsectors being granted compliance flexibility under this rule. Figure does not represent all sensitivities potentially impacting demand, and overall demand for virgin HFCs may be higher than shown in this figure based on additional factors not evaluated here (*e.g.,* lower or higher recovery-reuse rates, lower or higher leak rates, earlier or later transitions in subsectors not affected by this rulemaking).

Market Responses to Increased HFC Prices

For all years where projected demand exceeds the statutory cap for HFC production and consumption, the market is expected to undertake additional measures, such as conversions to alternative refrigerants in subsectors not covered by the current regulations, use of lower EVe alternatives than those chosen for compliance with current or future restrictions, reliance on stockpiled bulk HFCs produced before 2029, additional recovery and re-use, and/or forgoing or delaying the repair and recharging of existing HFC systems. The EPA has not evaluated these additional measures in this analysis or their costs. In aggregate, these market responses are expected to result in added costs and reduced emissions, such that engineering cost savings and emissions increases are partially offset by the indirect market effects.

4.2 Estimate of Potential HFC Price Changes

In order to estimate HFC price increases that could result from this rule, the EPA used a simple elasticity calculation. This was done by applying a range of potential elasticities of demand to the change in HFC demand. Because this analysis is not calibrated to the specific technology alternatives and because a range of elasticity values are plausible, this elasticity analysis should be viewed as illustrative. In addition, it focuses on a narrow time period around the 2029 step-down, not on price impacts across the entire analysis period. This approach was taken for purposes of simplification, and the EPA acknowledges that more dynamic price effects and market responses not fully evaluated in this analysis are likely to occur.[131]

Table 4-1 shows estimated impacts on HFC prices for the year 2029 in relation to the baseline scenario.

Table 4-1: Estimated Change in HFC Prices in 2029 as Result of the Final Rule (percent)

	Central Policy Scenario
Increase in HFC Demand, MTEVe,(Percent relative to statutory cap) (2029)	5.4 (6%)
Range of HFC Price Increase (2029, percent relative to baseline)	12-24%

The above estimates depend on a number of assumptions and are subject to significant uncertainty. For these estimates the EPA used an elasticity range of -0.25 to -0.5, representing relatively inelastic demand for HFCs. Inelasticity of HFC demand is expected to arise partly due to long equipment lifetimes across many types of refrigerant-containing equipment and high upfront costs. For example, an equipment owner (such as a home A/C owner) is likely to opt to repair equipment in lieu of purchasing a brand new system so long as repair and servicing costs of their existing system (including the cost of HFCs to replace or "top off" equipment due to leakage over time) are not prohibitive. Particularly in the case of equipment that is relatively new and/or still under warranty, consumers are likely to opt for repair and even replacement of significant components of their existing system in order to extend useful life rather than replace with a new system, even if it would use a less costly refrigerant. Inelasticity also arises due to the fact that HFCs are an intermediate input to consumer goods and services (such as home air conditioning or refrigerated goods) and so make up a relatively small portion of the overall cost of these consumer

[131] For example, some market participants may anticipate future price increases and thus transition to non-HFC technologies earlier than assumed in this analysis. For more details on specific assumptions made regarding technology uptake in response to HFC prices, see section 1.6.

goods. Finally, because the most cost-effective substitutions away from HFCs are in progress as part of the technology transition scenarios, additional mitigation activities beyond these levels are likely to be more constrained.

One commenter included a study[132] that modelled refrigerant supply and demand and reclamation to investigate the impact of the proposal and estimated that that finalizing a compliance date of 2032 could result in average HFC price increases of up to 300% between 2030 and 2032. The commenter analysis resulted in a significantly higher estimate of price impacts compared to the EPA's analysis, mainly because of methodological differences.

Section 5. Sensitivity: Incremental Costs and Market Uptake Assumptions

As described in Section 2 of this document, the EPA has relied on a combination of data identified in literature review and provided by stakeholders in comments in order to develop updated estimates of the comparative costs of equipment available as compliance options under thus rulemaking. While these estimates are therefore reflective of available public data and stakeholder input, we note that incremental costs are inherently uncertain, and that data in some cases diverged significantly between sources.

Given this uncertainty, the EPA conducted a sensitivity analysis on incremental costs of competing technologies to provide more information on how our overall results change based on differing assumptions. Specifically, we conducted a sensitivity on the incremental costs of CO_2-based refrigeration systems vis-à-vis HFC-based systems for supermarkets, since this subsector is the largest driver of the engineering cost savings presented in this analysis. Since a primary effect of this rulemaking is to allow an additional technology option (namely R-448A/R-449A) during an interim compliance period that would not have otherwise been allowable under the original rule, much of the cost savings resulting from this rule hinge upon the comparative costs of these two technologies. For example, if CO_2-based systems are already relatively cost-effective, then many market actors would transition to this technology regardless of the amendments in the final rule, and overall savings would be more muted (since the most

---

[132] This analysis was included as an attachment to the public comment from AHRI and the Alliance for Responsible Atmospheric Policy (see in the docket for this action at EPA-HQ-OAR-2025-0005-0153). The data underlying this analysis is different than that used by EPA. For example, the commenter used publicly available data from the 2024 Greenhouse Gas Inventory which offers 2022 HFC consumption data, while EPA relies on the Vintaging Model inclusive of updates detailed in section 1.5 of this document. Assumptions regarding the share of material available through recovery/re-use as well as the share of the market that may opt in to the additional flexibility provided by the amendments in this rule also differ from those described in this analysis. The commenter acknowledges that its analysis relied on "numerous simplifications and assumptions" (*i.e.* demand growth, servicing demand, and leak rates, uptake of flexibilities from this rule), and their model lacks the level of granularity (*i.e.* end-use level) that the VM offers.

cost-effective option for end users remains largely unchanged). On the other hand, if CO_2-based systems are relatively costly, most market actors will opt for the alternative technology options allowed by this rule and thus avoid significant costs relative to baseline.

Table 5-1 highlights overall results and key assumptions for two additional scenarios besides the central scenario presented elsewhere in this document:

- a "Low Incremental Costs" scenario where CO_2-based systems have 15% lower capital costs and 15% lower refrigerant costs (in $/kg) than our central scenario estimates, and no incremental maintenance costs relative to HFC-based systems are assumed
- a "High Incremental Costs" scenario where CO_2-based systems have 15% higher capital costs, 15% higher refrigerant costs (in $/kg) and 15% higher incremental maintenance costs relative to our central scenario estimates

Table 5-1: Sensitivity Results Based on Higher or Lower Incremental CO_2 Technology Costs

	Low Incremental Costs Scenario	***Final Rule Central Scenario***	***High Incremental Costs Scenario***
Engineering Cost Savings in Affected Subsectors			
3 Percent Discount Rate			
Present Value (million 2024$)	$435	$976	$1,560
Equivalent Annualized Value (million 2024$)	$25	$56	$90
7 Percent Discount Rate			
Present Value (million 2024$)	$294	$653	$1,039
Equivalent Annualized Value (million 2024$)	$25	$56	$89
Cost and Uptake Parameters			
Average Incremental Annualized Cost of CO_2 Refrigeration Systems			
In 2027	$2,011	$7,144	$11,041
2029 onwards	-$5,930	-$785	$3,099
Market uptake of CO_2 Refrigeration Systems			
In 2027	40%	20%	9%
In 2029	74%	53%	36%
2032 onwards	100%	100%	100%

The results of this sensitivity analysis are indicative of the very significant impact assumptions on the costs of these technologies have on our overall results. Notably, in the "Low Incremental Costs" scenario, CO_2 technology uptake is substantially higher, while overall savings from the rule are substantially lower. For the "High Incremental Costs" scenario, the opposite is true. In particular, we note that a plus or minus

15% change in cost assumptions has the effect of reducing or increasing overall estimated savings by approximately 55-60%.

Section 6. Uncertainties and limitations

6.1 Key sources of uncertainty

Throughout this memo, we considered a number of sources of uncertainty, both quantitatively and qualitatively, regarding the economic and environmental impacts of the final amendments. We summarize the key elements of our discussion of uncertainty here:

Transition technology characteristics (*e.g.*, the range of capital cost, energy efficiency, operation and maintenance costs, leak rates, or other technology characteristics figures from the literature and comments on various transition technologies). Results of this analysis are sensitive to a variety of transition technology characteristics. In this rulemaking, the EPA sought additional information on transition technology characteristics and incorporated additional information into the analysis. Section 2 describes the detailed assumptions we have made for various transition technologies, including a number of cases where we have used a statistical distribution to characterize impacts assuming a range for key characteristics among different facilities.

Two examples of technology characteristics that introduce uncertainty are the frequency of adiabatic coolers and differences between new and existing facilities. We have assumed for simplicity that 50% of CO_2 systems are paired with adiabatic coolers and the remaining 50% have no add-on equipment. We do not account for other additional technology which may be added to a system to improve energy or water efficiency, such as dry coolers, low pressure ejectors, high pressure ejectors, etc. Second, for many sources of literature and comments, it was not clear whether capital costs and other data were specific to a new store construction or conversion or changes to systems in an existing store or facility. Further refinement of market data may provide more detail on this potential distinction.

Indirect unquantified market impacts. The analysis presented here presents quantitative estimates of direct engineering cost savings resulting from the additional flexibilities in the final rule. However, the analysis also qualitatively discusses additional unquantified indirect effects. In particular, the analysis does not characterize compensating activities. Section 3 discusses impacts on equipment manufacturers and section 4 discusses indirect effects via HFC markets. Market impacts depend on various uncertain factors including demand elasticity and the extent of HFC reclamation activity.

Projected adoption rates of transition technologies in Technology Transitions Reconsideration Rule subsectors ahead of adjusted transition schedules. Constructing scenarios using the Vintaging Model requires specification of technology adoption rates and schedules which are dependent upon a variety of uncertain factors including technology characteristics and development, consumer preferences, and market dynamics. Section 5 explores sensitivity of cost savings results for low and high incremental cost scenarios that result in differing levels of transition technology adoption.

6.2 Additional limitations related to quantification of cost savings

In this analysis the EPA has quantified some—but not all—avoided costs (*i.e.*, savings) that are anticipated to arise from this rule. In particular, as described in detail in Section 2 our analysis focuses on direct engineering cost savings for equipment owners and operators that arise from the flexibility to use technologies with lower capital and/or operating costs relative to technology options that would have otherwise been required per the original restrictions in the 2023 rule. However, we acknowledge that this rule may result in other types of cost savings or additional distributional impacts that are not quantified in this analysis, as illustrated by the following examples.

Productivity losses. Under the baseline requirements of the 2023 restrictions, some semiconductor facilities using IPR equipment may have faced technically infeasible requirements. Such facilities may have been forced to delay operations or invest in costly pre-commercial technologies. To the extent productivity may have been impacted, the costs could have been significantly larger than the costs of refrigeration equipment.[133] Productivity losses may also have occurred for other subsectors for which stakeholders raised technical feasibility issues, including laboratory shakers, refrigerated centrifuges, and refrigerated transport – intermodal containers. In these cases, the EPA's understanding is that technology using a refrigerant that is compliant with 2023 restrictions that also meets the necessary thermophysical and other technical specifications required by these end uses may not yet be widely available and/or may require more time to undergo necessary product redesign and testing procedures than allowed for under the original compliance deadline, thus leading to potential productivity losses in the short term. However, given the significant uncertainty regarding what measures industry may have undertaken in the absence of the amendments in this rule, as well as regarding the degree of productivity losses and their economic value, we have not quantified these effects.

Stranded inventory. This rule removes a previous cutoff deadline for the installation of residential and light commercial AC/HP systems using refrigerants above a limit of 700. Per an interim final rule on December 26, 2023, this deadline had been set to January 1, 2026, so long as the equipment was

[133] Comment from SEMI: "The economic costs of downtime in semiconductor production are extraordinary. A modern fabrication plant can lose millions of dollars per day in halted output."

manufactured in the United States or imported into the United States before January 1, 2025. [134] With the removal of this deadline, this rule may relieve additional burden associated with residual as-yet-uninstalled inventory beyond January 2026 that would otherwise have been stranded. The EPA does not have sufficient information on the number of units still in inventory that may be affected by this provision, but notes that stakeholders have indicated that removal of the deadline will allow for installation of additional equipment that had been tied up due to construction delays. We also note that there is uncertainty regarding measures industry may have undertaken in the absence of this final rule, but one possibility is re-sale (likely at a loss) of stranded equipment to international markets without a similar restriction in place. Thus, while not quantified in this analysis, the EPA recognizes that this provision will have the likely effect of additional cost savings for stakeholders.

Other consumer price effects. In quantifying direct engineering cost savings for end users of HFC-containing equipment, the EPA has focused on direct costs to the equipment owners/operators and has not estimated the degree to which these engineering costs are passed on to downstream consumers. For example, as discussed earlier in this analysis, the EPA estimates that this rule will result in direct engineering cost savings for supermarkets (due to the flexibility provided in this rule as amended to use refrigeration systems that on average may be more cost effective) and has quantified these effects. Without these amendments, supermarkets may therefore have borne additional costs that would be passed on to consumers of their products. This is particularly true for an industry with narrow profit margins that is unlikely to internalize additional costs, which the EPA understands to be the case for supermarkets based on information provided in comments. Thus, an additional distributional impact of this rule is that a share of the cost savings estimated in this analysis may be passed on to consumers. However, these consumer cost savings may be partially offset to the extent that potential HFC price increases resulting from this rule (discussed in section 4) are also passed on to consumers. Given the significant uncertainties related to these dynamics, including the degree to which costs would be externalized and significance of these costs relative to annual revenues (which could vary significantly for smaller retailers versus large chains), we have not quantified these effects.

[134] S*ee* 88 FR 88825 (December 26, 2023).

Section 7. Appendices

7.1 Appendix A

Table A - 1: Annual Increase Emissions By Gas, Technology Transitions Reconsideration Rule Central Scenario vs. Baseline (kg EVe)

Year	*HFC-32*	*HFC-125*	*HFC-134a*	*HFO-1234yf*	*HFO-1234ze(E)*
2026	5.5	19.0	17.8	0.0	2.6
2027	154.8	183.0	167.3	89.3	28.2
2028	306.1	349.3	319.0	199.1	54.1
2029	396.3	457.2	418.0	249.4	70.8
2030	487.7	566.6	518.1	299.9	87.7
2031	579.8	676.9	619.0	350.9	104.7
2032	579.8	676.9	618.1	349.8	104.7
2033	579.8	676.9	617.3	348.7	104.7
2034	579.8	676.9	616.4	347.6	104.7
2035	579.8	676.9	615.6	346.5	104.7
2036	579.8	676.9	614.7	345.4	104.7
2037	579.8	676.9	613.8	344.3	104.7
2038	579.8	676.9	612.9	343.2	104.7
2039	579.8	676.9	612.1	342.1	104.7
2040	579.8	676.9	610.8	340.5	104.7
2041	579.8	676.9	610.5	340.1	104.7
2042	579.8	676.9	610.3	339.8	104.7
2043	579.8	676.9	610.0	339.5	104.7
2044	579.8	676.9	609.9	339.3	104.7
2045	501.5	598.0	538.4	270.1	92.2
2046	355.4	447.8	402.4	146.9	68.6
2047	236.1	314.1	280.6	65.1	47.8
2048	142.5	206.2	182.0	6.4	31.1
2049	48.7	97.0	82.0	0.0	14.2
2050	5.2	36.1	25.6	0.0	5.0

7.2 Appendix B

Table B - 1 provides a summary of estimated average annualized incremental costs—by technology transition— included in the EPA's analysis of compliance costs (or savings) associated with this rulemaking. As detailed in section 2 of this document, incremental annualized costs are a reflection of incremental capital costs, incremental refrigerant costs, and incremental operations and maintenance (O&M) costs, among other factors. Estimates below represent assumed average costs in the EPA's central scenario in year 2025. However, earlier in this document, costs are in some cases assumed to be variable over time and across model facilities.

Table B - 1: Summary of Incremental Annualized Costs of Transition Technologies in 2025 ($2024 USD)

End-Use	***Baseline Technology/ Refrigerant***	***Transition Technology/ Refrigerant***	***Total Incremental Annualized Cost / Unit***	***Abatement / Unit / Year (MtEVe)***	***Breakeven Cost ($ / MtEVe)***
Supermarkets - LRF	407A	448A/449A	$0	$194	$0
Supermarkets - LRF	404A/507A	448A/449A	$0	$695	$0
Supermarkets - LRF	448A/449A	Transcritical CO_2	$7,144	$378	$22
Supermarkets - LRF	404A/507A	Transcritical CO_2	$7,144	$1,071	$8
Supermarkets - LRF	407A	Transcritical CO_2	$7,144	$572	$15
Remote Condensing Units	404A/507A	448A/449A	$0	$3	$0
Remote Condensing Units	448A/449A	Transcritical CO_2	$60	$2	$43
Remote Condensing Units	404A/507A	A2Ls	$39	$4	$11
Remote Condensing Units	404A/507A	Transcritical CO_2	$60	$5	$15
Remote Condensing Units	A2Ls	Transcritical CO_2	$33	$0	$184
Intermodal Containers	404A	513A	$18	$8	$3
Refrigerated Transport	Intermodal Containers	134a	$61	$2	$36

Note: Costs are shown based on a model transition (*e.g.*, a single intermodal container or semiconductor chiller) to determine a breakeven cost and do not represent total costs to the industry or a particular stakeholder.

7.3 Appendix C

Table C-1 below summarizes information gaps that the EPA identified and requested comment on at the time of proposal, accompanied by a summary of information received. The EPA notes that this list is not necessarily exhaustive, and that individual stakeholders may deem other factors of importance in evaluating the costs and benefits of the changes in this rulemaking. Additional comments containing information not ultimately considered for the purposes of this analysis can be found in the docket to this rulemaking.

As illustrated by the table, commenters in some cases provided widely divergent quantitative data on the same or similar factors, some of which are significant drivers of the estimated economic impacts of this rule such as capital costs of supermarket systems and comparative energy efficiency of different supermarket systems. To the extent practical, the EPA has validated information received through verification of sources, supplementary literature review, and stakeholder outreach to determine suitable ranges to use for central estimates and sensitivity ranges.

Table C-1: Summary of Additional Information Provided in Comments and Used to Evaluate Economic Costs and/or Benefits

Subsector	***Information Gaps Identified in Proposed Rule***	***Summary of Information Received and Used to Inform Updated Assumptions***
Retail Food – Supermarkets and Remote Condensing Units	• Information on specific instances or regions where stores are unable to install refrigerant systems that are in compliance with the 2023 Final Rule due to building codes as well as administrative or other economic costs that would be associated with overcoming this barrier • Information on sunk costs (*e.g.*, capital expenditures, sales data) already invested in technologies that meet the 2023 Final Rule • Incremental costs from or associated with supply bottlenecks that industry may face as a result of the limits and deadlines in the 2023 Final Rule • Incremental learning curve costs (*e.g.*, costs associated with operating and	• Several commenters argued that there are no regulatory barriers such as building codes that prevent the use of A2L refrigerant use (*e.g.*, R-454C, R-454A) and that such refrigerants are already commercially available; other commenters suggested that A2L systems are not commercially viable for large supermarket systems, but are for remote condensing units • Significant investments have already been made to transition to alternatives that meet the 2023 restrictions which are now sunk costs • Thousands of retail food stores have already transitioned to CO_2 systems in the U.S., and many have near-term goals to continue the transition • Convenience stores (remote condensing units) have already transitioned to A2L over CO_2 and propane • Commenters offered a range of leak rates (5-25%) depending on

Subsector	Information Gaps Identified in Proposed Rule	Summary of Information Received and Used to Inform Updated Assumptions
	maintaining CO_2 equipment) and rates of decline of such learning curve costs • Information on incremental refrigerant leak rates in alternative technologies that would meet the 2023 Final Rule vis-a-vis technologies that would otherwise be used • Incremental water demand (*i.e.*, if needed for evaporative cooling) and associated costs for CO_2 retail food systems in regions of the United States with varying levels of water scarcity, vis-a-vis baseline technologies used • Incremental energy costs associated with operating CO_2, R-448A, or R-449A retail food systems under varying climatic zones and conditions in the United States, vis-a-vis baseline (*e.g.*, R-404A or R-407A) technologies used • Information on rates of market uptake of various technology options available under the 2023 Final Rule as well as the revised limits proposed (*e.g.*, current and potential future rates of transition to CO_2, R-448A, and R-449A)	refrigerant, system architecture, etc. across the retail food subsectors • Commenters disagreed widely on the energy efficiency of CO_2 relative to baseline technologies R-404A or R-407A) in supermarket systems. While some believe there are energy losses, others argued efficiency gains relative to baseline of between 7% and 40% • CO_2 systems, when equipped with an adiabatic cooler, consume tens of thousands of gallons of water annually depending on total refrigerant charge/store size. A store with 125 tons of refrigeration[135] uses more than 160,000 gallons of water annually • Some newer systems (*i.e.* CO_2) require more experienced technicians with specialized knowledge or skills, which, in the near term, can drive up maintenance costs • No additional information bottleneck costs were provided in comment were considered in this analysis
Cold Storage Warehouses	• Information on specific instances or regions where warehouses are unable to install refrigerant systems that are in compliance with	• 91% of the cold storage market already uses ammonia, while 5% uses CO_2 • Commenters disagree about the energy efficiency of ammonia relative

[135] Note that "tons of refrigeration" (TR) here is used as unit of measurement for cooling capacity rather than as a measure of weight of the refrigerant. One TR is equal to 12,000 BTU/hour. Therefore, a 125 TR store has a capacity of 1.5 million BTU/hour. According to TCW Group (2024), retail stores typically require cooling loads of about 30-40 BTU/hour per square foot. That implies that an average supermarket (assumed to be 42,553 square feet) requires between about 1.28 and 1.91 million BTU/hour. Thus, 125 TR is a reasonable cooling capacity equivalent to assume for the purposes of this analysis.

Subsector	Information Gaps Identified in Proposed Rule	Summary of Information Received and Used to Inform Updated Assumptions
	the 2023 Final Rule due to building codes as well as administrative or other economic costs that would be associated with overcoming this barrier • Information on costs of addressing safety concerns related to ammonia or CO_2 for cold storage warehouses not located in isolated, unpopulated areas • Information on sunk costs (*e.g.*, capital expenditures, sales data) already invested in technologies that meet the 2023 Final Rule • Incremental energy costs associated with operating R-513A cold storage systems under varying climatic zones and conditions in the US, vis-a-vis ammonia as well as vis-à-vis HFC technologies that would otherwise be used • Information on rates of market update of various technology options available under the 2023 Final Rule as well as the revised limits proposed (*e.g.*, current and potential future rates of transition to ammonia, CO_2, and R-513A)	to R-513A, with estimates ranging from a loss of 40% to a gain of 10-15% • No additional information regarding costs of addressing safety concerns, sunk costs, or specific instances where warehouses are unable to install compliant systems provided in comment were considered in this analysis
Industrial Process Refrigeration – Chillers and Process Refrigeration Equipment Used in Semiconductor Manufacturing, Refrigerated Centrifuges, and Laboratory Shakers	• Incremental costs associated with uptake of new technology that would meet compliance with the 2023 Final Rule • Information from Original Equipment Manufacturers (OEMs) on whether such technology is under development and associated incremental manufacturing costs • If a compliant technology is not yet available,	• A2L use in these sectors is possible and is not inhibited by a building code issue • CO_2 is commercially viable in Industrial Process Refrigeration subsectors; For refrigerated centrifuges, current non-flammable fluorinated refrigerants pose no known significant risk to operators from refrigeration system leaks; Suitable replacements, such as flammable refrigerants (*e.g.*, propane/R-290) or high-pressure refrigerants (*e.g.,* CO_2), may pose a

Subsector	*Information Gaps Identified in Proposed Rule*	*Summary of Information Received and Used to Inform Updated Assumptions*
	information on remaining barriers to market adoption of technology that would meet limits and deadlines in the 2023 Final Rule • Economic costs that would be faced by affected industries if compliant technology is not yet available or commercially mature by the original deadline • Incremental learning curve costs and rates of decline of such learning curve costs associated with uptake of new technology that would meet compliance with the 2023 Final Rule	risk to operators; more testing required • No additional information regarding economic costs, learning curve costs, or other incremental costs provided in comment were considered in this analysis
Refrigerated Transport – Intermodal Containers	• Information on barriers to market adoption of technology that would meet the 2023 Final Rule limits (*i.e.*, refrigerants below the 700 limit that can achieve and maintain box temperatures below −35 °C) • Information from OEMs on whether such technology is under development and associated incremental manufacturing costs vis-à-vis baseline technology used for intermodal containers with box temperatures below −35 °C • Information on any sunk costs (*e.g.*, capital expenditures, sales data) already invested in technologies that could meet the 2023 Final Rule for intermodal containers with box temperatures below −35 °C • Economic costs that would be faced by affected industries if compliant	• No additional information was provided in comments regarding market adoption barriers, availability of technology, economic or manufacturing costs, sunk costs, or learning curve costs specific to Refrigerated Transport – Intermodal Containers

Subsector	***Information Gaps Identified in Proposed Rule***	***Summary of Information Received and Used to Inform Updated Assumptions***
	technology is not yet available or commercially mature by the original deadline • Incremental learning curve costs and rates of decline of such learning curve costs associated with uptake of new technology that would meet compliance with the 2023 Final Rule, if such technology exists	

7.4 Appendix D

The EPA has tracked publicly available data on refrigerant prices over time. These prices were available to buyers in the general public and would presumably be higher than what some entities (*e.g.*, a manufacturer) buying a large quantity directly from a supplier (*e.g.*, an HFC manufacturer or large importer) would be able to negotiate. In short, from the data the Agency has seen, the typical prices for HFCs have increased over time, generally at higher rates than can be accounted for from overall economic inflation. This may be because allocations capping HFC consumption began in 2022, as well as other factors. These increases do not appear to be due to any shortages, which have not occurred during this timeframe (except for R-454B, an HFC/HFO blend, which is addressed in section III.H of the Preamble).

Table D-1: Sample of Refrigerant Costs Over Time

Chemical/Blend	Average Price[a] 2021-2023 (n=37 to 116)	Average Price[a] 2024-April 2026 (n=115 to 381)	Change
HFC-134a	$27.72/kg	$35.37/kg	+28%
R-404A	$42.87/kg	$56.21/kg	+31%
R-410A	$45.39/kg	$50.16/kg	+11%
R-448A	$33.13/kg	$38.29/kg	+16%
R-449A	$33.32/kg	$43.03/kg	+29%
HFO-1234yf	$121.24/kg	$123.55/kg	+2%

[a] Costs are shown in current dollars

For modeling purposes, in this analysis the EPA used average prices across a range of HFCs as the current price of HFCs. We adjusted these to 2024 dollars for purposes of this analysis. Following this methodology, we assume an average price of $51/kg. Our analysis also indicates that the demand for HFCs would exceed the amount available to allocate beginning in 2029 if no other actions are taken. Using a simple price elasticity analysis as described in section 4.1, we estimate a baseline increase the cost of HFCs (from current prices) of approximately 55%, resulting in an average price of $79/kg, and use this price in the analysis for years 2029 and later.

Section 8. References

ACE Refrigeration and Air Conditioning. (2026). *Why Choose Ammonia Refrigeration for Industrial Cold Storage: Benefits and Long-Term ROI.* https://acerefrigeration.ca/why-choose-ammonia-refrigeration-for-industrial-cold-storage-benefits-and-long-term-roi/

Air Conditioning, Heating, and Refrigeration NEWS (ACHR News). (2021). *Food Retailers Interested in Natural Refrigerants*. https://www.achrnews.com/articles/144720-food-retailers-interested-in-natural-refrigerants.

Air Conditioning, Heating, and Refrigeration NEWS (ACHR News). (2025). *A2L Commercial Refrigeration Equipment Hits the Market*. https://www.achrnews.com/articles/165195-a2l-commercial-refrigeration-equipment-hits-the-market.

Albertsons Companies (2024). Albertsons Companies. 2024. Albertsons Companies Releases 2023 ESG Report. Available online at: https://www.albertsonscompanies.com/newsroom/press-releases/news-details/2023/Albertsons-Companies-Releases-2023-ESG-Report/

American National Standards Institute (ANSI) / American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). (2024). *ANSI/ASHRE Standard 34-2024, Designation and Safety Classification of Refrigerants.* ASHRAE. Peachtree Corners, GA.

American Walk-In Coolers. (2025). *Regulatory Landscape and New Products*. https://www.americanwalkincoolers.com/wp-content/uploads/2025/01/AWIC-A2L-Presentation-2025.pdf.

ATMO. (2025). 2024 North American Food Industry: Economic Outlook. https://atmosphere.cool/wp-content/uploads/2025/02/2024_ATMO_Marketreport_03_NorthAmerica.pdf

ATMOsphere. (2023). *Natural Refrigerants: State of the Industry. Commercial and Industrial Refrigeration in North America, Europe, and Japan*. 2022 Edition. https://atmosphere.cool/marketreport-2022/

Barr Refrigeration. (2026). *3 HP Heatcraft Surplus Medium Temp System w/ electric defrost (1 ph 208/230v).* https://www.barrinc.com/product/5719/

Carrier. (2025). NaturaLINE Container Refrigeration Unit. https://www.carrier.com/container-refrigeration/en/worldwide/products/Container-Units/naturaline/

Chef's Deal Restaurant Equipment. (2026). *Turbo Air TS030MR404A3-T 3 HP Medium Temp Remote Refrigeration Unit with Scroll Compressor, 208-230V/3Ph/60Hz. https://www.chefsdeal.com/p/remote-*

refrigeration-units/turbo-air-ts030mr404a3-t?gad_source=4&gad_campaignid=20165435414&gbraid=0AAAAAD064AYV7Rx0HRl02YAHZqckOdEBN&gclid=Cj0KCQiAy6vMBhDCARIsAK8rOgnOYJlNXB7aiB864uW4gpIiounmPVj2xFEbufqdzSCBvInRHGQyGGkaAnwAEALw_wcB

Climate and Clean Air Coalition. (2016) "Lower GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO2, ammonia and HFO case studies." CCAC, Publication job number: DTI/2015/PA: https://www.ccacoalition.org/sites/default/files/resources/Lower%20GWP%20Alternatives%20in%20Commercial%20and%20Transport%20Refrigeration.pdf.

Coldparts. (2026). *A1C907 – 3 HP Refrigeration Condensing Unit – Medium Temp – R-404A.* https://coldparts.com/shop/refrigeration-application/condensing-units/r-404a-refrigeration-condensing-units/r-404a-230v-1ph-medium-temperature-condensing-units/a1c907-medium-temp-r-404a-3-hp-refrigeration-condensing-unit/

Cooling Post. (2024). Maersk adopts R1234yf for reefers. https://www.coolingpost.com/products/maersk-adopts-r1234yf-for-reefers/.

Danfoss. (2015). *Discover the opportunities of transcritical CO_2 with heat reclaim*. https://assets.danfoss.com/documents/latest/57233/BE181286422948en-000101.pdf

Danfoss. Ammonia (NH_3): https://www.danfoss.com/en/about-danfoss/our-businesses/cooling/refrigerants-and-energy-efficiency/refrigerants-for-lowering-the-gwp/ammonia-nh3/; accessed September 19th, 2025.

EIA. (2024). *ALDI becomes first U.S. food retailer to commit to natural refrigerants across all stores.* Available online at: https://eia.org/blog/aldi-becomes-first-u-s-food-retailer-to-commit-to-natural-refrigerants-across-all-stores/

Enns. (2025). *CO2 vs A2L Refrigerants: The Future of Refrigeration*. https://www.gaenns.com/blog/co2-vs-a2l-refrigerants.

Environmental Investigation Agency and International Institute of Ammonia Refrigeration. (2020). *Letter to California Air Resources Board.* https://eia.org/wp-content/uploads/2020/12/EIA_and_IIAR_Letter_to_CARB_Proposed_HFC_Regulation_Ice_Rinks_150_GWP_Full_List_of_Signatories.pdf

EPEE. (2020). *Sustainable cooling solutions: Emission Reduction in Food Factory with Panasonic CO2 Commercial Refrigeration*. European Partnership for Energy and the Environment.

https://countoncooling.eu/wp-content/uploads/2020/06/Sustainable-cooling-cases-Panasonic-CO2-Refrigeration.pdf

FMI. (2026). *Food Industry Facts.* The Food Industry Association. https://www.fmi.org/our-research/food-industry-factsGlobe Newswire. (2023). Food Lion's Ongoing Sustainability Efforts Recognized by the EPA's GreenChill Program. Available online at: https://www.globenewswire.com/news-release/2023/10/04/2754918/0/en/Food-Lion-s-Ongoing-Sustainability-Efforts-Recognized-by-EPA-s-GreenChill-Program.html

Gordon Brothers Industries. (2026). *Low Charge Ammonia NH3: A New Era of Industrial Refrigeration*. https://gordonbrothers.com.au/lowcharge-ammonia/

GreenChill. (2025). GreenChill Partnership Raw Data. Prepared by the EPA on August 5, 2025.

Heatcraft Refrigeration Products. (2024). *A2L Product Selection Guidelines*. https://www.meiersupply.com/customer/images/resources/A2L%20Product%20Selection%20Guidelines.pdf.

Heatcraft Refrigeration Products. (2025). https://www.heatcraftrpd.com/resources/news/next-gen-refrigerants-making-sense-of-changing-regulations.

Herrar & Obrien. (2025). *Sustainable Solutions for Agricultural Cold Storage: A Case Study. https://iiarcondenser.org/2025-technical-paper-14/*

Herzog C & Lepschat. (2025). *Operating Cost Comparison Between Transcritical CO2 and Ammonia Recirculation Systems in a Cold Storage Warehouse*. IIAR. https://iiarcondenser.org/operating-cost-comparison-between-transcritical-co2-and-ammonia-recirculation-systems-in-a-cold-storage-warehouse/

Hillphoenix. (2019). *DeCO2ded - Understanding the ROI on CO2 Refrigeration Systems*. Hillphoenix. https://www.hillphoenix.com/wp-content/uploads/2018/02/Advansor-White-Paper-RS-DeCO2ded-Understanding-ROI-on-CO2-Systems-Final-.pdf

Hillphoenix. (2022). *Which Refrigerants are Typically Used in Industrial Cold Storage Applications?* https://hillphoenixindustrial.com/which-refrigerants-are-typically-used-in-industrial-cold-storage-applications/

Hillphoenix. (2025) *Ammonia (R-717) Refrigerant for Industrial Applications.* Hillphoenix Industrial. https://hillphoenixindustrial.com/ammonia-r-717-refrigerant/#:~:text=An%20ammonia%2Dbased%20system%20requires%20less%20electricity%2C%20resulting,to%20other%20refrigerants%2C%20ammonia%20also%20performs%20favorably.

Honeywell (2014). Genetron Performax® LT (R407F): https://www.honeywell-refrigerants.com/europe/wp-content/uploads/2014/02/Performax-LT-4pp-130204-low-res.pdf

Honeywell. n.d. Solstice N40 (R-448A): Advanced Materials, https://advancedmaterials.honeywell.com/us/en/products/air-conditioning-refrigeration-and-heating/solstice-hfo-blends/solstice-n40-r-448a.

Hussmann. (2025). HE H-Series Condensing Units (High Efficiency). https://www.hussmann.com/products/refrigeration-systems/condensing-units/hseries-condensing-units-high-efficiency.

IARW. (2023). *Productivity and Benchmarking Survey.* Global Cold Chain Alliance. https://www.gcca.org/resource/iarw-productivity-and-benchmarking-tool-and-executive-summary/

Ice Machines Plus. (2025). Ice-O-Matic RC106C49 Remote Condenser R449 Refrigerant for Model CIM0636R. https://icemachinesplus.com/products/ice-o-matic-rc106c49-remote-condenser-r449-refrigerant-for-model-cim0636r.

IIAR. *IIAR Certificate Course PSM RMP*. IIAR. https://www.iiar.org/IIAR/iiar/education/iiar_certificate_course_psm_rmp.aspx

International Brotherhood of Teamsters. Ammonia Refrigeration in Warehouses: https://teamster.org/ammonia-refrigeration-warehouses/; accessed September 19, 2025.

IRPros. (2025). *Ammonia vs. CO2 vs. HFC: Choosing the Right Refrigerant for Your Industrial Facility*. https://irpros.com/ammonia-vs-co2-vs-hfc-choosing-the-right-refrigerant-for-your-industrial-facility/

Jensen, S. (2013). *Ammonia in the Traditional HFC Territory: How Does It Compare?* IIAR Technical Paper #2.

Jensen, S. (2017). *Energy Performance of Low Charge, Central Type, Dual Stage NH3 Refrigeration Systems in Practice.* IIAR.

Maersk Container Industry (MCI) Containers. (2024). New US Regulations on Refrigerants: Implications for Intermodal Containers. https://www.mcicontainers.com/stories/new-us-regulations-on-refrigerants-implications-for-intermodal-containers/

M&M Carnot & SubZero Constructors. (2023). *A Case Study for CO2 Condensing Units in Various Climates.* ATMO Summit. https://mmcarnot.com/wp-content/uploads/2023/02/2_FINAL_Andrews-Gilliland_MM-Carnot-SubZero.pdf

National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Climate at a Glance: Statewide Mapping: https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/mapping.

North American Sustainable Refrigeration Council (NASRC). (2024). *CO2 Case Study: Grocery Outlet.* NASRC. https://nasrc.org/wp-content/uploads/2024/08/NASRC_GroceryOutletCaseStudy_Final.pdf

Refindustry. (2024). *Understanding Ammonia Refrigeration Systems: Key Benefits and Applications*. https://refindustry.com/articles/techguides/a-concise-overview-of-ammonia-refrigeration-technology/

Refindustry. (n.d.). *Leader of the Rack*. https://refindustry.com/news/market-news/leader-of-the-rack/#:~:text=More%20than%2010%20projects%20so,based%20ALDI%20South%20(S%C3%BCd)

Rosenberg, E. (2025). Phasedown of Hydrofluorocarbons: Reconsideration of Certain Regulatory Requirements Promulgated Under the Technology Transitions Provisions of the American Innovation and Manufacturing Act of 2020. Public comment from The Chemours Company, FC, LLC. Available in the docket for this action at EPA-HQ-OAR-2025-0005-0132.

Scott, D. (2016). *Comparing Evaporative and Air-Cooled Condensing in Ammonia and HFC-507 Refrigeration Systems.* IIAR.

Shecco. (2020). *World Guide to Transcritical CO2 Refrigeration.* Shecco Market Development. https://atmosphere.cool/fact_sheets/world-guide-to-transcritical-co2-refrigeration/

TCW Group. (2024). *Choosing the Right Size and BTU/HR for your Air Conditioner: A Comprehensive Guide. https://www.mytcwgroup.com/post/air-conditioner-size-btu-calculator#:~:text=BTU/HR%20Guidelines%20for%20Room,for%20accurate%20HVAC%20system%20sizing,*

Tecumseh. (2024). *Condensing Units*. https://www.tecumseh.com/ProductFamily/SILENSYS/Catalog/product-type/condensing-units?attributeValueIds=f425844b-e369-448d-b42a-aff100a9dca5%2Cafaf3b3d-d067-4460-87d7-aff100a9de19&isInitialLoad=false&IncludeSubcategories=true

The Kroger Co. (2024). 2024 environmental, social & governance report: https://www.thekrogerco.com/wp-content/uploads/2025/03/Kroger-Co-2024-ESG-Report.pdf

TriplePundit. (2024). *How Aldi is Tackling Extremely Potent Greenhouse Gases.* https://triplepundit.com/2024/aldi-hfcs-natural-refrigerants/#:~:text=To%20date%2C%20more%20than%20700%20Aldi%20stores,are%20currently%20considered%20the%20most%20climate%2Dfriendly%20alternative

Turpin, J. (2025). *A2L Commercial Refrigeration Equipment Hits the Market.* ACHR News. https://www.achrnews.com/articles/165195-a2l-commercial-refrigeration-equipment-hits-the-market

United Nations Environment Program (UNEP). (2016). *Lower-GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO2, ammonia and HFO case studies.* Climate & Clean Air Coalition. https://www.ccacoalition.org/sites/default/files/resources/Lower%20GWP%20Alternatives%20in%20Commercial%20and%20Transport%20Refrigeration.pdf

U.S. Census Bureau. (2024). Annual estimates of the resident population by sex and age: April 1, 2020 to July 1, 2024 [Data file]: https://www2.census.gov/programs-surveys/popest/datasets/2020-2024/national/asrh/nc-est2024-agesex-res.csv

U.S. Department of Agriculture (USDA). (2024). Publication – *Capacity of Refrigerated Warehouses*. Latest release January 31, 2024. https://usda.library.cornell.edu/concern/publications/x059c7329.

U.S. Energy Information Administration (EIA). 2024a. Annual Energy Outlook 2025: Table 4: Residential: Key Indicators: Households. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=4-AEO2025&cases=ref2023&sourcekey=0

U.S. Energy Information Administration (EIA). 2024b. Annual Energy Outlook 2025: Table 38: Light-Duty Vehicle Sales by Technology Type. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=48-AEO2025&cases=ref2025&sourcekey=0

U.S. Environmental Protection Agency. (2018a). *Ammonia Refrigeration List of Key Safety Measurements*. https://www.epa.gov/sites/default/files/2018-05/documents/listofkeymeasurements.pdf

U.S. Environmental Protection Agency. (2018b). EPA's Vintaging Model of ODS Substitutes. EPA Report EPA-400-F-18-001. Available at https://www.epa.gov/sites/production/files/2018-09/documents/epas-vintaging-model-of-ods-substitutes-peer-review-factsheet.pdf.

U.S. Environmental Protection Agency. (2019a). *Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. EPA Report EPA-430-R-19-012. https://www.epa.gov/sites/production/files/201909/documents/nonco2_methodology_report.pdf.

U.S. Environmental Protection Agency. (2019b). *Global Mitigation of Non-CO2 Greenhouse Gases: 2010–2030*. EPA Report EPA-430-R-13-011. https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgs-report-20102030

U.S. Environmental Protections Agency (2021). Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs). https://www.regulations.gov/document/EPA-HQ-OAR-2021-0044-0227 (attachment 1).

U.S. Environmental Protection Agency. (2023). Costs and Environmental Impacts Technical Support Document: https://www.regulations.gov/document/EPA-HQ-OAR-2021-0643-0227 (attachment 8).U.S. Environmental Protection Agency. (2026a). Data and Information Used by WaterSense: https://www.epa.gov/watersense/data-and-information-used-watersense#Cost%20of%20Water

U.S. Environmental Protection Agency. (2026b). Technical Memorandum: Summary of Recent Data for the Large Retail Food End Use and Proposed Vintaging Model Updates. Available in the docket for this action.Whole Foods Market. (2024). *Retail Innovation for Climate Impact.* https://impact.wholefoods.com/retail-innovation.html