Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs)

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United States Environmental Protection Agency

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Executive Summary

The following is an analysis showing EPA's estimation of the regulatory impacts of implementing the phasedown of hydrofluorocarbons (HFCs) required under the American Innovation and Manufacturing Act of 2020 (AIM Act), as realized by promulgating this rule. This analysis is intended to provide the public with information on the relevant costs and benefits of this rulemaking and to comply with executive orders. This rulemaking determines the HFC production and consumption baselines, from which allowed production and consumption will decrease consistent with the statutory phasedown schedule; provides an initial approach to allocating calendar-year allowances and allowing for the transfer of those allowances; establishes provisions for the international transfer of allowances; and establishes recordkeeping and reporting requirements. Additionally, it establishes provisions to support implementation, compliance with, and enforcement of, statutory and regulatory requirements under the Act's phasedown provisions.[1] EPA estimates that for the years 2022–2036 this action will avoid cumulative consumption of 3,152 million metric tons of exchange value equivalent (MMTEVe) of HFCs in the United States. The rule could potentially also have localized impacts on communities that are already disadvantaged and overburdened by pollution living near HFC production facilities due to changes in the toxic feedstocks, catalysts, and byproducts associated with HFC production, although the effect of the rule on the magnitude of those effects is uncertain. However, it is important to recognize that the AIM Act provides for an overall phasedown of the production of this class of chemicals. Other provisions of the rule, such as

[1] While this rule establishes a framework for the allocation of allowances for the first two years, this analysis is based on the full statutory phasedown of HFCs on the schedule established by Congress. The alternative scenario is if the Act did not pass at all.

recordkeeping and reporting, are expected to have a lesser effect on the overall calculation of costs and benefits.

EPA estimates that in 2022, the annual net benefits are $1.7 billion, reflecting cost savings of $300 million and social benefits of $1.4 billion. In 2036, when the final phasedown step is reached at 15 percent of the statutorily defined HFC baseline, the estimated annual net benefits are $16.4 billion. Table ES-1 presents a summary of the annual costs and net benefits of the rule for selected years in the period 2022–2050 with the climate benefits discounted at 3 percent.

Table ES-1: Benefits, Costs, and Net Benefits of the Final Rule for 2022–2050 (billions of 2020$)[a,b,c]

Year	Climate Benefits (3% discount rate)	Costs (annual)	Net Benefits
2022	$1.4	-$0.3	$1.7
2024	$5.2	$0.1	$5.1
2029	$7.5	-$0.6	$8.1
2034	$12.4	-$0.9	$13.3
2036	$15.7	-$0.7	$16.4
2045	$25.1	-$0.9	$26.0
2050	$29.7	-$1.1	$30.8

[a] Benefits include only those related to climate. Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the social cost of HFCs (SC-HFCs): model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate. For the presentational purposes of this table, we show the benefits associated with the average SC-HFC at a 3 percent discount rate, but the Agency does not have a single central SC-HFC point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-HFC estimates. Please see Table 4-24 for the full range of SC-HFC estimates. As discussed in Chapter 4, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts. The costs presented in this table are annual estimates.
[b] Rows may not appear to add correctly due to rounding.
[c] These estimates are year-specific estimates.

Table ES-2 presents the sum of climate benefits across all HFCs reduced for the rule for 2022, 2024, 2029, 2034, 2036, 2045, and 2050.

Table ES-2: Climate Benefits for the Final Rule for 2022–2050 (billions of 2020$)[a]

Year	Climate Benefits by Discount Rate and Statistic			
	5% (average)	3% (average)	2.5% (average)	3% (95th percentile)
2022	0.5	1.4	1.9	3.7
2024	2.2	5.2	7.0	13.8
2029	3.2	7.5	10.0	20.0
2034	5.5	12.4	16.2	33.0
2036	7.2	15.7	20.4	42.0
2045	12.0	25.1	32.2	67.4
2050	14.6	29.7	37.7	79.5

[a] Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the SC-HFCs: model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate. The Interagency Working Group (IWG) emphasized the importance and value of considering the benefits calculated using all four estimates. As discussed in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

As part of fulfilling analytical guidance with respect to Executive Order (E.O.) 12866, EPA presents estimates of the present value (PV) of the benefits and costs over the 29-year period 2022 to 2050. To calculate the PV of the net benefits of the final rule, annual costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4. Climate benefits are discounted at 3 percent as described in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990* (IWG 2021). EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2022 to 2050, would yield a sum equivalent to the PV, discounted at 3 percent and 7 percent. The EAV represents the value of a constant cost or net benefit for each year of the analysis, in contrast to the year-specific estimates mentioned earlier in the RIA.

EPA estimates that the PV of cumulative net benefits evaluated from 2022 through 2050 is $260.9 billion at a 3 percent discount rate.[2] The PV of net benefits is calculated over the 29-year period from 2022–2050 to account for additional years that emissions will be reduced following the consumption reductions from 2022–2036. The EAV over the period 2022–2050 is $14.2 billion when using a 3 percent discount rate and $14.1 billion when using a 7 percent discount rate. Over the 15-year period of the phasedown of HFCs, the PV of cumulative abatement costs is negative $5.4 billion, or $5.4 billion in savings, and the PV of cumulative benefits is $94.8 billion, both at a 3 percent discount rate. Over the same 15-year period of the phasedown, the PV of cumulative net benefits is $100.2 billion. The comparison of benefits and costs in PV and EAV terms for the rule can be found in Table ES-3. Estimates in the table are presented as rounded values.

Table ES-3: Summary of Annual Values, Present Values, and Equivalent Annualized Values for the 2022–2050 Timeframe for Estimated Abatement Costs, Benefits, and Net Benefits for the Final Rule (billions of 2020$, discounted to 2022)[a,b,c]

Year	Climate Benefits (3% discount rate)[c]	Costs (annual)[d]	Net Benefits
2022	$1.4	-$0.3	$1.7
2023	$1.8	-$0.5	$2.3
2024	$5.2	$0.1	$5.2
2025	$6.4	$0.1	$6.2
2026	$6.8	$0.1	$6.7
2027	$7.7	-$0.1	$7.8
2028	$8.5	-$0.1	$8.5
2029	$7.5	-$0.6	$8.2
2030	$8.5	-$0.7	$9.3
2031	$9.4	-$0.8	$10.2
2032	$10.3	-$0.9	$11.2
2033	$11.3	-$1.0	$12.3
2034	$12.4	-$0.9	$13.3
2035	$13.4	-$1.0	$14.4
2036	$15.7	-$0.7	$16.4
2037	$16.5	-$0.8	$17.3

[2] Unless specified otherwise, costs and benefits are presented in 2020 U.S. dollars.

2038	$17.6	-$0.8		$18.4	
2039	$18.7	-$0.8		$19.5	
2040	$19.8	-$0.8		$20.6	
2041	$21.0	-$0.9		$21.9	
2042	$22.1	-$0.9		$23.0	
2043	$23.1	-$0.9		$24.0	
2044	$24.1	-$0.9		$25.0	
2045	$25.1	-$0.9		$26.0	
2046	$26.0	-$0.9		$26.9	
2047	$27.0	-$0.9		$27.9	
2048	$27.9	-$1.0		$28.9	
2049	$28.8	-$1.0		$29.8	
2050	$29.7	-$1.1		$30.8	
Discount Rate	**3%**	**3%**	**7%**	**3%**	**7%**
Present Value	**$260.9**	**-$11.8**	**-$6.4**	**$272.7**	**$267.4**
Equivalent Annualized Value	**$13.6**	**-$0.6**	**-$0.5**	**$14.2**	**$14.1**

[a] Rows may not appear to add correctly due to rounding.
[b] This table presents year-specific estimates, present-value estimates, and annualized estimates. The annualized present value of costs and benefits are calculated over a 29-year period from 2022 to 2050, discounted using both 3% and 7%.
[c] Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the SC-HFC (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the benefits (climate benefits and net benefits) associated with the model average at a 3 percent discount rate, but the Agency does not have a single central SC-HFC point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-HFC estimates. As discussed in Chapter 4, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[d] The costs presented in this table are consistent with the costs presented in Chapter 5, Table 5-1.

The benefits of this rule derive mostly from preventing the emissions of HFCs with high global warming potentials (GWPs), thus reducing the damage from climate change that would have been induced by those emissions. The reduction in emissions follows from a reduction in the production and consumption of HFCs, measured in metric tons of exchange value equivalent (MTEVe). The estimation of $272.7 billion in benefits due to reducing HFC emissions involved three steps. First, the difference between the consumption of HFCs allowed under the rule and the consumption that would have been expected in a business-as-usual (BAU) scenario was calculated for each year of the phasedown in exchange-value-weighted tons (exchange value equivalent, or EVe). Second, using EPA's Vintaging Model, the changes in consumption were used to estimate changes in HFC emissions, which generally lag consumption by some time as HFCs incorporated into equipment and products are eventually released to the environment. Finally, the climate benefits were calculated by multiplying the HFC emission reductions for each year by the appropriate social cost of HFCs to arrive at the monetary value of HFC emission reductions.[3]

EPA estimated the climate benefits for this rulemaking using a measure of the social cost of each HFC (abbreviated as SC-HFC) that is affected by the rule. The SC-HFC is the monetary value of the net harm to society associated with a marginal increase in HFC emissions in a given year, or the benefit of avoiding that increase. In principle, the SC-HFC includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-HFCs, therefore, reflect the societal value of reducing emissions of the gases in question by one metric ton. The SC-HFCs are the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect HFC emissions.

EPA estimates the total social benefits of HFC emission reductions expected from this rule using HFC-specific SC-HFC estimates. The SC-HFC estimates used in this analysis were developed using methodologies consistent with the methodologies underlying the interim estimates of the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O)—collectively referred to as social cost of greenhouse gases (SC-GHG)—published in February 2021 by the IWG. As a member of the IWG involved in the

[3] Calculations for the costs and benefits of the HFC-23 control provisions were performed slightly differently. For more information see Appendix G.

development of the February 2021 *Technical Support Document (TSD): Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990* (IWG 2021), EPA agrees that the interim SC-GHG estimates represent the most appropriate estimate of the SC-GHG until revised estimates have been developed reflecting the latest, peer-reviewed science. The interim SC-GHG estimates were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Therefore, EPA views the methods to be appropriate for estimating SC-HFCs for use in benefit-cost analysis.

The IWG, which included EPA and other executive branch agencies and offices, used three integrated assessment models (IAMs) to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). On January 20, 2021, President Biden issued E.O. 13990, which directed the IWG to ensure that the U.S. Government's (USG's) estimates of the social cost of carbon and other GHGs reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the estimates currently used by the USG and publishing interim estimates within 30 days of E.O. 13990 that reflect the full impact of GHG emissions, including taking global damages into account.[4] The SC-HFC estimates used here to estimate the climate benefits for this final rulemaking are consistent with the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates published in February 2021.

Tables ES-4 through ES-13 summarize the HFC-specific SC-HFC estimates for the years 2020 to 2050.[5] For purposes of capturing uncertainty around the SC-HFC estimates in analyses, we emphasize the importance of considering all four values for each SC-HFC. The SC-HFC increases over time within the models—e.g., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025—because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because gross domestic product (GDP) is growing over time and many damage categories are modeled as proportional to GDP.

Table ES-4: Social Cost of HFC-32, 2020–2050 (in 2020 dollars per metric ton HFC-32)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$18,000	$38,000	$50,000	$100,000
2025	$22,000	$45,000	$58,000	$120,000
2030	$27,000	$53,000	$67,000	$140,000
2035	$33,000	$62,000	$77,000	$170,000
2040	$39,000	$71,000	$88,000	$190,000
2045	$46,000	$81,000	$99,000	$220,000
2050	$53,000	$92,000	$110,000	$250,000

[4] The E.O. instructs the IWG to undertake a fuller update of the SC-GHG estimates by January 2022.
[5] The values are stated in $/metric ton of each HFC and vary depending on the year of emission reductions. All estimates are presented in 2020 dollars and are rounded to two significant figures. The annual unrounded estimates are available in Appendix E.

Table ES-5: Social Cost of HFC-125, 2020–2050 (in 2020 dollars per metric ton HFC-125)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$83,000	$210,000	$290,000	$550,000
2025	$99,000	$240,000	$330,000	$640,000
2030	$120,000	$280,000	$370,000	$730,000
2035	$140,000	$310,000	$410,000	$830,000
2040	$160,000	$350,000	$450,000	$930,000
2045	$180,000	$390,000	$500,000	$1,000,000
2050	$210,000	$430,000	$550,000	$1,100,000

Table ES-6: Social Cost of HFC-134a, 2020–2050 (in 2020 dollars per metric ton HFC-134a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$38,000	$87,000	$120,000	$230,000
2025	$46,000	$100,000	$130,000	$270,000
2030	$55,000	$120,000	$150,000	$310,000
2035	$65,000	$130,000	$170,000	$360,000
2040	$76,000	$150,000	$190,000	$410,000
2045	$88,000	$170,000	$210,000	$460,000
2050	$100,000	$190,000	$230,000	$510,000

Table ES-7: Social Cost of HFC-143a, 2020–2050 (in 2020 dollars per metric ton HFC-143a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$95,000	$270,000	$380,000	$700,000
2025	$110,000	$300,000	$420,000	$800,000
2030	$130,000	$340,000	$470,000	$910,000
2035	$150,000	$380,000	$520,000	$1,000,000
2040	$180,000	$430,000	$570,000	$1,100,000
2045	$200,000	$470,000	$620,000	$1,300,000
2050	$230,000	$520,000	$680,000	$1,400,000

Table ES-8: Social Cost of HFC-152a, 2020–2050 (in 2020 dollars per metric ton HFC-152a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$2,600	$5,400	$6,900	$14,000
2025	$3,200	$6,300	$8,100	$17,000
2030	$3,900	$7,400	$9,300	$20,000
2035	$4,700	$8,600	$11,000	$23,000
2040	$5,600	$10,000	$12,000	$27,000
2045	$6,700	$12,000	$14,000	$32,000
2050	$7,800	$13,000	$16,000	$37,000

Table ES-9: Social Cost of HFC-227ea, 2020–2050 (in 2020 dollars per metric ton HFC-227ea)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$74,000	$190,000	$270,000	$510,000
2025	$88,000	$220,000	$300,000	$580,000
2030	$100,000	$250,000	$340,000	$660,000
2035	$120,000	$280,000	$370,000	$750,000
2040	$140,000	$320,000	$410,000	$840,000
2045	$160,000	$350,000	$450,000	$930,000
2050	$180,000	$390,000	$500,000	$1,000,000

Table ES-10: Social Cost of HFC-236fa, 2020–2050 (in 2020 dollars per metric ton HFC-236fa)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$180,000	$640,000	$970,000	$1,700,000
2025	$210,000	$710,000	$1,100,000	$1,900,000
2030	$250,000	$790,000	$1,200,000	$2,100,000
2035	$290,000	$870,000	$1,300,000	$2,300,000
2040	$330,000	$960,000	$1,400,000	$2,600,000
2045	$380,000	$1,000,000	$1,500,000	$2,800,000
2050	$430,000	$1,100,000	$1,600,000	$3,100,000

Table ES-11: Social Cost of HFC-245fa, 2020–2050 (in 2020 dollars per metric ton HFC-245fa)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$29,000	$61,000	$80,000	$160,000
2025	$35,000	$72,000	$93,000	$190,000
2030	$42,000	$84,000	$110,000	$220,000
2035	$50,000	$97,000	$120,000	$260,000
2040	$59,000	$110,000	$140,000	$300,000
2045	$69,000	$130,000	$160,000	$340,000
2050	$79,000	$140,000	$170,000	$390,000

Table ES-12: Social Cost of HFC-43-10mee, 2020–2050 (in 2020 dollars per metric ton HFC-43-10mee)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$43,000	$100,000	$130,000	$260,000
2025	$52,000	$120,000	$150,000	$310,000
2030	$62,000	$130,000	$170,000	$360,000
2035	$73,000	$150,000	$200,000	$410,000
2040	$86,000	$170,000	$220,000	$470,000
2045	$99,000	$190,000	$240,000	$520,000
2050	$110,000	$220,000	$270,000	$570,000

Table ES-13: Social Cost of HFC-23, 2020–2050 (in 2020 dollars per metric ton HFC-23)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	$270,000	$970,000	$1,500,000	$2,600,000
2025	$320,000	$1,100,000	$1,600,000	$2,900,000
2030	$370,000	$1,200,000	$1,800,000	$3,200,000
2035	$430,000	$1,300,000	$1,900,000	$3,600,000
2040	$490,000	$1,500,000	$2,100,000	$3,900,000
2045	$570,000	$1,600,000	$2,300,000	$4,400,000
2050	$640,000	$1,700,000	$2,500,000	$4,800,000

This analysis also includes the benefits and costs of provisions governing the control, capture, and destruction of HFC-23, as well as the costs of provisions governing refillable cylinders. Only the costs for complying with the refillable cylinders provisions was included because EPA is concerned about the potential for double-counting emissions reductions. Additionally, this analysis explores the consequences of this rule on nearby populations and explores if there are disproportionately high and adverse human health impacts on disadvantaged communities as well as possible impacts to the labor force. Overall, this rule will reduce GHG emissions, which will have particular benefit to populations that may be especially vulnerable to damages associated with climate change. However, how producers transition due to the HFC phasedown may drive changes in future health risks for communities living near production facilities of HFCs and substitutes due to the use of feedstock chemicals, byproducts, and co-products that have local effects when released into the environment. Given limited information regarding how producers will transition, it is unclear to what extent health risks from hazardous air toxics for communities living near production facilities may be impacted by this rule.

HFCs have a wide range of uses; however, their predominant use is as refrigerants for air conditioning and refrigeration. HFCs were intentionally developed to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) which have largely been phased out in the United States through implementation of Title VI of the Clean Air Act.

Chapter 1: Introduction and Background

This analysis presents the EPA's estimates of costs and benefits associated with implementing the phasedown of HFCs as a result of the passage of the American Innovation and Manufacturing Act of 2020, as realized by promulgating this rule. Specifically, this analysis looks at the costs and climate benefits of phasing down U.S. HFC production and consumption through 2036 to 15 percent below an established baseline, the associated transition for sectors and subsectors from using certain HFC-based technology to alternative technologies, implementing an emission standard for HFC-23 controls, and the costs of the suite of enforcement and compliance mechanisms, including complying with a requirement to transition to refillable cylinders. In addition, this analysis examines potential localized impacts of implementing the rule in communities surrounding HFC producers. This analysis is intended to provide the public with information on the relevant costs and benefits of this action and to comply with executive orders.

The Agency estimates the present cumulative net benefits of phasing down HFCs to be $272.7 billion, discounted at a 3 percent rate. The present value of net benefits is calculated over the 29-year period from 2022–2050 to account for additional years that emissions will be reduced following the consumption reductions from 2022–2036. Over the 15-year period of the phasedown of HFCs, the present value of cumulative abatement costs is -$5.4 billion, or $5.4 billion in savings, and the present value of cumulative social benefits is $94.8 billion, both at a 3 percent discount rate. The present value of costs for complying with refillable cylinders over the same period is $494 million. Cumulatively over the 15-year period of the phasedown, the present value of net benefits is $100.2 billion. Benefits were calculated out to 2050 and discounted to the present at a 3 percent discount rate. EPA also estimates that for each major compliance period

(2022–2023, 2024–2028, etc.), the cumulative cost savings exceed costs prior to considering the impact of social (climate) benefits. These estimates are calculated assuming that currently deployed HFC-based technologies remain in use for their useful life.

It is important to note while the analyzed costs focus primarily on abatement costs and savings, there are several other assumptions and parameters that may result in higher costs, increased cost savings, or different estimates to the benefits. EPA conducted analyses of upper- and lower-bound estimates of abatement costs, spanning $13.1 billion in costs to at least $13.9 billion in savings, compared with the Agency's preferred estimate (see Table 3-8 for the full sensitivity analysis results).

Note that the results depend heavily on the assumed BAU forecast of HFC use and the calculated baseline from which the reduction schedule is set (i.e., what would happen in the absence of the AIM Act phasedown). The Agency's preferred analysis does not account for voluntary large-scale adoption of cost-saving technologies by industry in the BAU; hence, such cost savings are attributed to the implementation of the AIM Act. We do not know the extent that these cost-minimizing technologies would be adopted by users of HFCs in the absence of new regulations authorized by the AIM Act. For a more complete picture, this cost analysis should be considered alongside other analyses, such as projections of increased domestic manufacturing for export markets.[6] Further, non-climate-related health and environmental costs and benefits of the AIM Act were not analyzed, thus there are no monetized direct health benefits included in this memo.

Second, this analysis does not account for state-level action on HFCs. As of the date of this analysis, 12 states had promulgated regulations to limit the use of certain HFCs or HFC

[6] For example, see JMS Consulting and Inforum. November 9, 2018. Consumer Cost Impacts of U.S. Ratification of the Kigali Amendment.

blends for specific products and four additional states have indicated an intent to take similar action. These rules are similar in many respects to rules EPA promulgated under Clean Air Act (CAA) section 612 in 2015 and 2016 as part of the Significant New Alternatives Policy (SNAP) program.[7] None of these state actions phase down overall HFC consumption and production analogous to this rulemaking; however, they do affect availability of HFCs for specific applications. States with such limits are California, Colorado, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, Vermont, Virginia, and Washington. Other states, including Connecticut and Hawaii, are in the process of considering establishing GWP-based limitations on HFCs for specific applications. State actions combined with transitions already taking place suggest that a portion of the abatement costs and savings would be accrued irrespective of the AIM Act. State actions were not accounted for in this analysis in large part due to the differences between the state HFC limits and a phasedown in HFC production and consumption, as well as a lack of available data besides the analysis that accompanied the EPA SNAP regulations that inspired the state actions.[8] Including state actions into the BAU may decrease the BAU by up to about 6.6% by 2050. More information on state actions and the limiting factors of this analysis may be found in Appendix B.

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[7] Under CAA section 612, EPA issued a final rule on July 20, 2015, which, among, other things, changed listings under the SNAP program for certain HFCs and blends from acceptable to unacceptable in various end-uses in the aerosols, refrigeration and air conditioning, and foam blowing sectors. After a challenge to the 2015 rule, the U.S. Court of Appeals for the D.C. Circuit ("the court") issued a partial vacatur of the 2015 rule "to the extent [it] requires manufacturers to replace HFCs with a substitute substance," and remanded the rule to EPA for further proceedings. Later, the court issued a similar decision on portions of a similar CAA section 612 final rule issued December 1, 2016. *See Mexichem Fluor, Inc. v. EPA, 760 F. App'x 6 (D.C. Cir. 2019) (per curiam).*

[8] EPA estimated the benefits of the July 20, 2015, and December 1, 2016, rules under a "most likely" scenario to be a reduction of 68 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) in emissions in 2025, increasing to 128 $MMTCO_2e$ in 2035 (see https://www.regulations.gov/search?filter=EPA-HQ-OAR-2015-0663-0125). A first-order estimate of the emission reductions achieved by the 12 states listed with regulated limits would be to apportion by population, or approximately 32.4% of the estimated national emission reductions. (Resident populations from U.S. Census; https://www2.census.gov/programs-surveys/decennial/2020/data/apportionment/apportionment-2020-table02.pdf It should be noted, however, that the implementation dates for these 12 states vary and most often are later than those set under EPA's 2015 and 2016 rules.

In addition, other countries are implementing their own domestic regulations, which would also increase the global adoption of HFC alternatives and/or blends with lower GWPs in the absence of this regulation and likely would result in some changes to the U.S. market. Regulations in other countries would not preclude the continued production and use of HFCs in the United States. Given U.S. producers supply a significant portion of the U.S. market already and absent these regulations their production could increase, EPA recognizes that actions to restrict or limit HFCs taken by other countries would have an effect on the U.S. market, but those actions do not relate to these regulations. Moreover, if the United States stays entrenched in HFC technologies while other markets move to alternatives, it is likely that U.S. companies will find themselves at a comparative disadvantage. However, for this analysis, EPA did not account for the impact of global markets.

Finally, this analysis does not account for how future economies of scale, spurred by an increase in global demand for alternative technologies, would affect the results of the analysis. In developing this analysis, the Agency relied on our experience phasing out ozone-depleting substances (ODS) in most of the same sectors covered by the AIM Act. We have found that implementing Title VI of the CAA, which provides EPA the authority to phase out ODS, did not result in major disruptions to industry or prohibit consumers from accessing affected products and services. For example, the inflation-adjusted price for various air-conditioning and refrigeration equipment has declined over time, despite changes to the refrigerant and foam-blowing agent, increased energy efficiency standards, and the technology innovations needed to accommodate those changes.[9] While past cost analyses of the ODS phaseout provide important context, they also demonstrate that realized costs can be lower.[10,11]

1.1 Statutory Requirement

The AIM Act, enacted on December 27, 2020, directs EPA to address HFCs by providing new authorities in three main areas: to phase down the production and consumption of listed HFCs, manage these HFCs and their substitutes, and facilitate the transition to next-generation technologies. This analysis is associated with a rulemaking that focuses on the phasedown of the production and consumption of HFCs.

The Act lists 18 saturated HFCs, and by reference any of their isomers not so listed, that are covered by the statute's provisions, referred to as "regulated substances" under the Act.[12] Congress also assigned an "exchange value"[13] for each of the listed 18 HFCs (along with other chemicals that are used to calculate the baseline). For reference, the table in subsection (c)(1) of the Act is reproduced here in Table 1-1, which lists the regulated substances and their exchange values.

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[9] See the Technology and Economic Assessment Panel (May 2018) report related to energy efficiency, available at: http://conf.montreal-protocol.org/meeting/oewg/oewg-40/presession/Background-Documents/TEAP_DecisionXXIX-10_Task_Force_EE_May2018.docx

[10] "Overview of CFC and HCFC Phaseout." August 2018. Available at: https://www.regulations.gov/document?D=EPA-HQ-OAR-2016-0271-0025

[11] "Benefits and Costs of the Clean Air Act." Available at https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act

[12] Unless stated otherwise, this report uses "HFCs" and "18 HFCs" to refer to all the HFCs that are regulated substances in the AIM Act (e.g., including isomers not listed and for which an exchange value is not provided in the legislation).

[13] EPA has determined that the exchange values included in subsection (c) of the AIM Act are identical to the GWPs included in IPCC (2007). EPA uses the terms "global warming potential" and "exchange value" interchangeably. One MMTEVe is therefore equivalent to one $MMTCO_2e$.

Table 1-1: List of Regulated Substances and Their Exchange Values

Chemical Name	Common Name	Exchange Value
CHF_2CHF_2	HFC-134	1,100
CH_2FCF_3	HFC-134a	1,430
CH_2FCHF_2	HFC-143	353
$CHF_2CH_2CF_3$	HFC-245fa	1,030
$CF_3CH_2CF_2CH_3$	HFC-365mfc	794
CF_3CHFCF_3	HFC-227ea	3,220
$CH_2FCF_2CF_3$	HFC-236cb	1,340
CHF_2CHFCF_3	HFC-236ea	1,370
$CF_3CH_2CF_3$	HFC-236fa	9,810
$CH_2FCF_2CHF_2$	HFC-245ca	693
$CF_3CHFCHFCF_2CF_3$	HFC-43-10mee	1,640
CH_2F_2	HFC-32	675
CHF_2CF_3	HFC-125	3,500
CH_3CF_3	HFC-143a	4,470
CH_3F	HFC-41	92
CH_2FCH_2F	HFC-152	53
CH_3CHF_2	HFC-152a	124
CHF_3	HFC-23	14,800

In addition, the AIM Act requires EPA to phase down the consumption and production of the statutorily listed HFCs on an exchange value-weighted basis according to the schedule stated in (e)(2)(C), and requires that the EPA Administrator ensure the annual quantity of all regulated substances produced or consumed in the United States does not exceed the percentage listed for the production or consumption baseline. The AIM Act provides formulas for how to set a baseline. The equations are composed of an HFC component, a hydrochlorofluorocarbon (HCFC) component, and a chlorofluorocarbon (CFC) component. Specifically, EPA is directed to calculate the baselines by adding: (i) the average annual quantity of all regulated substances produced, or consumed, in the United States from January 1, 2011, through December 31, 2013;

and (ii) 15 percent of the production, or consumption, level of HCFCs in calendar year 1989; and (iii) 0.42 percent of the production, or consumption, level of CFCs in calendar year 1989 as outlined in Table 1-2.

Table 1-2: Phasedown Schedule

Date	Percentage of Production Baseline	Percentage of Consumption Baseline
2020 – 2023	90 percent	90 percent
2024 – 2028	60 percent	60 percent
2029 – 2033	30 percent	30 percent
2034 – 2035	20 percent	20 percent
2036 and thereafter	15 percent	15 percent

For a complete description of the statutory requirements, see section I.A of the final rule.

1.2 Background

HFCs are anthropogenic[14] fluorinated chemicals that have no known natural sources. HFCs are used in the same applications in which ODS have historically been used, such as refrigeration and air conditioning, foam-blowing agents, solvents, aerosols, and fire suppression. HFCs are potent GHGs with 100-year GWPs (a measure of the relative climatic impact of a GHG) that can be hundreds to thousands of times more potent than carbon dioxide (CO_2).

Although HFCs represent a small fraction (~1.5 percent) of the current total GWP-weighted amount of GHG emissions,[15] their use is growing worldwide due to the global phaseout of ODS under the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol), and the increasing use of refrigeration and air-conditioning equipment globally. HFC emissions had previously been projected to increase substantially over the next several decades,

[14] While the overwhelming majority of HFC production is intentional, HFC-23 can be a byproduct associated with the production of other chemicals, including but not limited to HCFC-22.
[15] World Meteorological Organization (WMO). *Scientific Assessment of Ozone Depletion: 2018*, World Meteorological Organization, Global Ozone Research and Monitoring Project – Report No. 58, 2018, 588 pp., Geneva, Switzerland. Available at https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf.

but global adherence to the Kigali Amendment to the Montreal Protocol (Kigali Amendment) would substantially reduce future emissions, leading to a peaking of HFC emissions before 2040.[16]

Atmospheric observations of most currently measured HFCs confirm their amounts are increasing in the global atmosphere at accelerating rates. Total emissions of HFCs increased by 23 percent from 2012 to 2016 and the four most abundant HFCs in the atmosphere, in GWP-weighted terms, are HFC-134a, HFC-125, HFC-23, and HFC-143a.[17]

In 2016, HFCs accounted for a radiative forcing of 0.025 W/m^2, not including additional forcing from HFC-23 of 0.005 W/m^2; this is a 36-percent increase in total HFC forcing relative to 2012.[18] This radiative forcing was projected to increase by an order of magnitude to 0.25 W/m^2 by 2050, not including additional forcing from HFC-23. In 2016, in Kigali, Rwanda, countries agreed to adopt an amendment to the Montreal Protocol, known as the Kigali Amendment, which provides for a global phasedown of the production and consumption of HFCs. If the Kigali Amendment were to be fully implemented, it would be expected to reduce the future radiative forcing due to HFCs (excluding HFC-23) to 0.13 W/m^2 in 2050, a reduction of about 50 percent compared to the radiative forcing projected in the BAU scenario of uncontrolled HFCs.[19] A global HFC phasedown consistent with the Kigali Amendment to the Montreal Protocol is expected to avoid up to 0.5°C of warming by 2100.[20]

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[16] Ibid.
[17] Ibid.
[18] Radiative forcing is a measure of the difference between the solar energy that is absorbed by the earth and the amount of that energy that is reflected back to space. The mix of gases in our atmosphere keeps some of the energy from escaping, which is what keeps the Earth warm enough to support life, and changes in that mix can change the equilibrium surface temperature. HFCs exert positive radiative forcing, which means that they contribute to the net gain of energy and contribute to the warming of the planet.
[19] WMO (2018).
[20] Ibid.

There are hundreds of possible HFC compounds. The 18 HFCs listed as regulated substances by the AIM Act are some of the most commonly used HFCs and have high impacts as measured by the quantity emitted multiplied by their respective GWPs. These 18 HFCs are all saturated, meaning they have only single bonds between their atoms and therefore have longer atmospheric lifetimes.

In the United States, HFCs are used primarily in refrigeration and air-conditioning equipment in homes, commercial buildings, and industrial operations (~75 percent of total HFC use in 2019) and in air conditioning in vehicles and refrigerated transport (~8 percent). Smaller amounts are used in foam products (~11 percent), aerosols (~4 percent), fire protection systems (~1 percent), and solvents (~1 percent).[21]

EPA considered the emissions reductions from an HFC consumption phasedown in the United States and presented the results in the 2016 Biennial Report to the United Nations Framework Convention on Climate Change (UNFCCC).[22] At that time, EPA provided a reductions estimate of 113 million metric tons of carbon dioxide equivalent (MMTCO$_2$e) of reduced HFC emissions in the United States associated with the implementation of an amendment proposal submitted in 2015 by the United States, Canada, and Mexico that was under consideration by the parties to the Montreal Protocol and was very similar to the Kigali Amendment. While the Kigali Amendment ultimately adopted under the Montreal Protocol has

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[21] Calculations based on EPA's Vintaging Model, which estimates the annual chemical emissions from industry sectors that historically used ODS, including refrigeration and air-conditioning, foam blowing agents, solvents, aerosols, and fire suppression. The model uses information on the market size and growth for each end use, as well as a history and projections of the market transition from ODS to alternatives. The model tracks emissions of annual "vintages" of new equipment that enter into operation by incorporating information on estimates of the quantity of equipment or products sold, serviced, and retired or converted each year, and the quantity of the compound required to manufacture, charge, and/or maintain the equipment. Additional information on these estimates is available in U.S. EPA, April 2016. EPA Report EPA-430-R-16-002. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014*. Available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014.

[22] U.S. Department of State. *Second Biennial Report of the United States of America Under the United Nations Framework Convention on Climate Change*. 2016. Available at: http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php.

certain marked differences from the AIM Act, given that the two documents have a nearly identical list of HFCs to be phased down following the same schedule, the 2016 Biennial Report provides useful information. The Biennial Report included estimates for HFC actions under CAA section 612 modeled in the *2016 Current Measures* scenario. HFC emissions reductions through additional measures in 2020 and 2025 relative to the *2016 Current Measures* scenario were presented under the *Additional Measures* scenario and included both options for continued action under the CAA and the implementation of an HFC phasedown in the United States, which is similar to the requirements of the AIM Act with an earlier start date.[23] The emissions reductions for the *Additional Measures* scenario were estimated to be 63 $MMTCO_2e$ in 2020 and 113 $MMTCO_2e$ in 2025.

1.3 Regulated Community

The HFC industry is composed of several types of entities. The regulated community analyzed for this rulemaking includes potentially any entity that supplies HFCs, ranging from producers, importers, and reclaimers that introduce HFCs into U.S. commerce, as well as companies that repackage and blend HFCs and companies that distribute HFCs to the ultimate end users. The companies supplying and distributing HFCs are directly regulated by this rule.[24] The regulated community also includes any of the six applications eligible for an allocation under section (e)(4)(B)(iv) of the AIM Act including: (i) propellants in metered dose inhalers

[23] The "Current Measures" scenario in the Biennial Report included HFC reductions estimated under a rule EPA issued on July 20, 2015, under section 612 of the CAA, which, among other things, changed listings under the Significant New Alternatives Policy program for certain HFCs and blends from acceptable to unacceptable in various end uses in the aerosols, refrigeration and air conditioning, and foam blowing sectors. The "Additional Measures" scenario in the Biennial Report included additional actions that EPA anticipated under a proposed amendment to the Montreal Protocol to phase down HFC production and consumption, some of which were included in a rule EPA issued on December 1, 2016, under section 612 of the CAA. Since the 2016 Biennial Report, after a challenge to the 2015 rule, the U.S. Court of Appeals for the D.C. Circuit ("the court") issued a partial vacatur of the 2015 rule "to the extent [it] requires manufacturers to replace HFCs with a substitute substance," and remanded the rule to EPA for further proceedings. Later, the court issued a similar decision on portions of the rule issued December 1, 2016. *See Mexichem Fluor, Inc. v. EPA, 760 F. App'x 6 (D.C. Cir. 2019) (per curiam).*

[24] North American Industry Classification (NAICS) codes for those potentially directly affected by this rule are included in Appendix F.

(MDIs); (ii) defense sprays; (iii) structural composite preformed polyurethane foam for marine use and trailer use; (iv) the etching of semiconductor material or wafers and the cleaning of chemical vapor deposition chambers within the semiconductor manufacturing sector; (v) onboard aerospace fire suppression; and (vi) mission-critical military end uses, such as armored vehicle engine and shipboard fire suppression systems and systems used in deployable and expeditionary applications. A description of these applications is included in Sections V and VII.C of the final rule.

HFCs may also be used as feedstock for the production of other chemicals, or as a process agent in the production of other chemicals. This rule does not restrict the use of HFCs for feedstock or as a process agent.

Chapter 2: Overview of the Regulatory Impact Analysis (RIA)

2.1. Organization of the RIA

This analysis identifies the principal costs and benefits of implementing this rulemaking. The analysis is laid out by presenting the principal costs in Chapter 3, the principal benefits in Chapter 4, and the net benefits in Chapter 5. Chapter 6 explores the potential for environmental justice concerns and provides information with respect to health effects, and Chapter 7 discusses uncertainty regarding the transition to HFC substitutes. Chapters 3 and 4, in addition to presenting EPA's estimate of net costs and benefits, also show related sensitivity analyses that demonstrate how areas of uncertainty may affect the principal conclusions. Additional information may be found in Chapter 8 (appendices).

2.2 Years of Analysis

This analysis estimated the costs of abatement with an HFC phasedown for the periods specified in the AIM Act, as implemented through this final rule. We have assumed here that compliance would begin in 2022 following implementation of this rulemaking. We evaluate consumption reductions through the last year when HFC consumption is phased down, i.e., 2036. For the purpose of evaluating the climate benefits due to emission reductions that lag the phasedown schedule, we look at consumption reductions and associated emission reductions through 2050 by modeling continued abatement with the cap through that period.[25]

[25] In the draft RIA, we used a model that provided only 5-year intervals and used proxy years for the compliance years called for in the AIM Act (e.g., 2030 was used for 2029).

Because emissions generally lag consumption, for example as leaks from equipment that can operate for decades, emission benefits are calculated annually for the period of 2022–2050. We note that additional benefits of an HFC phasedown would occur even beyond this period because compliance with the AIM Act continues and because of the long lifetime of emissions from some types of products that would reduce HFC consumption (e.g., certain closed-cell foams).

2.3 Factors Analyzed

The RIA takes into consideration the following effects resulting from the phasedown as implemented by this rulemaking: the cost of the needed abatement to comply with the regulations and the increased use of substitute chemicals and technologies; the environmental benefits of phasing down HFCs and the associated avoided costs of global warming; implementing offsets for traded allowances; and requiring industry to shift to using refillable cylinders instead of disposable cylinders.

The RIA also incorporates estimates of costs and benefits associated with requiring the control, capture, and destruction of HFC-23 that would otherwise be emitted from a facility.

Chapter 3 provides more detail on the cost of substituting chemicals and related technologies for HFCs, as well as the provisions for refillable cylinders, and recordkeeping and recording costs. Chapter 4 provides more detail on the environmental benefits resulting from phasing out HFCs.

The effect of implementing an allowance transfer offset has implications for both costs and benefits. For costs, a percentage of allowances reduced as a result of offsets decreases the overall amount of allowances and therefore could require additional actions, at additional costs, be taken to comply with these lower allowed levels of consumption. Section 3.4 discusses the effects of these offsets.

Chapter 3: Cost Estimates

3.1 Introduction

Three costs are incorporated in the RIA: (i) abatement costs associated with phasing down the consumption of HFCs and the control, capture, and destruction of HFC-23 that would otherwise be emitted;[26] (ii) compliance costs associated with the refillable cylinders provision; and (iii) recordkeeping and reporting costs. EPA analyzed the abatement cost of the selected option and other regulatory options considered for this rule. While social costs are the most comprehensive measure of costs of a regulation, estimation of the social costs associated with this rule are beyond the scope of the RIA. The abatement costs associated with the rule are described in this chapter along with the methodology and modeling tools EPA used to derive them.

3.2 Modeling Method for Abatement Costs

To generate abatement cost estimates for the rule EPA used the Vintaging Model, described below, to estimate baseline HFC demand and abatement potential. The abatement options (section 3.2.2) were used to estimate marginal abatement cost curves (MACCs) in a reduced-form marginal abatement cost (MAC) model in a manner similar to that presented in EPA's *Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation, 2015–2050* report.[27,28] The MACCs describe the supply of abatement available at a given cost in a particular

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[26] The final rule also includes a phasedown in the production of HFCs. Because the baseline for the HFC production phasedown is higher than that for the consumption phasedown, and because production is added into the calculation of consumption, we assume the consumption reduction is the limiting factor. This RIA therefore assumes the costs of abatement of HFC production are incorporated in the costs of abatement of HFC consumption analyzed here.

[27] MAC curves are constructed by estimating the "break-even" price at which the present-value benefits and costs for each mitigation option equilibrate. The methodology produces a curve where each point reflects the average price and reduction potential if a mitigation technology were applied across the sector.

[28] U.S. EPA. *Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation: 2015–2050.* September 2019. EPA Report EPA-430-R-19-010. Available at https://www.epa.gov/sites/production/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf.

year. When evaluated against the HFC phasedown schedule the cost of abatement can be determined.

3.2.1 Vintaging Model

EPA used the Vintaging Model to estimate a BAU forecast of HFC consumption that would occur in absence of the Act. The model tracks the use and emissions of each of the substances separately for each of the ages or "vintages" of equipment. The Vintaging Model is used to produce the estimates of GHG emissions in the official U.S. GHG Inventory and is updated and enhanced annually. Information on the version of the model used for this RIA, the various assumptions used, and HFC emissions may be found in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014*.[29] An overview of transitions to lower-GWP substances included in the BAU model is provided in section 3.3.2 below.

The peer-reviewed Vintaging Model utilizes detailed information on more than 60 end uses across the five major industrial sectors that previously relied on ODS and have more recently used HFCs (i.e., Refrigeration and Air Conditioning, Foams, Aerosols, Solvents, and Fire Suppression).[30,31] 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, 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 options—such as those analyzed here as options to reduce HFC consumption—the model tracks annual vintages and calculates the amount of each

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[29] U.S. EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014.* April 2016. EPA Report EPA-430-R-16-002. Available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014.
[30] U.S. EPA. *EPA's Vintaging Model of ODS Substitutes*. September 2018. 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.
[31] Appendix D provides detail on the end uses modeled as part of this RIA.

chemical in use, emitted, and the consumption needed to both support new products and service existing products (e.g., to "top-off" leaks from air conditioners). The Vintaging Model estimates the use and emissions of ODS substitutes—including HFCs and other substitutes—by taking the following steps:

1. Gather historical emission data. The Vintaging Model 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 Vintaging Model 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 estimate the HFC reductions achievable with such actions.
3. Estimate emissions of the ODS substitutes and HFC substitutes. The chemical use is estimated from the amount of substitutes that are required each year for the manufacture, installation, use, or servicing of products. The emissions are estimated from the emission profile for each vintage of equipment or product in each end use. By aggregating the emissions from each vintage, a time profile of emissions from each end use is developed.

To project into the future, each end use is assigned a growth rate based on the overall growth seen from the past several years. 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.[32]

3.2.2 Abatement Options Modeled

HFC abatement options evaluated in this analysis were compiled from sector-specific literature and studies referenced in the methodology documentation that accompanies the Non-CO_2 Greenhouse Gas Emission Projections & Mitigation reports and is summarized in Appendix D.[33,34] More information regarding HFC-23 abatement can be found in Appendix G. The technical effectiveness of each option was calculated by multiplying the option's technical applicability by its market share by its reduction efficiency. This calculation yields the percentage of baseline emissions that can be reduced at the national or regional level by a given option. Here, technical applicability accounts for the portion of emissions from a facility or region that a mitigation option could feasibly reduce based on its application, and reduction efficiency represents the percentage of technically achievable emission abatement for an option after it is applied to a given emission stream. The model assumes that existing HFC equipment continues to be used for its typical lifetime; i.e., there is no pre-retirement of equipment.[35] Market penetration of newer technologies is based on expert judgment and would apply as older HFC-using vintages adopt the new technologies. Abatement option technical applicability,

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[32] Annual Energy Outlook. *Annual Energy Outlook 2009 with Projections to 2030.* March 2009. Energy Information Administration, U.S. Department of Energy, Washington, DC 20585. DOE/EIA report DOE/EIA-0383(2009). Available at https://www.eia.gov/outlooks/archive/aeo09/pdf/0383(2009).pdf.

[33] U.S. EPA. *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. September 2019. EPA Report EPA-430-R-19-012. Available at https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.

[34] U.S. EPA. September 2019b. EPA Report EPA-430-R-13-011. *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010–2030.* Available at https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgs-report-2010-2030.

[35] Lifetimes are provided in U.S EPA (April 2016) and range from 1-year (e.g., aerosol cans) to multiple decades (e.g., chillers and certain types of foam). U.S. EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014.* April 2016. EPA Report EPA-430-R-16-002. Available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014.

market penetration, reduction efficiency, and technical effectiveness are discussed throughout section 5.2.8.2 of the above-referenced methodology documentation[33].

Within various end uses, EPA evaluated one or more options that would reduce, or eliminate, HFC consumption to achieve compliance with the AIM Act. Options generally fall into four strategies:

- reduce the amount of HFC used in a piece of equipment (e.g., lower charge sizes)
- reduce the amount needed for service (e.g., repair leaks)
- transition from using HFCs (e.g., to hydrocarbons, ammonia, hydrofluoroolefins (HFOs), or HFC/HFO blends)
- recover and reuse HFCs when equipment is decommissioned and disposed.

While all strategies are currently assumed to occur to some extent in the BAU forecast, the options evaluated assumed further or more uptake of these strategies (e.g., more transition to non-HFC options in additional end uses, even better practices when recovering refrigerant) that would be attributed to the implementation of the AIM Act. For each option, EPA used literature and technical expertise to estimate:

- capital cost (e.g., to remodel a factory to use a flammable foam-blowing agent)
- annual revenue (e.g., in the case where the new chemical used is cheaper than the HFC, or savings from increased energy efficiency)
- annual costs (e.g., in the case where the new chemical costs more than the HFC)
- net amount of HFC consumption abated at a model facility or equipment item undertaking the abatement option.

To calculate a mitigation option break-even price for a given year, an estimated mitigation option lifetime was used to calculate costs in present-value terms using an assumed opportunity cost of capital of 9.8 percent.[36] After calculating the break-even price, options could then be ordered from the most cost savings (in terms of dollars per EVe abated) to the highest costs.

This RIA documents significant cost savings from the adoption of some substitutes in some applications. These are based on engineering estimates produced by the MAC model described in this document. The applications and the abatement options that produce these cost savings (i.e., whose costs of abatement are less than zero) are listed in Table 3-1.

The first column of Table 3-1 lists the application and the second column lists the abatement options. The technical applicability is the percentage of HFC consumption in the relevant sector from that application that a mitigation option could feasibly reduce. The market penetration is the percentage of the technically applicable baseline emissions that the abatement option has penetrated. Market penetration varies over time and in general increases as the HFC equipment and products are replaced. Reduction efficiency is the percentage of technically achievable emissions abatement. For example, abatement options that use CO_2 as a refrigerant abate almost 100 percent of GWP-weighted emissions. The product of these three factors gives the amount of baseline emissions for each application that can be feasibly reduced by this mitigation option. The next four columns indicate what generates the cost savings: reduced energy consumption, reduced cost of refrigerants, reduced use of the refrigerant from reduced charge and leakage, and negative capital costs. Abatement options may have positive costs in any

[36] Taken as the average cost of capital over the last 8 quarters available (September 2018 to June 2020) in three industry segments: Chemicals and Allied Products; Industrial, Computers, Electronics, and Auto Manufacturing; and Wholesale and Retail Trade. Duff & Phelps, 2021. Available at https://dpcostofcapital.com/us-industry-benchmarking, accessed April 15, 2021.

of these items (e.g., an HFO generally costs more than an HFC); however, the present value break-even costs for these options are negative, indicating a savings.

Table 3-1: Abatement Options that produce cost savings

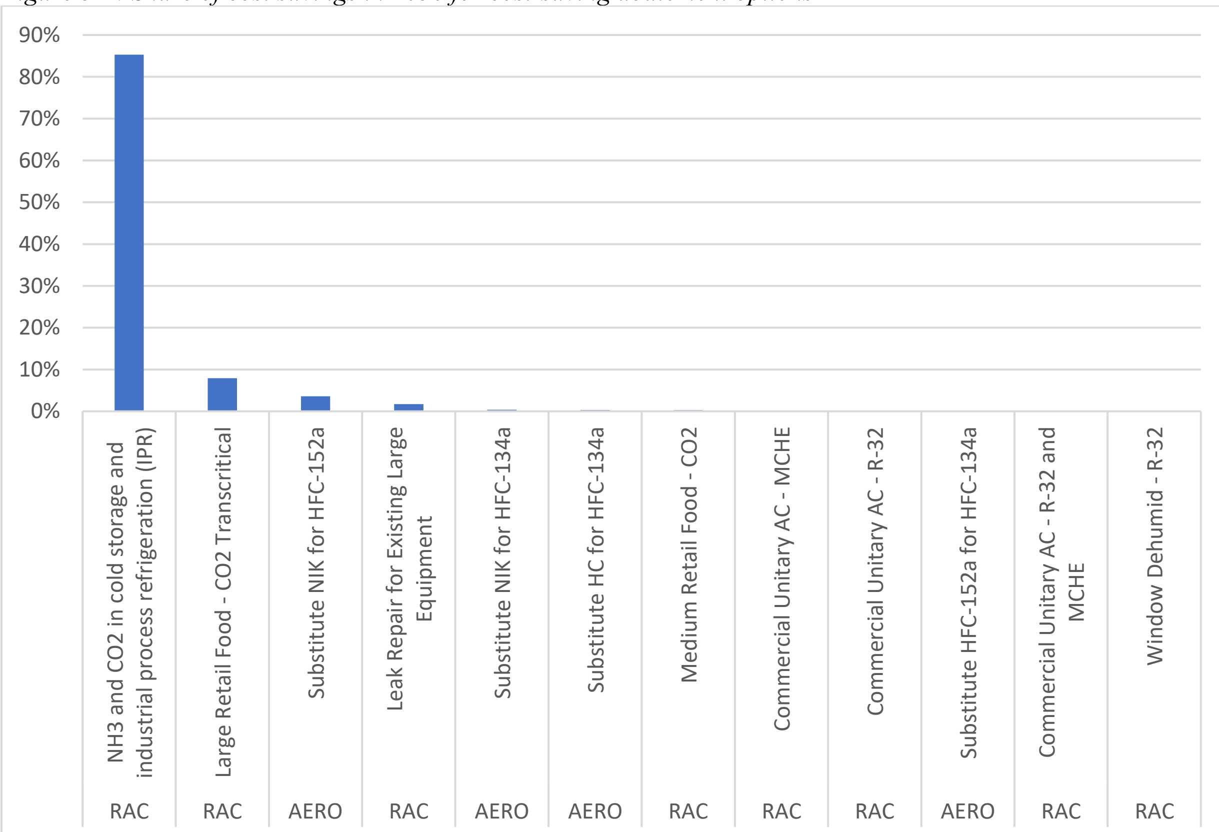
Application	Abatement Option	Technical Applicability (2030)[a]	Market Penetration (2030)	Reduction Efficiency	Energy Consumption Savings	Refrigerants/ Gas Cost Savings	Charge and Leakage Cost Savings	Capital Costs
New industrial process refrigeration (IPR) and cold-storage systems	NH_3 or CO_2	71%	100%	100%	11%	Yes	-	Yes
New large retail food refrigeration systems	Direct Expansion (DX) R-407A/R-407F	12%	34%	50%	13%	-	-	No
	Secondary Loop System (SLS) R-407A/R-407F	20%	33%	50%	5%	-	Yes	Yes
	CO_2 transcritical systems	11%	33%	100%	14%	Yes	-	Yes
New medium retail food refrigeration systems	CO_2	99%	33%	100%	20%	Yes	-	Neg
New small retail food refrigeration systems	Hydrocarbons (HCs)	68%	10%	100%	9%	Yes	-	Neg
New commercial unitary AC equipment	R-32 with microchannel heat exchanger (MCHE)	75%	50%	68%	-	Yes	Yes	Neg
	- R-32	84%	50%	68%	-	Yes	Yes	Neg
	- MCHE	100%	39%	38%	-	-	-	Neg
New window AC and dehumidifiers	- R-32	151%	50%	68%	2%	Yes	Yes	Neg
All existing large equipment (i.e., large retail food, IPR, cold storage, and chillers)	Leak repair	11%	100%	40%	-	-	Yes	Yes
Refrigerated appliances	HFC-134a to R-600a	100%	100%	100%	-	-	Yes	Yes
Flooding agents	Inert gas	142%	19%	100%	-	Yes	-	Yes
	Water mist	140%	3%	100%	-	Yes	-	Yes
Flexible polyurethane (PU) foam	Integral skin foam	99%	85%	100%	-	Yes	-	Yes

Extruded Polystyrene (XPS) boardstock foam	HFC-134a/CO_2 to Liquid CO_2 (LCD)/Alcohol	79%	80%	100%	-	Yes	-	Yes
PU boardstock	HFC-245fa Blend to HC	101%	100%	99%	-	Yes	-	Yes
Domestic refrigerator and freezer insulation	HFC-245fa to HCs	0%	50%	99%	-	Yes	-	Yes
Non-metered dose inhaler (MDI) aerosols	HFC-134a to HC	63%	20%	100%	-	Yes	-	Yes
	HFC-134a to HFC-152a	63%	10%	91%	-	Yes	-	Yes
	HFC-134a to Not-In-Kind (NIK)	63%	20%	100%	-	Yes	Yes	Yes
	HFC-152a to NIK	37%	40%	100%	-	Yes	Yes	Yes

[a] Technical applicability is back-calculated using reduction efficiency, market penetration, and technical effectiveness. In some instances, technical applicability is greater than 100% due to the fact that the options are given on a consumption basis
Source: EPA. 2019. *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. EPA-430-R-19-012. Available at https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf with updates for this analysis.

Because of the very large cost savings from reduced energy consumption, the abatement options for new industrial process refrigeration (IPR) and cold-storage systems and new large retail food refrigeration systems account for the vast majority of the negative cost savings from this rule (Figure 3-1). Some other applications (e.g., medium retail food and commercial unitary) have negative capital costs so they have an infinite rate of return, but the aggregate cost savings are small relative to the energy efficiency savings in the first two options. For this reason, we address the possible explanation for negative costs (i.e., savings) for these first two applications. Much of that discussion could apply to other abatement options, but they are not explicitly discussed.

Figure 3-1: Share of cost savings in 2030 for cost-saving abatement options



Source: Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation: 2015–2050

The market penetration is the critical assumption that drives the difference between the BAU scenario and policy scenario for this rule. We report these assumptions, taken from the Vintaging Model, in Table 3-2.

Table 3-2: Market penetration assumption in the BAU and policy scenarios for select cost-saving abatement options

Application	Abatement Option	BAU Market Penetration Assumptions	Policy Market Penetration Assumptions
New IPR and cold-storage systems*	NH_3 or CO_2	IPR - 0% Cold Storage - 5%	100%
New large retail food refrigeration systems	CO_2 transcritical systems	Large systems - 0%	33%
New medium retail food refrigeration systems	CO_2	Medium systems - 0% Small systems - 0%	33%

*The portion of the market that has historically used NH_3 and/or CO_2 is not modeled and hence not included in the market penetration assumptions.
Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016. Annex 3

New IPR and Cold-storage Systems

Use of NH_3 (ammonia) refrigeration systems is already common in refrigerated spaces over 200,000 sq. ft., but additional penetration is possible in spaces between 50,000 sq. ft. and 200,000 sq. ft. Improved technologies have also increased the potential for market penetration of CO_2 systems. CO_2 systems are generally used in low-temperature refrigeration (−30°C to −56°C), while ammonia/CO_2 systems can also be used for refrigeration. The annual savings for this abatement option is estimated to be approximately $54,500 per system due to lower refrigerant replacement costs and reduced energy consumption of 11 percent. There is still uncertainty as to the cost and energy savings from this option for medium- to small-size systems.

The energy savings for these mitigation options are large. The rate of return on capital in ammonia or CO_2 systems is 26 percent and the payback period is less than 4 years. While the Vintaging Model does assume limited market penetration for cold-storage units, the baseline assumption for market penetration of new industrial process refrigeration is 0 percent (for the portion of the market that has not historically used ammonia). While these assumptions should be revisited in the future, it is a fact that there has been a lack of adoption of the lower-cost technology in this industry.

This issue of a lack of technology diffusion arises in a wide number of applications, not just for environmental issues. Those examining actual experiences with technological diffusion and adoption have shown how slow it is for many technologies. For example, Geroski summarizes this literature[37] and concludes that "The central feature of most discussions of technology diffusion is the apparently slow speed at which firms adopt new technologies" (p. 604). Technology diffusion has also been observed to be slow in the manufacturing sector. Edwin Mansfield found that it took more than 10 years for half of major U.S. iron and steel firms to adopt byproduct coke ovens or continuous annealing lines.[38] Mokyr (1990) suggests that guilds and trade unions slowed adoption of new technologies during the industrial revolution,[39] and Parente and Prescott (1999) argue that monopoly power in factor supplies gave rise to slow rates of technology adoption.[40] Another area of research argues that that new technologies often trigger purchasing complementary technologies, and this takes longer to coordinate and adopt.[41]

New Large Retail Food Systems

One abatement option for large retail food refrigeration systems is replacing current systems with CO_2 transcritical systems, which eliminate the use of HFCs. This system operates 5–10 percent more efficiently than the current systems in locations with a cooler climate (maximum ambient temperature below 88°F or average annual temperature lower than 59°F) but

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[37] Geroski, P. A. "Models of Technology Diffusion." *Research Policy*, 29(45), 2000, pp. 603–625.
[38] Mansfield, E. "Technical Change and the Rate of Imitation." *Econometrica*, 29(4), 1961. pp. 741–766; and Mansfield, E. "The Diffusion of Industrial Robots in Japan and the United States." *Research Policy*, 43 18(4), 1989, pp. 183–192.
[39] Mokyr, J. "Punctuated equilibria and technological progress." *The American Economic Review*, 80(2), 1990, pp. 350–354.
[40] Parente, S.L. and Prescott, E.C. "Monopoly rights: A barrier to riches." *American Economic Review*, 89(5), 1999, pp. 1216–1233.
[41] See Rosenberg, N. *Inside the Black Box: Technology and Economics*. Cambridge UK: Cambridge University Press, 1982; David Atkin, Azam Chaudhry, Shamyla Chaudry, Amit Khandelwal, Eric Verhoogen. "Organizational Barriers to Technology Adoption: Evidence from Soccer Ball Producers in Pakistan," *The Quarterly Journal of Economics*, 2017, pp. 1101–1164; and Bresnahan, T. F., and M. Trajtenberg. "General Purpose Technologies: "Engines of Growth"?" J*ournal of Econometrics*, 65(1), 1995, pp. 83–108.

is less viable in warmer climates. The incremental capital cost for CO_2 transcritical systems is estimated to be $35,000 for a large (60,000 sq. ft.) supermarket, but total annual savings per supermarket are about $14,600, including refrigerant savings due to avoided HFC refrigerant leaks (approximately $2,000) and energy savings due to increased efficiency (approximately $12,600).

The BAU assumption for market penetration in this option is 0 percent, which should be revisited in the future, but, as with new IPR and cold-storage systems, there has been a lack of adoption of these systems despite the high rate of return and low payback period. Klemick et al. conducted a series of focus groups with industry buyers of refrigeration technologies and found that "uncertainty and imperfect information about the performance of new technologies, high opportunity costs of capital, and tradeoffs with other valued system attributes such as reliability and customer appeal were the most pervasive potential barriers discussed by participants, although split incentives between firms and contractors or employees also played a role for some firms."[42]

For this application, the cost savings accrue to the downstream users who adopt these new chemicals and associated technologies. However, since dependable refrigeration for these businesses (e.g., grocery stores) is so critical to successful operation, downstream users may be optimizing on systems with known high reliability. Successful businesses may be reluctant to swap out what they know are dependable technologies for less certain performance, even if it is less expensive. Swapping out technologies can also be disruptive to internal business operations if employees feel more comfortable operating existing technologies rather than new technologies (e.g., working pressure of CO_2, flammability of other options). Firms may decide to go with what

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[42] Klemick, Heather & Kopits, Elizabeth & Wolverton, Ann. "Potential Barriers to Improving Energy Efficiency in Commercial Buildings: The Case of Supermarket Refrigeration." *Journal of Benefit-Cost Analysis*. 8, 2017, pp. 1–31.

their employees prefer in order to minimize disruptions. Some business owners may likewise work exclusively with a limited set of suppliers that do not supply the technology. The same may be true if using a limited set of contractors and service personnel—which would most often be regionally constrained—if they did not possess the training or skills to install and service advanced technologies. Additionally, asymmetric information, training requirements, and risk aversion will all play a role in how fast these technologies are adopted. For example, business owners may choose the technology with the lowest capital cost, neglecting to account for lower energy consumption over the lifetime of the product, if top-line decisions like the purchase of refrigeration systems is made by someone other than those responsible for the energy costs. Finally, some owners might wait to see others adopt the technology, not wanting to be the first to do so. This reason for lack of adoption could be a major factor, considering that this type of technology faces regional constraints and limitations due to the local climate.

These two applications illustrate why abatement options with cost savings may exist in the market and help explain the cost savings associated with this rule. In addition, some cost-saving options may exist because of existing building and safety codes. For example, the residential and commercial equipment abatement options rely on the use of lower-GWP HFCs such as R-32. Unlike the HFCs that they replace, these lower-GWP substitutes are flammable. Under current building codes these flammable substitutes are either restricted from use or have extremely onerous code requirements that make them infeasible. This is in part why in the BAU forecast there is no market penetration of these abatement options. Even though these substitutes are flammable and fall within the class A2L safety rating, the flammability is low enough that new safety standards have been developed with a new class to specifically rate these refrigerants. In 2019 the ASHRAE safety standard with separate requirements for “lower flammable” A2L refrigerants was published. Currently, only Washington State has adopted the 2019 A2L safety standards into its state building codes. The AIM Act may speed the widescale adoption of A2L safety standards allowing for the adoption of cost-saving equipment that uses A2L refrigerants.

For these reasons, EPA believes that this regulation will appreciably increase the diffusion rate of these technologies and has included these cost savings as part of the impacts of this regulation. The models used for this analysis, including the estimated market penetration assumptions, are updated as new information becomes available and are expected to be used in future rulemakings under the AIM Act and other activities.

3.3 Baseline and BAU

3.3.1 Baseline for Allocation of Production and Consumption Allowances

In the rulemaking this analysis accompanies, EPA has determined both production and consumption baselines based on the formulas provided in the AIM Act. Applying the formula provided in the AIM Act to determine a consumption baseline, the rulemaking is establishing a consumption baseline to be 304 million metric tons of exchange value equivalent (MMTEVe).

3.3.2 BAU Projection of Consumption and Emissions

EPA uses the Vintaging Model to project the expected consumption and emissions of HFCs in the absence of the AIM Act. Although many economic analyses will use the term "baseline" to describe such a forecast, here we refer to this projection as a BAU forecast to distinguish it from the baselines described above from which maximum HFC production and consumption levels are to be calculated under the AIM Act. Table 3-3 shows the consumption-based BAU estimated from the Vintaging Model that is used to assess the costs and benefits of the HFC consumption phasedown specified by the AIM Act.[43]

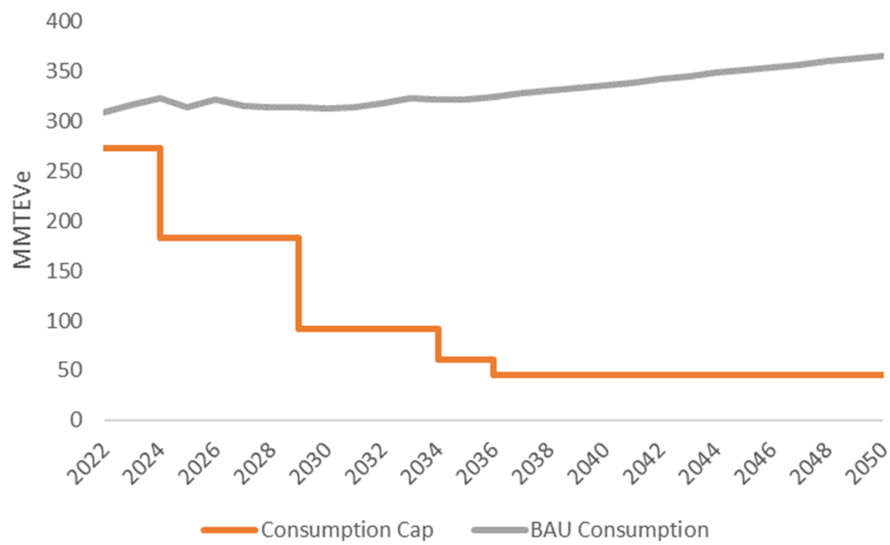
[43] More information regarding HFC-23 projected emissions can be found in Appendix G.

Table 3-3: Consumption BAU

Compliance Year	Consumption (MMTEVe)
2022	309.88
2024	324.43
2029	316.55
2034	326.44
2036	326.98
2045	352.14
2050	365.93

Figure 3-2 compares the BAU consumption scenario with the consumption cap mandated by the AIM Act. More information regarding the calculation of emissions can be found in Chapter 4.

Figure 3-2: Consumption Cap vs BAU scenario of consumption



As noted above, EPA issued regulations in 2015 and 2016 that would, among other actions, find certain HFCs and HFC blends unacceptable for certain end uses under the SNAP program. Such actions would reduce HFC consumption and would provide some, but certainly not all, of the reductions needed to comply with the AIM Act. As also noted above, court decisions led to the partial vacatur of these rules and a remand for further proceedings. Because of these court decisions, EPA is using a BAU forecast that does not assume compliance with the 2015 and 2016 regulations. However, the BAU forecast uses the best estimate of what had been occurring in the industry notwithstanding the court decisions. Some of these actions would have served to meet in part the 2015 and 2016 regulations and are included in the BAU forecast, reducing both the estimated future HFC consumption expected and the reductions required to go no higher than the maximum HFC production and consumption as set as a percentage of the respective baseline as required under the AIM Act. Changes in the industries using HFCs have been ongoing since at least 1978, when the United States banned the use of CFCs in certain types of aerosols. After much research, more changes began in the early 1990s to phase out CFCs in new equipment by 1996, in compliance with the CAA and Montreal Protocol. In this set of changes, some CFC applications moved to non-fluorocarbon options, some moved to HCFCs (although these were known to be an interim option given that the CAA and Montreal Protocol also called for those substances to be phased out), and some moved to HFCs. While those uses that transitioned to HCFCs began adopting HFCs, more research continued and new, no/low-GWP options were found, and both HCFC and HFC users began adopting them. In some cases, users moved from one HFC or HFC blend to another with a lower GWP. Transitions to those options were seen in many fields and are directly included in the BAU. An assessment of why such changes occurred was not performed; however, it is likely that some users found cost savings in those changes, others may have made such moves out of corporate responsibility and sustainability goals, and still others may have made changes to avoid potential negative press[44] and/or future regulations.

[44] For example, see Greenpeace (undated), *Greenfreeze: Refrigerants, Naturally*. Available at https://www.greenpeace.org/usa/victories/greenfreeze-refrigerants-naturally/.

Some examples of such changes from an initial HFC use integrated into the BAU model include:

- New light-duty motor vehicle air conditioners transitioning from HFC-134a to HFO-1234yf
- Chillers used in naval ships transitioning from HFC-236fa to HFC-134a
- Cold-storage warehouses transitioning from R-404A and R-507 to R-717 (ammonia)
- Large retail food (i.e., supermarket) systems transitioning from R-404A and R-507 to R-407A, R-422A, and R-422D
- Adoption of lower-charge, lower leak technologies—distributed refrigeration and secondary loop system—in large retail food equipment
- Small retail food (e.g., bottle coolers) equipment transitioning from HFC-134a and R-404A to R-744 (carbon dioxide) and R-290 (propane)
- Vending machines transitioning from HFC-134a to R-290, R-450A, and R-513A
- Road transport refrigeration units transitioning from R-404A and R-410A to R-744
- Intermodal transport refrigeration containers transitioning from HFC-134a, R-404A, and R-410A to R-744
- Aerosols (non-medical) transitioning from HFC-134a to HFC-152a
- Fire extinguishing flooding agents transitioning from HFC-227ea to Fluoroketone (FK)-5-1-12
- Domestic refrigerator-freezer foam transitioning from HFC-134a and HFC-245fa blowing agent to cyclopentane
- Polyolefin foam transitioning from HFC-152a to hydrocarbons

In the above list and in Appendix D, several blends are referenced. The following table describes the constituents of these blends.

Table 3-4: Composition by Weight of Common Refrigerant Blends

Refrigerant	HFC-32	HFC-125	HFC-134a	HFC-143a	HC-600a (isobutane)	HFO-1234yf	HFO-1234ze*E*
R-404A		44%	4%	52%			
R-407A	20%	40%	40%				
R-407C	23%	25%	52%				
R-407F	30%	30%	40%				
R-410A	50%	50%					
R-422A		85.1%	11.5%		3.4%		
R-422D		65.1%	31.5%		3.4%		
R-448A	26%	26%	21%			20%	7%
R-449A	24.3%	24.7%	25.7%			25.3%	
R-450A			42%				58%
R-452A	11%	59%				30%	
R-452B	67%	7%				26%	
R-454B	68.9%					31.1%	
R-507		50%		50%			
R-513A			44%			56%	

The cases above are not necessarily meant to indicate that the entire market made this transition, but that some such movement had occurred or is assumed to occur in the future (before the final 2036 compliance step in the AIM Act). Further adoption of such technologies by a larger share of the market is assumed in some of the abatement options used to construct the MAC cost model to estimate costs (or savings from) compliance with the HFC consumption reductions required under the AIM Act. Additional changes to those markets may also be assumed as an abatement option: for example, when a transition moved to a lower-GWP HFC, an abatement option may assume a second step to an even lower-GWP option.

3.4 Regulatory Option

As discussed above, transfer of allowances is allowed under the AIM Act provided that there is an offset (i.e., a reduction in allowances) for the transfer. As part of our base case, we assume 20 percent of the total allowances, including those issued to the six market segments receiving allocations, are transferred each year. The 20 percent is based on EPA's experience implementing the phaseout of ODS under Title VI of the CAA. For each allowance transfer, EPA is establishing in this rulemaking a transfer offset of 5 percent. For example, if one party transferred away 100 MTEVe to another company, the transfer offset would be 5 MTEVe from the transferring party and would amount to 105 MTEVe being deducted from its allowance balance.[45] The net effect of transfers, assuming 20 percent of allowances are transferred each year, would be to reduce the allowable consumption by 1 percent. For instance, using the 304 MMTEVe baseline, the maximum consumption at the 2022 step of 90 percent of the baseline amounts to a maximum consumption of 273 MMTEVe. A transfer offset of 5 percent would reduce allowances by about 3 MMTEVe each year during the 2022–2023 compliance step.

3.5 Costs of Abatement

To assess the costs of abatement, EPA used the BAU described in section 3.3.2 and compared it to the reduction schedule established by the AIM Act through 2036 estimating the associated costs. These are estimates of the costs to U.S. companies to implement changes (i.e., abatement options) that would reduce the consumption of HFCs to levels below the limits

[45] EPA finalized an offset of 1% for the application-specific allowances. Because the amount of such allowances is estimated to be much smaller than the remaining allowances, a 5% estimate for all the allowances represents only a slightly more conservative case. We expect this difference would be relatively minor compared to the estimated 20% of allowances traded, which is subject to market variability.

specified in the AIM Act. Table 3-5 shows the phasedown schedule through 2036, the BAU consumption, and the reduction needed to meet each step of the phasedown.

Table 3-5: Estimated Consumption Reductions Required under the AIM Act

AIM Act Compliance Years	Consumption Cap (% of Consumption Baseline)	Consumption Cap (MMTEVe)	BAU Consumption (MMTEVe)*	Reductions Needed (MMTEVe)
2022–2023	90%	273	310	37
2024–2028	60%	182	324	142
2029–2033	30%	91	317	226
2034–2035	20%	61	326	265
2036	15%	46	327	281

*Consumption levels shown are based on the first compliance year.

EPA calculated how much HFC consumption could be reduced by evaluating when each option could enter the market, how much of the market it could capture, and how quickly that would happen. By aggregating these consumption reductions in order of costs, EPA developed the MAC curves presented in Figure 3-3 below.

Figure 3-3: MAC Curves by compliance year

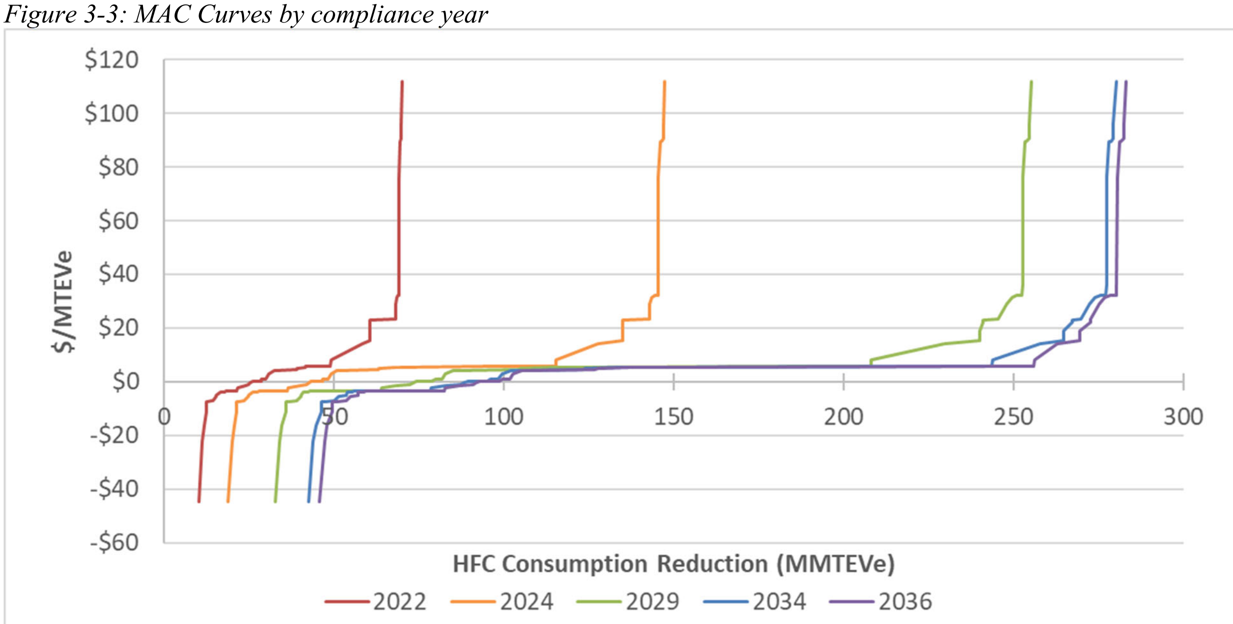


Figure 3-3 depicts the increasing cost ($ per MTEVe) to achieve additional HFC consumption reductions. Moving from left to right on the horizontal axis (i.e., from less abatement to higher abatement), savings decrease and eventually costs are incurred (i.e., moving from bottom to top of the vertical axis) for each additional MMTEVe avoided. Costs reflect capital (one-time) cost, revenue, and operating and maintenance costs (annual). They are present-value in 2020 dollars, utilizing a 9.8 opportunity cost of capital and 0 percent tax rate. By integrating these costs until the total reduction is at or exceeds the HFC reductions required under the AIM Act, we calculate the total costs of such actions.

Costs were analyzed based on abatement in years 2022, 2024, 2029, 2034, and 2036. Savings or costs generally grow during the intermediate years, as the abatement achieved grows. Total costs are summed from 2022 on a year-by-year basis. A year-by-year analysis accounts for the fact that most options require time for stock turnover to fully implement options. Exceptions include the refrigerant management options of leak repair, better recovery, and more reclaim, which can occur on current equipment stock. When required abatement falls between two options in our estimate, the higher-cost item is used to be conservative. Total annual costs or savings from 2022–2036 are displayed in Table 3-6 below and the consumption reductions are shown in Table 3-7 below.

Table 3-6: Costs of Abatement (2020$)

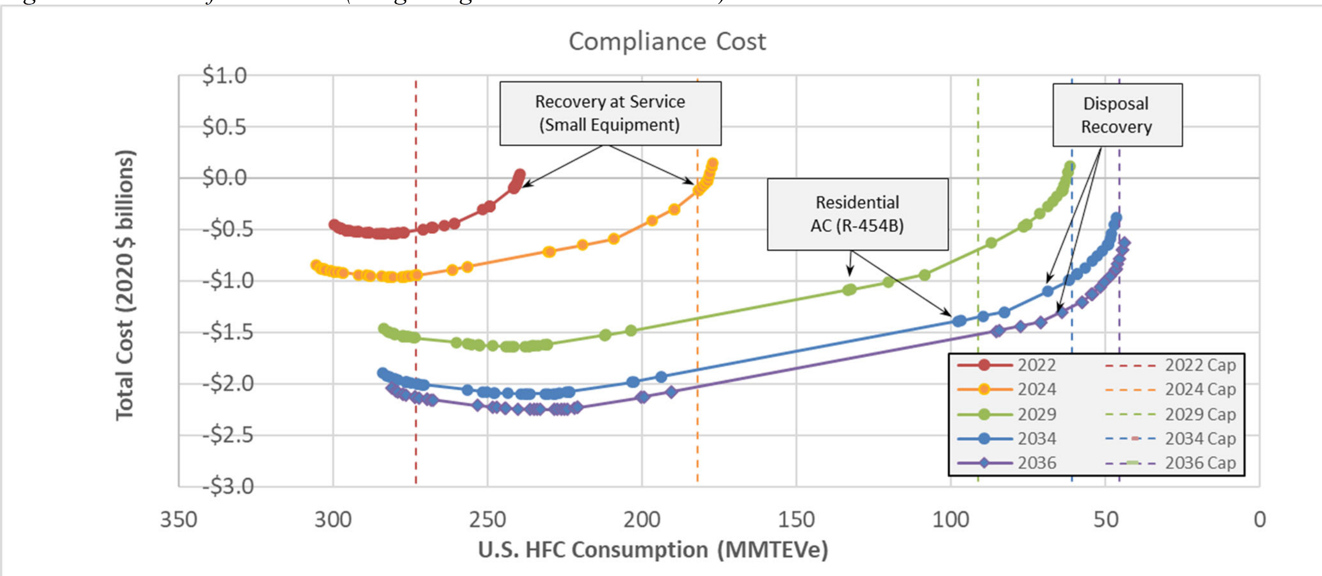
AIM Act Compliance Year	Consumption Cap	Total Annual Savings	Total Annual Costs	Net Annual Cost (Savings)
2022	90% (273 MMTEVe)	-$0.5B	$0.1B	-$0.5B
2024	60% (182 MMTEVe)	-$1.0B	$0.9B	-$0.1B
2029	30% (91 MMTEVe)	-$1.6B	$1.0B	-$0.6B
2034	20% (61 MMTEVe)	-$2.1B	$1.2B	-$0.9B
2036	15% (~46 MMTEVe)	-$2.2B	$1.5B	-$0.7B

Table 3-7: Consumption Reductions (MMTEVe)

AIM Act Compliance Years	Consumption Cap	Estimated Reductions for First Year in Compliance Period	Cumulative Reductions (2022 through First Year of Compliance Period)
2022–2023	90% (273 MMTEVe)	42	42
2024–2028	60% (182 MMTEVe)	144	241
2029–2033	30% (91 MMTEVe)	230	1,350
2034–2035	20% (61 MMTEVe)	267	2,600
2036	15% (46 MMTEVe)	282	3,152

The results can also be presented as the estimated HFC consumption and how it is reduced as additional options and their respective costs (or savings) are undertaken by the market. Each curve starts with the first option applied (hence, because this option achieves additional reduction over time, the 2024, 2029, 2034, and 2036 curves start successionally to the right of the 2022 curve). Moving right along the horizontal axis, additional abatement options are applied. With the additional options, HFC consumption is reduced, and savings begin to accrue from these additional abatement option, going down along the vertical axis. When such cost-saving options are exhausted, additional options are undertaken, increasing the total costs (moving up along the vertical axis). Eventually the curve crosses the corresponding dashed line, which represents the maximum amount allowed under the AIM Act, and the total cost or savings can be read off the vertical axis. Three example abatement options that achieve significant additional reductions (i.e., significantly to the right of the previous, lower-cost options) are highlighted in Figure 3-4 below.

Figure 3-4: Costs of Abatement (Integrating under the MAC Curve)



The model is sensitive to high-cost and high-savings options, as shown in the following sensitivity analyses, which were developed around the base case scenario. For each analysis, we developed a higher-bound cost of abatement and a lower-bound cost of abatement. These higher-bound cost and lower-bound cost estimates can be compared with the analysis presented in the report, which used our estimates for the abatement cost of various options to reduce HFC consumption.

The MAC graph (see Figure 3-3 of this report) displays a steep rise from the lowest cost—or highest saving—HFC option to the next few options (left side of graph). Also, as is typical for such graphs, there is a steep rise through a few higher-cost options to the option with the highest cost (right side of graph). This implies that the analysis will be sensitive to the lower-cost abatement options and could also be sensitive to the highest-cost options, depending on how far along the MAC curve is needed to reach the desired total reduction. To investigate these sensitivities, EPA developed a higher-bound cost and a lower-bound cost analysis.

For the higher-bound cost analysis, we assumed all abatement options that were analyzed to produce cost savings are instead cost-neutral. That is, rather than the estimated abatement costs of as low as -$45 per MTEVe of HFC consumption avoided, we assumed the marginal abatement costs were $0/MTEVe. This therefore eliminates all the monetary savings achieved from these options, resulting in total costs of $15.3 billion. As discussed above, the cost savings modeled in the main analysis come from the Vintaging Model and abatement options analyzed and reflect the fact that there has been a lack of adoption of existing lower-cost HFC-related technology. Slow market adoption is seen in many industries and may be due to factors such as uncertainty about the new technology, tradeoffs with other attributes such as performance or maintenance requirements, customer appeal, and split incentives between firms and contractors or employees. In addition, the adoption of some cost-saving options may require changing existing building and safety codes. These factors suggest that there may be additional costs associated with adopting these technologies (e.g., information, transaction, or transition costs) that are not considered in the main analysis. The higher-bound cost analysis assumes that these unobserved costs net out the observed cost savings, so no negative cost options exist. Importantly, we are not assuming that these cost savings abatement options are adopted in the absence of this rule, which would affect the benefits. We are assuming that there are unobserved or unmodeled costs that offset the cost savings.

For the lower-bound cost analysis, we varied all options for which we estimated a positive cost of abatement; i.e., all options that are above the $0/MTEVe axis on the marginal abatement cost graph. Prior experience with the ODS phaseout suggests that positive-cost technology options can often be achieved at lower than predicted costs.[46] This is consistent with economic literature that finds that many federal RIAs overestimate the realized cost of compliance. For example, Harrington, Morgenstern, and Nelson (2000) and Kopits, et al. (2014)

[46] WRI. *Ozone Protection in the US – Elements of Success*. https://files.wri.org/d8/s3fs-public/pdf/ozoneprotectionunitedstates_bw.pdf

find that ex-ante cost estimates are more often found to overestimate than underestimate realized costs and assume that ex-ante estimate is “accurate” if it falls within ±25 percent of the ex-ante estimate.[47,48] As a sensitivity analysis, we assumed all positive-cost options were only 50 percent of the cost of our best estimate, resulting in total savings of $15.7 billion (compared to a total savings of $8.1 billion under the base case). We looked at all such options rather than just the highest-cost option because we understood that to achieve the reductions required by the AIM Act, one would not need to undertake every option in our analysis. Had EPA only looked at the highest-cost option, there would be no effect on the overall estimated costs.

The net annual costs and cumulative cost to the given year, under the original estimate and the lower-bound and higher-bound cost estimates, for each year that the AIM Act requires a reduction in allowable consumption, are provided in Table 3-8 below.

Table 3-8: Estimated Annual and Cumulative Costs of Abatement

Year	Consumption Cap	Total Net Annual Cost*			Net Cumulative Cost*		
		Estimate	*Lower*	*Higher*	*Estimate*	*Lower*	*Higher*
2022	90% (273 MMTEVe)	($0.5 B)	($0.5 B)	$0.1 B	($0.5 B)	($0.5 B)	$0.1 B
2024	60% (182 MMTEVe)	($0.1 B)	($0.5 B)	$0.9 B	($1.2 B)	($1.7 B)	$1.0 B
2029	30% (91 MMTEVe)	($0.6 B)	($1.1 B)	$1.0 B	($2.0 B)	($5.7 B)	$7.3 B
2034	20% (61 MMTEVe)	($0.9 B)	($1.5 B)	$1.2 B	($6.4 B)	($12.7 B)	$12.6 B
2036	15% (46 MMTEVe)	($0.7 B)	($1.5 B)	$1.5 B	($8.1 B)	($15.7 B)	$15.3 B

* Negative costs, shown in parentheses, indicate cost savings.

This sensitivity analysis is important in recognizing the potential uncertainties that still remain. It is worth mentioning that this analysis does not take into account the potential price changes that could be induced in the relevant markets and the potential behavioral responses to those price changes, in addition to whether the assessment of the BAU could be further refined.

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47 Harrington, W., Morgenstern, R.D. and Nelson, P. “On the accuracy of regulatory cost estimates.” *Journal of Policy Analysis and Management: The Journal of the Association for Public Policy Analysis and Management*, 19(2), 2000, pp. 297–322.
48 Kopits, E., McGartland, A., Morgan, C., Pasurka, C., Shadbegian, R., Simon, N.B., Simpson, D. and Wolverton, A. “Retrospective cost analyses of EPA regulations: a case study approach.” *Journal of Benefit-Cost Analysis*, 5(2), 2014, pp. 173–193.

EPA is seeking information to help improve the BAU forecast (e.g., to incorporate the effect of state actions) and cost estimates.

With respect to the BAU, EPA analyzed two counterfactual BAU forecasts, one representing lower overall HFC consumption and one representing higher HFC consumption. These alternative BAU estimates and their effect on the results presented above are discussed in Appendix B.

3.6 Social Costs

As discussed in EPA's Guidelines for Preparing Economic Analyses, social costs are the total economic burden of a regulatory action.[49] This burden is the sum of all opportunity costs incurred due to the regulatory action, where an opportunity cost is the value lost to society of any goods and services that will not be produced and consumed as a result of reallocating some resources toward pollution mitigation. Estimates of social costs may be compared with the social benefits expected as a result of a regulation to assess its net impact on society. The social costs of a regulatory action are the abatement costs plus the opportunity costs of reduced output. The advantage of the abatement cost approach is that it allows the estimation and reporting of specific options and costs.

It should be noted that while this analysis focuses on the costs of abatement, there are potentially significant localized health effects of transitioning to substitute substances as HFCs are phased down. Chapter 6 of this analysis notes the potential negative health effects of being in

[49] U.S. Environmental Protection Agency (EPA). *Guidelines for Preparing Economic Analyses*. December 2010. EPA report 240-R-10-001. Available at https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses.

close proximity to HFC production and production of HFC substitutes, but these effects have not been monetized in the net benefits calculation.

The abatement cost estimates for the rule presented in this chapter are the change in expenditures by HFC equipment and product sectors required for compliance under each alternative. The change in the expenditures associated with abatement with the consumption cap represent costs and savings associated with moving to alternatives and implementing recovery and disposal practices, alongside monetary savings associated with energy efficiency improvements related to the use of the alternatives. However, some of the chemicals analyzed in this analysis are not expected to be higher-priced than others, such as the use of HFC-32 in lieu of R-410A (which is itself 50 percent HFC-32 and 50 percent another HFC). Also, the abatement path analyzed includes reducing charge sizes, lower leak rates, and better recovery, all of which reduce the amount of chemical needed to be purchased for such repairs.

Furthermore, energy efficiency improvements would be a saving to the user who pays for the electricity use. Based on thermodynamic properties, some HFC alternatives would lead to higher energy efficiency and hence cost savings but may not have been assumed to be used, or used to the fullest extent, in the BAU case. In some instances, it is only recently that safety standards and building codes have been revised to facilitate the use of some HFC alternatives (e.g., to address the flammability of some substitutes). In other instances, the HFOs had not yet been explored for use until recently, and only upon investigation, spurred on in the search for lower-GWP alternatives, did the industry realize the benefits that could be achieved. Finally, when designing a new model of equipment to use an HFC alternative, companies have the opportunity to redesign other components of the equipment to achieve greater energy efficiency (and vice-versa, when redesigning to meet new energy efficiency requirements, companies have the opportunity to integrate HFC alternatives). Thus, although the capital cost of newer equipment might be greater, the energy efficiency improvements achieved by the newer equipment could result in lower utility costs to the user.

3.7 Labor Impacts

This section discusses potential employment impacts of this regulation.[50] We focus our analysis primarily on the directly regulated facilities in the chemical manufacturing sector. We also discuss related industries, such as HFC importers, reclaimers, and downstream sectors that are end users of HFCs.

As economic activity shifts in response to a regulation, typically there will be a mix of declines and gains in employment in different parts of the economy over time and across regions. To present a complete picture, an employment impact analysis will describe the potential positive and negative changes in employment levels. There are significant challenges when trying to isolate the employment effects due to an environmental regulation from employment effects due to a wide variety of other economic changes, including the impact of the coronavirus pandemic on labor markets and the state of the macroeconomy generally. Considering these challenges, we look to the economics literature to provide a constructive framework and empirical evidence. To simplify, we focus on impacts on labor demand. Environmental

[50] This section relies on the following references: Berman, E. and L. T. M. Bui. "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." *Journal of Public Economics*. 79(2), 2001, pp. 265–295; Curtis, E. M. "Who loses under cap-and-trade programs? The labor market effects of the NOx budget trading program." *Review of Economics and Statistics* 100 (1), 2018, pp. 151–66; Curtis, E.M. "Reevaluating the ozone nonattainment standards: Evidence from the 2004 expansion." *Journal of Environmental Economics and Management*, 99, 2020, pp. 102–261; Deschênes, O. "Environmental regulations and labor markets." *IZA World of Labor*: 22, 2018, pp. 1–10; Ferris, A. E., R. Shadbegian, A. Wolverton. "The Effect of Environmental Regulation on Power Sector Employment: Phase I of the Title IV SO_2 Trading Program." *Journal of the Association of Environmental and Resource Economics* 1(4), 2014, pp. 521–553; Graff Zivin, J. and M. Neidell. "Air pollution's hidden impacts." *Science*. 359(6371), 2018, pp. 39–40; Greenstone, Michael. "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures." *Journal of Political Economy* 110, no. 6, 2002, pp. 1175–1219; Morgenstern, R.D., W.A. Pizer, and J. Shih. "Jobs Versus the Environment: An Industry-Level Perspective." *Journal of Environmental Economics and Management* 43, 2002, pp 412–436.

regulation may also affect labor supply through changes in worker health and productivity (Graff Zivin and Neidell 2018).

Economic theory of labor demand indicates that employers affected by environmental regulation may increase their demand for some types of labor, decrease demand for other types, or for still other types, not change it at all (Morgenstern et al. 2002, Deschênes 2018, Berman and Bui 2001). To study labor demand impacts empirically, a growing literature has compared employment levels at facilities subject to an environmental regulation to employment levels at similar facilities not subject to that environmental regulation; some studies find no employment effects, and others find significant differences. For example, see Berman and Bui (2001), Greenstone (2002), Ferris, Shadbegian and Wolverton (2014), and Curtis (2018, 2020).

A variety of conditions can affect employment impacts of environmental regulation, including baseline labor market conditions and employer and worker characteristics such as occupation and industry. The remainder of this section begins with a description of baseline conditions, focusing on the directly regulated industry and groups of affected workers. It then qualitatively discusses potential incremental changes in demand for labor due to the regulation in directly regulated and related sectors.

The directly regulated firms fall into two manufacturing sectors: (i) basic chemical manufacturing (NAICS 3251) and (ii) other chemical production and preparation manufacturing (NAICS 3259). In February, 2021, the chemical manufacturing sector (NAICS 3251) employed 850,000 employees nationally, with average annual earnings for the largest occupational categories ranging from $34,220 to $82,320 and an industry-specific unemployment rate of 2.8

percent.[51] The largest occupational categories of employment in the chemical manufacturing sector are chemical equipment operators and tenders, chemical technicians, chemists, and machine setters, operators, and tenders.[52] Over the past decade, the industry has experienced growth: the current level of 850,000 employees has increased from 782,000 employees in February, 2011.

These industries are capital-intensive. We relied on three public sources to obtain a range of estimates of employment per output by sector: (i) the Economic Census (EC) and (ii) the Annual Survey of Manufacturers (ASM), both provided by the U.S. Census Bureau, and (iii) employment and output data by industry provided by U.S. Bureau of Labor Statistics (BLS). The EC is conducted every five years, most recently in 2017. The ASM is an annual subset of the EC and is based on a sample of establishments. The latest set of data from the ASM is from 2019. Both sets of Census data provide detailed sector data, providing estimates at the 6-digit North American Industry Classification System (NAICS) level. They provide separate estimates of the number of employees and the value of shipments at the 6-digit NAICS, which we converted to a ratio in this employment analysis. The BLS data are provided only at the 4-digit NAICS level, which means less sector detail. Table 3-9 shows the sector definitions and the NAICS codes used to estimate the ratios of labor per $1 million value of shipments.

Table 3-9. Relevant Chemical Manufacturing Sectors

Sector Definition	NAICS
Basic chemical manufacturing	3251
Industrial gas manufacturing	325120
All other basic organic chemical manufacturing	325199

[51] BLS Employment, Hours, and Earnings from the Current Employment Statistics survey (National), All-employees, NAICS 325, CES3232500001, and BLS Industries at a Glance, Chemical Manufacturing: NAICS 325. Accessed March 10, 2021. Available at: https://www.bls.gov/iag/tgs/iag325.htm.

[52] BLS Industries at a Glance, Chemical Manufacturing: NAICS 325. Accessed March 10, 2021. Available at: https://www.bls.gov/iag/tgs/iag325.htm.

Other chemical product and preparation manufacturing	3259
All other miscellaneous chemical product and preparation manufacturing	325998

Tables 3-10 and 3-11 provide estimates of employment per $1 million of products sold by the sector for each data source, in 2017$.[53] While the ratios are not the same, they are similar across time at both the four-digit and six-digit NAICS. Within the six-digit NAICS code, other miscellaneous chemical product and preparation manufacturing seem to be the most labor-intensive sector followed by industrial gas manufacturing and other basic organic chemical manufacturing.

Table 3-10: Employment per $1 million Output (2017$) in the Chemical Manufacturing Sector (6-digit NAICS)

Sector	NAICS	Economic Census 2017	ASM 2019
Industrial gas manufacturing	325120	1.35	1.22
All other basic organic chemical manufacturing	325199	0.81	0.85
All other miscellaneous chemical product and preparation manufacturing	325998	1.64	1.77

The results are similar across data sources at the less disaggregated sectors. In general, the Census ratios are higher than the BLS ratios. Like the six-digit NAICS, the "all other miscellaneous chemical product and preparation manufacturing" sector seems to be the most labor-intensive sector across all data sources at the four-digit NAICS.

Table 3-11: Employment per $1 million Output (2017$) in the Chemical Manufacturing Sector (4-digit NAICS)

Sector	NAICS	Economic Census 2017	ASM 2019	BLS 2017	BLS 2019
Basic chemical manufacturing	3251	0.68	0.72	0.56	0.54
All other miscellaneous chemical product and preparation manufacturing	3259	1.75	1.84	1.87	1.85

[53] Adjusted to 2017 dollars using the Gross Domestic Product Implicit Price Deflator retrieved from the Federal Reserve Bank of St. Louis.

As discussed in this chapter, this regulation may lead to small changes in costs, potentially positive or negative, for HFC producers in the basic chemical industry, through the shift toward production of lower-cost HFC-substitute chemicals and the phaseout of HFCs. Overall, the impact on industry employment may be insubstantial, given that the magnitude of regulatory to total costs at the regulated firms in the basic chemical manufacturing sector is quite small, coupled with very low labor intensity of production in the chemical manufacturing sector.

In addition to impacts on directly regulated producers, there may be employment impacts for HFC importers and reclaimers, or downstream at firms that use the lower GHG-emitting manufactured products as inputs into their own production processes. As explained in more detail in the supporting small business analysis, most HFC importers may see cost savings from the shift to lower-cost HFC substitutes, and some portion of HFC importers may see increases in costs, which may affect labor demand at those entities. There are five sectors that represent the more than 60 end uses of HFCs, including Refrigeration and Air Conditioning, Foams, Aerosols, Solvents, and Fire Suppression. Labor, along with capital and materials, will be required for the conversion activities that will accommodate production of HFC substitutes. These will likely be transitional, short-run labor costs as production processes are adjusted.

The regulation may contribute to employment impacts caused by increased international demand for products manufactured by the regulated firms due to those products contributing lower GHG emissions.[54]

In sum, this section has highlighted baseline employment characteristics at the regulated firms as well as potential employment impacts due to compliance activities at the regulated

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[54] Economic Impacts of U.S. Ratification of the Kigali Amendment, Available at: https://www.ahrinet.org/App_Content/ahri/files/Resources/Economic_Impacts_of_US_Ratification_of_the_Kigali_Amendment.pdf

firms. Finally, it briefly discussed adjustment of production processes at downstream firms and increased demand from the international marketplace.

3.8 Recordkeeping and Reporting Costs

As part of the process to implement the recordkeeping and reporting requirements of the AIM Act, EPA has prepared and updated an information collection request (ICR), ICR Number 2685.01, and a Supporting Statement Part A for the ICR, all of which can be found in the docket. The information collection requirements are not enforceable until OMB approves them. Among other figures, EPA calculated the estimated time and financial burden over a three-year period (ICRs generally cover three-year time periods) to respondents for electronically reporting data to the Agency using an interactive, web-based tool called the Electronic Greenhouse Gas Reporting Tool (e-GGRT). A key summary of the respondent burden estimates follows, and the full methodology for these calculations can be found in the docket.

For the three years covered in the ICR, the total respondent burden associated with information collection will average 83,598 hours per year and the respondent cost will average $12,102,515 per year. This includes $2,737,392 per year for capital investment and operation and maintenance (O&M) and $9,365,123 per year for labor. The breakdown of the burden per year is provided in Table 3-12.

Table 3-12: Total Respondent Burden Costs Over the Three-Year ICR Period

Year	Total Responses	Total Hours	Total Labor Costs	Total O&M Costs	Total Costs
Year 1 (2022)	12,767	91,335	$10,310,605	$2,737,392	$13,047,997
Year 2 (2023)	12,245	78,905	$8,791,659	$2,737,392	$11,529,051
Year 3 (2024)	13,315	80,553	$8,993,106	$2,737,392	$11,730,498
3yr ICR Annual Average	**12,776**	**83,598**	**$9,365,123**	**$2,737,392**	**$12,102,515**

As detailed in the preamble of the final rulemaking, EPA has amended certain recordkeeping and reporting requirements, including but not limited to decreasing the frequency of certain reporting requirements and extending the time frame of when registration with the certification identification system must be completed. As detailed in the updated Supporting Statement Part A, the Agency has updated its burden assumptions for, among other tasks, recordkeeping and third-party audit costs. The resulting average cost of the three-year ICR period is higher than what EPA had projected at proposal, which was $4,443,945.

To provide a more comprehensive outlook for what the expected total burden costs would be to respondents as a result of the final recordkeeping and reporting requirements in tandem with updated burden assumptions, EPA's estimates for four years beyond the ICR period (seven years total) are provided in Table 3-13. The total costs per year vary over time, notably because in Year 1 (2022), there are required one-time reports that are due from certain respondents, and beginning in Year 3 (2024), certain respondents must begin, and continue to, register and/or perform data entry with respect to the certification ID system, as described in section IX.G. of the preamble, "How is EPA Tracking the Movement of HFCs in U.S. Commerce?"

Table 3-13: Total Respondent Burden Costs from 2022–2028

Year	Total Responses	Total Hours	Total Labor Costs	Total O&M Costs	Total Costs
Year 1 (2022)	12,767	91,335	$10,310,605	$2,737,392	$13,047,997
Year 2 (2023)	12,245	78,905	$8,791,659	$2,737,392	$11,529,051
Year 3 (2024)	13,315	80,553	$8,993,106	$2,737,392	$11,730,498
Year 4 (2025)	1,500,345	93,160	$10,533,620	$2,737,392	$13,271,012
Year 5 (2026)	8,192,720	129,035	$14,917,545	$2,737,392	$17,654,937
Year 6 (2027)	14,865,420	142,697	$16,587,103	$2,737,392	$19,324,495
Year 7 (2028)	14,865,420	142,697	$16,587,103	$2,737,392	$19,324,495
Annual Average	**5,637,462**	**108,340**	**$12,388,677**	**$2,737,392**	**$15,126,069**

EPA expects that the estimated burden for 2029 and onward would closely resemble the 2027 and 2028 figures, as all recordkeeping and reporting requirements as a result of the provisions and associated compliance dates in this final rulemaking will have been implemented.

3.9 Refillable Cylinders

3.9.1 Introduction

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

There are two primary types of cylinders. Disposable (also known as non-refillable) cylinders are used once before disposal, whereas refillable cylinders can be used multiple times throughout the cylinder lifetime. Refrigerants can be emitted from disposable and refillable cylinders due to several conditions, including overfilling and subsequent exposure to excessive heat or blunt contact, mechanical damage to valves, valve defects, cylinder corrosion, and human error. However, disposable cylinders are typically discarded with refrigerants still in the cylinders, including from amounts commonly referred to as heels (i.e., the small amount of refrigerant that remains in an “empty” cylinder). These residual refrigerants are emitted over time as they leak out or are expelled when the cylinder is crushed for disposal or metal recycling.

To prevent refrigerant remaining in disposable cylinders from being emitted to the atmosphere upon disposal, service technicians could recover the refrigerant heel before recycling the cylinders. However, for a number of reasons, refrigerant heels are not typically recovered, resulting in releases of refrigerant to the atmosphere when disposing of the cylinders.[55]

A number of countries, including Australia, Canada, India, and the European Union member states, have previously required a transition from disposable to refillable cylinders. These countries have implemented various approaches, including prohibitions on use, placement on market (i.e., sales), and prohibitions as conditions of the permits needed to handle refrigerants.

The analysis in this section combines and updates several previous analyses on the refrigerant cylinder market and associated emissions, which were prepared in 2010 and 2012 and included research and industry outreach.[56,57,58] This section evaluates the use of disposable and refillable refrigerant cylinders in the United States and estimates emissions from cylinders resulting from transport, storage, disposal, and heels. In addition, this section examines the impacts associated with replacing disposable refrigerant cylinders with refillable cylinders in the United States, including potential emission savings, costs, and other implications. The remainder of the section is organized as follows:

- **Section 3.9.2** provides an overview of disposable and refillable cylinders in the United States;
- **Section 3.9.3** provides estimates of emissions from cylinders resulting from transport, storage, improper disposal, and heels, and provides emissions savings estimates for replacing disposable with refillable cylinders;
- **Section 3.9.4** analyzes the costs associated with replacing disposable cylinders with refillable cylinders;

[55] Section 608 of the CAA required EPA to establish regulations to reduce emissions of ODS and their substitutes, including HFCs. 40 CFR Part 82, Subpart F details the rules and regulations that prohibit knowingly venting ODS and HFC refrigerant during maintenance, service, repair, or disposal of refrigeration and air-conditioning equipment.
[56] Environmental Impacts Resulting from Emissions during 30-lb Cylinder Transport and Storage. Report prepared for the U.S. Environmental Protection Agency under Contract #EP-W-10-032, Task Order 0109 by Stratus Consulting Inc., Boulder Colo. November 28.
[57] Analysis of Implications Resulting from Disposal of Non-Refillable Cylinders. Report prepared for the U.S. Environmental Protection Agency under Contract EP-W-06-010, Task Order 16 by Stratus Consulting Inc., Boulder, Colo. April 16.
[58] Options for Reducing Emissions from Disposal of Non-Refillable Cylinders. Memorandum prepared for the U.S. Environmental Protection Agency under Contract EP-W-06-010, Task Order 16 by Stratus Consulting Inc., Boulder, Colo. April 23.

- **Section 3.9.5** provides conclusions;
- **Appendix H.1** describes the methodology used to calculate emissions from cylinders during transport and storage;
- **Appendix H.2** describes the methodology used to calculate emissions from heels (theoretical and empirical) in disposable cylinders;
- **Appendix H.3** provides an estimation of emissions under various recovery scenarios from disposable cylinders during disposal; and
- **Appendix H.4** provides an estimation of annual emission changes from replacing disposable cylinders with refillable cylinders.

3.9.2 Cylinders in the United States

The "30-lb" cylinder is the most commonly used cylinder for air-conditioning and refrigerant servicing and is the focus of this report. Both virgin and reclaimed refrigerant[59] can be transported and stored in refillable and disposable 30-pound cylinders. Based on input from industry sources, it is estimated that approximately four to five million 30-pound HFC cylinders are used to charge and service stationary air-conditioning and refrigeration systems annually in the United States, including both disposable and refillable cylinders.[60,61] For the purposes of this report, it is assumed that 4.5 million HFC cylinders were sold in the United States in 2020. Industry estimates that refillable cylinders currently account for between less than 1 percent and 10 percent of all 30-pound cylinders used, with a general assumption that the quantity of refillable cylinders as a percentage of all 30-pound cylinders used is closer to 1 percent as of 2020.[62] Table 3-14 provides the breakdown for the current distribution of HFC refrigerant types assumed to be sold in 30-pound cylinders in the United States in 2020 based on refrigerant demand for servicing and charging equipment estimated by EPA's Vintaging Model.[63]

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[59] Refrigerant that is recovered from equipment, however, is transported and stored in special recovery cylinders that are designed differently from non-refillable and refillable cylinders. Recovery cylinders are outside the scope of this analysis.
[60] Personal communication between EPA and representatives of A-Gas. February 24, 2021
[61] Personal communication between EPA and representatives of Fluorofusion. March 26, 2021
[62] See notes 60 and 61. Personal communication between ICF and Maureen Beatty. February 19, 2021
[63] U.S. Environmental Protection Agency. 2020. Vintaging Model. Version VM IO file_v5.1_10.08.20.

Table 3-14: HFC Refrigerants in Cylinders

Refrigerant	Distribution of Refrigerants in Cylinders
HFC-134a	22%
R-410A	51%
R-407C	3%
R-404A	12%
R-507A	2%
R-407A	9%
Total	**100%**

Disposable Cylinders

Disposable cylinders are specifically manufactured to be single-use. These cylinders are charged with refrigerant, sold for use to fill or service equipment, and disposed.[64] Many stationary air-conditioning and refrigeration systems are serviced using refrigerants transported in disposable cylinders that receive classification from the U.S. Department of Transportation (DOT) as DOT-39 cylinders. These cylinders come in several sizes, including 15-pound, 30-pound, and 50-pound varieties, with the 30-pound cylinder being the most commonly used in the stationary air-conditioning and refrigeration system servicing industry.

DOT-39 cylinders have a single one-way valve, and because of this feature, DOT prohibits the refilling of these cylinders due to safety concerns.[65] They must be disposed of after use, either by recycling as scrap metal or disposed of as solid waste in a landfill. Disposable cylinder valves come with a rupture disk pressure-relief device that allows the contents to be released when the pressure limits are exceeded. Once activated, this type of relief device ruptures and cannot reseal. If cylinders are disposed of improperly (i.e., without recovering all refrigerant

[64] *Tip of the Iceberg: The Implications of Illegal CFC Production and Use*. Available at: https://eia-international.org/wp-content/uploads/Tip-of-the-Iceberg-CFCs-FINAL.pdf
[65] 49 CFR 178.65 (i)

remaining in the cylinder), the residual refrigerant is emitted to the atmosphere. Table 3-15 summarizes typical specifications for DOT-39 cylinders used for refrigerant gases.

Table 3-15: Specifications of "30-lb" DOT-39 cylinders

	Example 1	Example 2	Example 3
Service Pressure (psi)	260	308	400
Test Pressure (psi)	325	385	500
Water Capacity (lb)	30.4	30.4	30.4
Height (in)	16.8	16.8	16.8
Diameter (in)	9.5	9.5	9.5
Construction Standards	DOT39 TC39M	DOT39 TC39M	DOT39 TC39M

Source: AMTROL 2017, 40 CFR 178,65 (i)

As discussed above, for purposes of this analysis it is assumed that the vast majority of refrigerant cylinders sold annually in the United States (i.e., 99 percent) are disposable, or approximately 4.46 million cylinders. The remaining 45,000 cylinders (i.e., 1 percent) are assumed to be refillable.

Refillable Cylinders

Refillable cylinders reduce emissions of refrigerant resulting from the improper disposal of disposable cylinders and have been mandated in several countries.[66] Refillable cylinders have a combination valve with separate ports for refrigerant removal and refrigerant filling, and a safety-relief device. The refrigerant filling port is typically locked so that only the refrigerant supplier can fill the cylinder. Upon being emptied[67] by service technicians, refillable cylinders are typically returned to the wholesaler, who refunds the deposit paid when the cylinder was purchased. The empty refillable cylinders are collected by the wholesaler and returned to the refrigerant manufacturers to be refilled. The refrigerant manufacturers evaluate, clean, and refill the cylinders to be sent back onto the market. A refillable cylinder would be filled an average of

[66] Canada, Australia, and European Community member countries.
[67] As with disposable cylinders, refillable cylinders will not typically be 100 percent empty. Service technicians will generally stop using a cylinder once all the liquid-phase gas has been extracted while the vapor-phase gas remains as a heel.

1.5 times per year and could be filled up to 3–4.5 times per year.[68,69] Assuming refillable cylinders are properly maintained, they can be reused for more than 20 years. [70,71,72]

3.9.3 Emissions from Cylinders

Emissions from all refrigerant cylinders can occur under various conditions. The frequency with which these conditions occur and the amount of refrigerant released varies and depends in part on the type of cylinder. Refrigerant remaining in disposable cylinders—including amounts commonly referred to as refrigerant heels—are also emitted during disposal by leaking over time, once the cylinder breaks down, or when the cylinders are crushed.

Cylinder Transport and Storage

In order to allow for safe levels of gas expansion, cylinders should not be filled to more than 80 percent of their capacity.[73] Overfilling cylinders at levels above this capacity can lead to refrigerant losses from exposure to excessive heat. When temperatures increase, the liquid refrigerant in the cylinder will expand into the vapor space above the liquid. If the liquid is heated to approximately 130°F, it will fill the available space in the cylinder. Continued heating and expansion of the liquid will result in the cylinder pressure-relief valve releasing the contents to relieve excess pressure (in the case of refillable cylinders) or all of the refrigerant charge (in disposable cylinders). It could also result in the cylinder's rupture if the safety-relief valve is not functioning or not present and the temperature reaches a sufficiently high level. The United

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[68] Personal communication between Stratus Consulting and Jim Thomas, Refrigerant Services, September 12, 2012
[69]To be conservative, refillable cylinders were assumed to be filled one time per year.
[70] Personal communications between ICF and representatives of A-Gas. April 12, 2021
[71] Personal communication between ICF and Maureen Beatty. February 19, 2021
[72] *Lifecycle Analysis of High-Global Warming Potential Greenhouse Gas Destruction*. Prepared by ICF International for the California Air Resources Board. Available at: https://ww2.arb.ca.gov/sites/default/files/classic//research/apr/past/07-330.pdf
[73] United Nations Environment Programme. *Manual for Refrigeration Servicing Technicians*. Available at: http://www.unep.fr/ozonaction/information/mmcfiles/7443-e-ref_manual_servicing_technicians.pdf

Nations Environment Programme (UNEP) Manual for Refrigeration Servicing Technicians states that cylinders should never be exposed to temperatures above 52°C (~ 126°F).[74] This type of refrigerant loss is particularly concerning during cylinder transport, because temperatures inside closed vans or trucks can reach levels sufficient to cause cylinder overheating on hot, sunny days.[75] This type of refrigerant loss can also occur during cylinder storage. However, it is unlikely that cylinders would be stored in locations where they are exposed to temperatures above 126°F for a sufficient amount of time to bring the refrigerant to a sufficient temperature to cause a release or rupture.[76]

Cylinders that are overfilled—and thus under excessive pressure—are more vulnerable to rupturing when they come into blunt contact with something (e.g., with other cylinders if they are not well secured in the back of a truck, or with the ground if they fall out of a truck). Also, a damaged safety-relief valve can increase a cylinder's vulnerability to rupturing if the cylinder is overfilled. Mechanical damage to a cylinder valve can result in the refrigerant being lost to the atmosphere even if the cylinder is not overfilled. Valves can be damaged when cylinders are mishandled (e.g., if they are dropped or not properly secured in a truck); they can also function improperly if they are plugged (e.g., by dirt) or covered (e.g., by labels or plastic wrap).[77]

Valves that are poorly manufactured also can contribute to refrigerant loss. A valve that does not properly close will not provide a sufficient protective seal against the high-pressure contents within the cylinder. This type of refrigerant loss can occur during cylinder storage as well as transport.

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[74] Personal communication between Stratus Consulting and Rich Dykstra, Rapid Recovery, September 11 and November 16, 2012.
[75] R-410A FAQ. Available at: https://ww2.epatest.com/faq/r-410a-faq/. Accessed 2/19/2021.
[76] See note 74.
[77] See note 73.

Cylinders can also rust and corrode over time, which can result in pathways developing through the metal for refrigerant to escape. This refrigerant loss condition would not typically occur in cylinders in transport because those cylinders are generally in active use and would be regularly evaluated and resorted (as necessary) by refrigerant manufacturers. This condition is more applicable to cylinders in storage, especially those that are improperly stored outdoors where they may be exposed to the elements, although such storage conditions are unlikely.[78]

Cylinders can lose refrigerant if the individuals handling them open the valves (deliberately or accidentally). Over the course of its travels from refrigerant manufacturer to end use, a cylinder is typically transported to three or four locations (i.e., wholesalers, distributors, and end users, and potentially brokers) and can be handled as many as 10 to 20 times.[79] Thus, there are many opportunities for human error. This type of refrigerant loss can occur during cylinder storage as well as transport.

Refrigerant Loss Types and Prevalence of Refrigerant Losses

The amount of refrigerant that is emitted during cylinder transport and storage depends on the conditions under which the refrigerant is lost, such as ruptures, slow leaks, and safety-valve releases. Types of refrigerant losses and the prevalence of these refrigerant losses for refillable and disposable cylinders were identified through industry outreach.[80] Cylinders that rupture lose their entire refrigerant charge. When the cylinder ruptures, the pressure drop causes the liquid refrigerant to flash into vapor, which has an explosive effect. Slow leaks due to

[78] Ibid.
[79] See note 68.
[80] See note 56.

defective valves will eventually lose their entire charge (minus the heel) if the leaks are not detected in time.

If a refillable cylinder has a functional safety-relief valve and experiences an excessive increase in internal pressure (e.g., due to overfilling), the safety-relief valve will allow venting of a small amount of the refrigerant to prevent the cylinder from rupturing. The amount released will be only enough to bring the internal cylinder pressure back down to a safe level before the valve recloses. Depending on the internal pressure (which in turn depends on factors such as the atmospheric pressure and temperature), this amount could be as much as 20 percent of the cylinder's capacity (i.e., because a cylinder is considered to be overfilled if it is filled to greater than 80 percent capacity) or as little as 1 percent of the refrigerant in the cylinder.[81]

For disposable cylinders, the safety-relief valve has a rupture disk pressure-relief device that does not reseal once activated. As a result, the entire refrigerant charge will be lost if a disposable cylinder's safety-relief valve is activated.

The frequency of the different types of refrigerant losses can differ by cylinder type. For instance, defective valves are considered "very rare" among domestically manufactured disposable cylinders.[82] It is estimated that approximately 0.02 percent of all refillable cylinders have defective valves that result in refrigerant loss.[83]

Refillable cylinders are more prone to refrigerant losses associated with mechanical damage and corrosion because they are reused many times.[84] It is estimated that 0.02 percent of all refillable cylinders experience mechanical damage or corrosion that results in refrigerant loss.

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[81] See note 68.
[82] See note 74.
[83] See note 68.
[84] See note 74.

The overall percentage of refillable cylinders that experience refrigerant loss due to human error and overfilling is about 0.04 percent.

Table 3-16 summarizes the refrigerant loss types for disposable and refillable cylinders during transport and storage identified.[85]

Table 3-16: Summary of Refrigerant Loss Types from Cylinders during Transport and Storage

Type of refrigerant loss	% of refrigerant in cylinder that is emitted due to this type of loss	% of cylinders that experience this type of loss
Disposable Cylinders		
Mechanical damage to valve	96%[a]	0.01%[b]
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	100%	0.01%[b]
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	96%[a]	0.01%[b]
Refillable Cylinders		
Mechanical damage to valve	96%[a]	0.02%
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	100%	0.01%[b]
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	Up to 20%	0.01%[b]

[a] Assumes all refrigerant is lost, minus the heel. The heel is estimated to be approximately 0.96 lbs. (4 percent) (see Appendix A for full list of assumptions).
[b] The likelihood of these types of losses occurring is considered negligible. 0.01 percent is considered the smallest likelihood of a loss occurring.

Emission Estimates from Cylinder Transport and Storage

Based on the refrigerant loss types and prevalence of loss types for disposable and refillable cylinders, emissions from cylinders during transport and storage were updated for 2022 to 2050 to reflect an updated distribution of refrigerants sold annually in 30-pound cylinders. See Appendix H for a more detailed review of the methodology for these estimates.

Annual emissions from refrigerant losses during cylinder transport and storage total approximately 31,600 pounds of refrigerant (including approximately 31,200 pounds and 300 pounds emitted from disposable and refillable cylinders, respectively) in a BAU scenario. In

[85] See note 56.

total, these emissions contribute approximately 31,400 $MTCO_2e$ per year as shown in Table 3-17.

Table 3-17: Emissions from Cylinder Transport and Storage

Refrigerant	% of all refrigerants in cylinders	Pounds emitted	Metric tons emitted	$MTCO_2e$
Disposable Cylinders				
R-134a	22%	6,898	3.13	4,474
R-410A	51%	15,973	7.25	15,128
R-407C	3%	1,089	0.49	876
R-404A	12%	3,630	1.65	6,458
R-507A	2%	726	0.33	1,312
R-407A	9%	2,904	1.32	2,776
Total	**100%**	**31,221**	**14.2**	**31,025**
Refillable Cylinders				
R-134a	22%	74	0.03	48
R-410A	51%	172	0.08	163
R-407C	3%	12	0.01	9
R-404A	12%	39	0.02	70
R-507A	2%	8	0.00	14
R-407A	9%	31	0.01	30
Total	**100%**	**337**	**0.15**	**335**
Total (All Cylinders)	**-**	**31,558**	**14.31**	**31,360**

Note: Totals might not sum due to rounding.

Disposal of Disposable Cylinders

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

There is substantial uncertainty regarding the volume of refrigerant that remains in disposable cylinders at the point they are discarded, including the amount in the heels. To better assess the emissions from disposable cylinders, it is necessary to estimate emissions associated with the common practice of disposing of cylinders with refrigerant heels (i.e., deemed to be "empty") by service technicians. A 2010 report[86] contained a theoretical study conducted to estimate true heel ratios that would remain in cylinders under differing field servicing and recovery conditions. The report contained a second study that involved collecting empirical data on refrigerant remaining in cylinders collected after use in the field by service technicians for charging stationary refrigeration and air-conditioning systems. Based on the average heel amount found in the theoretical and empirical studies, an analysis of potential emissions from disposable cylinders under various recovery scenarios was also conducted.

Theoretical Heel Estimation

The theoretical heel estimation study included six refrigerants based on input from EPA technical experts and industry sources, as well as a review of available literature.

Table 3-18: Refrigerants included in theoretical study

Refrigerant	Constituents	Cylinder Masses
HCFC-22	HCFC-22	Disposable – 15 lbs., 30 lbs., 50 lbs. Refillable – 30 lbs., 125 lbs.
HFC-134a	HFC-134a	Disposable – 30 lbs. Refillable – 30 lbs., 125 lbs.
R-410A	HFC-32 and HFC-123	Disposable – 25 lbs. Refillable – 100 lbs.
R-407C	HFC-32, HFC-125, and HFC-134a	Disposable – 25 lbs. Refillable – 115 lbs.
R-404A	HFC-125, HFC-134a, HFC-143a	Disposable – 24 lbs. Refillable – 100 lbs.
R-507A	HFC-125 and HFC-143a	Disposable – 25 lbs. Refillable – 100 lbs.

The theoretical heel amount that would remain in a typical cylinder was estimated under two different scenarios. In the first scenario, the cylinder is assumed to have been emptied in the

[86] See note 57.

field and disposed of without a vapor recovery process. When the liquid phase refrigerant is being charged, the pressure in the cylinder approaches the system suction pressure.

The theoretical study described estimated heel amounts based on the thermodynamic properties of six refrigerants—HCFC-22, HFC-134a, R-410A, R-407C, R-404A, and R-507A—considering use and disposal of 13.5-L (822-cu in) disposable cylinders (i.e., 30-pound cylinders) exclusively. In this study, the heel amounts were theoretically estimated under three conditions:

1. Heel amounts in cylinders after field charging without recovery;
2. Heel amounts in cylinders after vapor recovery until the cylinder pressure reaches 10 percent of the initial cylinder pressure; and
3. Heel amounts in cylinders after vapor recovery until the cylinder pressure reaches certain vacuum pressures (0, 5, 10, 15, 20, 25, 29 inHg at vacuum).

For comparison with other studies, theoretical heel amounts estimated following field charging without recovery were also considered. The study results show that for cylinders after field charging, but without recovery, the heel amounts range from:

- 0.50 lbs. to 1.08 lbs. for air conditioning;
- 0.29 lbs. to 0.66 lbs. for medium-temperature refrigeration; and
- 0.15 lbs. to 0.35 lbs. for low-temperature refrigeration.

The average heel amounts included 0.31 pounds for HFC-134a and 0.65 pounds for R-410A.

Empirical Study of Heels

To complement the findings of the theoretical study, the same 2010 report for EPA[87] showed data collected from a refrigerant technician company measuring quantities of refrigerant remaining in disposable cylinders after being used to service stationary air-conditioning and refrigeration equipment in the field. The range in heel amounts estimated in the theoretical study are smaller than the amounts of refrigerant remaining generated in the empirical study. In the empirical study, the average amount of refrigerant remaining across all refrigerant types and applications was 1.08 lbs., with a range of 0.28 lbs. to 3.69 lbs. One reason why the amounts in the empirical study exceed the estimates in the theoretical study could be that a service technician will often decline to take a cylinder into the field if he determines, simply by lifting the cylinder, that there is not enough refrigerant remaining in the cylinder to make transporting it worthwhile. Service technicians would prefer to have their service vehicle loaded with full cylinders at the beginning of the day to minimize the number of trips back to the vehicle that would be necessary when charging systems in the field.

Comparison of Results to Other Studies

A comparison of the theoretical and empirical studies shows that the results of this analysis are comparable to the results of other studies (see Table 3-19). In a previous study of 30-pound disposable cylinders commissioned by EPA, the estimated heel amount after recovery to 29 psi was approximately 0.56 pounds[88] Another proprietary study of amounts of refrigerant remaining in disposable cylinders conducted by a private company indicates an average amount

[87] Ibid.
[88] U.S. Environmental Protection Agency. *Disposable Container Heel Testing Study Report*. 2007

of 0.59 pounds (approximately 2 percent) for 128 cylinders. In this study, cylinders containing HCFC-22 accounted for nearly 70 percent of all cylinders and had an average amount of 0.66 pounds. Cylinders containing R-404A, which accounted for approximately 25 percent of all cylinders, contained an average amount of 0.39 pounds. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) estimated that heel amounts in cylinders at system suction pressure (i.e., following use of cylinder for charging in the field) range from approximately 0.45 pounds (1.5 percent) to roughly 0.90 pounds (3 percent). These estimates were based on AHRI calculations; the specific assumptions made in these calculations were not provided.[89]

Table 3-19: Comparison of amount of refrigerant remaining from different sources

Source	Average Amount	Amount by Sector or Use
Theoretical study	NA	AC: 0.5 lbs. to 1.08 lbs. Medium-temp 0.29 lbs. to 0.66 lbs. Low-temp: 0.15 lbs. to 0.35 lbs.
Empirical study	1.08 lbs. (3%)	Appliance Servicing: 0.64 lbs. Residential AC: 1.02 lbs. Commercial AC: 1.13 lbs. Chillers: 1.15 lbs.
EPA, 2007	0.56 lbs. (2%)	NA
Airgas, 1998	1.65 lbs. (6%)	NA
AHRI, 2000	0.45 lbs. (2%) - 0.90 lbs. (3%)	NA
CARB, 2011[90]	1.1 lbs. (3.7%)	NA

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

[89] Comments by the Air-conditioning, Heating, and Refrigeration Institute at the EPA stakeholder meeting on May 16, 2000. EPA Docket A-2000-21, ID II-B-04.

[90] See note 72: *Lifecycle Analysis of High-Global Warming Potential Greenhouse Gas Destruction*. Prepared by ICF International for the California Air Resources Board. Available at: https://ww2.arb.ca.gov/sites/default/files/classic//research/apr/past/07-330.pdf

analysis was based on ideal operating conditions, such that the cylinder temperature achieves equilibrium with ambient air.

This assumes that the service technician spends more time charging the system and recovering the refrigerant than may be reasonable, where a technician might sacrifice refrigerant for the sake of expediency. As shown in Table 3-19, estimates of the amount of refrigerant remaining in cylinders at the time of their disposal vary. Industry sources contacted in the cited study confirmed the fact that there is uncertainty as to how much refrigerant remains in cylinders when they are determined to be "empty." In general, several sources suggested an estimate of approximately 0.96 pounds (roughly 4 percent of the 24 pounds of refrigerant in a 30-pound cylinder's capacity) would be reasonable.

Recent industry outreach indicated disposable cylinders contain approximately 1 to 1.25 pounds of residual heel and another estimated the typical heel in a disposable cylinder is approximately 1.5 pounds.[91] This analysis therefore assumes a residual heel of approximately 0.96 pounds.

Avoided Emissions Under Different Refrigerant Recovery Assumptions

Disposal emissions can be reduced by employing refrigerant recovery practices to minimize the heel or by utilizing refillable refrigerant cylinders that can be used multiple times before they need to be disposed. How service technicians dispose of used disposable cylinders will determine whether refrigerant that remains in the cylinder is released to the atmosphere or recovered for reuse. To understand whether refrigerant remaining in cylinders is emitted to the atmosphere, it is important to know:

[91] See notes 60 and 61

- when service technicians make the decision to switch to fresh cylinders;
- whether service technicians recover the refrigerant remaining in the cylinders before they dispose of them;
- how (and to whom) service technicians dispose of the cylinders; and
- whether there are downstream opportunities for refrigerant recovery after cylinders are no longer in the service technician's possession.

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

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

A 2012 study conducted for EPA[92] examined potential total avoided emissions under different refrigerant recovery practices based on the amount of refrigerant that remains in the cylinder and the percentage of cylinders that are vented. These emission estimates were updated for 2020 to reflect an updated distribution of HFC refrigerants sold annually in 30-pound

[92] Stratus Consulting. *Environmental Impacts Resulting from Emissions during 30-lb Cylinder Transport and Storage*. Report prepared for the U.S. Environmental Protection Agency under Contract #EP-W-10-032, Task Order 0109 by Stratus Consulting Inc., Boulder CO. November 28, 2012.

cylinders. Appendix H describes the full methodology and emission estimates across various recovery scenarios.

These estimates varied depending on the stringency of the recovery effort. The annual GHG emissions decrease substantially when refrigerant remaining in the cylinder is recovered to 0 inHg vacuum, compared with venting the refrigerant remaining in the cylinders. Increases in vacuum pressure during recovery lead to more substantial avoided emissions.

In the scenario where the typical amount of refrigerant remaining is approximately 1.0 pounds, estimated annual emissions can amount to between 0.44 $MMTCO_2e$ and 4.4 $MMTCO_2e$, depending upon the percentage of cylinders vented (see Appendix H). The assumed baseline is that 0.96 pounds of refrigerant remain in the cylinder that is vented unless recovered, and that 95 percent of all cylinders are vented.[93] Therefore, the assumed annual emissions are 4.2 $MMTCO_2e$.

Avoided emissions increases as refrigerant recovery vacuum pressure increases, as shown in Table 3-20. Based on the findings of the theoretical study, it is estimated that true heel amounts for different end uses are typically close to 0.5 pounds. The results of the empirical study revealed that cylinders are typically disposed of with an average of approximately 1.0 pounds of refrigerant remaining.

Table 3-20: Heel amounts (lbs.) assuming vapor recovery to various vacuum pressures

inHg vacuum	psig vacuum	kPa abs.	R-134a	R-410A	R-407C	R-404A	R-507A
0	0.00	101.35	0.13	0.09	0.11	0.12	0.12
5	2.46	84.42	0.11	0.07	0.09	0.10	0.10
10	4.91	67.49	0.08	0.06	0.07	0.08	0.08
15	7.37	50.56	0.06	0.04	0.05	0.06	0.06

[93] See notes 60 and 61.

Based on this analysis, it is apparent that there are benefits to be gained through recovering refrigerant from disposable cylinders and that these benefits become larger with more stringent recovery practices. More time is required to achieve higher vacuum pressures, ranging from approximately 3 minutes to reach a 0 inHg vacuum to approximately 9 minutes to reach a 15 inHg vacuum.[94]

Emission Reductions by Replacing Disposable with Refillable Cylinders

To understand the potential amount of emissions avoided by replacing disposable 30-pound cylinders with refillable cylinders, the calculations were run using the assumption that the 4.5 million 30-pound disposable cylinders containing HFCs that are sold each year are replaced with refillable cylinders to ensure no disruption in the supply chain if refillable cylinders are not returned within the same calendar year.[95]

To model the number of new refillable cylinders sold each year, it is assumed that a transition to a fully refillable cylinder fleet occurs over a five-year period starting in 2022 and an estimated 5 percent of the total fleet needs to be newly manufactured annually to account for disposals from refillable cylinders reaching end-of-life and to account for any damaged cylinders. Emissions from cylinder disposal were estimated assuming 0.96 pounds of refrigerant (4 percent) are remaining in the cylinders (see Appendix H). In addition, instead of assuming the HFC refrigerant mix remains the same over time (see Table 3-14), it is assumed that the mixture of HFCs and other refrigerants sold in cylinders changes over time due to the transition away

[94] See note 89.
[95] For the cost analysis (see Section 3.9.4), various replacement ratios between refillable and non-refillable cylinders are considered; however, it is assumed that an all-refillable scenario would still involve a total of 4.5 million cylinder trips per year because the volume of refrigerant produced, transported, and stored would not change simply due to the transition to all refillable cylinders.

from HFCs. This analysis also considers a low and high scenario under which refillable cylinders are assumed to contain a refrigerant heel of 0.44 pounds (1.85 percent) (low) and a refrigerant heel of 1.25 pounds (6 percent) (high).

The emissions between the BAU scenario, where the vast majority of cylinders are disposable and a small amount of refillable cylinders are used, and a scenario where all disposable cylinders are replaced with refillable cylinders is shown in

Table 3-21. Replacement of disposable cylinders with refillable cylinders in the United States would be estimated to prevent 29 MMTEVe in emissions from 2022 through 2050. Annual emission reductions and the low and high scenario are presented in Appendix H.

Table 3-21: Estimated Total Emission Changes over the Period 2022–2050 from Replacing Disposable Cylinders with Refillable Cylinders

Scenario	Pounds emitted	Metric tons emitted	$MMTCO_2e$
Transport and Storage			
BAU scenario (mostly disposable cylinders)	915,170	415	0.27
Most likely scenario (all refillable cylinders)	972,864	441	0.29
Change in emissions under most likely scenario	57,693.6	26	0.02
Disposal			
BAU scenario (mostly disposable cylinders)	124,089,840	56,286	37
Most likely scenario (all refillable cylinders)	14,472,000	6,564	8
Change in emissions under most likely scenario	-109,617,840	-49,722	-29
Total Change in Emissions	**-109,560,146**	**-49,696**	**-29**

3.9.4 Cost Analysis of Replacing Disposable Cylinders with Refillable Cylinders

Replacing disposable cylinders with refillable cylinders could have other implications for businesses in addition to emission savings. Estimating the economic impacts of replacing disposable cylinders with refillable cylinders must account for the costs associated with replacing the cylinders themselves and the costs associated with the change in procedure handling of refillable cylinders (i.e., returning the cylinders to be refilled).

Entities Potentially Subject to the Transition to Refillable Cylinders

Requiring a transition to the use of refillable cylinders would directly impact those companies that sell or distribute or repackage refrigerant in disposable cylinders. For this preliminary analysis, affected entities are assumed to be producers, importers, exporters, reclaimers, and companies that sell and distribute HFCs (e.g., blenders, repackagers, and wholesalers or distributors of refrigerants).[96] Table 3-22 lists the affected industries by NAICS code and the estimated number of businesses affected.

Table 3-22: List of Potentially Affected Industries by Transitioning to Refillable Cylinders by NAICS Code

NAICS Code	NAICS Industry Description	Estimated Number of Businesses Affected
325120	Industrial Gas Manufacturing	0[a]
562920	Materials Recovery Facilities	65[a]
423740	Refrigeration Equipment and Supplies Merchant Wholesalers	645[b]
423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers	2,220[b]
424690	Other Chemical and Allied Products Merchant Wholesalers	3,035[b]

Source: Census Bureau (2020)
[a] Based on known HFC producers and reclaimers.
[b] It was assumed that 50 percent of total businesses within these NAICS codes are refrigerant wholesalers and would be affected by the transition to refillable cylinders.

Estimated Costs

For the purposes of quantifying direct compliance costs for this analysis, it was assumed that reclaimers, wholesalers, and distributors of refrigerant cylinders currently sell refrigerant solely in disposable cylinders.[97]

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[96] For the purposes of this preliminary analysis, it is conservatively assumed that producers transport refrigerant primarily in containers larger than 30-pound cylinders and therefore the total inventory of 4.5 million cylinders was distributed across importers, exporters, reclaimers, and companies that sell and distribute HFCs (e.g., blenders, repackagers, and wholesalers or distributors of refrigerants) defined by the NAICS codes in Table 3-22

[97] Industry estimates that refillable cylinders account for between less than 1 percent and 10 percent of all 30-pound cylinders used, with a general assumption that the quantity of refillable cylinders as a percentage of all 30-pound cylinders used is closer to 1 percent (A-Gas 2021a, National Refrigerants 2021, Fluorofusion 2021). For the purposes of this analysis, it is assumed that all cylinders sold in the United States are non-refillable.

Cost of cylinders. Industry estimates that refillable cylinders are approximately three to eight times the cost of a disposable cylinder, due to the need for a particular valve.[98] This analysis assumes a disposable cylinder costs approximately $16 and a refillable cylinder is $80, based on public comments received.[99,100] While the price of a refillable cylinder is higher than that of a disposable cylinder, a refillable cylinder has a lifetime of 20 years and is refilled an average of 1.5 times per year and could be refilled as much as 3-4.5 times per year.[101] However, this analysis conservatively assumes that refillable cylinders are filled once per year and replace disposable cylinders in a 2:1 ratio to ensure no disruption in the supply chain if refillable cylinders are not returned within the same calendar year.[102] Assuming all refillable cylinders are refilled once per year, approximately 9 million refillable cylinders would need to be purchased over an assumed period of five years starting in 2022 to fully replace disposable cylinders. An estimated 5 percent of the total fleet is assumed to be newly manufactured every year to account for replacement of refillable cylinders reaching end-of-life annually and to account for any damaged or unreturned cylinders. Cylinder sales were distributed across businesses in proportion to their annual sales.[103]

This analysis also considers a low scenario, in which assumptions are made which would result in lower compliance costs and/or greater savings from recaptured refrigerant, and a high scenario, with assumptions leading to higher costs and/or lower savings. For example, in the low

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[98] See notes 60 and 71.

[99] Comment submitted on draft rulemaking: Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program under the American Innovation and Manufacturing Act. EPA-HQ-OAR-2021-0044-0215. Available at: https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0044-0215

[100] Comment submitted on draft rulemaking: Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program under the American Innovation and Manufacturing Act. EPA-HQ-OAR-2021-0044-0216. Available at: https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0044-0216

[101] See notes 60 and 70.

[102] This analysis assumed that an all-refillable scenario would still involve 4.5 million cylinder trips per year because the volume of refrigerant produced, transported, and stored would not change simply due to the transition to all refillable cylinders.

[103] 2017 SUSB Annual Data Tables by Establishment Industry. Available at: https://www.census.gov/data/tables/2017/econ/susb/2017-susb-annual.html

scenario refillable cylinders cost $36, replace disposable cylinders on a 1:1 basis, have 5 percent cylinder turnover per year, and are always returned with a recoverable heel. Conversely, in the high scenario refillable cylinders cost $80 and replace disposable cylinders on a 2.5:1 basis, have a 10 percent turnover per year, and are only returned with a heel that can be recaptured 50 percent of the time.

Cost of cylinder maintenance. Refillable cylinders have an average lifetime of approximately 20 years, but typically undergo maintenance every five years, including cleaning, inspection, repainting, hydrostatic testing, or replacing the valve. This cost is applied to cylinders every five years and is assumed to be approximately $13 per cylinder.[104] This analysis also considers a low- and high-cost scenario, in which maintenance is assumed to be $13 (low) and $15 (high).

Cost of transport. Refillable cylinders are only marginally heavier than the largest quantity disposable cylinder on the market. For example, a refillable cylinder containing R-410A weighs approximately 42 pounds (25 pounds for the gas and 17 pounds for the cylinder) and a standard disposable cylinder of HFC-134a is 39 pounds (30 pounds for the gas and 9 pounds for the cylinders).[105] However, refillable cylinders require additional trips throughout their use cycle compared with a disposable cylinder. Disposable cylinders are assumed to travel from gas producer/filler to the wholesale distributor, wholesale distributor to end user/technician, and end user/technician to steel recycler.

Refillable cylinders are assumed to travel from the gas producer/filler to the wholesale distributor and from the wholesale distributor to the end user/technician. After cylinders are

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[104] See note 72.
[105] Personal communication with Patrick McInerney, August 8, 2021.

returned to the wholesale distributor, for approximately half of cylinders sold, distributors would send returned refillable cylinders directly to the gas producers, who would then remove the refrigerant heel and store it until a significant amount has accumulated before sending to the reclaimer. The other half are assumed to be sent from the wholesale distributor to the reclaimer and then back to the gas producer/filler.

Transportation costs were updated to account for the distance traveled for each trip and the use of company fleets to transport cylinders based on the CARB analysis. It is assumed that companies already own or lease the proper vehicle fleet to transport cylinders.

Table 3-23 summarizes distances per shipment for disposable and refillable cylinders. EPA did not assume changes in the locations at which HFCs are primarily packaged into cylinders. Based on the location of chemical production facilities around the United States, located primarily along the East Coast, Midwest, South, and California, it is assumed that a cylinder would travel an average of 1,000 miles from producer to the wholesale distributor. As in the CARB analysis, the distance between wholesale distributor and end user/technician is assumed to be 25 miles. For the refillable scenario, it is assumed that a distributor is regularly dropping off new refrigerant to its customers and would pick up their empty, refillable cylinders on the same trip (or the end user would drop off their empty cylinders to pick up new ones, such that no additional trip for the return of cylinders is necessary). Other distances were also based on the CARB analysis.

Table 3-23: Travel Distances for Disposable Cylinders and Refillable Cylinders

Trip	Disposable	Refillable
Gas producer/filler to wholesale distributor	1,000	1,000
Wholesale distributor[a] to end user/technician	25	25
End user/technician to steel recycler	75	N/A
Wholesale distributor[a] to reclaimer	N/A	50[b]
Wholesale distributor[a] OR reclaimer to gas producer/filler	N/A	1,000
Total Miles	**1,100**	**2,050**

[a] The wholesale distributor is assumed to regularly drop off new refrigerant and pick up empty, refillable cylinders on the same trip.
[b] Only assumed for 50 percent of shipped cylinders.

Table 3-24 provides additional assumptions related to fuel use and labor associated with transporting cylinders.

Table 3-24: Additional Transportation Assumptions

Parameter	Assumption
Average Fuel Efficiency	6 miles per gallon[a]
Diesel Fuel Cost	$3.367/gallon[b]
Average Truck Speed	50 miles per hour[c]
Labor Rate (Truck Transport)	$49.896[d]

[a] International Council on Clean Transportation. 2015. *Eighteen wheels and ten miles per gallon*. Available at: https://theicct.org/blogs/staff/eighteen-wheels-and-ten-miles-gallon
[b] Environmental Investigation Agency. *Search, Reuse and Destroy: How States Can Take the Lead on a 100 Billion Ton Climate Problem*.
[c] See footnote 72.
[d] Labor rate for Heavy and Tractor-Trailer Truck Drivers from Bureau of Labor Statistic's Employer Costs for Employee Compensation – May 2020. Median hourly wages rates were multiplied by a factor of 2.1 to reflect the estimated additional costs for overhead (Bureau of Labor Statistics. 2021). https://www.bls.gov/oes/current/oes533032.htm

Transportation costs were then calculated on a per-cylinder basis. This analysis conservatively estimates transportation costs on a per-cylinder basis assuming a truck could fit approximately 1,120 disposable cylinders or 870 refillable cylinders. Recent information about cylinder transport indicates that refillable cylinders are typically shipped in metal containers that are approximately the same size as a pallet of disposable cylinders, but because containers for refillable cylinders are more durable and can be stacked higher, they offer improved storage efficiency compared to disposable cylinders.[106] Table 3-25 summarizes the transport cost per cylinder based on the assumptions presented above. Transportation costs are assumed to be the same under both the low and high scenarios.

Table 3-25: Transportation Assumptions per Cylinder

	Fuel Costs	Labor	Total
Disposable	$0.55	$0.98	$1.53
Refillable	$1.32	$2.35	$3.67

Recovered heel. A portion of refillable cylinders returned to the wholesale distributor are assumed to contain a refrigerant heel that can be recovered and sold back into the market. It was assumed that approximately 75 percent of returned refillable cylinders per year contain a heel of approximately 0.96 pounds (4 percent) based on the CARB analysis and expert judgment. Recovered refrigerant is assumed to be resold at approximately $4 per pound based on average refrigerant costs.

Under the low scenario, 100 percent of returned cylinders are assumed to contain a refrigerant heel of 0.44 pounds (1.85 percent); under the high scenario, 50 percent of returned cylinders are assumed to contain a refrigerant heel of 1.25 pounds (6 percent).

Table 3-26 summarizes the cost assumptions associated with replacing disposable cylinders with refillable cylinders.

Table 3-26: Cost Assumptions for BAU and Most Likely Estimate plus Low and High Scenario from Transitioning to Refillable Cylinders

Assumption	BAU	Most Likely Estimate	Low Scenario	High Scenario
Disposable Cylinder Price	$16	$16	$16	$16
Refillable Cylinder Price	$80	$80	$36	$80
Cylinder Maintenance Cost	$13 every 5 years	$13 every 5 years	$13 every 5 years	$15 every 5 years
Refillable Cylinder Turnover Rate	5%	5%	5%	10%
Number of Refillable Cylinders to Replace 1 Disposable Cylinder	n/a	2	1	2.5

[106] Ibid.

Assumption	BAU	Most Likely Estimate	Low Scenario	High Scenario
Number of Refillable Cylinders Purchased	45,000	9,000,000[a]	4,500,000	11,250,000[a]
Total Transport Cost per Disposable Cylinder	$1.53[a]	$1.53	$1.53	$1.53
Total Transport Cost per Refillable Cylinder	$3.63	$3.63	$3.63	$3.63
Cylinder Heel Amount (lbs.) and Percent of Cylinder	1.25 (5%)	0.96 (4%)	0.44 (1.85%)	1.44 (6%)
Average Refrigerant Price ($/lbs.)	$3.98	$3.98	$3.98	$3.98
Maximum Cylinders Returned per Year	n/a	4,275,000	4,275,000	4,050,000
Percentage of Cylinders Returned with Heel	50%	75%	100%	50%

[a] Although additional refillable cylinders are needed to account for possible lags in cylinders being returned to the distributor for reuse, it assumed that only 4.5 million cylinders containing HFCs are sold into the market per year.

Management Costs. Because refillable refrigerant cylinders need to be returned to a reclaimer or wholesaler/distributor for reuse, it is assumed that each company will utilize approximately 5 percent of a full-time employee (i.e., 2 hours per week) to coordinate the return of refrigerant cylinders. Under the high scenario, it is assumed that up to 10% of a full-time employee (i.e., 4 hours per week) may be required. The cost assumptions for each industry to maintain a cylinder return program are presented in Table 3-27**.**

Table 3-27: Costs to Manage a Cylinder Return Program

NAICS Code	NAICS Industry Description	FTE Annual Wage[a]	Most Likely and Low Scenario		High Scenario	
			% of FTE	Annual Cost per Firm	% of FTE	Annual Cost per Firm
562920	Materials Recovery Facilities	$42,260[b]	5%	$2,113	10%	$4,226
423740	Refrigeration Equipment and Supplies Merchant Wholesalers	$38,400[c]	5%	$1,920	10%	$3,840
423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers	$39,570[d]	5%	$1,979	10%	$3,957
424690	Other Chemical and Allied Products Merchant Wholesalers	$38,400[c]	5%	$1,920	10%	$3,840

[a] FTE annual wage is for occupation code 43-5000: Material Recording, Scheduling, Dispatching, and Distributing Workers.
[b] Bureau of Labor Statistics. 2020. https://www.bls.gov/oes/current/naics4_562900.htm.
[c] Bureau of Labor Statistics. 2020. https://www.bls.gov/oes/current/naics4_4240A2.htm.
[d] Bureau of Labor Statistics. 2020. https://www.bls.gov/oes/current/naics4_4230A1.htm.

Using the methodology and additional assumptions described above, Table 3-28: Summary of Incremental Costs of Cylinder Provisions for 2022–2050 (millions of 2020$, discounted to 2022)

presents estimates of the annual and total PV of incremental costs associated with the cylinder provisions over the 29-year period 2022 to 2050, under the most likely, low, and high scenario assumptions. Annual incremental costs were discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4.

Table 3-28: Summary of Incremental Costs of Cylinder Provisions for 2022–2050 (millions of 2020$, discounted to 2022)

Year	Most Likely	Low	High
2022	$132	$24	$176
2023	$125	$15	$180
2024	$118	$3	$185
2025	$113	-$10	$191
2026	$125	-$13	$212
2027	-$10	-$43	$55
2028	-$9	-$42	$59
2029	-$7	-$41	$64
2030	-$6	-$41	$69
2031	-$14	-$45	$46
2032	-$11	-$43	$53
2033	-$9	-$42	$59
2034	-$7	-$41	$65
2035	-$5	-$40	$71
2036	-$15	-$45	$44
2037	-$12	-$44	$50
2038	-$9	-$42	$58
2039	-$7	-$41	$64
2040	-$4	-$40	$71
2041	-$14	-$45	$50
2042	-$10	-$43	$51
2043	-$6	-$41	$56
2044	$1	-$38	$63
2045	$7	-$34	$71
2046	-$10	-$43	$57
2047	-$10	-$43	$58
2048	-$10	-$43	$59
2049	-$9	-$42	$59
2050	-$9	-$42	$58

Discount Rate	3%	7%	3%	7%	3%	7%
PV	**$441**	**$434**	-$594	-$324	$1,719	$1,248
EV	$21.8	$35.3	-$31.0	-$26.4	$89.6	$102

Table 3-29 below summarizes the estimated number of businesses potentially affected by the transition to refillable cylinders as well as the PV of incremental costs over the 29-year period 2022 to 2050.

Table 3-29: Detailed Incremental PV Costs of Cylinder Provisions for 2022–2050 (millions of 2020$, discounted to 2022) by Businesses Impacted

NAICS Code	Estimated Number of Businesses Impacted	Discounted at 7%			Discounted at 3%		
		Most Likely	Low	High	Most Likely	Low	High
562920	65	$1.41	-$1.05	$4.05	$1.43	-$1.93	$5.58
423740	323	$11.4	-$8.5	$27.6	$11.6	-$15.6	$45.3
423730	1,110	$97	-$73	$235	$99	-$133	$385
424690	3,035	$324	-$242	$782	$329	-$443	$1,283
Total	**4,533**	**$434**	**-$324**	**$1,049**	**$441**	**-$594**	**$1,719**

Table 3-30 presents detailed cost estimates for each scenario.

Table 3-30: Detailed Incremental PV Costs of Cylinder Provisions for 2022–2050 (millions of 2020$, discounted to 2022)

	Discounted at 7%			Discounted at 3%		
Cost	**Most Likely**	**Low**	**High**	**Most Likely**	**Low**	**High**
Cylinder Purchases	$185	-$543	$857	$11	-$958	$1,060
Maintenance	$182	$90	$212	$322	$160	$373
Transportation	$100	$100	$100	$165	$165	$165
Logistics Support	$108	$108	$216	$168	$168	$337
Recovered Refrigerant Heel	-$141	-$79	-$137	-$225	-$130	-$216

3.9.5 Conclusion

Refrigerant losses can occur from cylinders under a variety of circumstances during transport, storage, and disposal, the frequency and severity of which depend in part on the type of cylinder. In 2020, virtually all 30-pound refrigerant cylinders sold in the United States were disposable, which can result in approximately 31,000 $MTCO_2e$ in emissions from transport and storage per year from 4.45 million cylinders. In addition, disposable cylinders can experience emissions during disposal if unrecovered refrigerant is released. The amount of refrigerant heel remaining in disposable cylinders can vary by refrigerant type and recovery practices by servicing technicians, but is estimated to be approximately 0.96 pounds of refrigerant per cylinder. Disposal emissions from disposable cylinders can therefore equal approximately 4,200,000 $MTCO_2e$ per year, assuming the heel is completely released from 95 percent of the cylinders. By comparison, refillable cylinders can also experience refrigerant losses during transport and storage of approximately 335 $MTCO_2e$ per year from approximately 45,000 cylinders in the United States. While refillable cylinders have emissions during disposal, they have a lifetime of 20 years and are continually refilled throughout their lifetime, reducing annual disposal emissions relative to disposable cylinders due to a smaller proportion of refillable cylinders disposed of per year compared with disposable cylinders.

Replacement of disposable cylinders with refillable cylinders in the United States would therefore be estimated to avoid approximately 29,500,000 $MTCO_2e$ in emissions over the years 2022–2050, with emissions from cylinders without transition from disposable cylinders estimated at 37,500,000 $MTCO_2e$ and emissions from cylinders with the provision estimated to be 8,100,000 $MTCO_2e$. These reductions in emissions translate into additional HFCs that are available for reclamation and reuse. They are also reflected in the cost savings discussed in Chapter 3.9.4 associated with the recovered refrigerant heel. Note that these estimates assume the other provisions of this rule are in force, and for that reason these emissions are not spread evenly over the 29-year period. As higher-GWP HFCs are phased down, the average climate impact of each ton of gas emitted from cylinders would decrease from both disposable and refillable cylinders, so the emissions in both the scenario with disposable cylinders and the scenario without disposable cylinders, as well as the net emissions (difference between the two scenarios) would generally be lower in later years than in earlier years.

There are other implications associated with replacing disposable cylinders with refillable cylinders, including potentially higher costs associated with purchasing and transporting refillable cylinders. As noted in memo to the docket, many other countries, including those that are developed and developing, have successfully transitioned to requiring refillable cylinders. As noted in the preamble, this provision is an important compliance tool.

Chapter 4: Benefits

The benefits of this rule derive mostly from preventing the emissions of HFCs with high GWPs, thus reducing the damage from climate change that would have been induced by those emissions. The reduction in emissions follows from a reduction in the production and consumption of HFCs, measured in MTEVe. It is assumed that all HFCs produced or consumed would be emitted eventually, either in their initial use (e.g., as propellants), during the lifetime of HFC-containing products (e.g., off-gassing from closed-cell foams or leaks from refrigeration systems), or during servicing or disposal of HFC-containing products.

The reductions in units of MMTEVe are calculated for each year by summing the tons abated for the options utilized for that year. Appendix C provides a list of mitigation options included in each time step. Table 4-1 below shows the consumption reductions in each year corresponding to the phasedown schedule. It is estimated that for the years 2022–2036 this action will avoid cumulative consumption of 3,152 MMTEVe of HFCs in the United States. In order to calculate the climate benefits associated consumption abatement, the consumption changes need to be expressed in terms of emissions reductions. Accordingly, Table 4-2 shows the resulting emission reductions in each year corresponding to the phasedown schedule and continues out to 2050 to capture the lag between changes in consumption and changes in the eventual emissions. It is estimated that for the years 2022–2050 this action will avoid cumulative emissions of 4,560 MMTEVe of HFCs in the United States. Figure 4-1 is a graphical representation of the consumption reductions and emissions reductions.

Table 4-1: Consumption reductions by year (MMTEVe)

AIM Act Compliance Years	Consumption Reductions in Year*
2022–2023	42
2024–2028	144
2029–2033	230
2034–2035	267
2036	282

Table 4-2: Emission reductions by year (MMTEVe)

Year	Emission Reductions in Year[a]
2022	22
2024	78
2029	98
2034	142
2036	171
2045	224
2050	239

Figure 4-1: Consumption and Emissions reductions by year (MMTEVe)

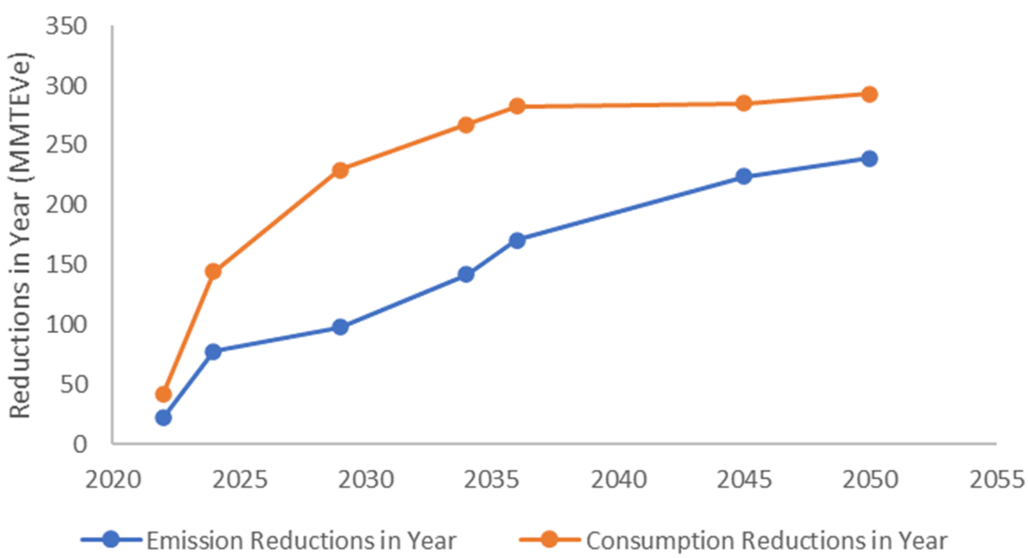

Table 4-3 further disaggregates the emission reductions by metric tons of each gas abated for the same timesteps. It is these values that are used to calculate the climate-related benefits using the SC-HFC values as described in the remainder of this chapter.

Table 4-3: Metric tons of gas abated in year

	2022	2024	2029	2034	2036	2045	2050
HFC-32	221	8,113	7,088	7,975	40,593	14,544	15,218
HFC-125	1,632	10,732	13,543	22,398	22,748	38,528	40,491
HFC-134a	1,532	9,878	11,068	11,215	11,504	12,763	14,047
HFC-143a	1,459	2,504	3,789	5,373	5,956	7,796	8,442
HFC-152a	5,645	6,324	7,480	7,877	8,004	8,599	8,948
HFC-227ea	12	19	41	72	86	135	152
HFC-236fa	2	6	0	0	0	0	0
HFC-245fa	1,936	3,532	6,811	11,238	12,949	17,870	20,749
HFC-43-10mee	462	528	713	888	1,411	1,516	1,578
HFC-23	260	253	257	255	255	255	255

The monetary value of these benefits is estimated by multiplying the tons of emissions abated of each HFC by the appropriate SC-HFC for the year of the abatement, and the monetary value discounted to present value.

4.1 The Social Cost of HFC Emissions

While CO_2 is the most prevalent GHG emitted by humans, it is not the only GHG with climate impacts. The EPA Endangerment Finding (2009) recognized a basket of six gases, comprising CO_2, methane (CH_4), nitrous oxide (N_2O), HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The climate impact of the emission of a molecule of each of these gases is generally a function of their lifetime in the atmosphere and the radiative efficiency of that molecule.[107] We estimate the climate benefits for this rulemaking using a measure of the social cost of each HFC (collectively referred to as SC-HFC) that is affected by the rule. The SC-HFC is the monetary value of the net harm to society associated with a marginal increase in HFC emissions in a given year, or the benefit of avoiding that increase. In principle, SC-HFC includes the value of all climate change impacts, including (but not limited to) changes in net agricultural

[107] In the case of CH_4, the climate effect can encompass the atmospheric reactions of the gas that change the abundance of other substances with climatic effects, such as ozone (O_3) and stratospheric water vapor (H_2O).

productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-HFC, therefore, reflects the societal value of reducing emissions of the gas in question by one metric ton. The SC-HFC is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect HFC emissions.

We estimate the global social benefits of HFC emission reductions expected from this rule using gas-specific SC-HFC estimates. These SC-HFC estimates were developed using methodologies that are consistent with the methodology underlying the social cost of carbon, methane, and nitrous oxide estimates presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG 2021). The social cost of GHG estimates presented in IWG (2021) are interim values developed under E.O. 13990 for use in benefit-cost analyses until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. Therefore, EPA views the SC-HFC estimates used in analysis to be appropriate for use in benefit-cost analysis until improved estimates of the social cost of other GHGs are developed.

The SC-HFC estimates used in this analysis were developed using methodologies consistent with the methodology underlying estimates of the social cost of other GHGs (SC-CO_2, SC-CH_4, and SC-N_2O) that were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, an interagency working group that included EPA and other executive branch agencies and offices used three IAMs to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). On January 20, 2021, President Biden issued E.O. 13990, which directed the IWG to ensure that the USG estimates of the social cost of carbon and other GHGs reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the estimates currently used by the USG and publishing interim estimates within 30 days of E.O. 13990 that reflect the full impact of GHG emissions, including taking global damages into account.[108]

The SC-HFC estimates used in this analysis were developed using methodologies consistent with the methodologies underlying the interim estimates of the SC-CO_2, SC-CH_4, and SC-N_2O (collectively referred to as SC-GHG) published in February 2021 by the IWG. As a member of the IWG involved in the development of the February 2021 TSD: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990 (IWG 2021), EPA

[108] The E.O. instructs the IWG to undertake a fuller update of the SC-GHG estimates by January 2022 that takes into consideration the advice of the National Academies (2017) and other recent scientific literature.

agrees that the interim SC-GHG estimates represent the most appropriate estimate of the SC-GHG until revised estimates have been developed reflecting the latest, peer-reviewed science. As such, we first summarize the general findings of the IWG review and interim update, and then provide more discussion of the modeling decisions specific to the estimation of the social cost of non-CO_2 GHGs.

The February 2021 TSD provides a complete discussion of the IWG's initial review conducted under E.O. 13990. In particular, the IWG found that the SC-GHG estimates used since E.O. 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG found that a global perspective is essential for SC-GHG estimates because climate impacts occurring outside U.S. borders can directly and indirectly affect the welfare of U.S. citizens and residents. Thus, U.S. interests are affected by the climate impacts that occur outside U.S. borders. Examples of affected interests include: direct effects on U.S. citizens and assets located abroad, international trade and tourism, and spillover pathways such as economic and political destabilization and global migration. In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. Therefore, in this rule EPA centers attention on a global measure of SC-HFC. This approach is the same as that taken in EPA regulatory analyses over 2009 through 2016. As noted in the February 2021 TSD, the IWG will continue to review developments in the literature, including more robust methodologies for estimating SC-GHG values based on purely domestic damages, and explore ways to better inform the public of the full range of carbon impacts, both global and domestic.

As an active member of the IWG, EPA will likewise continue to follow developments in the literature pertaining to this issue.

Second, the IWG found that the use of the social rate of return on capital (7 percent under current OMB Circular A-4 guidance) to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG. Consistent with the findings of the National Academies (2017) and the economic literature, the IWG continued to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context (IWG 2010, 2013, 2016a, 2016b), and recommended that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates. As a member of the IWG involved in the development of the February 2021 TSD, EPA agrees with this assessment, and will continue to follow developments in the literature pertaining to this issue.

While the IWG works to assess how best to incorporate the latest, peer-reviewed science to develop an updated set of SC-GHG estimates, it set the interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. As explained in the February 2021 TSD, the IWG has determined that it is appropriate for agencies to revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates as were used in regulatory analyses between 2010 and 2016 and subject to public comment. For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3 percent estimate of the discount rate. As explained in the February 2021 TSD, this update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

Since the original 2010 SC-CO_2 TSD did not include direct estimates of the social cost of non-CO_2 GHGs and did not endorse the use of GWP metrics to approximate the value of non-CO_2 emission changes in regulatory analysis,[109] more work was needed following 2010 to link non-CO_2 GHG emission changes to economic impacts. The IWG calculated the SC-CH_4 and SC-N_2O estimates following the approach used in Marten et al. (2015). In order to develop SC-CH_4 and SC-N_2O estimates consistent with the methodology underlying the SC-CO_2 estimates, Marten et al. (2015) needed to minimally augment the IWG modeling framework in two respects: (1) augment the climate model of two of the IAMs to explicitly consider the path of additional radiative forcing from a CH_4 or N_2O perturbation, and (2) add more specificity to the

[109] The potential of non-CO_2 GHGs to change the Earth's climate relative to CO_2 is commonly represented by their 100-year GWP. GWPs measure the contribution to warming of the Earth's atmosphere resulting from emissions of a given gas (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. As such, GWPs are often used to convert emissions of non-CO_2 GHGs to CO_2 equivalents to facilitate comparison of policies and inventories involving different GHGs. While GWPs allow for some useful comparisons across gases on a physical basis, using the social cost of carbon dioxide (SC-CO_2) to value the damages associated with changes in CO_2-equivalent emissions is not optimal. This is because non-CO_2 GHGs differ not just in their potential to absorb infrared radiation over a given time frame, but also in the temporal pathway of their impact on radiative forcing, which is relevant for estimating their social cost but not reflected in the GWP. Physical impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike CH_4 and other GHGs, contribute to ocean acidification. Likewise, damages from CH_4 emissions are not offset by any positive effect of CO_2 fertilization on agriculture. Thus, transforming gases into CO_2- equivalents using GWP, and then multiplying the CO_2-equivalents by the SC-CO_2, is not as accurate as a direct calculation of the social costs of non-CO_2 GHGs. For more detailed discussion of the limitations of using a GWP based approach to valuing non-CO_2 GHG emission changes, see, e.g., Marten et al. (2012).

assumptions regarding post-2100 baseline CH_4 and N_2O emissions. The August 2016 TSD Addendum (IWG 2016b) provides detailed discussion of these two modeling modifications and the peer review and public comment processes accompanying their development. The approach used for developing the SC-HFC estimates in this RIA mirrors that of the peer-reviewed SC-CH_4 and SC-N_2O estimates (Marten et al. 2015, TSD 2016a/b), which require two modeling modifications specific to HFCs. These two modifications are described below.

Regarding the climate modeling, both the DICE and PAGE models as implemented by the IWG to estimate SC-CO_2 use an exogenous projection of aggregate non-CO_2 radiative forcing, which prevents one from introducing a direct perturbation of HFC emissions into the models and then observing its effects.[110] Therefore, to estimate the SC-HFC, we applied a one-box atmospheric gas cycle model to explicitly consider the path of additional radiative forcing from the HFC perturbation, which is then added to the exogenous non-CO_2 radiative forcing projection to estimate the incremental damages compared with the baseline. The one-box atmospheric gas cycle model appended to DICE and PAGE used exponential decay functions to project atmospheric HFC concentrations from the HFC emissions projections, respectively, in the five socioeconomic emissions scenarios. Consistent with the SC-CH_4 and SC-N_2O, the average lifetime of each HFC follow the findings of the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) (Forster et al. 2007). The direct radiative forcing associated with the atmospheric HFC concentration was estimated using the functional relationships for each gas presented in the IPCC's Third Assessment Report (Ramaswamy et al. 2001) and used in AR4.

[110] The FUND model is the only one of the three IAMs that explicitly considers CH_4 and N_2O using a one-box atmospheric gas cycle models for these gases, with geometric decay toward pre-industrial levels, based on the IPCC's Third Assessment Report (TAR) (Ramaswamy et al. 2001). FUND augments the TAR expression for the additional radiative forcing from CH_4 to account for the influences of stratospheric water vapor and tropospheric ozone changes.

The second modeling modification was needed because the SC-CO_2 modeling exercise assumed that overall radiative forcing from non-CO_2 sources remains constant past 2100 without specifying the projections for individual GHGs that were implicit in that assumption. This broad assumption was sufficient for the purposes of estimating the SC-CO_2; however, estimating SC-HFC requires explicit projections of baseline emissions of each HFC to determine the atmospheric concentration and radiative forcing off of which to compare the perturbation. We chose to interpret the SC-CO_2 assumption for non-CO_2 radiative forcing past 2100 as applying to each gas individually, such that the emissions of each gas fall to their respective rate of atmospheric decay. This has the effect of holding global mean radiative forcing due to atmospheric HFCs constant past 2100.

4.2 SC-HFC Results

Tables 4-4 through 4-13 summarize the SC-HFC estimates for the years 2020 through 2050. The values are stated in $/metric ton of each gas and vary depending on the year of emission reductions. All estimates are presented in 2020 dollars and are rounded to two significant figures. The annual unrounded estimates are available in Appendix E. For purposes of capturing uncertainty around the SC-HFC estimates in analyses, we emphasize the importance of considering all four values for each HFC affected by the rule. The SC-HFC increases over time within the models—i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025—because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 4-4: Social Cost of HFC-32, 2020–2050 (in 2020 dollars per metric ton HFC-32)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	18000	38000	50000	100000
2025	22000	45000	58000	120000
2030	27000	53000	67000	140000
2035	33000	62000	77000	170000
2040	39000	71000	88000	190000
2045	46000	81000	99000	220000
2050	53000	92000	110000	250000

Table 4-5: Social Cost of HFC-125, 2020–2050 (in 2020 dollars per metric ton HFC-125)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	83000	210000	290000	550000
2025	99000	240000	330000	640000
2030	120000	280000	370000	730000
2035	140000	310000	410000	830000
2040	160000	350000	450000	930000
2045	180000	390000	500000	1000000
2050	210000	430000	550000	1100000

Table 4-6: Social Cost of HFC-134a, 2020–2050 (in 2020 dollars per metric ton HFC-134a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	38000	87000	120000	230000
2025	46000	100000	130000	270000
2030	55000	120000	150000	310000
2035	65000	130000	170000	360000
2040	76000	150000	190000	410000
2045	88000	170000	210000	460000
2050	100000	190000	230000	510000

Table 4-7: Social Cost of HFC-143a, 2020–2050 (in 2020 dollars per metric ton HFC-143a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	95000	270000	380000	700000
2025	110000	300000	420000	800000
2030	130000	340000	470000	910000
2035	150000	380000	520000	1000000
2040	180000	430000	570000	1100000
2045	200000	470000	620000	1300000
2050	230000	520000	680000	1400000

Table 4-8: Social Cost of HFC-152a, 2020–2050 (in 2020 dollars per metric ton HFC-152a)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	2600	5400	6900	14000
2025	3200	6300	8100	17000
2030	3900	7400	9300	20000
2035	4700	8600	11000	23000
2040	5600	10000	12000	27000
2045	6700	12000	14000	32000
2050	7800	13000	16000	37000

Table 4-9: Social Cost of HFC-227ea, 2020–2050 (in 2020 dollars per metric ton HFC-227ea)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	74000	190000	270000	510000
2025	88000	220000	300000	580000
2030	100000	250000	340000	660000
2035	120000	280000	370000	750000
2040	140000	320000	410000	840000
2045	160000	350000	450000	930000
2050	180000	390000	500000	1000000

Table 4-10: Social Cost of HFC-236fa, 2020–2050 (in 2020 dollars per metric ton HFC-236fa)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	180000	640000	970000	1700000
2025	210000	710000	1100000	1900000
2030	250000	790000	1200000	2100000
2035	290000	870000	1300000	2300000
2040	330000	960000	1400000	2600000
2045	380000	1000000	1500000	2800000
2050	430000	1100000	1600000	3100000

Table 4-11: Social Cost of HFC-245fa, 2020–2050 (in 2020 dollars per metric ton HFC-245fa)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	29000	61000	80000	160000
2025	35000	72000	93000	190000
2030	42000	84000	110000	220000
2035	50000	97000	120000	260000
2040	59000	110000	140000	300000
2045	69000	130000	160000	340000
2050	79000	140000	170000	390000

Table 4-12: Social Cost of HFC-43-10mee, 2020–2050 (in 2020 dollars per metric ton HFC-43-10mee)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	43000	100000	130000	260000
2025	52000	120000	150000	310000
2030	62000	130000	170000	360000
2035	73000	150000	200000	410000
2040	86000	170000	220000	470000
2045	99000	190000	240000	520000
2050	110000	220000	270000	570000

Table 4-13: Social Cost of HFC-23, 2020–2050 (in 2020 dollars per metric ton HFC-23)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2020	270000	970000	1500000	2600000
2025	320000	1100000	1600000	2900000
2030	370000	1200000	1800000	3200000
2035	430000	1300000	1900000	3600000
2040	490000	1500000	2100000	3900000
2045	570000	1600000	2300000	4400000
2050	640000	1700000	2500000	4800000

There are a number of limitations and uncertainties associated with the SC-HFC estimates presented in Tables 4-4 to 4-13. Some uncertainties are captured within the analysis, while other areas of uncertainty have not yet been quantified in a way that can be modeled.[111] As illustrated in the above tables, the assumed discount rate plays a critical role in the ultimate estimate of the SC-HFC. This is because HFC emissions today continue to impact society far out into the future, so with a higher discount rate, costs that accrue to future generations are weighted less, resulting in a lower estimate.

Since the SC-HFC estimates presented in Tables 4-4 to 4-13 are based on the same methodology underlying the SC-GHG estimates presented in the IWG February 2021 TSD, they

[111] Tables A-1 through A-9 (Appendix A) present the quantified sources of uncertainty in the models that reflect uncertainty in key model parameters such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. As discussed in the 2021 TSD, there are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates.

share a number of limitations that are common to those SC-GHG estimates. First, the current scientific and economic understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change are likely to be less than 3 percent, near 2 percent or lower (IWG 2021). Second, the IAMs used to produce these estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their "damage functions"—i.e., the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages—lags behind the most recent research. For example, limitations include the incomplete treatment of catastrophic and non-catastrophic impacts in the IAMs, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons. Likewise, the socioeconomic and emissions scenarios used as inputs to the models do not reflect new information from the last decade of scenario generation or the full range of projections.

The modeling limitations do not all work in the same direction in terms of their influence on the SC-HFC estimates. However, as discussed in the February 2021 TSD, the IWG has recommended that, taken together, the limitations suggest that the SC-GHG estimates likely underestimate the damages from GHG emissions. In particular, the IPCC Fourth Assessment Report (IPCC 2007), which was the most current IPCC assessment available at the time the IWG decision over the ECS input was made, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC's Fifth Assessment report (IPCC 2014) and other recent scientific assessments (e.g., IPCC 2018, 2019a, 2019b; U.S. Global Change Research Program (USGCRP) 2016, 2018; and National Academies 2016b, 2019). These assessments confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. For example, sea level rise projections from the IPCC's Fourth Assessment report ranged from 18 to 59 centimeters by the 2090s relative to 1980–1999, while excluding any dynamic changes in ice sheets due to the limited understanding of those processes at the time (IPCC 2007). A decade later, the Fourth National Climate Assessment projected a substantially larger sea level rise of 30 to 130 centimeters by the end of the century relative to 2000, while not ruling out even more extreme outcomes (USGCRP 2018). The 2021 TSD briefly previews some of the recent advances in the scientific and economic literature that the IWG is actively following and that could provide guidance on, or methodologies for, addressing some of the limitations with the interim SC-GHG estimates, which also apply to the SC-HFC.

4.3 Monetized Climate Benefits Results

For each HFC regulated under this rule, the monetary benefits of avoiding emissions of that HFC is calculated by multiplying the change in emissions of that HFC in a given year, as shown in Table 4-3, by the appropriate global SC-HFC value from Tables 4-4 through 4-13.[112]

[112] To correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for impacts that occur within U.S. borders, climate impacts occurring outside U.S. borders that directly and indirectly affect the welfare of U.S. citizens and residents, and spillover effects from climate action elsewhere. The SC-GHG estimates used in regulatory analysis under revoked E.O. 13783 were an approximation of the climate damages occurring within U.S. borders only. Applying the same methodology to the SC-HFC estimates used in this RIA yields an approximation of the climate damages occurring within U.S. borders only from a ton of HFC emissions. These estimates range from $737 (HFC-152a) to $82,000 (HFC-236fa) using a 3% discount rate for emissions occurring in 2022 and $1,700 (HFC-52a) to $140,000 (HFC-236fa) using a 3% discount rate for emissions occurring in 2050. Applying these estimates (based on a 3% discount rate) to the HFC emission reduction expected under the final rule would yield benefits from climate impacts within U.S. borders of $406 million in 2022, increasing to $4 billion in 2050. However, as discussed at length in the IWG's February 2021 TSD, estimates focusing on the climate impacts occurring solely within U.S. borders are an underestimate of the benefits of GHG mitigation accruing to U.S. citizens and residents, as well as being subject to a considerable degree of uncertainty due to the manner in which they are derived.

The results of the monetized benefits calculations by gas and by year are given in Table 4-14 through Table 4-23. Appendix E lists the annual unrounded SC-HFC estimates for the same substances.

Table 4-14: Estimated Global Climate Benefits from Changes in HFC-32 Emissions, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$4	$9	$12	$24
2024	$176	$356	$457	$947
2029	$185	$363	$460	$968
2034	$251	$477	$597	$1,286
2036	$1,372	$2,576	$3,208	$6,976
2045	$663	$1,181	$1,443	$3,258
2050	$806	$1,400	$1,696	$3,865

Table 4-15: Estimated Global Climate Benefits from Changes in HFC-125, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$146	$364	$494	$958
2024	$1,028	$2,529	$3,407	$6,680
2029	$1,531	$3,634	$4,839	$9,626
2034	$2,973	$6,801	$8,947	$18,107
2036	$3,211	$7,247	$9,492	$19,328
2045	$7,019	$14,967	$19,252	$40,050
2050	$8,392	$17,390	$22,158	$46,258

Table 4-16: Estimated Global Climate Benefits from Changes in HFC-134a, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$64	$142	$187	$375
2024	$441	$974	$1,274	$2,574
2029	$590	$1,261	$1,630	$3,349
2034	$710	$1,466	$1,874	$3,928
2036	$777	$1,586	$2,018	$4,258
2045	$1,125	$2,176	$2,719	$5,842
2050	$1,413	$2,663	$3,298	$7,113

Table 4-17: Estimated Global Climate Benefits from Changes in HFC-143a, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$149	$411	$575	$1,082
2024	$272	$741	$1,032	$1,962
2029	$483	$1,264	$1,738	$3,355
2034	$799	$2,010	$2,730	$5,340
2036	$940	$2,329	$3,147	$6,187
2045	$1,578	$3,667	$4,859	$9,772
2050	$1,941	$4,368	$5,731	$11,665

Table 4-18: Estimated Global Climate Benefits from Changes in HFC-152a, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$16	$32	$42	$86
2024	$20	$39	$50	$103
2029	$28	$54	$68	$143
2034	$36	$66	$82	$178
2036	$39	$71	$89	$193
2045	$57	$100	$122	$278
2050	$70	$120	$144	$335

Table 4-19: Estimated Global Climate Benefits from Changes in HFC-227ea, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$1	$2	$3	$7
2024	$2	$4	$5	$11
2029	$4	$10	$13	$26
2034	$8	$20	$26	$53
2036	$11	$25	$33	$66
2045	$22	$47	$61	$125
2050	$28	$59	$75	$156

Table 4-20: Estimated Global Climate Benefits from Changes in HFC-236fa, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$0.4	$1.5	$2	$4
2024	$1.3	$4.4	$7	$12
2029	$0	$0	$0	$0
2034	$0	$0	$0	$0
2036	$0	$0	$0	$0
2045	$0	$0	$0	$0
2050	$0	$0	$0	$0

Table 4-21: Estimated Global Climate Benefits from Changes in HFC-245fa, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$60	$127	$165	$336
2024	$119	$247	$318	$654
2029	$275	$554	$706	$1,473
2034	$545	$1,061	$1,334	$2,853
2036	$673	$1,294	$1,621	$3,494
2045	$1,232	$2,252	$2,771	$6,135
2050	$1,649	$2,939	$3,584	$7,999

Table 4-22: Estimated Global Climate Benefits from Changes in HFC-43-10mee, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$22	$49	$65	$130
2024	$27	$60	$78	$157
2029	$43	$93	$121	$247
2034	$63	$132	$170	$355
2036	$107	$222	$283	$594
2045	$150	$294	$368	$786
2050	$177	$339	$422	$905

Table 4-23: Estimated Global Climate Benefits from Changes in HFC-23, 2022–2050 (millions of 2020 dollars)

Year	5% Average	3% Average	2.5% Average	3% 95th Pct.
2022	$76	$263	$401	$700
2024	$81	$269	$408	$721
2029	$95	$305	$455	$817
2034	$110	$336	$495	$909
2036	$126	$370	$538	$1,005
2045	$144	$405	$582	$1,109
2050	$163	$442	$628	$1,214

Table 4-24 presents the sum of climate benefits across all HFCs reduced for the rule for 2022, 2024, 2029, 2034, 2036, 2045, and 2050.

Table 4-24: Climate Benefits for the Final Rule for 2022–2050 (billions of 2020$)[a]

Year	Climate Benefits by Discount Rate and Statistic			
	5% (average)	3% (average)	2.5% (average)	3% (95th percentile)
2022	0.5	1.4	1.9	3.7
2024	2.2	5.2	7.0	13.8
2029	3.2	7.5	10.0	20.0
2034	5.5	12.4	16.2	33.0
2036	7.2	15.7	20.4	42.0
2045	12.0	25.1	32.2	67.4
2050	14.6	29.7	37.7	79.5

[a] Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; and 95th percentile at 3 percent discount rate). The IWG emphasized the importance and value of considering the benefits calculated using all four estimates. As discussed in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

4.4 Comparing a GWP Approach with Direct Modeling of the Social Cost of Non-CO_2 Gases

Key advances in the ability to estimate the social cost of non-CO_2 gases were made in a series of papers (Marten and Newbold, 2011, Marten et al. 2015) that directly modeled the SC-CH_4 and the SC-N_2O by using the lifetimes and radiative efficiencies from the fourth assessment report from the IPCC (AR4) to perturb the radiative forcing calculations in the IAMs that did not include non-CO_2 GHGs. These directly modeled estimates were incorporated by the IWG in 2016 (IWG, 2016). The calculations showed that the GWP approach and the directly modeled social cost approach yielded different results, with the GWP approach yielding lower social costs than the directly modeled approach. These differences were attributed in large part to the inclusion of the carbon fertilization effect in the SC-CO_2, which depressed the SC-CO_2 relative to a hypothetical gas without carbon fertilization properties. Since the non-CO_2 GHGs do not have carbon fertilization properties, and the GWP does not account for carbon fertilization, scaling the SC-CO_2 by the GWP to arrive at a social cost for a non-CO_2 gas yields a lower value than would be calculated based on climate properties alone. Additionally, the IWG noted that discrepancies between the GWP and the directly modeled approach would change with the use of different discount rates. This is particularly true for gases with much shorter lifetimes than CO_2, such as CH_4. Because of the shorter lifetime, the damages caused would occur earlier and would not be discounted as much as the later damages caused by CO_2 in a directly modeled approach, but because the GWP approach does not account for this, damages relative to CO_2 will increase at high discount rates, leading to larger underestimates when using the GWP approach. These limitations of the GWP approach based on CH_4 and N_2O would similarly apply to HFCs.

Despite the limitations involved in the GWP approach, EPA is presenting estimates of the SC-HFC using GWPs in order to place the directly modeled estimates in context. The use of exchange values (equivalent to GWPs) elsewhere in the rule adds additional value to this comparison. One key update relative to earlier attempts to use GWP scaling is that rather than using the SC-CO_2 multiplied by the GWP to estimate the SC-GHG, EPA is now using the SC-CH_4 scaled by the ratio between the HFC GWP and the CH_4 GWP. This avoids any discrepancy related to the carbon fertilization effect, which had been a large driver of the underestimates resulting from use of the GWP approach previously.

Tables 4-25 through 4-27 show how the GWP-based approximation approach compares to the direct SC-HFC estimates used in this RIA for HFC-134a, HFC-125, and HFC-143a. These are the three gases whose mitigation yields the largest monetized benefits in 2050 using a 3 percent discount rate, and together account for almost three-quarters of radiative forcing in 2012 resulting from elevated HFC concentrations (WMO, 2018). The ratio of the GWP-based estimate and the direct SC-HFC in the last two columns of the tables show that, for the most part, the direct estimation approach and the GWP approach scaled by the SC-CH_4 produce estimates of an

SC-HFC that agree to within 10 percent. This comparison suggests that for an HFC where a directly modeled estimate is not available, use of the GWP scaled by the SC-CH_4 can provide a reasonable approximation until direct estimates are developed. The tables show values using the 3 percent discount rate, as Sarofim and Giordano (2018), and Mallapragada and Mignone (2020)[113] both suggest that the 100-year GWP is most consistent with a damage function based on a 3 percent discount rate. Therefore, there might be more confidence in using the 100-year GWP to estimate the social cost of HFCs (SC-HFCs) for a 3 percent discount rate. The use of estimates based on higher discount rates, the more the use of the 100-year GWP will overvalue long-lived gases relative to using a damage-based metric, whereas lower discount rates will cause the use of the 100-year GWP to overvalue short-lived gases.

Table 4-25: GWP Approximation vs. Direct Estimation, SC-HFC134a

	CH_4 GWP-based Approximation	N_2O GWP-based Approximation	SC-HFC134a Direct Estimation	Ratio CH_4	Ratio N_2O
Year	**3% Discount Rate**	**3% Discount Rate**	**3% Discount Rate**	**Approx./Direct**	**Approx./Direct**
2020	84946	88321	87120	0.98	1.01
2025	98370	98808	101449	0.97	0.97
2030	111795	109295	117006	0.96	0.93
2035	127632	121097	134162	0.95	0.90
2040	143468	132900	152534	0.94	0.87
2045	159459	145602	170482	0.94	0.85
2050	175450	158303	189573	0.93	0.84

Note: CH_4 GWP-based approximation is calculated as SC-CH_4*(100-yr GWP for HFC-134a/100-yr GWP for CH_4). N_2O GWP-based approximation is calculated as SC-N_2O*(100-yr GWP for HFC-134a/100-yr GWP for N_2O). Dollar values in columns 1 through 3 are in 2020 dollars per metric ton of HFC.

[113] Mallapragada, D.S., Mignone, B.K. "A theoretical basis for the equivalence between physical and economic climate metrics and implications for the choice of Global Warming Potential time horizon." *Climatic Change* 158, 2020, pp. 107–124. https://doi.org/10.1007/s10584-019-02486-7

Table 4-26: GWP Approximation vs. Direct Estimation, SC-HFC125

Year	CH_4 GWP-based Approximation 3% Discount Rate	N_2O GWP-based Approximation 3% Discount Rate	SC-HFC125 Direct Estimation 3% Discount Rate	Ratio CH_4 Approx./Direct	Ratio N_2O Approx./Direct
2020	207911	216170	210912	0.99	1.02
2025	240767	241837	241780	1.00	1.00
2030	273623	267505	275003	0.99	0.97
2035	312385	296392	310808	1.01	0.95
2040	351146	325279	349592	1.00	0.93
2045	390285	356368	388472	1.00	0.92
2050	429424	387456	429469	1.00	0.90

Note: CH_4 GWP-based approximation is calculated as SC-CH_4*(100-yr GWP for HFC-134a/100-yr GWP for CH_4). N_2O GWP-based approximation is calculated as SC-N_2O*(100-yr GWP for HFC-134a/100-yr GWP for N_2O). Dollar values in columns 1 through 3 are in 2020 dollars per metric ton of HFC.

Table 4-27: GWP Approximation vs. Direct Estimation, SC-HFC143a

Year	CH_4 GWP-based Approximation 3% Discount Rate	N_2O GWP-based Approximation 3% Discount Rate	SC-HFC143a Direct Estimation 3% Discount Rate	Ratio CH_4 Approx./Direct	Ratio N_2O Approx./Direct
2020	265532	276079	267249	0.99	1.03
2025	307494	308861	303095	1.01	1.02
2030	349456	341642	341342	1.02	1.00
2035	398960	378535	382260	1.04	0.99
2040	448464	415428	425892	1.05	0.98
2045	498450	455132	470309	1.06	0.97
2050	548436	494837	517419	1.06	0.96

Note: CH_4 GWP-based approximation is calculated as SC-CH_4*(100-yr GWP for HFC-134a/100-yr GWP for CH_4). N_2O GWP-based approximation is calculated as SC-N_2O*(100-yr GWP for HFC-134a/100-yr GWP for N_2O). Dollar values in columns 1 through 3 are in 2020 dollars per metric ton of HFC.

Chapter 5: Comparison of Benefits and Costs

The rule's abatement costs are estimated using the Vintaging Model and an evaluation of marginal abatement cost curves. As shown in section 3.5, Table 3-6, the estimated annual abatement costs to implement the rule, as described in this document, are approximately -$0.5 billion in 2022 and -$0.7 billion in 2036 (2020$). As described in section 3.6, this RIA uses abatement costs as a proxy for social costs. As shown in section 3.8, Table 3-12, the recordkeeping and reporting costs are approximately $13 million in 2022 and $15 million in 2036 (2020$). The estimated costs associated with refillable cylinders are $132 million in 2022 and -$15 million in 2036 (2020$). Table 5-1 summarizes the annual abatement, annual recordkeeping and reporting, refillable cylinder, and total annual costs for selected years.

Table 5-1: Summary of Costs of the Final Rule for 2022–2050 (millions of 2020$)

Year	Abatement Costs (annual)	Recordkeeping & Reporting Costs (annual)	Refillable Cylinder Costs (annual)	Total Annual Costs
2022	($481)	$13	$132	($336)
2024	($60)	$12	$118	$70
2029	($628)	$15	($7)	($620)
2034	($933)	$15	($7)	($925)
2036	($698)	$15	($15)	($698)
2045	($918)	$15	$7	($896)
2050	($1,097)	$15	($9)	($1,091)

As shown in Chapter 4, the estimated monetized climate benefits from implementation of the rule are approximately $2.8 billion in 2022 (2020$, using a 3 percent discount rate). For 2036, the estimated monetized climate benefits from implementation of the rule are approximately $17 billion (using a 3 percent discount rate). We present the costs and benefits for the years 2022 through 2050 at real discount rates of 3 and 7 percent in Table 5-3.

EPA calculates the net benefits of the rule by subtracting the estimated abatement costs from the estimated benefits in 2022, 2024, 2029, 2034, and 2036. The benefits include those to climate. The annual net benefits of the rule in 2022 (in 2020$) are approximately $2.6 billion. The annual net benefits of the rule in 2024 are approximately $6.5 billion. The annual net benefits of the rule in 2029 are approximately $10.8 billion. The annual net benefits of the rule in 2034 are approximately $14.4 billion. The annual net benefits of the rule in 2036 are approximately $17.9 billion. Table 5-2 presents a summary of the costs and net benefits of the rule for selected years in the time period 2022–2050, but with the climate benefits discounted at 3 percent.

Table 5-2: Benefits, Costs, and Net Benefits of the Final Rule for 2022–2050 (billions of 2020$)[a,b]

Year	Climate Benefits (3% discount rate)	Costs (annual)	Net Benefits
2022	$1.4	-$0.3	$1.7
2024	$5.2	$0.1	$5.1
2029	$7.5	-$0.6	$8.1
2034	$12.4	-$0.9	$13.3
2036	$15.7	-$0.7	$16.4
2045	$25.1	-$0.9	$26.0
2050	$29.7	-$1.1	$30.8

[a] Benefits include only those related to climate. Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For the presentational purposes of this table, we show the benefits associated with the average SC-HFC at a 3 percent discount rate, but the Agency does not have a single central SC-HFC point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-HFC estimates; the additional benefit estimates for the final rule range from $0.5 billion to $3.7 billion in 2022, $2.2 billion to $13.8 billion in 2024, $3.2 billion to $20.0 billion in 2029, $5.5 billion to $33.0 billion in 2034, $7.2 billion to $42.0 billion in 2036, $12.0 billion to $67.4 billion in 2045, and $14.6 billion to $79.5 billion in 2050. Please see Table 4-24 for the full range of SC-HFC estimates. As discussed in Chapter 4, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts. The costs presented in this table are annual estimates.
[b] Rows may not appear to add correctly due to rounding.

As part of fulfilling analytical guidance with respect to E.O. 12866, EPA presents estimates of the PV of the benefits and costs over the 29-year period 2022 to 2050. To calculate the present value of the social net benefits of the final rule, annual benefits and costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4. EPA also presents the EAV, which represents a flow of constant annual values that, had they occurred in each year from 2022 to 2050, would yield a sum equivalent to the PV. The EAV represents the value of a typical cost or benefit for each year of the analysis, in contrast to the year-specific estimates mentioned earlier in the RIA.

For the 29-year period of 2022 to 2050, the PV of the net benefits, in 2020$ and discounted to 2022, is $272.7 billion when using a 3 percent discount rate and $267.4 billion when using a 7 percent discount rate. The EAV is $14.2 billion when using a 3 percent discount rate and $14.1 billion when using a 7 percent discount rate. The comparison of benefits and costs in PV and EAV terms for the rule can be found in Table 5-3. Estimates in the table are presented as rounded values.

Table 5-3: Summary of Annual Values, Present Values, and Equivalent Annualized Values for the 2022–2050 Timeframe for Estimated Abatement Costs, Benefits, and Net Benefits for the Final Rule (billions of 2020$, discounted to 2022)[a,b,c]

Year	Climate Benefits (3%)[c]	Costs (annual) [d]	Net Benefits (3% Benefits, 3% or 7% Costs)
2022	$1.4	-$0.3	$1.7
2023	$1.8	-$0.5	$2.3
2024	$5.2	$0.1	$5.2
2025	$6.4	$0.1	$6.2
2026	$6.8	$0.1	$6.7
2027	$7.7	-$0.1	$7.8
2028	$8.5	-$0.1	$8.5
2029	$7.5	-$0.6	$8.2
2030	$8.5	-$0.7	$9.3
2031	$9.4	-$0.8	$10.2
2032	$10.3	-$0.9	$11.2
2033	$11.3	-$1.0	$12.3
2034	$12.4	-$0.9	$13.3
2035	$13.4	-$1.0	$14.4
2036	$15.7	-$0.7	$16.4
2037	$16.5	-$0.8	$17.3
2038	$17.6	-$0.8	$18.4
2039	$18.7	-$0.8	$19.5
2040	$19.8	-$0.8	$20.6
2041	$21.0	-$0.9	$21.9
2042	$22.1	-$0.9	$23.0

2043	$23.1	-$0.9		$24.0	
2044	$24.1	-$0.9		$25.0	
2045	$25.1	-$0.9		$26.0	
2046	$26.0	-$0.9		$26.9	
2047	$27.0	-$0.9		$27.9	
2048	$27.9	-$1.0		$28.9	
2049	$28.8	-$1.0		$29.8	
2050	$29.7	-$1.1		$30.8	
Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**
PV	**$260.9**	**-$11.8**	**-$6.4**	**$272.7**	**$267.4**
EAV	**$13.6**	**-$0.6**	**-$0.5**	**$14.2**	**$14.1**

[a] Rows may not appear to add correctly due to rounding.
[b] The annualized present value of costs and benefits are calculated over a 29-year period from 2022 to 2050.
[c] Climate benefits are based on changes (reductions) in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the benefits (climate benefits and net benefits) associated with the model average at a 3 percent discount rate, but the Agency does not have a single central SC-HFC point estimate. We emphasize the importance and value of considering the benefits calculated using all four SC-HFC estimates. As discussed in Chapter 4, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[d] The costs presented in this table are consistent with the costs presented in Chapter 5, Table 5-1.

Chapter 6: Environmental Justice Analysis

6.1 Background

E.O. 12898 (59 FR 7629; February 16, 1994) establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States. EPA defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.[114] E.O. 14008 (86 FR 7619; January 27, 2021) calls on agencies to make achieving environmental justice part of their missions "by developing programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts." It also declares a policy "to secure environmental justice and spur economic opportunity for disadvantaged communities that have been historically marginalized and overburdened by pollution and under-investment in housing, transportation, water and wastewater infrastructure and health care." Under E.O. 13563, federal

[114] Fair treatment occurs when "no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies" (U.S. EPA, 2011). Meaningful involvement occurs when "1) potentially affected populations have an appropriate opportunity to participate in decisions about a proposed activity [i.e., rulemaking] that will affect their environment and/or health; 2) the population's contribution can influence [the EPA's] rulemaking decisions; 3) the concerns of all participants involved will be considered in the decision-making process; and 4) [the EPA will] seek out and facilitate the involvement of population's potentially affected by EPA's rulemaking process" (U.S. EPA, 2015). A potential EJ concern is defined as "actual or potential lack of fair treatment or meaningful involvement of minority populations, low-income populations, tribes, and indigenous peoples in the development, implementation and enforcement of environmental laws, regulations and policies" (U.S. EPA, 2015). See also https://www.epa.gov/environmentaljustice.

agencies may consider equity, human dignity, fairness, and distributional considerations, where appropriate and permitted by law. EPA also released its "Technical Guidance for Assessing Environmental Justice in Regulatory Analysis"[115] to provide recommendations that encourage analysts to conduct the highest quality analysis feasible, recognizing that data limitations, time and resource constraints, and analytic challenges will vary by media and circumstance.

This rule will begin the United States' phasedown of HFC production and consumption, which will mitigate the impacts of climate change by reducing the emissions of regulated chemicals with very high GWPs. In the 2009 Endangerment Finding, the Administrator found under section 202(a) of the CAA that elevated atmospheric concentrations of six key well-mixed GHGs—CO_2, CH_4, N_2O, HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—"may reasonably be anticipated to endanger the public health and welfare of current and future generations." (74 FR 66523). That finding, together with the extensive scientific and technical evidence in the supporting record, documented that climate change caused by anthropogenic emissions of GHGs (including HFCs) threatens the public health of the U.S. population. In 2016, the Administrator similarly issued *Endangerment and Cause or Contribute Findings* for GHG emissions from aircraft under section 231(a)(2)(A) of the CAA (81 FR 54422). As part of these Endangerment Findings, the Administrator considered climate change risks to minority populations and low-income populations, finding that certain parts of the population may be especially vulnerable based on their characteristics or circumstances. These groups include economically and socially disadvantaged communities; individuals at vulnerable life stages, such as the elderly, the very young, and pregnant or nursing women; those already in poor health or

[115] EPA. *Technical Guidance for Assessing Environmental Justice in Regulatory Analysis*. 2016. Available at: https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis

with comorbidities; the disabled; those experiencing homelessness, mental illness, or substance abuse; and/or Indigenous or minority populations dependent on one or limited resources for subsistence due to factors including but not limited to geography, access, and mobility.[116]

Scientific assessment reports produced over the past decade by the U.S. Global Change Research Program (USGCRP) [117,118] the IPCC, [119,120,121,122] and the National Academies of Science, Engineering, and Medicine[123,124] add more evidence that the impacts of climate change raise potential environmental justice concerns. These reports conclude that poorer or predominantly non-White communities can be especially vulnerable to climate change impacts

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[116] A 2021 EPA report, *Climate Change and Social Vulnerability in the United States: A Focus on Six Impact Sectors*, estimates the likelihood that more socially vulnerable individuals, defined on the basis of income, educational attainment, race and ethnicity, and age, currently live in areas projected to face the highest impacts of climate change. See https://www.epa.gov/cira/social-vulnerability-report.

[117] USGCRP. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 2018, 1515 pp. doi: 10.7930/NCA4.2018.

[118] USGCRP. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 2016, 312 pp. http://dx.doi.org/10.7930/J0R49NQX

[119] Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi. "Emergent risks and key vulnerabilities." In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, pp. 1039-1099.

[120] Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso. "Food security and food production systems." In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, pp. 485-533.

[121] Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn. "Human health: impacts, adaptation, and co-benefits." In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, pp. 709-754.

[122] IPCC. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. 2018, In Press.

[123] National Research Council. *America's Climate Choices*. Washington, DC: The National Academies Press, 2011. https://doi.org/10.17226/12781.

[124] National Academies of Sciences, Engineering, and Medicine. *Communities in Action: Pathways to Health Equity*. Washington, DC: The National Academies Press, 2017. https://doi.org/10.17226/24624.

because they tend to have limited adaptive capacities and are more dependent on climate-sensitive resources such as local water and food supplies or have less access to social and information resources. Some communities of color, specifically populations defined jointly by ethnic/racial characteristics and geographic location, may be uniquely vulnerable to climate change health impacts in the United States. In particular, the 2016 scientific assessment on the *Impacts of Climate Change on Human Health*[125] found with high confidence that vulnerabilities are place- and time-specific, life stages, and ages are linked to immediate and future health impacts, and social determinants of health are linked to greater extent and severity of climate change-related health impacts.

Individuals living in socially and economically disadvantaged communities, such as those living at or below the poverty line or who are experiencing homelessness or social isolation, are at greater risk of health effects from climate change. This is also true with respect to people at vulnerable life stages, specifically women who are pre- and perinatal, or are nursing; *in utero* fetuses; children at all stages of development; and the elderly. Per the Fourth National Climate Assessment, "Climate change affects human health by altering exposures to heat waves, floods, droughts, and other extreme events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being."[126] Many health conditions, such as cardiopulmonary or respiratory illness and other health impacts, are associated with and exacerbated by an increase in GHGs and climate change outcomes, which is problematic as these diseases occur at higher rates within vulnerable communities.

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[125] USGCRP. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,* 2016

[126] Ebi, K.L., J.M. Balbus, G. Luber, A. Bole, A. Crimmins, G. Glass, S. Saha, M.M. Shimamoto, J. Trtanj, and J.L. White-Newsome. "Human Health." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 2018, pp. 539–571. doi: 10.7930/NCA4.2018.CH14

Importantly, negative public health outcomes include those that are physical in nature, as well as mental, emotional, social, and economic.

To this end, the scientific assessment literature, including the aforementioned reports, demonstrates that there are myriad ways in which these populations may be affected at the individual and community levels. Individuals face differential exposure to criteria pollutants, in part due to the proximities of highways, trains, factories, and other major sources of pollutant-emitting sources to less-affluent residential areas. Outdoor workers, such as construction or utility crews and agricultural laborers, who frequently comprise already at-risk groups, are exposed to poor air quality and extreme temperatures without relief. Furthermore, individuals within environmental justice populations of concern face greater housing and clean water insecurity and bear disproportionate economic impacts and health burdens associated with climate change effects. They have less or limited access to healthcare and affordable, adequate health or homeowner insurance. Finally, resiliency and adaptation are more difficult for economically disadvantaged communities: They have less liquidity, individually and collectively, to move or to make the types of infrastructure or policy changes to limit or reduce the hazards they face. They frequently are less able to self-advocate for resources that would otherwise aid in resiliency and hazard reduction and mitigation.

The assessment literature cited in EPA's 2009 and 2016 Endangerment Findings, as well as *Impacts of Climate Change on Human Health*, also concluded that certain populations and life stages, including children, are most vulnerable to climate-related health effects. The assessment literature produced from 2016 to the present strengthens these conclusions by providing more detailed findings regarding related vulnerabilities and the projected impacts youth may experience. These assessments—including the *Fourth National Climate Assessment* (2018) and

The Impacts of Climate Change on Human Health in the United States (2016)—describe how children's unique physiological and developmental factors contribute to making them particularly vulnerable to climate change. Impacts to children are expected from heat waves, air pollution, infectious and waterborne illnesses, and mental health effects resulting from extreme weather events. In addition, children are among those especially susceptible to allergens, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households.

The Impacts of Climate Change on Human Health (USGCRP, 2016) also found that some communities of color, low-income groups, people with limited English proficiency, and certain immigrant groups (especially those who are undocumented) live with many of the factors that contribute to their vulnerability to the health impacts of climate change. While difficult to isolate from related socioeconomic factors, race appears to be an important factor in vulnerability to climate-related stress, with elevated risks for mortality from high temperatures reported for Black or African American individuals compared with the risks for White individuals after controlling for factors such as air conditioning use. Moreover, people of color are disproportionately exposed to air pollution based on where they live, and disproportionately vulnerable due to higher baseline prevalence of underlying diseases such as asthma, so climate exacerbations of air pollution are expected to have disproportionate effects on these communities.

Native American Tribal communities possess unique vulnerabilities to climate change, particularly those impacted by degradation of natural and cultural resources within established reservation boundaries and threats to traditional subsistence lifestyles. Tribal communities whose health, economic well-being, and cultural traditions depend upon the natural environment will likely be affected by the degradation of ecosystem goods and services associated with climate change. The IPCC indicates that losses of customs and historical knowledge may cause communities to be less resilient or adaptable.[127] The *Fourth National Climate Assessment* (2018) noted that while Indigenous peoples are diverse and will be impacted by the climate changes universal to all Americans, there are several ways in which climate change uniquely threatens Indigenous peoples' livelihoods and economies.[128] In addition, there can be institutional barriers to their management of water, land, and other natural resources that could impede adaptive measures.

For example, Indigenous agriculture in the Southwest is already adversely affected by changing patterns of flooding, drought, dust storms, and rising temperatures leading to increased soil erosion, irrigation water demand, and decreased crop quality and herd sizes. The Confederated Tribes of the Umatilla Indian Reservation in the Northwest have identified climate risks to salmon, elk, deer, roots, and huckleberry habitat. Housing and sanitary water supply infrastructure are vulnerable to disruption from extreme precipitation events.

The *Fourth National Climate Assessment* (2018) noted that Indigenous peoples often have disproportionately higher rates of asthma, cardiovascular disease, Alzheimer's, diabetes, and obesity, which can all contribute to increased vulnerability to climate-driven extreme heat

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[127] Porter, John & Xie, Liyong & Challinor, Andrew & Chhetri, Netra & Nepal, Usa & Garrett, Karen & Aggarwal, P.K. & Hakala, Kaija & Jordan, Joanne & Barros, R & Dokken, D & Mach, K & Mastrandrea, T & Bilir, M & Chatterjee, K & Ebi, Y & Estrada, R & Genova, B & Girma, Endalkachew & White,. (2014). 7 *Food Security and Food Production Systems* Coordinating Lead Authors: Lead Authors: Contributing Authors: Review Editors: Volunteer Chapter Scientist.

[128] Jantarasami, L.C., R. Novak, R. Delgado, E. Marino, S. McNeeley, C. Narducci, J. Raymond-Yakoubian, L. Singletary, and K. Powys Whyte. "Tribes and Indigenous Peoples." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 2018, pp. 572–603. doi: 10.7930/NCA4.2018.CH15

and air pollution events. These factors also may be exacerbated by stressful situations, such as extreme weather events, wildfires, and other circumstances.

The *Fourth National Climate Assessment* (2018) (NCA) and IPCC Fifth Assessment Report[129] also highlighted several impacts specific to Alaskan Indigenous Peoples. Coastal erosion and permafrost thaw will lead to more coastal erosion, exacerbated risks of winter travel, and damage to buildings, roads, and other infrastructure—including impacts on archaeological sites, structures, and objects that will lead to a loss of cultural heritage for Alaska's Indigenous people. In terms of food security, the NCA discussed reductions in suitable ice conditions for hunting, warmer temperatures impairing the use of traditional ice cellars for food storage, and declining shellfish populations due to warming and acidification. While the NCA also noted that climate change provided more opportunity to hunt from boats later in the fall season or earlier in the spring, the assessment found that the net impact was an overall decrease in food security.

With regard to phasing down the production and consumption of HFCs, EPA sees several areas that are potentially relevant to understanding the potential for disproportionately high and adverse human health, environmental, climate-related, and other cumulative impacts on disadvantaged communities, including (i) what impacts are associated with reducing emissions of HFCs; (ii) whether emissions of HFCs cause localized health or environmental impacts; (iii) whether there are other disproportionate impacts associated with HFC use and production, e.g., from the import, export, and destruction of HFCs, the chemical feedstock used in the production of HFCs, or the use of HFCs themselves as a feedstock in the production of other chemicals; and

[129] Porter, John & Xie, Liyong & Challinor, Andrew & Chhetri, Netra & Nepal, Usa & Garrett, Karen & Aggarwal, P.K. & Hakala, Kaija & Jordan, Joanne & Barros, R & Dokken, D & Mach, K & Mastrandrea, T & Bilir, M & Chatterjee, K & Ebi, Y & Estrada, R & Genova, B & Girma, Endalkachew & White,. (2014). 7 *Food Security and Food Production Systems* Coordinating Lead Authors: Lead Authors: Contributing Authors: Review Editors: Volunteer Chapter Scientist.

(iv) how localized impacts may be affected as facilities that currently produce HFCs switch to producing lower-GWP HFCs, substitutes for HFCs or other unrelated chemicals or products.

6.2 Analysis of Potential Environmental Justice Concerns

As a first step toward evaluating potential environmental justice concerns, EPA has conducted an analysis to characterize baseline environmental conditions faced by communities living near HFC production facilities subject to the rule. The relatively small number of facilities affected by the rule has enabled EPA to assemble a granular assessment of the characteristics of these facilities and the communities where they are located. While this rule regulates both the consumption and production of these HFCs, this analysis mainly focuses on production. HFCs are well-mixed GHGs, meaning their atmospheric lifetimes are long enough so that they are relatively homogeneously mixed in the troposphere such that emissions are not associated with impacts localized at the point of release.

For the 18 HFCs regulated by the rule listed in Table 1.1, the production facilities were identified by a two-step process. First, 14 facilities were identified as reporting HFC emissions under the Greenhouse Gas Reporting Program (GHGRP) Subparts L (Fluorinated Gas Production) and O (HCFC-22 production and HFC-23 destruction source) for the year 2019 (the most recent year available).[130] EPA used commercial[131] and internal market reports, facility web pages, data reported to the GHGRP and direct communication with companies to determine which of the 14 facilities would likely be subject to this rule. Based on this information, EPA determined that eight of these facilities produce HFCs or are subject to this rule. (Table 6-1).

[130] One additional company was identified as producing HFCs in response to the Notice of Data Availability published February 11, 2021 (86 FR 9059). The company, Iofina Chemical, is located in Covington, KY, and produces HFC-41.
[131] "Fluorocarbons." IHS Chemical Economics Handbook. June 2020. https://www.ihs.com/products/fluorocarbons-chemical-economics-handbook.html.

Table 6-1: HFC production facilities subject to this rule

Facility Name	City	State	FRS ID*	GHGRP ID^	Number of Employees
Arkema, Inc.	Calvert City	Kentucky	110000380061	1005721	200
Chemours - Corpus Christi Plant	Gregory	Texas	110000746532	1006314	250
Chemours El Dorado	El Dorado	Arkansas	110033151540	1003890	21
Chemours Louisville	Louisville	Kentucky	110000378494	1004133	127
Daikin America	Decatur	Alabama	110045447469	1005062	200
Honeywell - Geismar Complex	Geismar	Louisiana	110033659878	1006070	250
Iofina Chemical Inc.	Covington	Kentucky	110003255888	N/A	100
Mexichem Fluor Inc.	Saint Gabriel	Louisiana	110043796023	1006675	67

Source: Greenhouse Gas Reporting Inventory
*FRS ID is the facility registration service (FRS) identification number assigned to a specific facility to integrate information across separate data sources.
^GHG ID is the identification number assigned to a facility reporting to EPA's Greenhouse Gas Reporting Program.

The facilities range widely in size as measured by the number of employees and are located in five states (Alabama, Arkansas, Kentucky, Louisiana, and Texas). Most of these HFC production facilities are located along major waterways and are in a mixed of urban and rural areas (the Chemours Corpus Christi, Chemours Louisville, Daikin America, and Iofina Chemical facilities are classified as urban). This information is used later in the analysis to identify an appropriate comparison group for approximating impacts on communities living near the facilities.

The production of HFCs in the United States has been trending downward over the last decade, from 323 million metric tons of CO_2e per year in 2011 to 218 million metric tons in 2019.[132] Facility-level HFC production data is reported under subpart OO of the GHGRP but this information is considered confidential business information and is not publicly available.[133] Because production facilities emit fluorinated GHGs during HFC production, the emissions of

[132] https://www.epa.gov/ghgreporting/fluorinated-greenhouse-gas-emissions-and-supplies-reported-ghgrp#aim
[133] Consistent with this final rule under the AIM Act, EPA intends to release allowance holders' facility-level chemical-specific production data, including total production, and production for feedstock and destruction going forward.

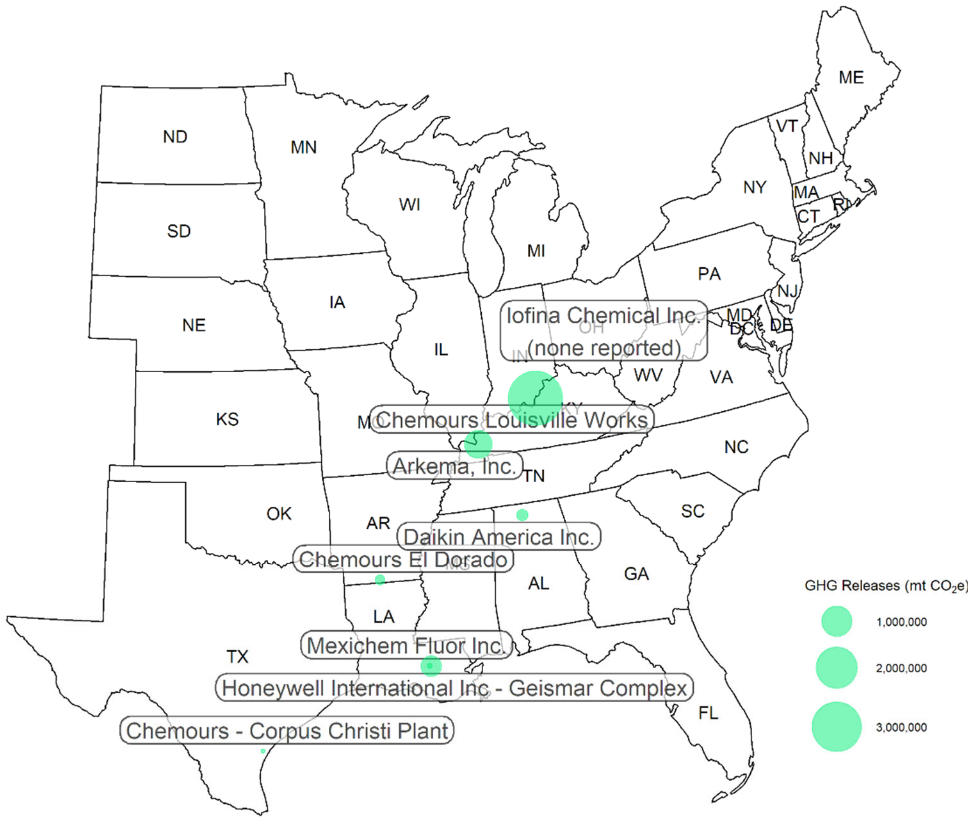
HFCs are correlated with HFC production and are publicly available. Table 6-2 reports the total annual quantity of HFCs emitted in carbon dioxide equivalents (CO_2e) by each of the eight HFC facilities subject to this rule from 2015 to 2019. Iofina Chemical Inc. did not report any HFC emissions to the GHGRP prior to 2020, but data for 2020 are not yet available. For those reporting emissions in 2019, they ranged widely across facilities, from about 5,300 metric tons CO_2e to more than 3.7 million metric tons. Although HFC emissions have been trending downward over time, there are a few exceptions at the facility level. For example, the Chemours Corpus Christi facility emitted more in 2019 than it did in 2015. Figure 6-1 provides a map of facility locations for those facilities emitting HFCs; the size of the circles corresponds to the quantity of HFCs emitted in 2019.

Table 6-2: Quantity of HFCs emitted (Metric Tons CO_2e) by Facility, 2015–2019

Facility Name	2015	2016	2017	2018	2019
Arkema, Inc.	1,200,045	1,120,898	1,085,768	958,739	843,010
Chemours - Corpus Christi Plant	10,538	13,776	10,524	11,045	17,240
Chemours El Dorado	68,753	60,795	69,026	83,636	66,990
Chemours Louisville	4,258,715	2,792,553	5,156,202	3,276,291	3,707,770
Daikin America	5,409	4,051	4,828	4,156	5,297
Honeywell - Geismar Complex	567,322	306,499	330,371	425,451	413,584
Iofina Chemical Inc.	NR	NR	NR	NR	NR
Mexichem Fluor Inc.	23,407	20,089	15,794	18,626	18,331

Source: Greenhouse Gas Reporting Inventory
Note: None Reported (NR) is for facilities whose data have not yet been released in the GHGRP.

Figure 6-1: Emissions of HFCs (Metric Tons CO2e) subject to this rule, 2019



While there are environmental justice concerns associated with climate change, briefly discussed above, HFCs are not a local pollutant and have low toxicity to humans. However, chemicals used as feedstocks or catalysts in the production of HFCs or produced as byproducts may have localized effects if released into the environment. These feedstock chemicals are typically converted to other substances or products during the production process. Carbon tetrachloride (CTC); 1,1,1-trichloroethane (TCA or methyl chloroform); trichloroethylene (TCE); and hydrogen fluoride are some examples of feedstocks that are sources of chlorine and fluorine atoms for the eventual production of HFCs. The Agency considered whether changes in the production or location of destruction of HFCs due to this rule might be associated with local health risks. The Agency notes that facilities are already destroying HFCs as a portion of the other materials they destroy. These facilities are subject to other environmental statutes such as the Resource Conservation and Recovery Act, the Emergency Planning and Community Right-to-Know Act, and the CAA. As a result, this rule is not expected to affect local emissions at offsite destruction facilities.

The HFCs regulated under this rule use a wide array of chemicals as feedstocks or catalysts for production or produce them as byproducts, some of which are hazardous when released into the environment or when workers or other occupational non-users are exposed to them. For instance, Table 6-3 summarizes the main chemical feedstocks, catalysts and byproducts used to produce HFCs that are also toxic chemicals as well as the health effects associated with them.

Many toxic chemicals are known carcinogens and/or may lead to other serious health impacts. Carbon tetrachloride, for example, affects the liver, kidneys, and central nervous system. EPA has classified carbon tetrachloride as “likely to be carcinogenic to humans.”[134] Some feedstock chemicals also are associated with non-carcinogenic effects. Acute inhalation exposure of workers to hydrogen fluoride, for example, can result in severe respiratory damage, while chronic exposure has resulted in skeletal fluorosis, a bone disease.[135]

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[134] Integrated Risk Information System (IRIS). Carbon Tetrachloride. Last revised on 03/31/2010. Available at https://iris.epa.gov/ChemicalLanding/&substance_nmbr=20

[135] Agency for Toxic Substances and Disease Registry. 2003. Toxicological Profile for Fluorides, Hydrogen Fluoride, and Fluorine (Update). Available: http://www.atsdr.cdc.gov/toxprofiles/tp11.pdf

Table 6-3: Toxic chemicals used as a feedstock or catalyst or released as a byproduct of HFC production

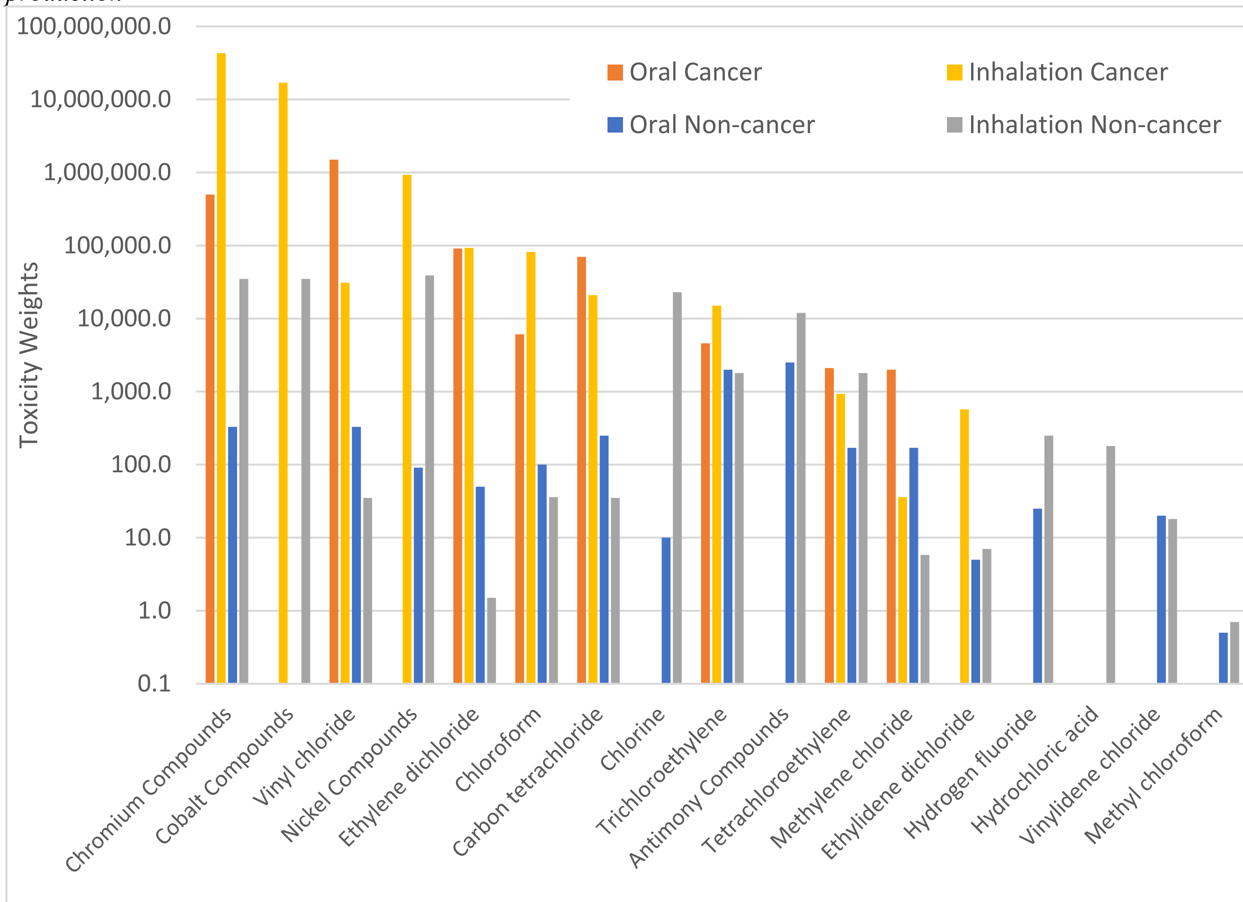
Chemical Name	**Health Effects**[136]
Antimony Compounds*	Metabolic, Other Systemic
Carbon tetrachloride	Cancer, Developmental, Hepatic, Reproductive
Chlorine	Ocular, Respiratory
Chloroform	Cancer, Developmental, Hepatic, Renal, Respiratory
Chromium Compounds*	Cancer, Gastrointestinal, Hematological, Respiratory
Cobalt Compounds*	Cancer, Hematological, Respiratory
Ethylidene dichloride (1,1-Dichloroethane)	No information available
Ethylene dichloride (1,2-Dichloroethane)	Cancer, Hepatic, Renal
Hydrochloric acid	Respiratory
Hydrogen fluoride	Ocular, Respiratory
Methylene chloride (Dichloromethane)	Cancer, Hematological, Hepatic, Neurological
Nickel Compounds*	Body Weight, Cancer, Hematological, Immunological, Respiratory
Tetrachloroethylene (Perchloroethylene)	Body Weight, Cancer, Developmental, Hepatic, Neurological, Ocular, Renal, Respiratory
Methyl chloroform (1,1,1-Trichloroethane)	Body Weight, Hepatic, Neurological
Trichloroethylene	Cancer, Cardiovascular, Developmental, Immunological, Neurological, Ocular
Vinyl chloride (chloroethene)	Cancer, Developmental, Hepatic, Neurological, Ocular, Respiratory
Vinylidene chloride (1,1-dichloroethylene)	Hepatic, Other Systemic

Notes: * Denotes toxic chemicals that are used as a catalyst in HFC production.

Figure 6-2 presents the toxicity weights associated with cancer and non-cancer risks for the toxic chemicals in Table 6-3 from EPA's Risk-Screening Environmental Indicators (RSEI) model. The vertical axis (log scale) provides a relative measure of the toxicity associated with two endpoints (cancer and non-cancer health effects) via two potential routes of exposure (oral and inhalation) that can be compared across chemicals. Higher bars in the graph indicate a greater risk associated with the endpoint or route indicated. EPA tends to rely on the toxicity weights for the oral route of exposure for water releases and the inhalation route for air releases.

[136] Chemical health effects information comes from the Occupational Safety and Health Administration (OSHA) Carcinogen List and the TRI-Chemical Hazard Information Profiles (CHIP) available at: https://www.epa.gov/toxics-release-inventory-tri-program/tri-chemical-hazard-information-profiles-tri-chip.

Figure 6-2: RSEI toxicity weights for chemicals used as a feedstock or catalyst or released as a byproduct of HFC production



Source: EPA's Risk-Screening Environmental Indicators (RSEI) model.

Table 6-4 summarizes aggregate toxics released onsite into the air, water, or land, or transferred offsite for disposal by HFC production facilities in 2019 (transfers offsite for other purposes such as recycling, reuse, or energy recovery are not shown).[137] Facilities varied widely in terms of the magnitude of their releases. For instance, total air releases ranged from about 20 pounds to more than 243,000 pounds. Water releases varied even more widely, with four plants reporting no water releases and one reporting almost 19,000 pounds. Land disposal of toxic chemicals was a very small proportion (less than 5 percent) of the total releases. For one facility

[137] US EPA. *Toxic Releases Inventory*, 2019. Available at https://www.epa.gov/toxics-release-inventory-tri-program

(Honeywell – Geismar Complex), offsite transfers for waste management accounted for a significant portion of the chemicals reported. This represents a transfer of the chemical away from the facility but does not necessarily represent the release of the chemical into the environment.

Table 6-4: 2019 Reported Total Releases into Air, Water, and Land and Disposed of Offsite by Production Facility (in pounds)

Facility	Location	Air Releases	Water Releases	Land Disposal	Offsite Transfers
Arkema, Inc.	Calvert City, KY	243,194	896	5,845	501
Chemours - Corpus Christi	Gregory, TX	61,295			
Chemours El Dorado	El Dorado, AR	26,038			
Chemours Louisville	Louisville, KY	657,191			6
Daikin America	Decatur, AL	169,339	18,607		30
Honeywell - Geismar Complex	Geismar, LA	122,651	4,722	12,786	158,859
Iofina Chemical Inc.	Covington, KY	20			
Mexichem Fluor Inc.	Saint Gabriel, LA	22,593	40		73

Source: U.S. EPA. Toxic Releases Inventory. 2019

Given the sizable quantities of total releases across several media for several HFC production facilities in Table 6-4, further investigation seems warranted. Table 6-5 presents the quantities of onsite air and water releases, and quantities transferred offsite for disposal for the subset of toxic chemicals that are used as feedstocks or catalysts or are produced as byproducts of HFC production (for a list of toxic HFC-related chemicals see Table 6-3). Note that toxic releases from a given facility are not only associated with the production of HFCs; many chemical facilities have multiple production lines involved in varied syntheses, transformations, and processing.

Columns 2 and 3 report total pounds of air releases for toxic chemicals used in HFC production, though they may also be associated with other products manufactured at these same facilities, and the ratio of the HFC-associated releases to total air releases from the same facility. Air releases of toxic chemicals used in HFC production ranged from 0 pounds to 58,000 pounds in 2019 and represented between 0 percent (Iofina Chemical Inc.) and 57 percent (Chemours – Corpus Christi facility) of total reported air releases. Water releases for chemicals associated with HFC production are described in columns 4 and 5. Water releases of toxic chemicals used in the production of HFCs ranged from 0 to 499 pounds but are much smaller in magnitude than the total reported air releases.

Table 6-5: 2019 Reported Toxic Releases Associated with HFC Production (in pounds)

Facility	Air releases for toxic HFC production chemicals	Ratio of toxic HFC-related to total air releases	Water releases for toxic HFC production chemicals	Ratio of toxic HFC-related to total water releases	Offsite transfers of toxic HFC production chemicals	Ratio of toxic HFC-related to total offsite transfers
Arkema, Inc.	58,043	0.24	456	0.51	501	1
Chemours - Corpus Christi	34,876	0.57				
Chemours El Dorado	9,868	0.38				
Chemours Louisville	3,724	0.01			196	1
Daikin America	3,313	0.02	22		30	1
Honeywell - Geismar Complex	51,282	0.42	499	0.11	62,543	0.39
Iofina Chemical Inc.						
Mexichem Fluor Inc.	4,369	0.19	28	0.70	73	1

Source: U.S. EPA. Toxic Releases Inventory. 2019

The quantities of toxic chemicals associated with HFC production that are taken for offsite disposal are presented in columns 6 and 7. The Honeywell facility had significant total transfers offsite for disposal, but only 39 percent of these are associated with HFC production. The vast majority (99%) of these HFC-related offsite transfers are chromium. Because air releases of toxic chemicals specific to HFC production are in the tens of thousands of pounds and a large proportion of total air releases for several of these facilities, Table 6-6 further disaggregates air releases in 2019 for toxic chemicals used in HFC production (though they may also be used in other production processes at a given facility). These releases are reported in pounds but their potential impact on the surrounding community can be inferred from the toxicity weights in Figure 6-2 and the descriptions of the health risks described in Table 6-3. To make this crosswalk somewhat simpler, we have included the maximum RSEI toxicity weight across two health endpoints and two exposure pathways in Table 6-6.

Table 6-6: 2019 TRI Air Releases (lbs.) for Toxic Chemicals used in HFC Production

Chemical	Maximum RSEI Toxicity Weight*	Arkema, Inc.	Chemours - Corpus Christi	Chemours El Dorado	Chemours Louisville	Daikin America	Honeywell - Geismar Complex	Iofina Chemical Inc.	Mexichem Fluor Inc.
Chromium Compounds	43,000,000						0.301		1
Cobalt Compounds	17,000,000								
Vinyl chloride	1,500,000		939			1,853			
Nickel Compounds	930,000								
Ethylene dichloride	93,000	1							
Chloroform	82,000		385		233	64	383		
Carbon tetrachloride	70,000		16,808	3,631					
Chlorine	23,000	5,298	740		282		6,752		
Tetrachloroethylene	15,000		3,806				8,013		
Trichloroethylene	15,000	1,905							6
Antimony Compounds	12,000						26		
Methylene chloride	2,000	791							
Ethylidene dichloride (1,1-Dichloroethane)	570								
Hydrogen fluoride	250	8,004	5,760	6,237	506	772	23,138		3,095
Hydrochloric acid	180	39,717	6,437		2,703	624	12,970		1,267
Vinylidene chloride	20								
Methyl chloroform	0.7	2,327							
Total for HFC-Related Subset		**58,043**	**34,876**	**9,868**	**3,724**	**3,313**	**51,282**	**0**	**4,369**

Source: U.S. EPA. Toxic Releases Inventory. 2019
* The maximum RSEI toxicity weight is the highest weight of the four presented in Figure 6-2: oral cancer, inhalation cancer, oral non-cancer, and inhalation non-cancer.

Some releases of carbon tetrachloride, chlorine, and tetrachloroethylene are sizable. For example, in addition to the TRI releases in Table 6-6, modeling based on air concentrations estimates that the majority of carbon tetrachloride emissions in the United States occur along the Gulf Coasts of Texas and Louisiana, where some of the HFC production facilities are located.[138]

[138] Hu, L., Montzka, S.A., Miller, B.R., Andrews, A.E., Miller, J.B., Lehman, S.J., Sweeney, C., Miller, S.M., Thoning, K., Siso, C. and Atlas, E.L.. "Continued emissions of carbon tetrachloride from the United States nearly two decades after its phaseout for dispersive uses." *Proceedings of the National Academy of Sciences*, 113(11), 2016, pp.2880-2885.

These chemicals have a higher potential risk for cancer and non-cancer effects. There are also releases of hydrochloric acid and hydrogen fluoride across the facilities, and these chemicals display inhalation non-cancer risk. Also of potential relevance is the extent to which an HFC production facility releases toxic chemicals due to remedial actions, catastrophic events, or other one-time events not associated with production processes.

Table 6-7: 2010–2019 TRI Non-production Releases (lbs.) for Toxic Chemicals used in HFC Production

Chemical	Maximum RSEI Toxicity Weight*	Arkema, Inc.	Chemours - Corpus Christi	Chemours El Dorado	Chemours Louisville	Daikin America	Honeywell - Geismar Complex	Iofina Chemical Inc.	Mexichem Fluor Inc.
Chromium Compounds	43,000,000						0.001		
Cobalt Compounds	17,000,000								
Vinyl chloride	1,500,000								
Nickel Compounds	930,000								
Ethylene dichloride	93,000	6							
Chloroform	82,000				5				
Carbon tetrachloride	70,000								
Chlorine	23,000				10		72		
Tetrachloroethylene	15,000						43		
Trichloroethylene	15,000	80							
Antimony Compounds	12,000								
Methylene chloride	2,000								
Ethylidene dichloride (1,1-Dichloroethane)	570								
Hydrogen fluoride	250	1,118			236		6,731		
Hydrochloric acid	180	2,954			847		1,177		
Vinylidene chloride	20								
Methyl chloroform	0.7	837							
Total for HFC-Related Subset		**4,994**	**0**	**0**	**1,098**	**0**	**8,023**	**0**	**0**

Table 6-7 reports non-production releases for hazardous air pollutant chemicals used in HFC production from 2010–2019; into which media is not specified. The Honeywell Geismar, Arkema, Inc., and Chemours Louisville facilities released over 1,000 pounds in non-production releases between 2010 and 2019, with substantial quantities of hydrogen fluoride (6,078 pounds, 1,118 pounds, and 236 pounds, respectively) and hydrochloric acid (1,177 pounds, 2,954 pounds, and 847 pounds, respectively).

Table 6-8: Risk Evaluations for Existing Chemicals under TCSA of relevant feedstock chemicals used in the production of HFCs

Chemical Name	Risk Evaluations for Existing Chemicals under TSCA
Carbon tetrachloride	Risk evaluation published November 2020*
Tetrachloroethylene (Perchloroethylene)	Risk evaluation published December 2020*
Trichloroethylene	Risk evaluation published November 2020*
Dichloromethane (Methylene Chloride)	Risk evaluation published June 2020*
1,1-Dichloroethane	Final scope published September 2020 and undergoing risk evaluation
1,2-Dichloroethane	Final scope published September 2020 and undergoing risk evaluation

Source: EPA, Chemicals Undergoing Risk Evaluation under TSCA
*Note: In June 2021, EPA announced that the Agency would revisit the approach taken in the first 10 risk evaluations. This has the potential to change the basis for the unreasonable risk determinations for some of the first 10 chemicals.

Table 6-8 identifies the existing chemicals whose risk evaluations have been completed, or are undergoing risk evaluation under TSCA, that are relevant feedstock chemicals used in the production of HFCs. Four of those chemicals (carbon tetrachloride, perchloroethylene, trichloroethylene, and methylene chloride) have risk evaluations that were published in 2020, and two of the chemicals (1,1-dichloroethane and 1,2-dichloroethane) have final scopes that were published in 2020 and are undergoing risk evaluation under TSCA.

In June 2021, EPA announced that it would conduct supplemental analyses to the risk evaluations for seven of the first 10 chemicals, including the four chemicals in Table 6-8 with risk evaluations completed in 2020 and which are relevant feedstock chemicals used in the production of HFCs. The Agency is revisiting the approach taken in the first 10 risk evaluations, which generally did not assess air, water, or disposal exposures to the general population when these exposure pathways are or could be regulated under other EPA-administered statutes. The Agency announced it will undertake these analyses, which will be peer reviewed, to ensure that the risk evaluations did not overlook risk to fenceline communities (i.e., communities near industrial facilities). In addition, EPA is revisiting the assumed use of personal protective equipment for purposes of risk determination. Following these supplemental analyses, EPA will issue revised risk determinations on the whole chemical substance, rather than on each condition of use. This has the potential to change the basis for the unreasonable risk determinations for some of the first 10 chemicals, which include carbon tetrachloride, tetrachloroethylene, trichloroethylene, and methylene chloride; however, the risk evaluations completed in 2020 already identify processing as a reactant/intermediate as a driver for the unreasonable risk for carbon tetrachloride, tetrachloroethylene, and trichloroethylene.

6.3 Aggregate Average Characteristics of Communities with HFC Production Facilities

A key issue relevant to evaluating the potential for environmental justice concerns is the extent to which individuals are already exposed to a variety of environmental risks that may interact with or signal pre-existing vulnerabilities including—but not limited to—releases from HFC production. EPA has not undertaken an analysis of how the emissions of HFC feedstocks, catalysts, and byproducts or other chemicals from these facilities affect nearby communities (e.g., through the use of a fate and transport model or the modeling of main exposure pathways). Nor does it have information at this time on how workers may be exposed to these chemicals or the characteristics of workers at these facilities.

However, a proximity-based approach can identify correlations between the location of HFC production facilities and effects of their releases (both HFC- and non-HFC-related) on nearby communities. Specifically, this approach assumes that individuals living within a specific distance of an HFC production facility are more likely to be exposed to releases from these facilities while those living further away are less likely to be exposed. Census block groups that are located within 1 mile and 3 miles of the facility are selected as potentially relevant distances to proxy for exposure. We also explored larger radii (5 and 10 miles) in response to comments that releases from these facilities may travel longer distances. Socioeconomic and demographic data from the American Community Survey 5-year data release for 2019 (the most recent year available) are used to examine whether a greater percentage of population groups of concern live within a specific distance of an HFC production facility compared with the national average. The national average for rural areas is also presented since four of the eight HFC production facilities subject to the rule are classified as rural.[139]

In addition, National Air Toxic Assessment (NATA) data from 2014 (the most recent year available) for Census tracts within and outside of a specified distance are used to approximate the cumulative baseline cancer and respiratory risk due to exposure to a wide variety of air toxics for communities near an HFC production facility.[140] The total cancer risk is reported as the risk per million people if exposed continuously to the specific concentration over an assumed lifetime. The total respiratory risk is reported as a hazard quotient, which is the exposure to a substance divided by the level at which no adverse effects are expected. Both total risk measures are the sum of the individual risk values for all of the chemicals evaluated in the NATA database. Note that these risks are not necessarily only associated with a specific HFC

[139] The U.S. Census definition of "rural" is used. The term rural is applied to census areas that are not classified as urbanized areas or urban clusters and have a population density below 2,500 people per square mile. Census also looks at other factors before classifying an area as rural including adjacency to an urban area. For the 1-mile radius, population density near an HFC production facility ranges from 46 people per square mile to 80 people per square mile for each of the four facilities in rural areas. For the 3-mile radius, population density near a rural facility ranges from 46 people per square mile to 151 people per square mile. However, if the majority of census blocks within our buffer are urban-adjacent, we continue to use the overall national or state level average as a basis of comparison.

[140] Available at https://www.epa.gov/national-air-toxics-assessment

production facility. Industrial activity is often concentrated, so multiple plants located within the same geographic area may contribute to these elevated risks.

Table 6-9 presents the density of TRI facilities (nearby facilities that could contribute to the cumulative NATA cancer and respiratory risk) located within a given distance of each HFC production facility. As expected, the farther the distance from a HFC production facility the more plants contribute to the cumulative NATA scores. All but one facility have five or fewer neighboring TRI facilities within a one-mile radius. Chemours Louisville, which is in an urban area, is an outlier at this distance with 14 neighboring TRI facilities. Expanding the radius to three miles increases the number of neighboring TRI facilities substantially for four of the eight HFC facilities: Arkema (from three neighboring TRI facilities to 11), Daikin America (3 to 16), Mexichem Flour (5 to 17), and Honeywell International (5 to 20). Increasing the radius to 5 or 10 miles increases the number of neighboring facilities even further.

Table 6-9: Total Number of TRI Facilities Near HFC Production Facilities

Facility	Location	Neighboring TRI Facilities within a 1-Mile Radius	Neighboring TRI Facilities within a 3-Mile Radius	Neighboring TRI Facilities within a 5-Mile Radius	Neighboring TRI Facilities within a 10-Mile Radius
Arkema, Inc.	Calvert City, KY	3	11	11	13
Chemours - Corpus Christi	Gregory, TX	2	4	6	6
Chemours El Dorado	El Dorado, AR	2	2	2	12
Chemours Louisville	Louisville, KY	14	19	34	66
Daikin America	Decatur, AL	3	16	22	28
Honeywell - Geismar Complex	Geismar, LA	5	20	31	37
Iofina Chemical Inc.	Covington, KY	2	2	15	46
Mexichem Fluor Inc.	Saint Gabriel, LA	5	17	21	37

Source: U.S. EPA. Toxic Releases Inventory. 2019

Given the high concentration of industrial activity around these plants, it is not surprising that these communities also rank high with regard to other types of pollutants. Data from EJSCREEN indicate that the vast majority of these facilities are located in Census block groups that are in the 95th–100th percentile of the distribution for wastewater discharges relative to the national average (the exceptions are the Chemours Corpus Christi and Daikin plants).[141] Five of the plants (Arkema, Daikin, Chemours Louisville, Honeywell, and Mexichem Fluor) are located in Census block groups that are in the 80th percentile or above of the distribution for proximity to hazardous waste compared with the national average.[142]

Summary statistics presented earlier in this section also describe other types of TRI emissions associated with feedstocks, catalysts, or byproducts of HFC production (i.e., water and land emissions, offsite disposal, and non-production releases). These aspects of risk have not been explicitly incorporated into the proximity analysis, though they may be worthy of further investigation.

Table 6-10 presents summary information averaged across the eight communities near HFC production facilities compared with the overall and rural national average. Recall that four of the facilities are located in urban areas; four are in rural areas. The values in the last four columns reflect population-weighted averages across the Census block groups within a particular distance (i.e., 1, 3, 5, or 10 miles) of the facility.

[141] Block groups typically contain between 600 and 3,000 people.
[142] None of the facilities are located in Census block groups with ozone levels above the 80th percentile of the distribution, while two facilities are located in Census block groups with particulate matter 2.5 in the 80–90th percentile of the distribution (Honeywell and Mexichem Fluor).

Table 6-10: Overall Community Profile and NATA Risks for Communities near HFC Production Facilities

	Overall National Average	Rural Areas National Average	Within 1 mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	72	84	80	65	70	75
% Black or African American (race)	13	7.5	16	30	24	19
% Other (race)	15	8.2	3.7	4.5	5.9	6
% Hispanic (ethnic origin)	18	10	7.5	6.7	7.6	6
Median Household Income (1k 2019$)	71	67	76	62	56	61
% Below Poverty Line	7.3	6.8	5.8	8	9.1	8.3
% Below Half the Poverty Line	5.8	5.1	6	6.9	7.9	7.2
Total Cancer Risk (per million)	32	28	53	47	41	43
Total Respiratory Risk (hazard quotient)	0.44	0.38	0.66	0.56	0.53	0.53

Notes: Demographic definitions are as described in the 2019 American Community Survey (U.S. Census 2021). The "hazard quotient" is defined as the ratio of the potential exposure to a substance and the level at which no adverse effects are expected (calculated as the exposure divided by the appropriate chronic or acute value). A hazard quotient of 1 or lower means adverse non-cancer effects are unlikely and, thus, can be considered to have negligible hazard. For hazard quotients greater than one, the potential for adverse effects increases, but we do not know by how much. Total cancer and respiratory risk are drawn from the National Air Toxic Assessment (NATA, 2018).

While it is not possible to disaggregate the risk information from NATA by race, ethnicity, or income, the total cancer and respiratory risk for communities near the eight HFC production facilities is markedly greater than either national average (e.g., total cancer risk within one mile of an HFC production facility is 66 percent higher than the national average), though it falls with distance from the plant (Table 6-10). Combining all eight facilities, a higher percentage of Black or African American individuals live within 1 to 10 miles of an HFC production facility (ranging from 16 percent to 30 percent) compared with the rural and overall national averages (7.5 percent and 13 percent, respectively). A lower percentage of Hispanic individuals live near an HFC production facility regardless of distance. The median income is lower and the percentage in poverty is higher for households living near an HFC facility compared with either national average, except at the 1-mile distance.

6.4 Characteristics of Communities with HFC Production Facilities by Facility

Since the averages reported in Table 6-10 may obfuscate potentially large differences in the community characteristics surrounding individual production facilities, it is also important to examine the socioeconomic and demographic community characteristics for each facility separately. For example, cumulative cancer and respiratory risks in communities within a 1-mile distance of an HFC production facility vary widely: from being similar to the statewide average to being up to three (cancer) or five (respiratory) times the state average (Figures 6-3 and 6-4).

Figure 6-3: Relative Cancer Risk of Communities within 1 mile of HFC Facilities to State Averages

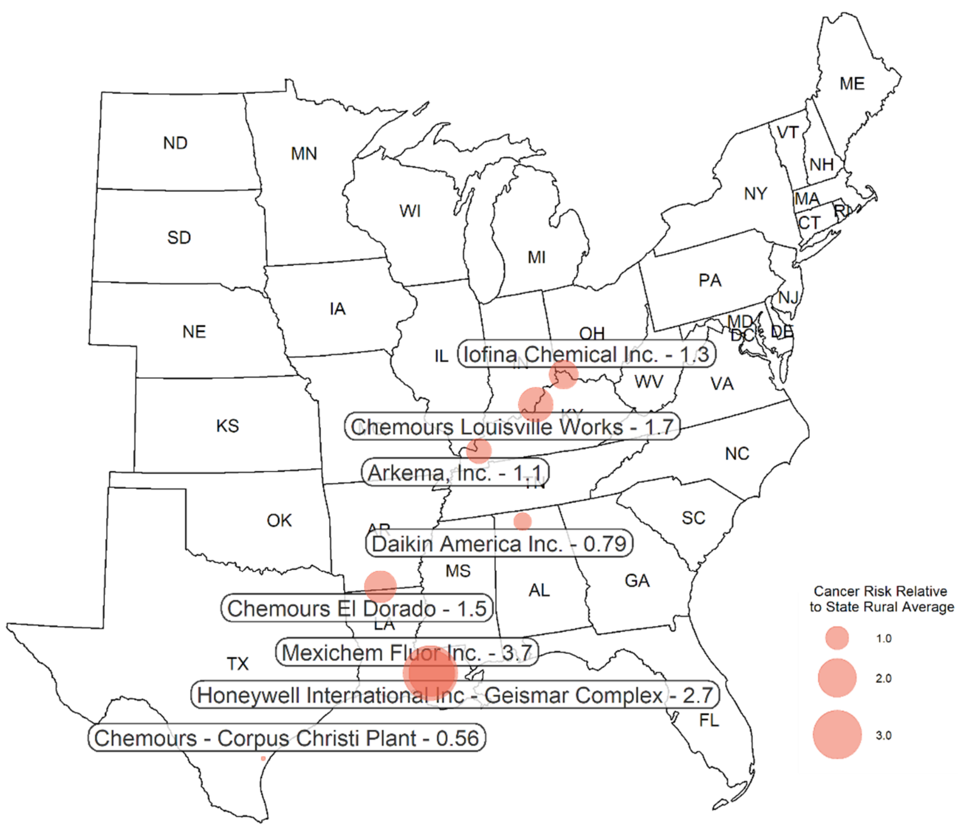
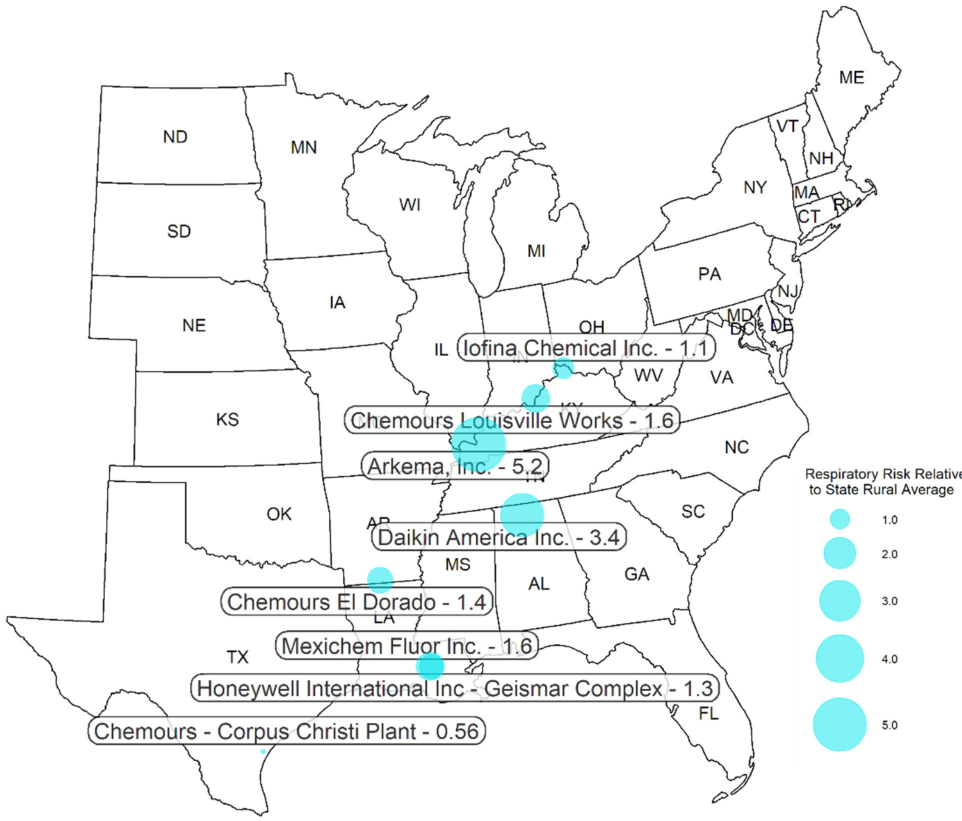


Figure 6-4: Relative Respiratory Risk of Communities within 1 mile of HFC Facilities to State Averages



Tables 6-11 through 6-18 present information about race, ethnicity, income, and exposure risks in nearby communities by individual HFC production facility compared with the applicable national and state-level averages (i.e., rural or overall). Community characteristics near each facility vary, but they generally have larger cancer and respiratory exposure risks than the relevant comparison population. We begin with a discussion of the characteristics of the surrounding communities at the 1- and 3-mile radius, before turning to how these characteristics change when the community affected is defined at a broader scale (i.e., 5- and 10-mile radius).

The communities surrounding Arkema Inc., Chemours El Dorado, and Iofina Chemical facilities (Tables 6-11, 6-13, and 6-17) have substantially increased risk for one of the two NATA risk indicators (e.g., for Arkema, respiratory risk is 4.5 to 5.5 times that of the relevant comparison population; see also Figure 6-5). Arkema and Chemours El Dorado are qualitatively similar with regard to the communities surrounding them when comparing race and ethnicity to the state and national rural averages at the 1- and 3-mile distances: they have lower percentages of Black or African American and Hispanic individuals nearby. How the income and poverty variables compare to state and national averages depends on the distance used. Communities near the Iofina Chemical facility also have lower or similar percentages of Black or African American individuals living nearby but higher median income and percentage of Hispanic individuals regardless of the average used for comparison. The percentage in poverty near the Iofina Chemical plant is sensitive to the distance used.

Communities around three HFC production facilities (Chemours Corpus Christi, Chemours Louisville, Daikin America) have noticeably higher risks from air toxics than the applicable state and national averages at the 1- and 3-mile distances. However, the socioeconomic characteristics of the surrounding communities differ. The communities living near the Chemours Louisville and Daikin America facilities are both characterized by higher percentages of Black or African American individuals, lower median household incomes, and higher percentages in poverty compared with state and national averages (see Tables 6-14 and 6-15). The percentage of Hispanic individuals is sensitive to the distance and basis of comparison. There are lower percentages of Black or African American and Hispanic individuals within 1 and 3 miles of the Chemours Corpus Christi facility compared with the national and state averages (see Table 6-12). Median household income and percentage of individuals in poverty are similar to state-level averages.

Characteristics around the two facilities in Louisiana (Honeywell Geismar and Mexichem Fluor) have very high baseline risks from air toxics (2.5 to 6 times the cancer risk and 1.3 to 2.4

times the respiratory risk compared with the state and national rural averages) at the 1- and 3-mile distances (see Tables 6-16 and 6-18). These facilities are also surrounded by notably higher proportions of Black or African American populations (1.5 to 3 times the proportion in state and national rural averages). Households living within 1 mile of the Mexichem Fluor facility have markedly lower median incomes compared with the state and national rural average. For purposes of this rulemaking, the extent to which HFC-related production and production of HFC substitutes are potential contributors to the elevated risk and exposure for nearby communities and how the production of those substances is expected to change as a result of this action are important for understanding how these communities might be affected.

As the distance from an HFC production facility grows (i.e., to 5 or 10 miles), total cancer and respiratory risks tend to decline, but the overall trend remains the same in most cases (i.e., elevated for some facilities compared with the average; similar to the average for others). Two exceptions are the Chemours Louisville facility, where cancer risks are much higher at 5 and 10 miles compared with shorter distances to the plant, and the Iofina Chemical facility, where respiratory risks follow a similar pattern.

Community characteristics at 5- and 10-mile distances from a facility look similar to those at 1 and 3 miles with regard to race and ethnicity for several facilities (Arkema, Chemours Louisville, Mexichem Fluor). In a few cases, the percentage of Black or African American individuals returns to or is even lower than the state-level average at a 10-mile distance (Honeywell Geismar, Iofina). For three facilities, however, larger shifts in racial and ethnic composition are evident. For instance, at the 5-mile radius the percentage of Black or African American individuals near the Chemours Corpus Christi and Chemours El Dorado plants are similar to state-level averages but increase substantially at 10 miles (percentage of Hispanic individuals remains low at all distances). At the Daikin plant, the percentage of Black or African American individuals living near the plant is low at 10 miles, while the percentage of Hispanic individuals is significantly higher than the state-level average.

Median household income and poverty rates either remain unchanged (Arkema, Honeywell, Mexichem Fluor) or improve (Chemours Louisville, Daikin, Iofina) with distance for many of the facilities. The exceptions are near the Chemours Corpus Christi and Chemours El Dorado plants where median household income is substantially lower and poverty rates are substantially higher at a 10-mile distance than closer to the plant.

Commenters raised questions about the most relevant distance for characterizing the potential health risks imposed by HFC production facilities on nearby communities. To examine the extent to which the 1, 3, 5, and 10-mile distance buffers used in the proximity analysis adequately identify communities that are likely most affected by emissions from these facilities, including those unrelated to HFC production, we used RSEI Geographic Microdata (RSEI-GM) to map the toxicity-weighted concentration of all air releases from each facility.[143] RSEI-GM microdata provide high-resolution (810 meter by 810 meter) concentration, toxicity-weighted concentrations, and RSEI Score spatial data. These data are detailed in that they provide modeled concentrations that cover the entire United States for each air release in TRI. Using toxicity weights these releases can be aggregated across chemical releases for each cell within 50 km of a facility. The toxicity weights are the chronic inhalation toxicity. Concentrations are multiplied by these toxicity weights and then added up to determine the toxicity-weighted concentration.

For each facility we provide a detailed map of the inhalation toxicity-weighted concentrations in Figures 6-5 through 6-12. Because these toxicity-weighted concentrations can

[143] Available at https://www.epa.gov/rsei/rsei-geographic-microdata-rsei-gm.

vary by orders of magnitude, the scale is adjusted using the natural logarithm. Therefore, a one-unit difference on the scale implies that the toxicity-weighted concentration is 2.72 higher in one cell relative to another. The blue color represents areas with low or zero values. The red color on each map represents the highest values for a facility. The maps are also overlaid with the 1, 3, 5- and 10-mile buffers used for the proximity-based analysis. In general, the maps show that the highest concentrations are immediately adjacent to the facilities (i.e., within a mile). Toxicity-weighted concentrations decline with distance from the facility as these releases disperse. The area with moderate concentrations (depicted in yellow) are mostly within the 10-mile buffer. However, because of prevailing wind directions, toxicity-weighted concentrations are not uniformly distributed around the facilities and, in some cases, communities outside of the 10-mile buffer are still exposed to elevated concentration. Linking these toxicity-weighted concentrations with specific communities of concern is an area of investigation to improve environmental justice analyses.

Table 6-11: Community Profiles and NATA Risks for Arkema, Inc. – Calvert City, KY

	Rural Areas National Average	Rural Areas State Average	Within 1 mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	84	94	99	99	98	96
% Black or African American (race)	7.5	3.2	0.0	0.36	0.57	1.8
% Other (race)	8.2	3.2	0.85	1.0	1.1	1.8
% Hispanic (ethic origin)	10	2.4	1.8	3.1	2.8	2.0
Median Household Income (1k 2019$)	67	51	53	55	56	54
% Below Poverty Line	6.8	10	5.7	4.7	4.2	5.6
% Below Half the Poverty Line	5.1	7.7	8.2	7.2	6.8	6.0
Total Cancer Risk (per million)	28	30	34	33	33	32
Total Respiratory Risk (hazard quotient)	0.38	0.42	2.2	1.9	1.8	1.2

Figure 6-5: Geographical dispersion of RSEI Toxicity Concentration for Arkema, Inc. – Calvert City, KY

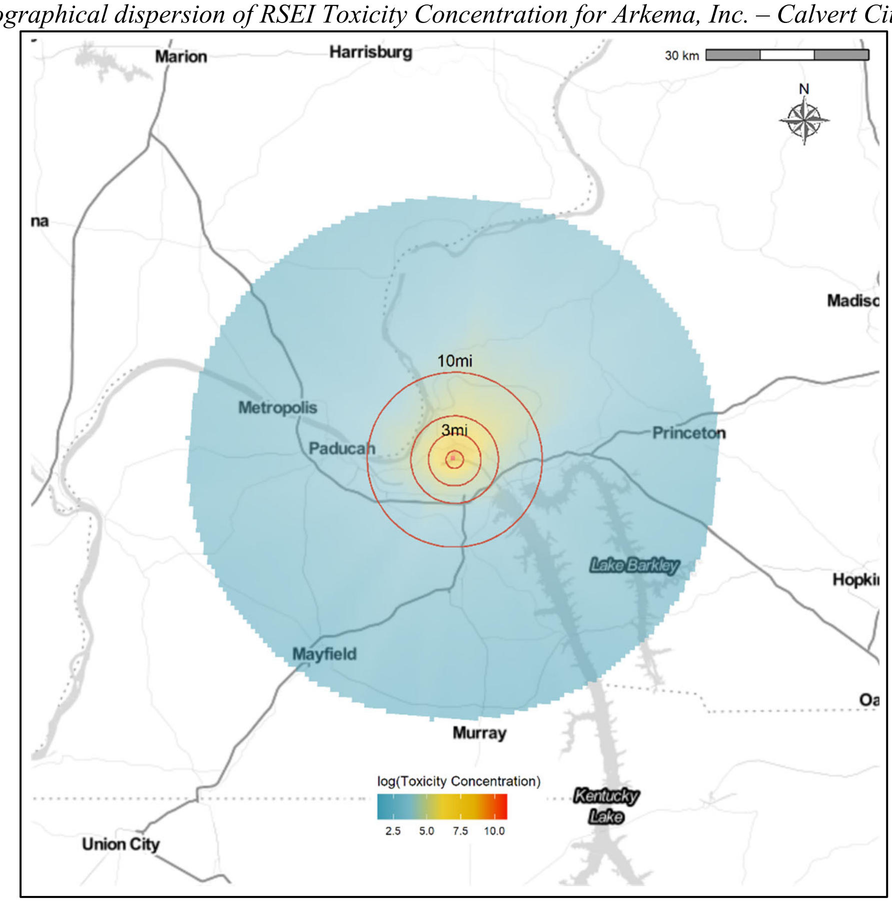


Table 6-12: Community Profiles and NATA Risks for Chemours Corpus Christi Plant – Gregory, TX

	Overall National Average	Overall State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	72	74	94	94	82	62
% Black or African American (race)	13	12	1.4	1.4	15	35
% Other (race)	15	14	4.7	4.7	2.9	3.4
% Hispanic (ethic origin)	18	39	2.4	2.4	3.4	4.5
Median Household Income (1k 2019$)	71	69	66	66	54	45
% Below Poverty Line	7.3	8.2	8	8	11	13
% Below Half the Poverty Line	5.8	6.2	5.2	5.2	4.2	7.7
Total Cancer Risk (per million)	32	35	54	54	50	47
Total Respiratory Risk (hazard quotient)	0.44	0.43	0.68	0.68	0.65	0.65

Figure 6-6: Geographical dispersion of RSEI Toxicity Concentration for Chemours – Gregory, TX

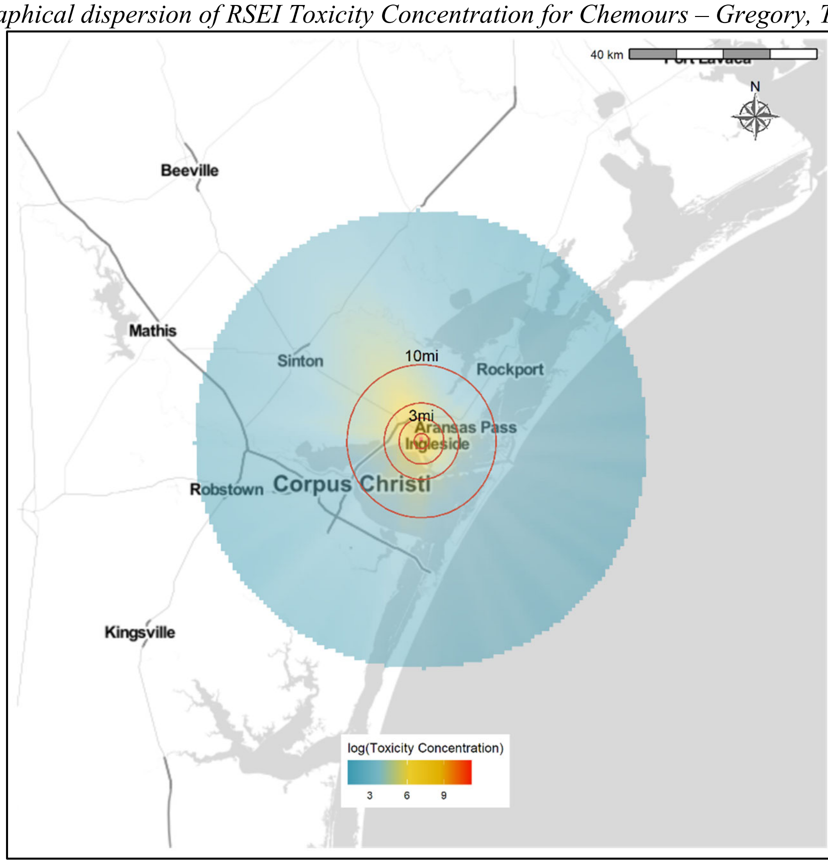


Table 6-3: Community Profiles and NATA Risks for Chemours El Dorado – El Dorado, AR

	Rural Areas National Average	Rural Areas State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	84	83	94	94	82	62
% Black or African American (race)	7.5	11	1.4	1.4	15	35
% Other (race)	8.2	5.9	4.7	4.7	2.9	3.4
% Hispanic (ethic origin)	10	5.3	2.4	2.4	3.4	4.5
Median Household Income (1k 2019$)	67	51	66	66	54	45
% Below Poverty Line	6.8	9.6	8.0	8.0	11	13
% Below Half the Poverty Line	5.1	6.2	5.2	5.2	4.2	7.7
Total Cancer Risk (per million)	28	35	54	54	50	47
Total Respiratory Risk (hazard quotient)	0.38	0.5	0.68	0.68	0.65	0.65

Figure 6-7: Geographical dispersion of RSEI Toxicity Concentration for Chemours El Dorado – El Dorado, AR

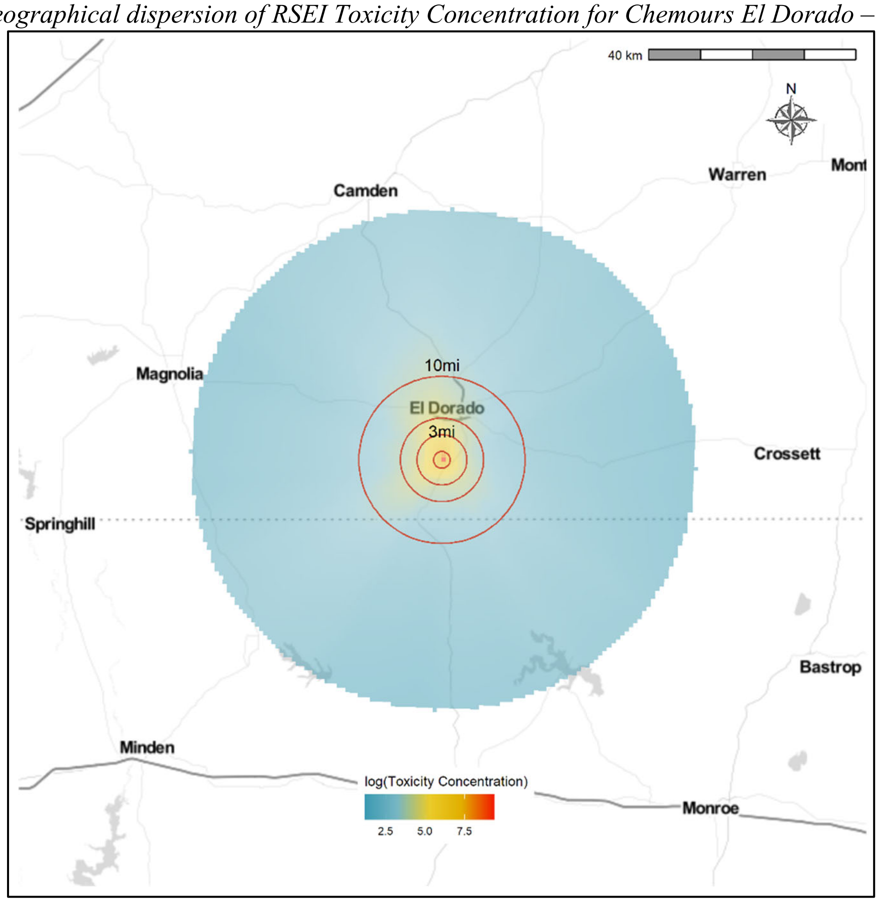


Table 6-4: Community Profiles and NATA Risks for Chemours Louisville – Louisville, KY

	Overall National Average	Overall State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	72	87	59	30	62	66
% Black or African American (race)	13	8.1	37	64	36	27
% Other (race)	15	5.0	4.7	4.2	3.0	7.1
% Hispanic (ethic origin)	18	3.7	4	5.3	2.9	5.1
Median Household Income (1k 2019$)	71	55	40	35	80	79
% Below Poverty Line	7.3	9.5	13	15	2.8	5.7
% Below Half the Poverty Line	5.8	7.3	12	11	5.5	4.9
Total Cancer Risk (per million)	32	31	36	37	130	97
Total Respiratory Risk (hazard quotient)	0.44	0.43	0.46	0.49	0.79	0.72

Figure 6-8: Geographical dispersion of RSEI Toxicity Concentration for Chemours Louisville – Louisville, KY

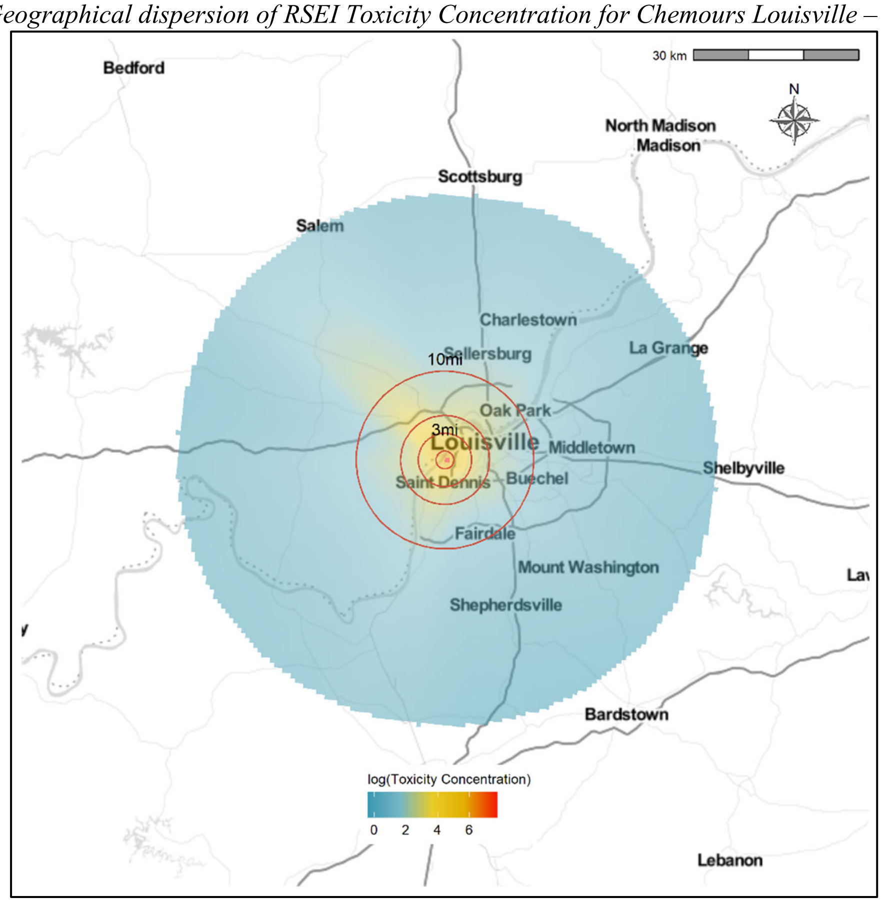


Table 6-5: Community Profiles and NATA Risks for Daikin America Inc. – Decatur, AL

	Overall National Average	Overall State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	72	68	35	53	92	91
% Black or African American (race)	13	27	59	39	2.2	2.1
% Other (race)	15	5.3	18	14	6.2	7.1
% Hispanic (ethic origin)	18	4.3	5.7	8.3	44	40
Median Household Income (1k 2019$)	71	55	36	42	69	61
% Below Poverty Line	7.3	9.1	21	17	3.4	6.0
% Below Half the Poverty Line	5.8	7.2	13	8.1	3.7	4.9
Total Cancer Risk (per million)	32	43	52	45	19	19
Total Respiratory Risk (hazard quotient)	0.44	0.65	0.69	0.62	0.21	0.21

Figure 6-9: Geographical dispersion of RSEI Toxicity Concentration for Daikin America Inc. – Decatur, AL

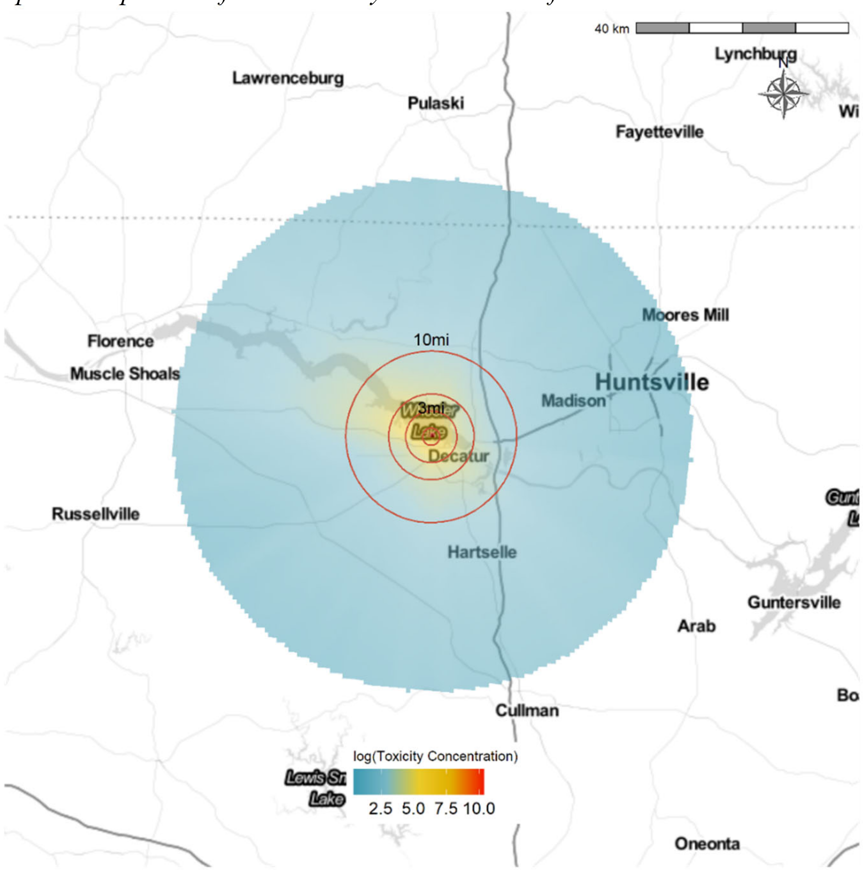


Table 6-6: Community Profiles and NATA Risks for Honeywell Geismar Complex – Geismar, LA

	Rural Areas National Average	Rural Areas State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	84	70	57	63	62	66
% Black or African American (race)	7.5	26	38	34	36	27
% Other (race)	8.2	4.7	5.4	2.5	3.0	7.1
% Hispanic (ethic origin)	10	3.6	3.8	2.7	2.9	5.1
Median Household Income (1k 2019$)	67	52	79	84	80	79
% Below Poverty Line	6.8	9.9	2.3	2.5	2.8	5.7
% Below Half the Poverty Line	5.1	7.9	7.2	5.0	5.5	4.9
Total Cancer Risk (per million)	28	49	130	140	130	97
Total Respiratory Risk (hazard quotient)	0.38	0.59	0.77	0.79	0.79	0.72

Figure 6-0: Geographical dispersion of RSEI Toxicity Concentration for Honeywell Geismar– Geismar, LA

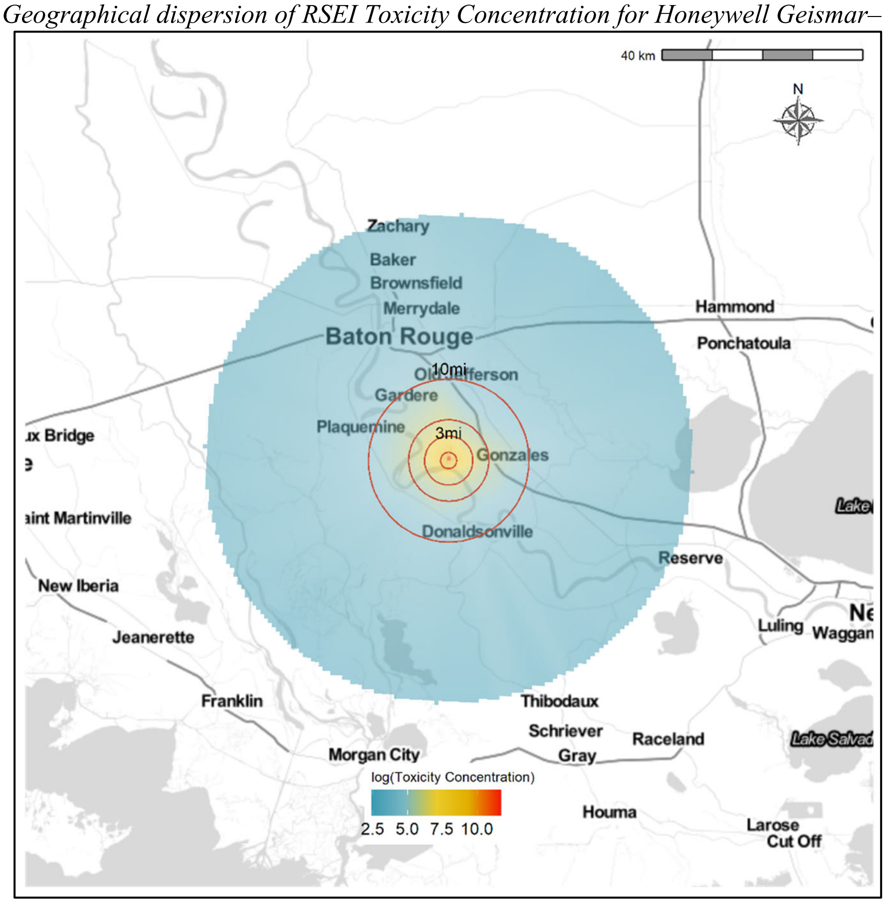


Table 6-7: Community Profiles and NATA Risks for Iofina Chemical Inc. – Covington, KY

	Overall National Average	Overall State Average	Within 1 Mile of HFC Production Facility	Within 3 Miles of HFC Production Facility	Within 5 Miles of HFC Production Facility	Within 10 Miles of HFC Production Facility
% White (race)	72	87	87	70	98	96
% Black or African American (race)	13	8.1	6.6	20	1.0	1.8
% Other (race)	15	5	6.6	10	1.1	1.8
% Hispanic (ethic origin)	18	3.7	9.6	12	2.8	2.0
Median Household Income (1k 2019$)	71	55	62	57	56	54
% Below Poverty Line	7.3	9.5	6.2	10	4.2	5.6
% Below Half the Poverty Line	5.8	7.3	2.9	5.8	6.8	6.0
Total Cancer Risk (per million)	32	31	40	52	33	32
Total Respiratory Risk (hazard quotient)	0.44	0.43	0.46	0.42	1.8	1.2

Figure 6-1: Geographical dispersion of RSEI Toxicity Concentration for Iofina Chemical Inc. – Covington, KY

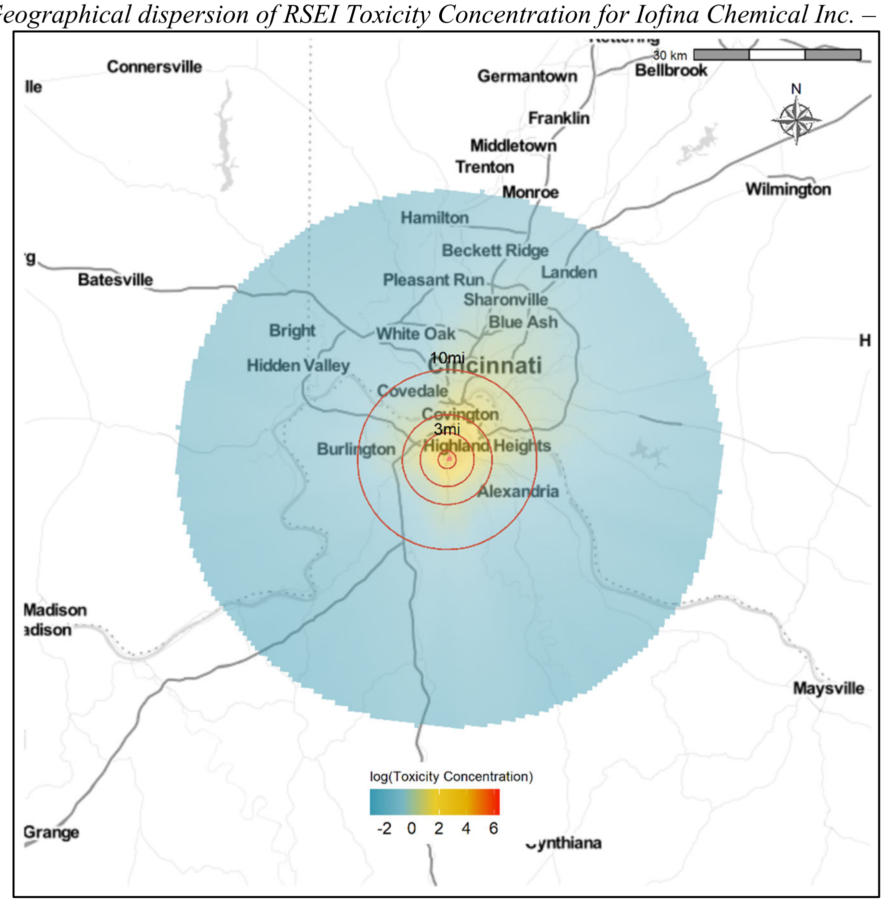
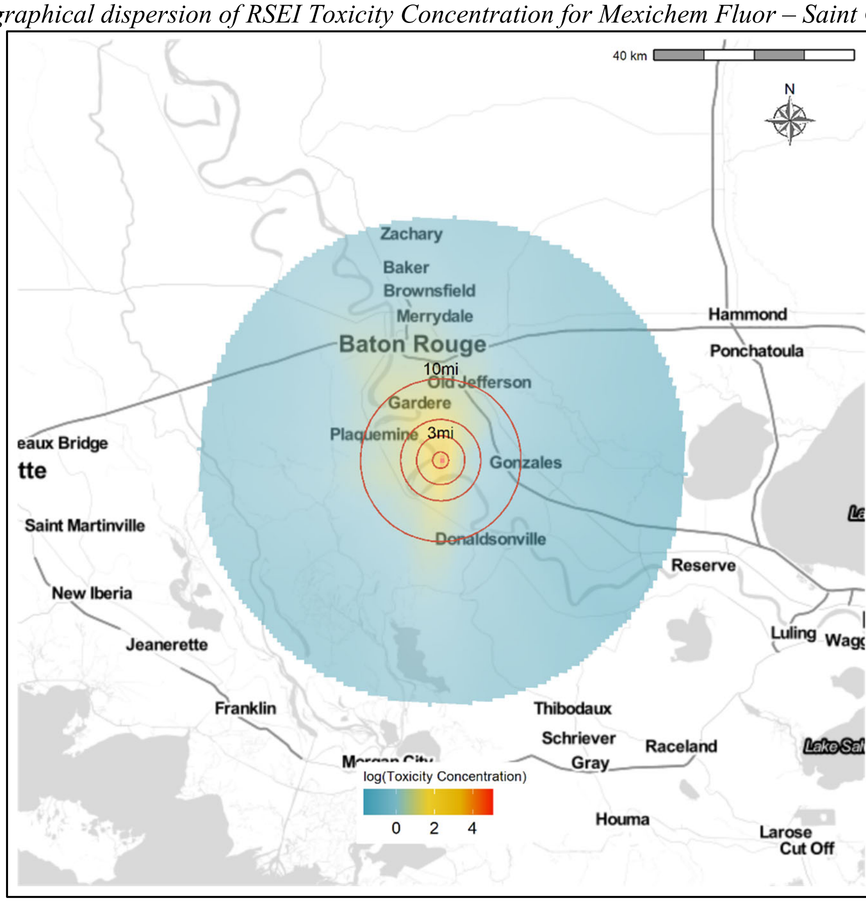


Table 6-8: Community Profiles and NATA Risks for Mexichem Fluor – Saint Gabriel, LA

	Rural Areas National Average	**Rural Areas State Average**	**Within 1 Mile of HFC Production Facility**	**Within 3 Miles of HFC Production Facility**	**Within 5 Miles of HFC Production Facility**	**Within 10 Miles of HFC Production Facility**
% White (race)	84	70	25	55	58	62
% Black or African American (race)	7.5	26	75	42	40	31
% Other (race)	8.2	4.7	0.24	2.6	2.2	7.4
% Hispanic (ethic origin)	10	3.6	4.6	2.6	2.5	5.2
Median Household Income (1k 2019$)	67	52	31	65	78	82
% Below Poverty Line	6.8	9.9	4.6	3.3	2.8	6.2
% Below Half the Poverty Line	5.1	7.9	35	4.4	4.6	5.3
Total Cancer Risk (per million)	28	49	180	140	140	98
Total Respiratory Risk (hazard quotient)	0.38	0.59	0.94	0.83	0.82	0.76

Figure 6-2: Geographical dispersion of RSEI Toxicity Concentration for Mexichem Fluor – Saint Gabriel, LA



6.5 Previous Violations and Enforcement Actions

Tables 6-19 and 6-20 present the number of informal and formal enforcement actions and quarters of non-compliance for each of the eight HFC production facilities under the major statutes for air (CAA), hazardous waste (Resource Recovery and Conservation Act - RCRA), water (Clean Water Act - CWA), and drinking water (Safe Drinking Water Act - SDWA). These data were obtained from EPA's Enforcement and Compliance History Online (ECHO).[144] Note that these enforcement actions are not necessarily specific to the HFC production process. Most of the facilities have between zero and four total enforcement actions One of the two HFC production facilities that have similar cumulative risk profiles for nearby communities compared with the national and state-level rural averages, Chemours – Corpus Christi Plant, has had no enforcement actions under any of these environmental statutes in the last five years.

[144] US EPA. Enforcement and Compliance History Online (ECHO). Available at https://echo.epa.gov/

Table 6-19: Number of Informal and Formal Enforcement Actions in Last Five Years

Facility Name	RCRA		CAA		SDWA		CWA	
	Informal	Formal	Informal	Formal	Informal	Formal	Informal	Formal
Arkema, Inc.			2					
Chemours - El Dorado	3	2	1	1				
Chemours - Corpus Christi Plant								
Chemours - Louisville	2						2	
Daikin America			2				1	
Honeywell - Geismar Complex	1			2				
Iofina Chemical Inc.	2							
Mexichem Fluor Inc.			1					

Source: EPA's Enforcement and Compliance History Online (ECHO). Note: While EPA places a high priority on ensuring the integrity of the national enforcement and compliance databases, some incorrect data may be present due to the large amount of information compiled across multiple streams of data from state, local, and tribal agencies. Known data quality problems are discussed at https://echo.epa.gov/resources/echo-data/known-data-problems

Six of the eight HFC facilities have been in non-compliance with one or more of the major environmental statutes at least once in the last 12 quarters.[145] Non-compliance with the RCRA and CWA has been more common.

Table 6-0: Quarters of Non-Compliance (Out of 12)

Facility Name	Location	RCRA	CAA	SDWA	CWA
Arkema, Inc.	Calvert City, KY		1		
Chemours - El Dorado	El Dorado, AR	12			
Chemours - Corpus Christi Plant	Gregory, TX				
Chemours - Louisville	Louisville, KY				3
Daikin America	Decatur, AL		2		4
Honeywell - Geismar Complex	Geismar, LA	5			10
Iofina Chemical Inc.	Covington, KY	1			
Mexichem Fluor Inc.	Saint Gabriel, LA				

Source: EPA's Enforcement and Compliance History Online (ECHO). Note: While EPA places a high priority on ensuring the integrity of the national enforcement and compliance databases, some incorrect data may be present due to the large amount of information compiled across multiple streams of data from state, local, and tribal agencies. Known data quality problems are discussed at https://echo.epa.gov/resources/echo-data/known-data-problems

6.6 Transition Pathways

Inherent in the design of this allowance allocation and trading program is the goal of transitioning production and consumption of high-GWP HFCs to lower-GWP HFCs and HFC substitutes. Allowances are being allocated as metric tons of exchange value equivalent

[145] Non-compliance in the ECHO database is a "count of the number of quarters, out of the last twelve quarters, in which the permit or site is considered either with violations, in noncompliance (NC) status, or in significant noncompliance (SNC), serious violator, or high priority violation (HPV) status." Non-compliance designations are statute-specific. For example, HPV pertains to the Clean Air Act, SNC pertains to the Clean Water Act or Resource Conservation and Recovery Act, and serious violator pertains to the Safe Drinking Water Act.

(equivalent to metric tons of carbon dioxide equivalent). A company will be able to use those allowances to produce and/or import any of the 18 HFCs regulated under the AIM Act. Depending on the exchange value of each HFC, companies will be able to produce and import larger or smaller quantities of HFCs. To determine the total number of allowances needed, producers and importers must multiply the quantity of the HFC they seek to produce or import, in kilograms, by its exchange value and then divide by 1,000. For example, an importer would need to expend 1.43 allowances to produce one kilogram of HFC-134a (exchange value of 1,430). Given the variation in exchange values, one would need to expend between 0.053 allowances to produce one kg of HFC-152 and 14.8 allowances to produce one kg of HFC-23. This flexibility could result in companies choosing to switch from producing a high-exchange-value HFC to a lower-exchange-value HFC as the number of allowances allocated decreases.

One mechanism for compliance stipulated in the AIM Act is the ability to transfer (or trade) allowances for production and consumption to other companies. Trading mechanisms are a common way to allow facilities subject to regulatory requirements greater flexibility in when and how they comply, and thereby potentially reduce the social cost of the policy while still delivering comparable aggregate improvements in environmental quality in general (relative to a more prescriptive regulatory design). However, policies based on trading mechanisms can result in heterogeneous changes in emissions across facilities, raising equity concerns.[146] The potential for trading to increase pollution, or at least deliver fewer emission reductions, in some communities compared with others can have distributional implications. For example, if facilities

[146] U.S. EPA. *Guidance on Considering Environmental Justice During the Development of Regulatory Actions*. May 2015; Banzhaf, Spencer, Lala Ma, and Christopher Timmins. "Environmental justice: The economics of race, place, and pollution." *Journal of Economic Perspectives*, 2019.; Cushing L, Blaustein-Rejto D, Wander M, Pastor M, Sadd J, Zhu A, et al. "Carbon trading, co-pollutants, and environmental equity: Evidence from California's cap-and-trade program (2011–2015)." *PLoS Med* 15(7), 2018, e1002604; Hernandez-Cortes, D. and Meng, K.C.. "Do environmental markets cause environmental injustice? Evidence from California's carbon market" 2020 (No. w27205), NBER; Mansur, E. and Sheriff, G., "On the measurement of environmental inequality: Ranking emissions distributions generated by different policy instruments." 2021.

located in low-income or minority communities purchase allowances (i.e., the right to continue polluting a certain amount) from other facilities outside of these communities instead of reducing emissions, this could result in an uneven distribution of the benefits of the policy, and in some cases cause or exacerbate hot spots for elevated chemical emissions. It is also possible that compliance with the regulation results in changes in the emissions of other pollutants released by a facility and that these changes are unevenly distributed across communities in ways that impact low-income and minority communities differentially. Note, however, that trading could have the opposite effect if allowances are purchased by facilities outside of the disadvantaged communities (e.g., more modern and efficient facilities with lower marginal abatement costs). It is also possible the HFC phasedown schedule prescribed by Congress—with a 10 percent reduction by 2022, a 40 percent reduction by 2024, a 70 percent reduction by 2029, an 80 percent reduction by 2034 and an 85 percent reduction by 2036—may reduce the potential for a facility to increase emissions above current levels for a prolonged period. Additionally, this rule affects a small number of entities through a distinct allocation program, and therefore EPA is not signaling through this analysis that any of these findings would be broadly applicable.

This rule under the AIM Act phases down the production and consumption of the regulated HFCs identified in Table 1-1. The annual cap on allowances is determined by reducing exchange value-weighted production and consumption relative to a baseline. This mechanism is intended to incentivize the production and consumption of lower-exchange-value (measured in terms of global warming potential in CO_2 equivalents) HFCs instead of higher-exchange-value HFCs. While this does not account for the potential localized effect, it does give some insight into what substitutes might be produced. Lower-exchange-value alternatives to high-GWP HFCs include other HFCs, hydrofluoroolefins (HFOs), hydrocarbons (HCs), carbon dioxide, and ammonia, among other substitutes.

Allowances are allocated at the company, not the facility level. A company with multiple facilities such as Chemours can use them across its facilities or to cover imports. In addition, EPA anticipates that many of the existing HFC production facilities will produce substitutes. This makes it difficult to predict how much trading will occur and between which companies (i.e., who is likely to be a buyer or seller of allowances). Nor is EPA able to identify which substitutes, in what quantities, or where substitutes for high-exchange-value HFCs will be produced. Taken together, these factors limit the ability to evaluate the environmental justice implications of trading under this rule. EPA intends to collect and release allowance holders' facility-level chemical-specific HFC production data as part of the reporting requirements of this rule. This information will be helpful for monitoring changes in HFC production over time at each of the eight production facilities.

Table 6-21 lists the anticipated substitutes for each of the HFCs subject to the rule and their respective exchange values. Which substitutes are likely to be used to replace a particular HFC or HFC blend depend on the application. For example, HFC-134a has many uses including as a refrigerant, aerosol propellant, and foam-blowing agent. For each of these uses, the list of alternatives will vary. In addition, due to the long time period over which HFCs will be phased down (15 years), the substitute used could vary over the life of the program.[147] Both of these aspects of the program further complicate predictions of which and for how long different substitutes will be produced.

[147] For example, some lower-exchange-value HFCs may be used as substitutes for higher-exchange-value HFCs in the early years of the program instead of low-GWP HFC substitutes, such as HFOs or non-fluorinated refrigerants.

Table 6-1: Possible substitutes for HFCs produced in the United States and subject to the rule

HFC Subject to the Rule	Exchange Value	Substitutes †
HFC-134a	1,430	HFO-1234yf, HFO-1234ze
HFC-125	3,500	HFC-32, HFO-1234yf, NH_3
HFC-32	675	HC, CO_2
HFC-152a	124	HFO-1234yf, HFO-1234ze, HC
HFC-245fa	1,030	Cyclopentane, HCFO-1233zd(*E*)
HFC-143a	4,470	HFC-32, HFC-134a, HFO-1234yf, HFO-1234ze, CO_2, NH_3
HFC-236fa	9,810	C6-perfluoroketone, dry chemical, 2-BTP (in aircraft only)
HFC-227ea	3,220	C6-perfluoroketone, dry chemical, 2-BTP (in aircraft only)

†HFCs and their substitutes are often used as components of blends. Substitutes listed in this table may be constituents of blends used to replace HFCs rather than chemical-for-chemical replacements.

Some substitutes or their feedstocks, catalysts, or byproducts may have human health effects associated with their release into the environment, at least in the near term. Many of the lower-exchange-value HFCs rely on toxic chemicals as feedstocks. For example, HFC-32 (CH_2F_2) production can start with chloroform ($CHCl_3$), a known human carcinogen, which in some production processes is first converted to HCFC-22 through fluorine substitution for two of its chlorine atoms, and then to HFC-32 by substituting a hydrogen atom for its last chlorine. While the phasedown of high-exchange-value HFCs will lower the use of some toxic chemicals, the increase in production of other HFCs is anticipated to increase the use of others. The net effect on local air emissions is therefore uncertain.

HFOs have very low GWPs (significantly less than the exchange value threshold of 53 for adding HFCs to the list of regulated HFCs). They also have double bonds that make the molecules more susceptible to chemical breakdown in the atmosphere. This leads to HFOs having shorter atmospheric lifetimes. The transition from HFCs to HFOs or blends containing HFOs is expected for many applications to reduce the impacts of climate change, including on vulnerable communities. However, the shorter atmospheric lifetimes of HFOs also means that any impacts from their breakdown products are more likely to have local effects where they are released, although not necessarily where they are produced.[148]

One breakdown byproduct of certain HFOs that has been studied as a potential source of adverse health and environmental impact is trifluoroacetic acid (TFA). TFA is also a breakdown product of the most widely used HFC, HFC-134a. HFO-1234yf produces about three times as much TFA per molecule as HFC-134a, and the TFA produced is more contained in the local area near the release of the HFO, so a transition from HFC-134a to HFO-1234yf may lead to increased environmental concentrations of TFA in some areas. EPA's SNAP program considered the potential risk associated with increased concentrations of TFA when HFO-1234yf was first listed as acceptable subject to use conditions in motor vehicle air conditioners. It cited myriad studies that concluded that the additional TFA from HFO-1234yf did not pose a significant additional risk, even if it were assumed to be used as the only refrigerant in all refrigeration and air conditioning equipment (76 FR 17492-17493; March 29, 2011). More recently, the World Meteorological Organization concluded that "[t]here is increased confidence that [TFA] produced from degradation of HFCs, HCFCs, and HFOs will not harm the environment over the next few decades" while also calling for periodic reevaluation of this conclusion.[149]

Production of HFOs uses toxic chemicals as feedstocks or catalysts and produces toxic chemicals as byproducts. Table 6-22 lists the chemicals used as feedstocks or catalysts or produced as a byproduct in the production of HFOs. All of the chemicals on this list are also used in the production of HFCs. Given there are typically multiple pathways to produce HFCs

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148 This is in contrast with the products formed when HFCs break down, which primarily happens in the stratosphere where they are well mixed, leading to a global distribution of breakdown products. HFCs can have an atmospheric lifetime of 1.5 years to over 200 years, whereas HFOs have an atmospheric lifetime of less than 90 days. See https://www.fluorocarbons.org/wp-content/uploads/2020/07/2020_07_27_Fluorocarbon-Molecules-environmental-properties-and-main-applications-2020-July.pdf.

149 World Meteorological Organization (WMO), Executive Summary: *Scientific Assessment of Ozone Depletion: 2018*, World Meteorological Organization, Global Ozone Research and Monitoring Project – Report No. 58, 67 pp., Geneva, Switzerland, 2018. Available at https://ozone.unep.org/sites/default/files/2019-04/SAP-2018-Assessment-report-ES-rev%20%281%29.pdf.

and their substitutes, the impact of transitioning from HFCs to HFOs on toxic releases will depend upon which method is currently being used to produce HFCs and which method companies will use to produce HFOs or other HFC substitutes.

Table 6-2: Toxic Chemicals in the TRI used as a feedstock or catalyst or released as a byproduct of HFO production

Chemical Name	HFC Substitutes	Health Effects[150]
Antimony Compounds*	HFO-1234yf, HFO-1234ze	Metabolic, Other Systemic
Carbon tetrachloride	HFO-1234yf, HFO-1234ze	Cancer, Developmental, Hepatic, Reproductive
Chlorine	HFO-1234yf, HFO-1234ze	Ocular, Respiratory
Chloroform	HFO-1234yf, HFO-1234ze	Cancer, Developmental, Hepatic, Renal, Respiratory
Chromium Compounds*	HFO-1234yf, HFO-1234ze	Cancer, Gastrointestinal, Hematological, Respiratory
Hydrochloric acid	HFO-1234yf, HFO-1234ze	Respiratory
Hydrogen fluoride	HFO-1234yf, HFO-1234ze	Ocular, Respiratory
Methyl bromide (Bromomethane)	HFO-1234yf, HFO-1234ze	Cancer, Hepatic, Renal
Methyl chloride (Chloromethane)	HFO-1234yf, HFO-1234ze	Hepatic, Neurological
Nickel Compounds*	HFO-1234yf, HFO-1234ze	Body Weight, Cancer, Hematological, Immunological, Respiratory

Notes: * denotes toxic chemicals that are used as a catalyst in HFO production.

Hydrocarbons such as propane and isobutane, and blends containing them, also may be used as substitutes for HFC refrigerants in certain refrigeration and air-conditioning applications, and these and other hydrocarbons (e.g., cyclopentane) are used as alternatives to HFCs as foam-blowing agents. Unlike the HFCs they replace, these hydrocarbons are highly flammable, and the transition from HFCs to hydrocarbons could conceivably increase risks of burns to users of products containing them or workers producing or servicing those products. In practice, such potential risks are addressed through regulations and standards limiting where hydrocarbons can be used, the amount used, and precautionary equipment design and procedures. Given the much larger use of hydrocarbons for purposes other than as substitutes in end uses that use HFCs, any

[150] Chemical health effects information comes from the Occupational Safety and Health Administration (OSHA) Carcinogen List and the TRI-CHIP datasets (https://www.epa.gov/toxics-release-inventory-tri-program/tri-chemical-hazard-information-profiles-tri-chip).

change in the volume of hydrocarbons produced due to this rule would have no discernible effect on human health.

A potential risk to people living or working near emissions of hydrocarbons that differs from the risks from the HFCs they replace is the formation of ground-level ozone. EPA's SNAP program assessed this and other risks, and in 2014 (79 FR 29682) and 2015 (80 FR 19453) exempted several hydrocarbons from refrigerant venting prohibitions. In those 2014 and 2015 actions, EPA determined that the venting, release, or disposal of such hydrocarbon refrigerant substitutes in the specified end uses does not pose a threat to the environment, considering both the inherent characteristics of these substances and the limited quantities used in the relevant applications. EPA further concluded that other authorities, controls, or practices that apply to such refrigerant substitutes help to mitigate environmental risk from the release of those hydrocarbons. In 2016, EPA listed as unacceptable the use of a certain HC (propylene or R-1270) and an HC blend (R-443A) in residential and light commercial AC and heat pumps, centrifugal chillers and positive displacement chillers, and cold storage. The SNAP program determined that their use in these applications may negatively impact local air quality (80 FR 42870).

Carbon dioxide can substitute for most refrigerants and is gaining market penetration in some end uses. When used as a refrigerant, it does not pose any health risks due to direct exposure. While releases of very large amounts in enclosed spaces could displace oxygen and lead to asphyxiation, the amount used in a refrigerant circuit is small enough that any such risk is negligible. The production of CO_2 for uses replacing HFCs does not use or emit any chemicals that are hazardous.

Ammonia is mainly used as a substitute for HFCs in cold food storage and processing in place of the blend R-404A, which contains HFC-143a, HFC-125, and a small amount of HFC-134a. Ammonia has excellent refrigerant properties, a characteristic pungent odor, no long-term atmospheric risks, and low cost. It is, however, moderately flammable and toxic. Ammonia may be used safely if existing OSHA and ASHRAE standards are followed. It is currently used in locations where public exposure risk is minimal, such as cold-storage warehouses. Building codes limit where and how ammonia may be used as a refrigerant. For example, these systems are typically split systems so that the refrigerant lines that contain ammonia do not run through enclosed spaces. Ammonia is produced in large amounts to produce fertilizers and as a feedstock for many chemical syntheses. Therefore, the amount of ammonia potentially produced to be used as a substitute for HFCs is very small compared with total ammonia production, and any change in risks to human health due to increases in ammonia production due to this rule would be negligible by comparison.

6.7 Conclusion

Overall, this rule will reduce GHG emissions, which will benefit populations that may be especially vulnerable to damages associated with climate change. However, how producers transition from high-GWP HFCs will drive changes in future risk for communities living near HFC production facilities due to the use of feedstock chemicals that have local effects when released into the environment. The environmental justice analysis demonstrates that:

- The characteristics of the community near HFC production facilities are heterogeneous;
- Total baseline cancer risk and total respiratory risk from air toxics (not all of which stem from HFC production) varies, but is generally higher, and in some cases much higher close to an HFC production facility;

- Higher percentages of low-income and Black or African American individuals live near HFC production facilities compared with the overall or rural average at the national level;
- It is not clear the extent to which these baseline risks are directly related to HFC production, but some of HFC feedstocks and byproducts are toxic; and
- Multiple HFC alternatives are available, many of which have toxic profiles for the chemicals used as feedstocks in their production.

It is also possible the HFC phasedown schedule prescribed by Congress—with an 85 percent reduction by 2036—may reduce the potential for a facility to increase emissions above current levels for a prolonged period. Given limited information regarding which substitutes will be produced where, it is unclear to what extent this rule will impact baseline risks from hazardous air toxics for communities living near HFC production facilities.[151] EPA intends to collect and release allowance holders' facility-level chemical-specific HFC production data as part of the reporting requirements of this rule. This information will be helpful for monitoring changes in HFC production overtime at each of the eight production facilities.

[151] Statements made in this chapter on the environmental justice concerns of the AIM Act draw support from the following citations: Banzhaf, Spencer, Lala Ma, and Christopher Timmins. 2019. Environmental justice: The economics of race, place, and pollution. Journal of Economic Perspectives; Hernandez-Cortes, D. and Meng, K.C., 2020. Do environmental markets cause environmental injustice? Evidence from California's carbon market (No. w27205). NBER; Hu, L., Montzka, S.A., Miller, B.R., Andrews, A.E., Miller, J.B., Lehman, S.J., Sweeney, C., Miller, S.M., Thoning, K., Siso, C. and Atlas, E.L., 2016. Continued emissions of carbon tetrachloride from the United States nearly two decades after its phaseout for dispersive uses. Proceedings of the National Academy of Sciences; Mansur, E. and Sheriff, G., 2021. On the measurement of environmental inequality: Ranking emissions distributions generated by different policy instruments.; U.S. EPA. 2011. Plan EJ 2014. Washington, DC: U.S. EPA, Office of Environmental Justice.; U.S. EPA. 2015. Guidance on Considering Environmental Justice During the Development of Regulatory Actions. May 2015.; USGCRP. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC.

Chapter 7: Uncertainty

This RIA provides the Agency's estimate of the costs and benefits of this rulemaking. To address uncertainty in these estimates, it also provides a sensitivity analysis to show other plausible though less likely values for costs and benefits to inform the public.

EPA has modeled its estimate of transition from high-GWP HFCs using longstanding, peer-reviewed models. However, the Agency notes uncertainty concerning the speed with which transition may happen. For example, during the phaseout of ODS, U.S. production and consumption were regularly below the amounts allocated by EPA, indicating transition to alternatives may have occurred faster than expected.[152] Additional discussion of uncertainties and sensitivity analysis around the estimated costs and benefits of the HFC phasedown are discussed in Chapters 3 and 4.

EPA has considered the costs and benefits associated with transitioning to the use of refillable cylinders in this document. This analysis addresses the costs associated with replacing the cylinders themselves and the costs associated with the change in the procedure for handling of refillable cylinders (i.e., returning the cylinders to be refilled). However, it has not considered the cost of convenience associated with such a prohibition for the final user of the HFCs (e.g., an AC service contractor). For example, we have not assessed the value of the convenience associated with not returning a refillable cylinder to a wholesaler or distributor. We have also not assessed a cost associated with the time needed to return an empty cylinder, as the Agency expects the individual would return the cylinder to the same location where they would purchase a full cylinder, likely negating extra time needed compared with current practices. Contractors complying with the requirement under CAA section 608 to recover refrigerant from appliances

[152] UNEP Ozone Secretariat. United States Country Data. Available online at https://ozone.unep.org/countries/profile/usa

containing HFC refrigerants routinely bring recovery cylinders (a type of refillable cylinder used by contractors to recover refrigerant from appliances for reclamation) back to wholesalers and distributors, indicating this change in practice would have limited effect on a contractor's time and convenience. More discussion on the costs is included in the preamble (section IX.B) and in this document.

EPA identified two areas of uncertainty associated with safety-related risks. The first is related to potential risks associated with changes in HFC and substitutes production, in particular how localized impacts may be affected as facilities that currently produce HFCs switch to producing lower-GWP HFCs, substitutes for HFCs, or other unrelated chemicals or products. EPA anticipates that many of the existing HFC production facilities will produce lower-GWP HFCs and substitutes. In addition, there may be other facilities that produce lower-GWP substitutes and increase their production. EPA is not able to identify which lower-GWP HFCs and substitutes, in what quantities, or where the lower-GWP HFCs and substitutes for high-exchange-value HFCs will be produced. This uncertainty is partly due the fact that the HFCs and substitutes ultimately produced will be determined by the transitions from those HFCs that have the lowest associated marginal cost of abatement and where those lower-GWP HFCs and substitutes are produced. This can result in heterogeneous changes in emissions across facilities. There is uncertainty associated with the HFCs and substitutes individual facilities will choose to produce. These uncertainties and the potential risks are discussed in the environmental justice analysis in Chapter 6 of the RIA and in section IV of the final rule.

The second area relates to the safety of certain alternative technologies that may replace HFCs. Some lower-GWP HFCs and HFC substitutes have health and safety considerations (e.g., flammability and toxicity). Some substitutes (e.g., transcritical CO_2 systems) run at higher pressures, which require additional safety features. In this analysis, the Agency has not considered costs associated with the improper use (e.g., from accidents) of the low-GWP HFCs and substitutes. It should be noted that this rule does not dictate which HFCs or HFC substitutes must be used; however, EPA anticipates that it may where appropriate consider safety as a factor when the Agency implements other subsections of the AIM Act. For example, under subsection (h), Management of Regulated Substances, Congress directed EPA to promulgate regulations to control certain practices, processes, or activities "[f]or purposes of maximizing reclaiming and minimizing the release of a regulated substance from equipment and ensuring the *safety* of technicians and consumers" (emphasis added). Under subsection (i), EPA may "restrict, fully, partially, or on a graduated schedule, the use of a regulated substance in the sector or subsector in which the regulated substance is used." Both (i)(4) and (i)(5) list factors for the Agency to consider and in both instances safety is listed.

Further, the transition scenarios modeled in Chapters 3 and 4 are based on use of alternatives that have already been reviewed by EPA. Under the SNAP program, which EPA implements under section 612 of Title VI of the CAA, EPA has evaluated the impact to human health and the safety of alternatives through a comparative risk analysis of available and potentially available alternatives. A guiding principle is that alternatives listed as acceptable under SNAP must pose no higher risk than other alternatives in the same end use, but do not have to be risk-free. EPA engages with industry and standards-setting bodies and has often required conditions on use of alternatives to address risks such as flammability and toxicity, deferring to other environmental regulations or safety standards where these are available. In addition, EPA has and continues to provide information and support training to enhance the safe use of alternatives. As such, while EPA has not assessed safety in this RIA, the Agency is relying on transitions to alternatives that it has evaluated previously and could further evaluate in future under other subsections of the AIM Act.

An additional area of uncertainty relates to the effect that this rule could have on the industry composition. By design, the rule will produce changes in the industries that use HFCs (e.g., refrigeration and air conditioning, foam blowing, aerosols, solvents, and fire suppression) and this could potentially affect the industry composition and concentration. For example, to the degree that there are economies of scale associated with producing or servicing equipment using lower-GWP substitutes, the rule could affect the industry concentration. EPA does not expect this to be a significant effect, but the impact has not been modeled in this analysis.

There are a number of limitations and uncertainties associated with the SC-HFCs estimates. In particular, there are uncertainties surrounding the discount rate and the parameters set by model developers in the IAMs. More discussion of these uncertainties can be found in Chapter 4 and Appendix A.

Chapter 8: Appendices

Appendix A: Uncertainty Surrounding the Social Costs of Hydrofluorocarbons

The U.S. Government has released a series of technical guidance documents covering the social cost of greenhouse gases (SC-GHGs) (IWG 2010, IWG 2013, IWG 2016a, IWG 2016b, IWG 2021). The estimates of the social cost of hydrofluorocarbons (SC-HFCs) presented in this analysis are estimated in a way that is consistent with the assumptions and methods used in developing the U.S. Government's SC-GHGs.

Given the consistency in underlying modeling methods and inputs, the SC-HFC estimates presented above share many of the same uncertainties and limitations as the SC-GHG estimates. Thus, the estimates of the SC-HFCs that are presented in Chapter 4 and throughout this analysis should be updated over time to reflect increasing knowledge of the science and economics of climate impacts. A number of areas where additional research is needed are discussed in the February 2021 Technical Support Documentation produced by the Interagency Working Group (IWG 2021). Tables A-1 through A-10 present the quantified sources of uncertainty in the models that reflect uncertainty in key model parameters such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. For presentational purposes, we present the distribution of estimates in each model at the 3 percent constant discount rate for only 2020 emissions. As discussed in the 2021 TSD, there are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates.

Table A-1: Social Cost of HFC-32, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	38383	27388	43848	2784	6174	16391	45241	101492	234450
DICE 2010	50000	29431	25534	19375	9029	11792	18103	36881	58996	74821
FUND 3.8	50000	41604	35440	29556	4003	10871	22855	53403	93244	141267
PAGE 2009	50000	44114	19633	66304	2083	3853	9430	47333	178412	330605

Table A-2: Social Cost of HFC-125, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	210912	151188	237804	15748	34971	93220	243634	551979	1343553
DICE 2010	50000	172564	151108	93942	54784	71064	108206	215129	339448	436400
FUND 3.8	50000	201353	171239	131486	23785	55421	111083	257957	447918	656628
PAGE 2009	50000	258879	118288	373879	11442	21390	54996	286974	1040381	1872973

Table A-3: Social Cost of HFC-134a, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	87120	62186	99408	6344	14212	38001	101275	228428	550050
DICE 2010	50000	68790	60057	40978	21772	28196	42876	85750	135422	172230
FUND 3.8	50000	88426	75264	60015	8486	23743	48569	113221	197862	296962
PAGE 2009	50000	104152	46730	154090	4802	8844	22071	113398	421061	768346

Table A-4: Social Cost of HFC-143a, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	267249	192226	298666	20034	44866	118887	307981	699660	1702727
DICE 2010	50000	225143	197421	119713	71080	92309	141259	280733	443970	580417
FUND 3.8	50000	242840	206464	156443	32368	68708	134309	312041	537334	779650
PAGE 2009	50000	333869	154936	471394	14089	27087	71409	374169	1339377	2362288

Table A-5: Social Cost of HFC-152a, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	5360	3816	6642	390	856	2271	6349	14162	32471
DICE 2010	50000	4072	3515	2961	1237	1618	2489	5100	8184	10387
FUND 3.8	50000	5933	5061	6111	591	1545	3262	7609	13261	20021
PAGE 2009	50000	6074	2700	9151	287	533	1303	6497	24622	45650

Table A-6: Social Cost of HFC-227ea, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	193090	138495	217520	14335	32063	85467	222676	506009	1232236
DICE 2010	50000	159422	139514	88009	50452	65798	100115	198675	312450	401960
FUND 3.8	50000	181624	154395	118601	21595	50298	100148	233006	404090	591709
PAGE 2009	50000	238275	109369	341923	10392	19604	50652	264846	956626	1716412

Table A-7: Social Cost of HFC-236fa, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	635692	454822	705090	50359	114135	282708	726496	1671593	4142737
DICE 2010	50000	545929	483561	273010	167096	220460	343544	687400	1085993	1381734
FUND 3.8	50000	522308	446286	325360	84883	154784	292392	671301	1144277	1609818
PAGE 2009	50000	839625	410362	1118772	33479	67840	186237	974955	3321009	5503160

Table A-8: Social Cost of HFC-245fa, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	61301	43753	69919	4439	9923	26397	71960	161391	378564
DICE 2010	50000	47402	41290	29633	14737	19225	29352	59358	94384	119785
FUND 3.8	50000	65008	55372	44975	5973	17098	35664	83434	145722	219892
PAGE 2009	50000	71497	31872	107037	3353	6188	15223	77015	289208	532507

Table A-9: Social Cost of HFC-43-10mee, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	100136	71417	114419	7330	16347	43766	116228	262543	634276
DICE 2010	50000	79657	69334	49427	25083	32649	49594	99071	156397	198441
FUND 3.8	50000	100487	85559	67656	9803	27066	55235	128658	224924	334200
PAGE 2009	50000	120275	54114	177316	5508	10166	25486	131187	485649	885317

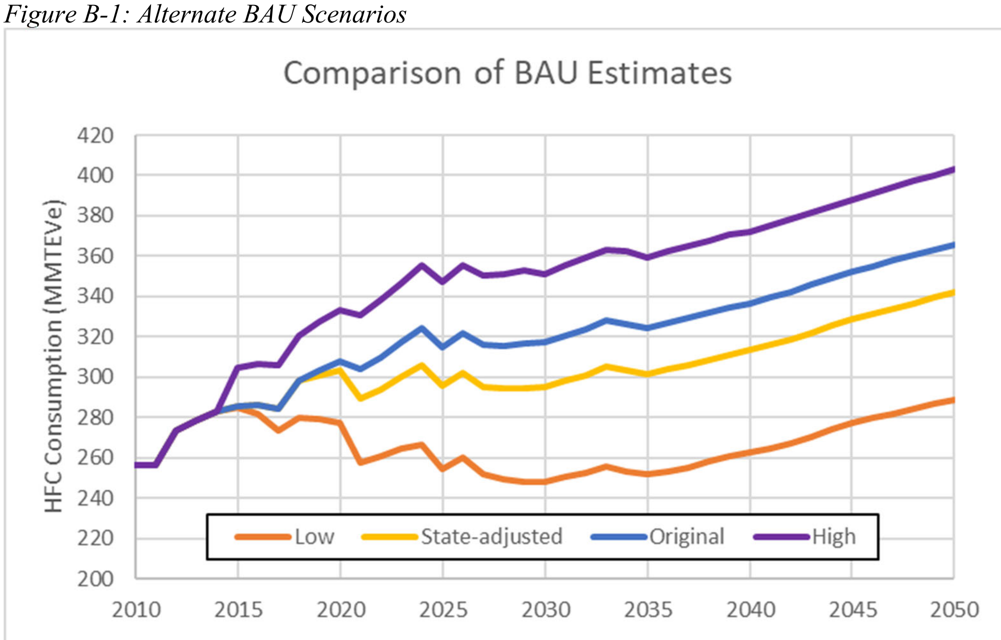
Table A-10: Social Cost of HFC-23, 2020 Emissions, 3% Discount Rate

Model	runs	mean	med.	s.d.	1.0%	5.0%	25.0%	75.0%	95.0%	99.0%
All	150000	965975	690741	1063974	75802	173049	428290	1106246	2566380	6222984
DICE 2010	50000	826055	732965	408044	250613	332564	520176	1047582	1638589	2058718
FUND 3.8	50000	790808	676072	491344	131311	235405	443188	1016372	1732025	2435343
PAGE 2009	50000	1282958	626031	1687712	50098	100634	283013	1512706	5016490	8354092

Appendix B: Alternative BAUs, State Actions

As stated in the report, this RIA relied in part on EPA's Vintaging Model to estimate current and future HFC consumption under a BAU scenario and EPA's analysis of abatement options that could be implemented in response to the AIM Act. As a sensitivity analysis, we discuss in this Appendix three alternative BAU scenarios displayed in Figure B-1. The Low and State-adjusted BAUs make certain assumptions related to EPA regulations issued in 2015 and 2016 under the SNAP program (see SNAP Rules 20 and 21).[153] The High BAU scenario assumes that the growth of all end uses is higher than in the original BAU.

Figure B-1: Alternate BAU Scenarios



B.1 SNAP Rules

The EPA's SNAP program requires EPA to evaluate substitutes for ODS and generates lists of acceptable and unacceptable substitutes for end uses within each of the major industrial use sectors. In 2015 and 2016, EPA issued two rules (SNAP Rules 20 and 21) that changed

[153] Available at https://www.epa.gov/snap/snap-regulations#Rules.

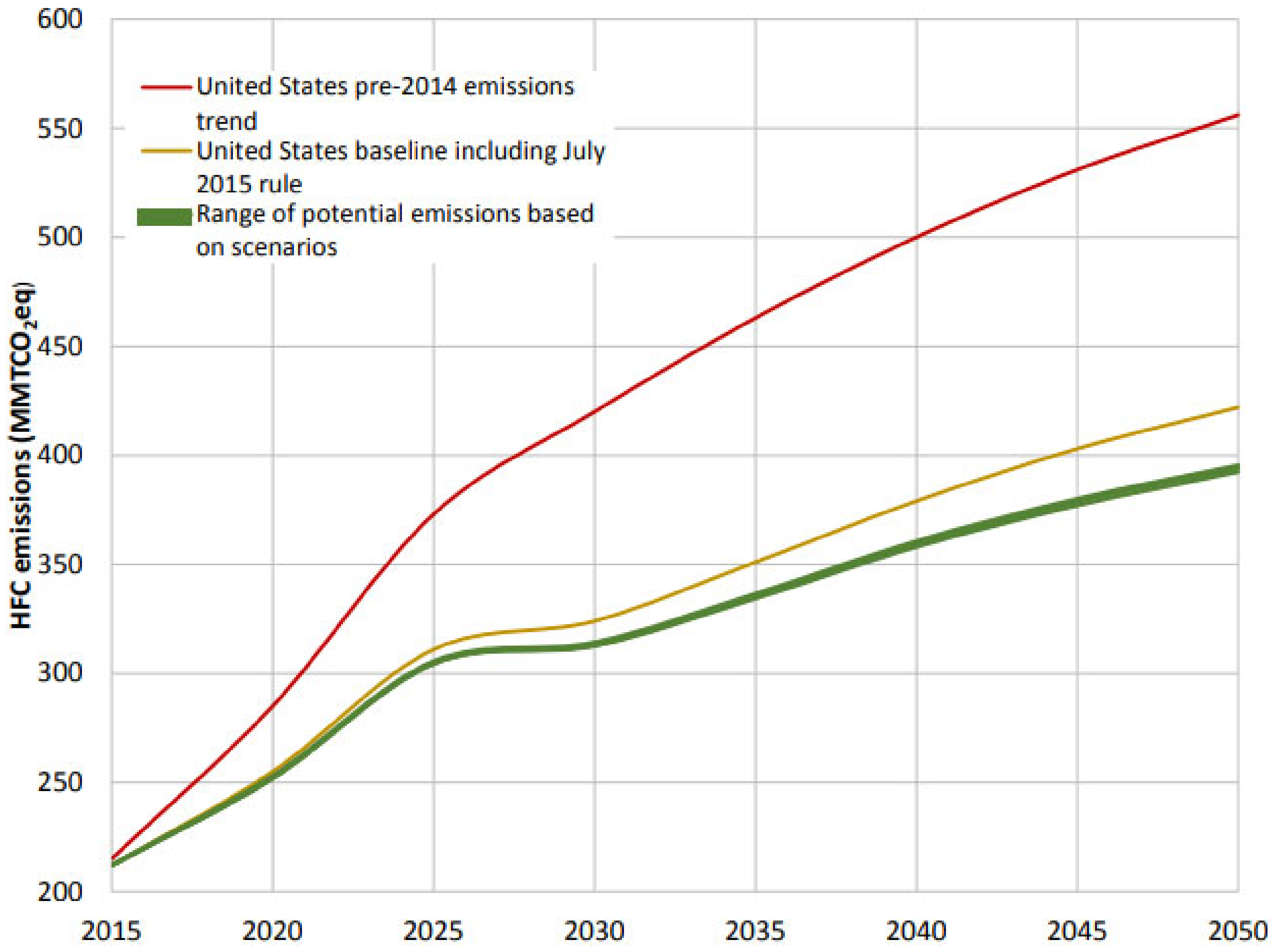
listings under SNAP for certain HFCs and blends from acceptable to unacceptable in the refrigeration and air conditioning, foam blowing, and aerosol propellant sectors. These rules were designed with a considerably narrower scope compared with the economy-wide phasedown of HFC production and consumption being finalized in this rule.[154] As discussed in section B.4 below, there were also state-level actions in a few states since 2015 that were similar in many respects to the federal SNAP rules and thus also were narrower than the HFC phasedown rule being finalized.

When developing SNAP Rules 20 and 21, EPA estimated the likely effects the rules would have on HFC emissions for the entire United States including territories and all 50 states.[155] Under these scenarios, the trajectory of HFC emissions is reduced significantly, but was still increasing. Figure B-2 shows the emissions scenarios and HFC emissions baseline as calculated for SNAP Rules 20 and 21, as well as what would have been the likely outcome if the rules were implemented on a national basis.

[154] Under CAA section 612, EPA issued a final rule on July 20, 2015, which, among, other things, changed listings under the SNAP program for certain HFCs and blends from acceptable to unacceptable in various end-uses in the aerosols, refrigeration and air conditioning, and foam blowing sectors. After a challenge to the 2015 rule, the U.S. Court of Appeals for the D.C. Circuit ("the court") issued a partial vacatur of the 2015 rule "to the extent [it] requires manufacturers to replace HFCs with a substitute substance," and remanded the rule to EPA for further proceedings. Later, the court issued a similar decision on portions of a similar CAA section 612 final rule issued December 1, 2016. *See Mexichem Fluor, Inc. v. EPA, 760 F. App'x 6 (D.C. Cir. 2019) (per curiam).*

[155] See the technical support document analyzing climate benefits for SNAP rule 21 at https://www.regulations.gov/document/EPA-HQ-OAR-2015-0663-0008

Figure B-2: Emissions scenarios from SNAP Rules 20 and 21[156]



B.2 Counterfactual BAU Scenario with Lower HFC Consumption

The Low BAU scenario utilizes the version of the Vintaging Model[157] used in EPA's 2019 Non-CO_2 Greenhouse Gas report.[158] The model used in that report included several developments compared to the model used in the base case for this RIA described in Chapter 3. The most important feature in that model is that it assumed certain transitions occurred in the BAU to comply with EPA regulations issued in 2015 and 2016. Although those regulations have been partially vacated and remanded to the EPA, several states have included similar

[156] Ibid.
[157] U.S. Environmental Protection Agency. 2017. Vintaging Model. Version VM IO file_v4.4_02.22.17.xls
[158] U.S. EPA. *Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation*. September 2019. EPA Report EPA-430-R-19-012. Available at https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.

requirements in their state regulations (see section B.4 below), albeit with later compliance dates in most cases. This alternative BAU model assumes that in the absence of this rulemaking, industries would comply with the SNAP rules and hence supply the same products to the rest of the country as are required by the state-level actions and under the timeframe set forth in the 2015 and 2016 regulations.

Use of such a BAU would not be expected to influence the calculated HFC production and consumption baselines, as those calculations rely on data from years before the SNAP regulations and state-level actions took effect. Therefore, for this analysis we use the same baseline as calculated in section 3.3 for our base case analysis, i.e., 304 MMTEVe.

To represent compliance with the AIM Act under this alternative Low BAU, we utilize the same abatement options as presented in the main analysis. Many of the options are similar to or exactly the same as the actions assumed in the Low BAU to comply with the 2015 and 2016 regulations, and therefore do not achieve any additional abatement. Abatement options within end uses that were not covered by the SNAP regulations would apply and their full abatement and savings or costs are included in this sensitivity analysis.

Under the base case cost estimate, total savings using the Low BAU are higher than those using the original BAU. Because there is lower consumption in this BAU, the level of abatement to achieve compliance is less, and so the model does not assume as much need for abatement from higher-cost options. This base case estimate is presented in Table B-1, as well as the estimates using the lower and higher cost estimates from the sensitivity analyses. In our higher cost sensitivity analysis (presented in the main report), we assume that all options determined to have savings potential are instead cost-neutral. In that sensitivity analysis, the total abatement costs through 2036 to reach the AIM Act phasedown requirements are approximately one-third lower under this alternate BAU compared to the original BAU. In the lower cost sensitivity analysis, the cost savings technologies were assumed to be the same, but the costs of all other options were assumed to be half of the engineering analysis cost. For the same reason as the base case estimate, the Low BAU result in higher savings overall for the lower sensitivity analysis.

*Table B-1: Estimated Cumulative Costs of Abatement**

Year	Consumption Cap	Original BAU			Low BAU		
		Base Case Estimate	*Lower*	*Higher*	*Base Case Estimate*	*Lower*	*Higher*
2022	90% (273 MMTEVe)	($0.5 B)	($0.5 B)	$0.1 B	($0.5 B)	($0.5 B)	$0.0 B
2024	60% (182 MMTEVe)	($1.2 B)	($1.7 B)	$1.0 B	($1.8 B)	($2.0 B)	$0.4 B
2029	30% (91 MMTEVe)	($2.0 B)	($5.7 B)	$7.3 B	($5.6 B)	($7.7 B)	$4.2 B
2034	20% (61 MMTEVe)	($6.4 B)	($12.7 B)	$12.6 B	($11.8 B)	($16.0 B)	$8.5 B
2036	15% (46 MMTEVe)	($8.1 B)	($15.7 B)	$15.3 B	($15.0 B)	($20.0 B)	$10.1 B

* Negative costs, shown in parentheses, indicate cost savings.

Because fewer abatement options are required to meet the HFC phasedown requirements of the AIM Act, the consumption reductions from the Low BAU are also lower. Through 2036, using the original BAU, total reductions of 3,152 MMTEVe were achieved, whereas using the Low BAU, total reductions are 2,525 MMTEVe. Annual consumption reductions and totals through the first year of each of the compliance steps are shown in Table B-2.

Table B-2: Consumption Reductions (MMTEVe)

Year	Consumption Cap	Original BAU		Low BAU	
		Reductions for year	*Cumulative Reductions (2022 through year)*	*Reductions for year*	*Cumulative Reductions (2022 through year)*
2022	90% (273 MMTEVe)	42	42	11	11
2024	60% (182 MMTEVe)	144	241	106	132
2029	30% (91 MMTEVe)	230	1,350	194	984
2034	20% (61 MMTEVe)	267	2,600	219	2,072
2036	15% (46 MMTEVe)	282	3,152	230	2,525

B.3 Counterfactual BAU Scenario with Higher HFC Consumption

The High BAU scenario assumes that the growth of all end uses is higher than in the original BAU. Using the same model used for the original BAU, the High BAU assumes a growth rate of 10 percent greater for every end use, starting in 2015. These higher growth rates are applied relative to the growth rates assumed in the original BAU; for instance, if the growth rate for a particular end use was assumed to be 2% per year in the original BAU, it was revised to 2.2% per year for the High BAU.

As with the Low BAU, the method to develop the High BAU would not be expected to influence the calculated HFC production and consumption baselines, as these calculations rely on data from years no later than 2013, before the assumed increase in growth rates is applied. Therefore, for this analysis we use the same baseline as calculated for our base case analysis, i.e., 304 MMTEVe.

We use the same abatement options used in the main analysis to estimate costs of compliance. While the estimated consumption using this alternate BAU is higher, so would the potential abatement. These two counteracting effects are not equal in magnitude. Using the High BAU, more abatement options are needed to reduce consumption to meet the AIM Act requirements, which are based on the same baseline as used in the original BAU. For example, seven additional abatement options on the MAC curve are required to meet the 2022 consumption level using the High BAU, driving costs higher or overall savings lower. This causes a lack of compliance in a few years of analysis because the counterfactual increase in consumption is such that even if all the abatement options analyzed are assumed to be used, the reductions are not enough to comply with the AIM Act under the static baseline. This occurs in 2024, when a relatively large decrease in consumption is required by the Act but for which little time has passed for the abatement to build. However, after only one additional year of consumption reductions, compliance is reached for the remaining years of that compliance period (i.e., 2025-2028). The same situation occurs in 2036 and each subsequent year thereafter, where growth of end uses that have not abated or only partially abated (e.g., a lower but non-zero GWP HFC is assumed) causes consumption to increase above the Act's requirements.

If these situations were to occur, compliance could be achieved by accelerating the implementation of certain abatement options or choosing other/additional options (e.g., increased reclamation, and/or sourcing of HFCs from prior year inventory). For example, more reductions could be achieved by giving preference to the higher-achieving option where two or more options exist for the same end use (e.g., more transcritical CO_2 systems rather than R-407A/R-407F in large retail food operations), or developing new abatement options that either reduce consumption in end uses for which abatement options were not proposed or that achieve more consumption reductions than the options analyzed (e.g., by using an alternative with a GWP even lower than that assumed in the abatement option). Such hypothetical changes are not analyzed here; instead, we report costs below in Table B-3 based on the entire set of abatement options for 2024 and 2036.

The higher costs or lower savings seen in the main analysis also occurs in the higher and lower cost sensitivity analyses presented in the main report. For at least one year (2029) an overall savings becomes an overall cost using the High BAU. In both the base case and lower cost sensitivity estimate, the savings decrease for the remainder of the years for which we calculate reaching compliance (i.e., 2022 and 2034 for both the base case and the lower cost sensitivity, and 2029 under the lower cost sensitivity). Likewise, under the higher cost sensitivity analysis, costs using the High BAU are greater than those under the original BAU.

*Table B-3: Estimated Cumulative Costs of Abatement**

Year	Consumption Cap	Original BAU			High BAU		
		Base Case Estimate	*Lower*	*Higher*	*Base Case Estimate*	*Lower*	*Higher*
2022	90% (273 MMTEVe)	($0.5 B)	($0.5 B)	$0.1 B	($0.3 B)	($0.5 B)	$0.3 B
2024	60% (182 MMTEVe)	($1.2 B)	($1.7 B)	$1.0 B	>($0.4 B)	>($1.4 B)	>$2.1 B
2029	30% (91 MMTEVe)	($2.0 B)	($5.7 B)	$7.3 B	$0.5 B	($4.9 B)	$10.7 B
2034	20% (61 MMTEVe)	($6.4 B)	($12.7 B)	$12.6 B	($3.3 B)	($12.1 B)	$17.5 B
2036	15% (46 MMTEVe)	($8.1 B)	($15.7 B)	$15.3 B	>($4.8 B)	>($15.2 B)	>$21.0 B

* Negative costs, shown in parentheses, indicates cost savings.

Because additional abatement options are needed to reduce the High BAU to the levels required by the AIM Act, the amount of reductions is greater in each year and cumulatively at any point in the future. For instance, a total reduction of 67 MMTEVe is obtained meeting the 2022 compliance step using the High BAU, whereas only 42 MMTEVe in reductions would occur using the original BAU. Through 2036, using the original BAU, total reductions of 3,152 MMTEVe were achieved, whereas using this the High BAU, total reductions of 3,639 MMTEVe are available from the abatement options analyzed, and those are not enough to meet the AIM Act requirement, meaning even more reductions would be achieved. Annual consumption reductions and totals through the first year of each of the compliance steps are shown in Table B-4.

Table B-4: Consumption Reductions (MMTEVe)

Year	Consumption Cap	Original BAU		High BAU	
		Reductions for year	*Cumulative Reductions (2022 through year)*	*Reductions for year*	*Cumulative Reductions (2022 through year)*
2022	90% (273 MMTEVe)	42	42	67	67
2024	60% (182 MMTEVe)	144	241	>165	>335
2029	30% (91 MMTEVe)	230	1,350	265	1,585
2034	20% (61 MMTEVe)	267	2,600	303	3,020
2036	15% (46 MMTEVe)	282	3,152	>316	>3,639

B.4 Counterfactual BAU Scenario Estimating Known State HFC Limitations

B.4.1 Introduction

In addition to considering alternative High and Low BAUs, EPA assessed the potential effect of state-level action to reduce the use of HFCs. Actions taken by states to reduce HFC usage (e.g., by prohibiting the use of certain HFCs in some end uses) that is independent of the federal action would affect the modeled BAU for consumption used by EPA in the main analysis of this RIA. The motivation for this sensitivity analysis is that several states adopted regulations similar in many respects to EPA's regulations promulgated in the 2015 and 2016 SNAP rules. The discussion in this section provides a sensitivity analysis of a situation in which these state-level actions would be implemented even if the national phasedown of HFC was not.

Given the difference in scope between this rulemaking and actions taken by 12 states to develop state regulations that are similar in many respects to SNAP Rules 20 and 21 into their own regulations, EPA developed a State-adjusted BAU, which only reflects the reductions associated with the 12 states that finalized their own regulations.

B.4.2 Overview of State actions

To date, 16 states have indicated an intent to act on HFCs, with 12 of those states having finalized regulations. These states are shown in Table B-5 and the table includes the year of the finalized state regulation if applicable. While some of states may be considering additional HFC regulations, no states are pursuing a statewide phasedown of HFC production and consumption analogous to the phasedown described in this RIA.

Table B-5: States that have indicated an intent to limit use of certain HFCs in specific end uses

State	Year requirements begin
California	2019
Colorado	2021
Connecticut	*N/A*
Delaware	2021
Hawaii	*N/A*
Maine	2022
Maryland	2021
Massachusetts	2021
New Jersey	2020
New York	2021
Oregon	*N/A*
Pennsylvania	*N/A*
Rhode Island	2021
Vermont	2022
Virginia	2021
Washington	2021

Collectively, the 12 states that have enacted regulations to limit the use of HFCs comprise a significant proportion of the U.S. population (~33 percent in 2020). One way to assess the effect of these state limitations, which are analogous in many respects to the partially vacated SNAP rules, is to approximate their effect on the BAU commensurate with their relative population size. Under the assumption that only these states regulate HFCs, and that consumption is proportional to population, the reductions in U.S. consumption associated with the SNAP rules would decrease by roughly 5.1 percent in 2022 and 6.6 percent in 2050.[159] The State-adjusted BAU in Figure B-1 shows an estimate of the relative decrease to the original BAU due to state actions. The figure assumes that as of the year requirements begin (as listed in Table B-5), all the limitations imposed by the states on HFC use are in place. This overstates the

[159] As shown in Table B-5, the state regulations on HFCs were promulgated several years after the SNAP rules and in some cases have later compliance dates for various limitations that would further limit how the regulations affect the BAU. Future populations are based on linear extrapolation.

impact of the state action, because in reality many of the states have a phased approach by end use and each state's rules miss the reductions.

B.4.3 Mitigating factors

The primary difficulty with analyzing the effects of states is estimating the market share of HFC consumption. EPA does not have information at the state level indicating the quantity of HFCs consumed or the state-by-state differences in HFC end uses. Factors such as the number of cooling degree days, building codes, building size, energy use regulations, the cost of energy, and regional weather differences, may all drive or limit demand of HFCs. These differences imply that the distribution of HFC consumption by population as assumed in Figure B-1 is inaccurate, but we are unable to indicate the magnitude or direction of this inaccuracy.

Market Spillover and Leakage Effects

An alternative to assuming that consumption is proportional to population is to use the regulated chemical's market share, but this would be misleading as regional differences in HFC equipment and product use (owing to building codes, equipment types, weather patterns, and other factors) can greatly skew the overall HFC use. Furthermore, it is possible that HFC use could change because of these regulations due to shifts between states with and without regulations. Two competing effects, market spillover and leakage, may either increase or decrease the effect of the GWP limits the state regulations place on specific end uses. If market spillover effects are present, then the market size in states such as California is large enough to influence equipment manufacturers and HFC producers to treat a general region of states as a single market, and thus effectively expand the geographic footprint of the regulations. If market leakage effects are present, then the reduction in the use of HFCs in California and other states with similar regulations could lead to a decrease in national price and subsequently increase use in states not enacting regulations. Evaluating either of these two effects would require disaggregating national HFC prices on a state-by-state basis, which is currently unavailable to the EPA.

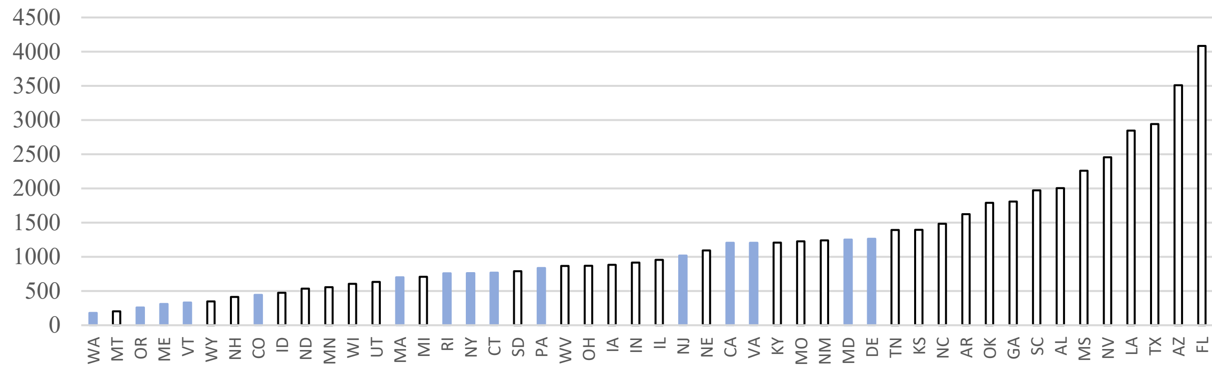
The discussion above assumes that there is no decrease in national production capacity of HFCs. This is because state regulations are analogous to SNAP Rules 20 and 21 in that use is limited by GWP in certain types of equipment (and only in some end uses), but not the manufacturing of HFCs. As noted in Chapter 6, there is only one HFC-producing facility subject to this rule that exists in a state that is promulgating HFC regulations (Chemours in New Jersey). Since production is unaffected by these state rules, it is reasonable to assume that the market supply for HFCs in states that have not adopted regulations would not directly be affected by state requirements.

Regional Differences in Weather, Cooling Degree Days

Since air conditioning is one of the primary uses of HFCs, one consideration about the impact of state-level regulation is the relative difference in the climate for each of the states. One metric that can be used is cooling degree days,[160] which measures the number of days in a given year where the temperature is greater than 65 degrees, as well as *how much* greater than 65 degrees those days are. Figure B-3 shows the total number of cooling degree days for 2020 for the contiguous 48 states, ordered from greatest to smallest, highlighting those states that have pledged to reduce HFCs.

[160] For more information on cooling degree days, visit https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php

Figure B-3: Cooling Degree Days in 2020 for the lower 48 states



As shown above, none of the states with the largest number of cooling degree days have taken action to limit use of HFCs. For example, California, the most populous state with regulations to limit HFC use, ranks 21st for the number of cooling degree days. In this instance, cooling degree days are acting as a proxy for the need for air conditioning use (measuring both the number of hot days and the degree to which they are hot). Given that air conditioning constitutes a significant end use for HFCs, we assume that cooling degree days would positively correlate to HFC use. Analysis of regional per-population emissions confirm that HCFCs and HFCs typically used in air conditioning are higher in the south and southeast of the United States.[161] Since regional differences in temperature are not taken into account in Figure B-1, these data indicate that the effect of state actions to date on the BAU may be considerably narrower than shown in Figure B-1.

B.4.4 Conclusions from analysis of State HFC Limitations

To consider the effect of state regulations on U.S. HFC consumption, EPA considered the regulations promulgated by 12 states and considered by four additional states. These regulations

[161] Hu, L., et al. "Considerable contribution of the Montreal Protocol to declining greenhouse gas emissions from the United States." *Geophys. Res. Lett.*, 44, 2017, pp. 8075–8083, doi:10.1002/2017GL074388.

are not phasedowns similar to this EPA rule; instead, they are a set of limitations on the use of a particular HFC or HFC blend for a specific end use.

EPA lacks state-level data of HFC use to accurately capture the effect of state regulations in the economic baseline. State-by-state HFC consumption data would need to include both the specific HFC or HFC blend and the quantity. However, this section describes several factors that demonstrate the limitations of a population-only approach. While EPA believes it is reasonable to assume that the state actions would have some effect on the BAU, their impact, for the purposes of this nationwide regulation of greater scope, are likely to be relatively small.

Appendix C: Mitigation Options Modeled

This Appendix lists the mitigation options that are included in each modeling time step in order to meet the reduction levels specified by the phasedown schedule.

2022

- IPR CS - NH_3/CO_2
- non-MDI Aerosols HFC-152a to NIK
- Large Retail Food - DX R-407A/R-407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC
- R-12 Small Retail Food (Low Temperature) - HCs
- Flooding Agents - Water Mist
- non-MDI Aerosols - HFC-134a to NIK
- Commercial Unitary A/C - R-32 and MCHE
- Commercial Unitary A/C - MCHE
- CFC-12 Refrigerated Appliances - HFC-134a to R-600a
- non-MDI Aerosols - HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to LCD/Alcohol
- Medium Retail Food - CO_2
- non-MDI Aerosols - HFC-134a to HC
- Commercial Unitary A/C - R-32
- Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs
- Leak Repair for Large Equipment
- Window AC, Dehumidifiers - R-32
- Large Retail Food - R-407A/R-407F SLS
- Medium Retail Food - DX R-407A/R-407F
- Precision Cleaning applications - retrofitted HFC to HFE
- Electronic Cleaning applications - retrofitted HFC to HFE
- Ice Makers - R-290
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs
- non-MDI Aerosols - HFC-152a to HC
- Flooding Agents - FK-5-1-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(*E*)

- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HFO-1234ze(*E*)

2024

- IPR CS - NH_3/CO_2
- non-MDI Aerosols - HFC-152a to NIK
- Large Retail Food - DX R-407A/R-407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC
- R-12 Small Retail Food (Low Temperature) - HCs
- Flooding Agents - Water Mist
- non-MDI Aerosols - HFC-134a to NIK
- Commercial Unitary A/C - R-32 and MCHE
- Commercial Unitary A/C - MCHE
- CFC-12 Refrigerated Appliances - HFC-134a to R-600a
- non-MDI Aerosols - HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to LCD/Alcohol
- Medium Retail Food - CO_2
- non-MDI Aerosols - HFC-134a to HC
- Commercial Unitary A/C - R-32
- Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs
- Leak Repair for Large Equipment
- Window AC, Dehumidifiers - R-32
- Large Retail Food - R-407A/R-407F SLS
- Medium Retail Food - DX R-407A/R-407F
- Precision Cleaning applications - retrofitted HFC to HFE
- Electronic Cleaning applications - retrofitted HFC to HFE
- Ice Makers - R-290
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs
- non-MDI Aerosols - HFC-152a to HC
- Flooding Agents - FK-5-1-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(*E*)

- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(*E*)
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)
- R-12 Small Retail Food (Low Temperature) - R-448A/R-449A
- Residential Unitary A/C - R-454B and MCHE
- non-MDI Aerosols - HFC-134a to HFO-1234ze(*E*)
- Screw Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- Reciprocating Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(*E*)
- Recovery at Disposal for All Equipment
- Scroll Chillers - R-410A/R-407C replaced w/ R-452B
- Vending Machines - R-450A/R-513A
- Transport - R-452A
- R-12 Small Retail Food (Low Temperature) - R-450A/R-513A
- R-12 Small Retail Food (Medium Temperature) - R-448A/R-449A
- Recovery at Service for Small Equipment
- CFC-114 Chillers - HFC-134a replaced w/ R-450A/R-513A
- CFC-11 Centrifugal Chillers - HFC-134a replaced w/ R-450A/R-513A
- CFC-12 Centrifugal Chillers - HFC-134a replaced w/ R-450A/R-513A

2029

- IPR CS - NH_3/CO_2
- non-MDI Aerosols - HFC-152a to NIK
- Large Retail Food - DX R-407A/R-407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC
- R-12 Small Retail Food (Low Temperature) - HCs
- Flooding Agents - Water Mist
- non-MDI Aerosols - HFC-134a to NIK
- Commercial Unitary A/C - R-32 and MCHE
- Commercial Unitary A/C - MCHE
- CFC-12 Refrigerated Appliances - HFC-134a to R-600a
- non-MDI Aerosols HFC-134a to HFC-152a

- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to LCD/Alcohol
- Medium Retail Food - CO_2
- non-MDI Aerosols HFC-134a to HC
- Commercial Unitary A/C - R-32
- Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs
- Leak Repair for Large Equipment
- Window AC, Dehumidifiers - R-32
- Large Retail Food - R-407A/R-407F SLS
- Medium Retail Food - DX R-407A/R-407F
- Precision Cleaning applications - retrofitted HFC to HFE
- Electronic Cleaning applications - retrofitted HFC to HFE
- Ice Makers - R-290
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs
- non-MDI Aerosols - HFC-152a to HC
- Flooding Agents - FK-5-1-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(*E*)
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)
- R-12 Small Retail Food (Low Temperature) - R-448A/R-449A
- Residential Unitary A/C - R-454B and MCHE
- non-MDI Aerosols - HFC-134a to HFO-1234ze(*E*)
- Screw Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- Reciprocating Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(*E*)
- Recovery at Disposal for All Equipment

2034

- IPR CS - NH_3/CO_2
- non-MDI Aerosols - HFC-152a to NIK
- Large Retail Food - DX R-407A/R-407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs

- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC
- R-12 Small Retail Food (Low Temperature) - HCs
- Flooding Agents - Water Mist
- non-MDI Aerosols - HFC-134a to NIK
- Commercial Unitary A/C - R-32 and MCHE
- Commercial Unitary A/C - MCHE
- CFC-12 Refrigerated Appliances - HFC-134a to R-600a
- non-MDI Aerosols - HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to LCD/Alcohol
- Medium Retail Food - CO_2
- non-MDI Aerosols - HFC-134a to HC
- Commercial Unitary A/C - R-32
- Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs
- Leak Repair for Large Equipment
- Window AC, Dehumidifiers - R-32
- Large Retail Food - R-407A/R-407F SLS
- Medium Retail Food - DX R-407A/R-407F
- Precision Cleaning applications - retrofitted HFC to HFE
- Electronic Cleaning applications - retrofitted HFC to HFE
- Ice Makers - R-290
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs
- non-MDI Aerosols - HFC-152a to HC
- Flooding Agents - FK-5-1-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(*E*)
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)
- R-12 Small Retail Food (Low Temperature) - R-448A/R-449A
- Residential Unitary A/C - R-454B and MCHE
- non-MDI Aerosols - HFC-134a to HFO-1234ze(*E*)
- Screw Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- Reciprocating Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(*E*)
- Recovery at Disposal for All Equipment

- Scroll Chillers - R-410A/R-407C replaced w/ R-452B
- Vending Machines - R-450A/R-513A
- Transport - R-452A

2036

- IPR CS - NH_3/CO_2
- non-MDI Aerosols - HFC-152a to NIK
- Large Retail Food - DX R-407A/R-407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC
- R-12 Small Retail Food (Low Temperature) - HCs
- Flooding Agents - Water Mist
- non-MDI Aerosols - HFC-134a to NIK
- Commercial Unitary A/C - R-32 and MCHE
- Commercial Unitary A/C - MCHE
- CFC-12 Refrigerated Appliances - HFC-134a to R-600a
- non-MDI Aerosols - HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to LCD/Alcohol
- Medium Retail Food - CO_2
- non-MDI Aerosols - HFC-134a to HC
- Commercial Unitary A/C - R-32
- Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs
- Leak Repair for Large Equipment
- Window AC, Dehumidifiers - R-32
- Large Retail Food - R-407A/R-407F SLS
- Medium Retail Food - DX R-407A/R-407F
- Precision Cleaning applications - retrofitted HFC to HFE
- Electronic Cleaning applications - retrofitted HFC to HFE
- Ice Makers - R-290
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs
- non-MDI Aerosols - HFC-152a to HC
- Flooding Agents - FK-5-1-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(*E*)

- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)
- R-12 Small Retail Food (Low Temperature) - R-448A/R-449A
- Residential Unitary A/C - R-454B and MCHE
- non-MDI Aerosols - HFC-134a to HFO-1234ze(*E*)
- Screw Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- Reciprocating Chillers - R-410A/R-407C replaced w/ HFO-1234ze(*E*)
- PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(*E*)
- Recovery at Disposal for All Equipment
- Scroll Chillers - R-410A/R-407C replaced w/ R-452B
- Vending Machines - R-450A/R-513A
- Transport - R-452A
- R-12 Small Retail Food (Low Temperature) - R-450A/R-513A
- R-12 Small Retail Food (Medium Temperature) - R-448A/R-449A
- Recovery at Service for Small Equipment
- CFC-114 Chillers - HFC-134a replaced w/ R-450A/R-513A
- CFC-11 Centrifugal Chillers - HFC-134a replaced w/ R-450A/R-513A
- CFC-12 Centrifugal Chillers - HFC-134a replaced w/ R-450A/R-513A
- R-500 Chillers - HFC-134a replaced w/ R-450A/R-513A
- Electronic Cleaning applications - retrofitted Not-in-kind Aqueous
- Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous
- CFC-12 Centrifugal Chillers - 245 replaced w/ HCFO-1233zd(*E*)
- R-500 Chillers - 245 replaced w/ HCFO-1233zd(*E*)
- CFC-11 Centrifugal Chillers – HFC-134a replaced w/ HCFO-1233zd(*E*)

Appendix D: Summary of Mitigation Technologies Modeled by End Use

Table D-1: Market Penetration by year

Sector	End Use	Abatement Option	Option Lifetime (years)	2020	2025	2030	2035	2040	2045	2050
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HC	10	0%	20%	20%	20%	20%	20%	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFC-152a	10	0%	10%	10%	10%	10%	10%	10%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFO-1234ze	10	8%	14%	20%	20%	20%	20%	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to NIK	10	20%	20%	20%	20%	20%	20%	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HC	10	10%	20%	20%	20%	20%	20%	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HFO-1234ze	10	8%	14%	20%	20%	20%	20%	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to NIK	10	40%	40%	40%	40%	40%	40%	40%
Fire	Flooding Agents	Flooding Agents – FK-5-1-12	20	18%	35%	35%	35%	35%	35%	35%
Fire	Flooding Agents	Flooding Agents - Inert Gas	20	0%	10%	19%	29%	29%	29%	29%
Fire	Flooding Agents	Flooding Agents - Water Mist	20	0%	1%	3%	4%	4%	4%	4%
Foam	Commercial Refrigeration Foam	Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) – HFC-245fa to HCFO-1233zd(*E*)	25	33%	100%	100%	100%	100%	100%	100%
Foam	Flexible PU Foam: Integral Skin Foam	Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) – HFC-134a to HCs	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock – HFC-245fa Blend to HC	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCFO-1233zd(*E*)	25	50%	50%	50%	50%	50%	50%	50%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCs	25	50%	50%	50%	50%	50%	50%	50%
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam – HFC-134a to HFO-1234ze(*E*)	25	5%	30%	30%	30%	30%	30%	30%
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-134a to HCs	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-245fa/CO_2 to HCFO-1233zd(*E*)	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) – HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)	25	12%	70%	70%	70%	70%	70%	70%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) – HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)	25	5%	30%	30%	30%	30%	30%	30%
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - 134a/CO_2 to LCD/Alcohol	25	0%	51%	85%	85%	85%	85%	85%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	25	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233(*E*)	25	20%	100%	100%	100%	100%	100%	100%

Refrigeration & A/C	Chillers	CFC-114 Chillers – HFC-134a replaced w/ R-450A/R-513A	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	27	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	27	20%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-134 replaced w/ R-450A/R-513A	27	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	27	20%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - MCHE	15	50%	83%	39%	16%	0%	0%	0%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32	15	0%	0%	50%	50%	50%	50%	50%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32 and MCHE	15	0%	0%	50%	50%	50%	50%	50%
Refrigeration & A/C	Disposal	Recovery at Disposal for ALL Equipment	7	100%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Heat Pumps	HP - R-32/R-452B	15	0%	0%	50%	50%	50%	50%	50%
Refrigeration & A/C	Ice Makers	Ice Makers - R-290	8	0%	19%	50%	50%	50%	50%	50%
Refrigeration & A/C	Industrial Process/Cold Storage (CS)	IPR CS - NH_3/CO_2	25	17%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Large Retail Food	Large Retail Food – R-407A/R-407F SLS	18	33%	33%	33%	33%	33%	33%	33%
Refrigeration & A/C	Large Retail Food	Large Retail Food - CO_2 Transcritical	18	33%	33%	33%	33%	33%	33%	33%
Refrigeration & A/C	Large Retail Food	Large Retail Food - DX R-407A/R-407F	18	34%	34%	34%	34%	34%	34%	34%
Refrigeration & A/C	Leak Repair	Leak Repair for Large Equipment	5	17%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - CO_2	20	33%	33%	33%	33%	33%	33%	33%
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - DX R-407A/R-407F	20	67%	67%	67%	67%	67%	67%	67%
Refrigeration & A/C	PD Chillers	Reciprocating Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Screw Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Scroll Chillers – R-410A/R-407C replaced w/ R-452B	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances – HFC-134a to R-600a	14	50%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Residential Unitary	Residential Unitary A/C - R-454B and MCHE	15	0%	75%	100%	100%	100%	100%	100%
Refrigeration & A/C	Service	Recovery at Service for Small Equipment	7	40%	40%	40%	40%	40%	40%	40%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) – HCs	10	10%	10%	10%	10%	10%	10%	10%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-448A/R-449A	10	0%	70%	70%	70%	70%	70%	70%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-450A/R-513A	10	0%	20%	20%	20%	20%	20%	20%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Medium Temperature) - R-448A/R-449A	10	0%	30%	30%	30%	30%	30%	30%
Refrigeration & A/C	Transport	Transport - R-452A	12	0%	0%	50%	50%	50%	50%	50%
Refrigeration & A/C	Vending Machines	Vending Machines – R-450A/R-513A	10	29%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Vending Machines	Vending Machines - R-290	11	3%	10%	10%	10%	10%	10%	10%
Refrigeration & A/C	Window AC, Dehumidifiers	Window AC, Dehumidifiers - R-32	12	5%	27%	50%	50%	50%	50%	50%
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted HFC to HFE	15	40%	53%	67%	80%	80%	80%	80%
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Aqueous	15	2%	5%	7%	10%	10%	10%	10%
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous	15	2%	5%	7%	10%	10%	10%	10%
Solvents	Precision Cleaning	Precision Cleaning applications - retrofitted HFC to HFE	15	60%	73%	87%	100%	100%	100%	100%

Table D-2: Percent reduction Off baseline

Sector	End Use	Abatement Option	Reduction Efficiency	Percent Reduction off Baseline (i.e., Technical Effectiveness) (%), Relative to Consumption from Model Facility Type						
				2020	2025	2030	2035	2040	2045	2050
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HC	100%	0%	13%	13%	13%	13%	13%	13%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFC-152a	91%	0%	6%	6%	6%	6%	6%	6%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFO-1234ze	100%	5%	9%	13%	13%	13%	13%	13%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to NIK	100%	13%	13%	13%	13%	13%	13%	13%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HC	95%	4%	7%	7%	7%	7%	7%	7%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HFO-1234ze	95%	3%	5%	7%	7%	7%	7%	7%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to NIK	100%	15%	15%	15%	15%	15%	15%	15%
Fire	Flooding Agents	Flooding Agents – FK-5-1-12	100%	33%	40%	43%	44%	25%	25%	25%
Fire	Flooding Agents	Flooding Agents - Inert Gas	100%	0%	13%	27%	44%	50%	47%	39%
Fire	Flooding Agents	Flooding Agents - Water Mist	100%	0%	2%	4%	6%	7%	6%	5%
Foam	Commercial Refrigeration Foam	Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) – HFC-245fa to HCFO-1233zd(*E*)	99%	33%	99%	99%	99%	99%	99%	99%
Foam	Flexible PU Foam: Integral Skin Foam	Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) – HFC-134a to HCs	100%	33%	100%	100%	100%	100%	100%	100%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock – HFC-245fa Blend to HC	99%	33%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCFO-1233zd(*E*)	99%	16%	0%	0%	0%	0%	0%	0%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCs	99%	17%	0%	0%	0%	0%	0%	0%
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam – HFC-134a to HFO-1234ze(*E*)	100%	31%	94%	94%	94%	94%	94%	94%
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-134a to HCs	100%	20%	59%	59%	59%	59%	59%	59%
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-245fa/CO_2 to HCFO-1233zd(*E*)	99%	14%	41%	41%	41%	41%	41%	41%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) – HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)	99%	12%	69%	69%	69%	69%	69%	69%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) – HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)	99%	5%	30%	30%	30%	30%	30%	30%
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) – HFC-134a/CO_2 to LCD/Alcohol	100%	0%	51%	84%	84%	84%	84%	84%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	57%	0%	48%	55%	64%	67%	93%	45%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	99%	6%	31%	34%	38%	38%	45%	20%

Sector	End Use	Abatement Option	Reduction Efficiency	Percent Reduction off Baseline (i.e., Technical Effectiveness) (%), Relative to Consumption from Model Facility Type						
				2020	2025	2030	2035	2040	2045	2050
Refrigeration & A/C	Chillers	CFC-114 Chillers – HFC-134a replaced w/ R-450A/R-513A	57%	0%	0%	100%	100%	100%	57%	57%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	57%	0%	54%	61%	70%	77%	85%	74%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	99%	3%	19%	20%	23%	24%	26%	15%
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-134a replaced w/ R-450A/R-513A	57%	0%	54%	61%	71%	77%	85%	74%
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	99%	3%	19%	20%	23%	24%	26%	15%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - MCHE	38%	13%	22%	11%	1%	0%	0%	0%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32	68%	0%	0%	28%	37%	45%	34%	34%
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32 and MCHE	68%	0%	0%	26%	36%	46%	40%	40%
Refrigeration & A/C	Disposal	Recovery at Disposal for ALL Equipment	85%	4%	9%	10%	11%	5%	4%	4%
Refrigeration & A/C	Heat Pumps	HP - R-32/R-452B	67%	0%	0%	53%	65%	63%	59%	51%
Refrigeration & A/C	Ice Makers	Ice Makers - R-290	100%	0%	25%	72%	61%	50%	50%	50%
Refrigeration & A/C	Industrial Process/Cold Storage	IPR CS - NH_3/CO_2	100%	9%	60%	71%	94%	100%	100%	100%
Refrigeration & A/C	Large Retail Food	Large Retail Food – R-407A/R-407F SLS	50%	1%	2%	3%	3%	3%	3%	3%
Refrigeration & A/C	Large Retail Food	Large Retail Food - CO_2 Transcritical	100%	1%	2%	4%	4%	4%	4%	4%
Refrigeration & A/C	Large Retail Food	Large Retail Food - DX R-407A/R-407F	50%	1%	1%	2%	2%	2%	2%	2%
Refrigeration & A/C	Leak Repair	Leak Repair for Large Equipment	40%	1%	5%	4%	4%	4%	4%	4%
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - CO_2	100%	19%	24%	33%	38%	32%	32%	32%
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - DX R-407A/R-407F	50%	20%	25%	34%	38%	33%	33%	33%
Refrigeration & A/C	PD Chillers	Reciprocating Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	100%	0%	87%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Screw Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	100%	0%	92%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Scroll Chillers – R-410A/R-407C replaced w/ R-452B	64%	0%	62%	100%	100%	100%	63%	63%
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances – HFC-134a to R-600a	100%	100%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Residential Unitary	Residential Unitary A/C - R-454B and MCHE	78%	0%	39%	73%	96%	92%	86%	86%
Refrigeration & A/C	Service	Recovery at Service for Small Equipment	95%	7%	6%	4%	2%	1%	1%	1%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) – HCs	100%	18%	16%	7%	7%	7%	7%	7%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-448A/R-449A	65%	0%	37%	28%	21%	22%	22%	21%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-450A/R-513A	57%	0%	20%	15%	8%	8%	8%	8%
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Medium Temperature) - R-448A/R-449A	57%	0%	1%	1%	1%	1%	1%	1%
Refrigeration & A/C	Transport	Transport - R-452A	20%	0%	0%	9%	16%	20%	19%	19%
Refrigeration & A/C	Vending Machines	Vending Machines – R-450A/R-513A	63%	29%	87%	80%	70%	70%	70%	70%
Refrigeration & A/C	Vending Machines	Vending Machines - R-290	100%	10%	29%	27%	23%	23%	23%	23%
Refrigeration & A/C	Window AC, Dehumidifiers	Window AC, Dehumidifiers - R-32	68%	3%	26%	51%	47%	38%	34%	34%
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted HFC to HFE	85%	34%	46%	57%	68%	68%	68%	68%

Sector	End Use	Abatement Option	Reduction Efficiency	Percent Reduction off Baseline (i.e., Technical Effectiveness) (%), Relative to Consumption from Model Facility Type						
				2020	2025	2030	2035	2040	2045	2050
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Aqueous	100%	2%	5%	7%	10%	10%	10%	10%
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous	100%	2%	5%	7%	10%	10%	10%	10%
Solvents	Precision Cleaning	Precision Cleaning applications - retrofitted HFC to HFE	85%	31%	38%	44%	51%	51%	51%	51%

Table D-3: Summary of Costs and Revenue of Abatement options

Sector	End Use	Abatement Option	Capital Cost (2015 USD)	Annual Revenue (2015 USD)	Annual O&M Costs (2015 USD)	Abatement Amount ($mtCO_2e$)	Break-even Cost (2015 USD / $mtCO_2e$)
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HC	$325,000	$2,551,500	$0	807,124.5	($3.10)
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFC-152a	$500,000	$2,551,500	$0	740,502.0	($3.34)
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFO-1234ze(*E*)	$500,000	$0	$4,252,500	807,408.0	$5.37
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to NIK	$250,000	$4,536,000	$500,000	810,810.0	($4.93)
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HC	$325,000	$0	$0	66,622.5	$0.79
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HFO-1234ze(*E*)	$500,000	$0	$6,804,000	66,906.0	$102.90
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to NIK	$250,000	$1,984,500	$500,000	70,308.0	($20.54)
Fire	Flooding Agents	Flooding Agents – FK-5-1-12	$9.49	$0.00	$4.72	2.0	$2.86
Fire	Flooding Agents	Flooding Agents - Inert Gas	$11.21	$15.18	$0.20	2.0	($6.72)
Fire	Flooding Agents	Flooding Agents - Water Mist	$13.24	$15.18	$0.40	2.0	($6.50)
Foam	Commercial Refrigeration Foam	Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) – HFC-245fa to HCFO-1233zd(*E*)	$0	$0	$280,000	71,610.0	$3.91
Foam	Flexible PU Foam: Integral Skin Foam	Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) – HFC-134a to HCs	$405,000	$135,000	$0	42,705.0	($2.13)
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock – HFC-245fa Blend to HC	$695,500	$520,000	$0	66,527.5	($6.68)
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCFO-1233zd(*E*)	$0	$0	$2,147,162	549,136.6	$3.91
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCs	$5,610,000	$4,351,836	$0	549,405.0	($6.81)
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam – HFC-134a to HFO-1234ze(*E*)	$399,000	$0	$1,320,480	185,780.7	$7.34
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-134a to HCs	$201,500	$2,038,500	$2,490,000	644,845.5	$0.73
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous & Discontinuous) – HFC-245fa/CO_2 to HCFO-1233zd(*E*)	$0	$0	$1,812,000	463,419.0	$3.91
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) – HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)	$250,000	$0	$230,124	58,854.2	$4.37
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) – HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)	$550,000	$0	$230,124	58,911.7	$4.92
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) – HFC-134a/CO_2 to LCD/Alcohol	$5,856,000	$4,770,000	$915,000	1,007,942.4	($3.19)
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	$12,695	$0	$762	74.2	$28.84
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	$53,800	$0	$168	71.8	$83.62
Refrigeration & A/C	Chillers	CFC-114 Chillers – HFC-134a replaced w/ R-450A/R-513A	$16,793	$0	$1,008	111.3	$26.53
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	$13,057	$0	$783	73.2	$29.70
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	$53,880	$0	$173	71.7	$82.51
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-134a replaced w/ R-450A/R-513A	$13,057	$0	$783	73.2	$29.70

Sector	End Use	Abatement Option	Capital Cost (2015 USD)	Annual Revenue (2015 USD)	Annual O&M Costs (2015 USD)	Abatement Amount ($mtCO_2e$)	Break-even Cost (2015 USD / $mtCO_2e$)
Refrigeration & A/C	Chillers	R-500 Chillers – HFC-245fa replaced w/ HCFO-1233zd(*E*)	$53,880	$0	$173	71.7	$82.51
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - MCHE	($27)	$2	$0	1.7	($3.53)
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32	($30)	$3	$0	2.1	($3.08)
Refrigeration & A/C	Commercial Unitary	Commercial Unitary A/C - R-32 and MCHE	($46)	$4	$0	2.1	($4.72)
Refrigeration & A/C	Disposal	Recovery at Disposal for ALL Equipment	$2,026	$445	$1,084	79.6	$13.23
Refrigeration & A/C	Heat Pumps	HP - R-32/R-452B	$4	$0	$1	0.3	$4.64
Refrigeration & A/C	Ice Makers	Ice Makers - R-290	$107,125	$9,587	$0	14,213.1	$0.73
Refrigeration & A/C	Industrial Process/Cold Storage	IPR CS - NH_3/CO_2	$193,000	$50,180	$0	711.6	($41.09)
Refrigeration & A/C	Large Retail Food	Large Retail Food – R-407A/R-407F SLS	$36,932	$4,574	$0	429.4	($0.30)
Refrigeration & A/C	Large Retail Food	Large Retail Food - CO_2 Transcritical	$19,610	$13,445	$0	1,096.4	($10.11)
Refrigeration & A/C	Large Retail Food	Large Retail Food - DX R-407A/R-407F	$0	$10,365	$0	695.4	($14.91)
Refrigeration & A/C	Leak Repair	Leak Repair for Large Equipment	$1,870	$1,224	$0	533.4	($1.37)
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - CO_2	($108)	$13	$0	8.1	($3.16)
Refrigeration & A/C	Medium Retail Food	Medium Retail Food - DX R-407A/R-407F	$0	$0	$0	5.2	$0.00
Refrigeration & A/C	PD Chillers	Reciprocating Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	$2,048	$0	$123	66.8	$5.39
Refrigeration & A/C	PD Chillers	Screw Chillers – R-410A/R-407C replaced w/ HFO-1234ze(*E*)	$1,950	$0	$117	63.6	$5.39
Refrigeration & A/C	PD Chillers	Scroll Chillers – R-410A/R-407C replaced w/ R-452B	$3,334	$0	$200	40.9	$14.33
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances – HFC-134a to R-600a	($201,075)	$3,156	$0	8,798.0	($3.43)
Refrigeration & A/C	Residential Unitary	Residential Unitary A/C - R-454B and MCHE	$28	$0	$2	1.2	$5.18
Refrigeration & A/C	Service	Recovery at Service for Small Equipment	$4,050	$351	$870	62.8	$21.43
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) – HCs	($4)	$0	$0	0.1	($6.54)
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-448A/R-449A	$6	$0	$1	0.3	$5.04
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Low Temperature) - R-450A/R-513A	$9	$0	$1	0.1	$21.04
Refrigeration & A/C	Small Retail Food	R-12 Small Retail Food (Medium Temperature) - R-448A/R-449A	$9	$0	$1	0.1	$21.04
Refrigeration & A/C	Transport	Transport - R-452A	$86	$0	$28	2.0	$20.44
Refrigeration & A/C	Vending Machines	Vending Machines – R-450A/R-513A	$5	$0	$0	0.1	$17.31
Refrigeration & A/C	Vending Machines	Vending Machines - R-290	$305,950	$191	$0	554.0	$88.76
Refrigeration & A/C	Window AC, Dehumidifiers	Window AC, Dehumidifiers - R-32	($0)	$0	$0	0.1	($0.83)
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted HFC to HFE	$0	$0	$0	159.0	$0.00
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Aqueous	$50,000	$1,000	$700	186.0	$33.33
Solvents	Electronics Cleaning	Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous	$55,000	$0	$5,900	186.0	$70.16
Solvents	Precision Cleaning	Precision Cleaning applications - retrofitted HFC to HFE	$0	$0	$0	159.0	$0.00

Appendix E: Annual Unrounded SC-HFC Estimates

Table E-1: SC-HFC-32 (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	49786.59	38382.85	101492.44	18352.27
2021	51413.109	39762.257	105300.205	19177.965
2022	53039.625	41141.666	109107.972	20003.655
2023	54666.141	42521.076	112915.739	20829.346
2024	56292.657	43900.486	116723.505	21655.036
2025	57919.173	45279.895	120531.272	22480.727
2026	59668.379	46770.953	124530.702	23384.736
2027	61417.586	48262.010	128530.133	24288.746
2028	63166.793	49753.068	132529.563	25192.755
2029	64916.000	51244.125	136528.993	26096.764
2030	66665.207	52735.183	140528.424	27000.774
2031	68704.221	54500.880	145708.294	28120.592
2032	70743.235	56266.578	150888.165	29240.411
2033	72782.249	58032.275	156068.035	30360.229
2034	74821.262	59797.972	161247.906	31480.048
2035	76860.276	61563.670	166427.777	32599.866
2036	79039.580	63453.666	171852.464	33805.174
2037	81218.884	65343.662	177277.151	35010.483
2038	83398.188	67233.659	182701.838	36215.792
2039	85577.491	69123.655	188126.525	37421.100
2040	87756.795	71013.652	193551.212	38626.409
2041	90054.034	73050.354	199639.692	40012.789
2042	92351.273	75087.056	205728.172	41399.170
2043	94648.512	77123.758	211816.651	42785.551
2044	96945.751	79160.460	217905.131	44171.931
2045	99242.990	81197.162	223993.611	45558.312
2046	101685.333	83363.003	229987.399	47034.247
2047	104127.677	85528.844	235981.188	48510.182
2048	106570.020	87694.685	241974.976	49986.118
2049	109012.364	89860.526	247968.764	51462.053
2050	111454.707	92026.367	253962.552	52937.988

Table E-2: SC-HFC-125 (2020$)

Year	Discount rate and statistic 2.5%	3%	3% 95th Percentile	5%
2020	287355.72	210911.81	551978.95	82898.26
2021	294887.556	217085.503	569594.501	86120.505
2022	302419.397	223259.193	587210.048	89342.751
2023	309951.238	229432.882	604825.595	92564.996
2024	317483.079	235606.572	622441.142	95787.241
2025	325014.920	241780.261	640056.689	99009.487
2026	333092.365	248424.768	657741.554	102515.118
2027	341169.809	255069.275	675426.418	106020.750
2028	349247.254	261713.782	693111.283	109526.382
2029	357324.698	268358.289	710796.148	113032.013
2030	365402.142	275002.796	728481.012	116537.645
2031	373919.994	282163.781	748470.546	120583.985
2032	382437.846	289324.765	768460.080	124630.326
2033	390955.698	296485.750	788449.614	128676.666
2034	399473.550	303646.735	808439.148	132723.006
2035	407991.402	310807.719	828428.682	136769.347
2036	417251.781	318564.552	849636.684	141137.117
2037	426512.159	326321.385	870844.685	145504.888
2038	435772.537	334078.219	892052.687	149872.658
2039	445032.916	341835.052	913260.688	154240.429
2040	454293.294	349591.885	934468.690	158608.199
2041	463371.229	357367.866	955473.401	163321.348
2042	472449.163	365143.847	976478.111	168034.498
2043	481527.097	372919.828	997482.822	172747.647
2044	490605.032	380695.809	1018487.533	177460.797
2045	499682.966	388471.790	1039492.244	182173.946
2046	509191.467	396671.327	1060081.206	187192.272
2047	518699.968	404870.864	1080670.168	192210.597
2048	528208.468	413070.400	1101259.130	197228.922
2049	537716.969	421269.937	1121848.092	202247.248
2050	547225.470	429469.474	1142437.054	207265.573

Table E-3: SC-HFC-134a (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	115195.66	87119.97	228428.24	38251.06
2021	118631.241	89985.780	236470.182	39855.749
2022	122066.820	92851.589	244512.121	41460.442
2023	125502.399	95717.398	252554.059	43065.136
2024	128937.977	98583.206	260595.998	44669.829
2025	132373.556	101449.015	268637.937	46274.522
2026	136095.427	104560.437	277134.079	48030.441
2027	139817.297	107671.858	285630.222	49786.361
2028	143539.168	110783.280	294126.365	51542.280
2029	147261.038	113894.701	302622.507	53298.200
2030	150982.909	117006.122	311118.650	55054.119
2031	155005.633	120437.385	320909.232	57112.544
2032	159028.356	123868.648	330699.814	59170.968
2033	163051.080	127299.910	340490.396	61229.393
2034	167073.804	130731.173	350280.978	63287.817
2035	171096.528	134162.436	360071.560	65346.242
2036	175389.925	137836.695	370127.217	67566.620
2037	179683.323	141510.954	380182.874	69786.999
2038	183976.720	145185.214	390238.532	72007.377
2039	188270.117	148859.473	400294.189	74227.755
2040	192563.514	152533.732	410349.846	76448.134
2041	196659.573	156123.295	419827.206	78783.486
2042	200755.632	159712.859	429304.565	81118.839
2043	204851.691	163302.422	438781.925	83454.191
2044	208947.750	166891.985	448259.285	85789.543
2045	213043.809	170481.549	457736.644	88124.896
2046	217389.754	174299.885	467468.878	90619.705
2047	221735.699	178118.221	477201.111	93114.514
2048	226081.644	181936.558	486933.344	95609.324
2049	230427.590	185754.894	496665.577	98104.133
2050	234773.535	189573.230	506397.811	100598.942

Table E-4: SC-HFC-143a (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	376193.35	267248.70	699659.97	94760.56
2021	385135.835	274417.932	720658.392	98266.435
2022	394078.320	281587.166	741656.813	101772.315
2023	403020.806	288756.399	762655.234	105278.195
2024	411963.291	295925.632	783653.655	108784.074
2025	420905.777	303094.866	804652.076	112289.954
2026	430387.114	310744.202	824860.325	116084.243
2027	439868.451	318393.538	845068.575	119878.532
2028	449349.789	326042.873	865276.824	123672.821
2029	458831.126	333692.209	885485.074	127467.109
2030	468312.464	341341.545	905693.323	131261.398
2031	478233.222	349525.185	927712.023	135636.429
2032	488153.980	357708.824	949730.723	140011.459
2033	498074.738	365892.464	971749.423	144386.489
2034	507995.497	374076.103	993768.122	148761.520
2035	517916.255	382259.743	1015786.822	153136.550
2036	528472.557	390986.280	1038786.095	157824.770
2037	539028.859	399712.818	1061785.367	162512.990
2038	549585.161	408439.355	1084784.640	167201.210
2039	560141.463	417165.892	1107783.912	171889.431
2040	570697.765	425892.430	1130783.185	176577.651
2041	581211.345	434775.654	1155302.921	181741.799
2042	591724.925	443658.878	1179822.656	186905.946
2043	602238.506	452542.102	1204342.392	192070.094
2044	612752.086	461425.325	1228862.128	197234.242
2045	623265.667	470308.549	1253381.863	202398.390
2046	634393.420	479730.705	1279066.864	207892.147
2047	645521.173	489152.860	1304751.864	213385.904
2048	656648.926	498575.015	1330436.864	218879.662
2049	667776.679	507997.171	1356121.864	224373.419
2050	678904.432	517419.326	1381806.865	229867.176

Table E-5: SC-HFC-152a (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	6928.87	5359.89	14161.65	2624.61
2021	7156.181	5553.929	14701.064	2743.788
2022	7383.489	5747.968	15240.479	2862.965
2023	7610.797	5942.007	15779.895	2982.142
2024	7838.105	6136.046	16319.310	3101.319
2025	8065.412	6330.085	16858.726	3220.497
2026	8311.446	6540.784	17413.200	3351.178
2027	8557.479	6751.482	17967.675	3481.860
2028	8803.513	6962.181	18522.149	3612.542
2029	9049.546	7172.879	19076.624	3743.223
2030	9295.580	7383.578	19631.099	3873.905
2031	9585.902	7636.208	20372.275	4037.234
2032	9876.225	7888.838	21113.452	4200.563
2033	10166.548	8141.468	21854.629	4363.891
2034	10456.871	8394.098	22595.806	4527.220
2035	10747.194	8646.728	23336.983	4690.548
2036	11057.865	8917.251	24105.852	4866.255
2037	11368.537	9187.774	24874.721	5041.962
2038	11679.209	9458.297	25643.590	5217.668
2039	11989.880	9728.820	26412.458	5393.375
2040	12300.552	9999.343	27181.327	5569.081
2041	12670.904	10326.176	28217.415	5790.383
2042	13041.256	10653.009	29253.503	6011.685
2043	13411.608	10979.842	30289.591	6232.987
2044	13781.960	11306.676	31325.678	6454.288
2045	14152.312	11633.509	32361.766	6675.590
2046	14542.565	11978.535	33387.545	6909.980
2047	14932.817	12323.562	34413.324	7144.371
2048	15323.070	12668.589	35439.104	7378.761
2049	15713.322	13013.615	36464.883	7613.151
2050	16103.575	13358.642	37490.662	7847.542

Table E-6: SC-HFC-227ea (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	265356.49	193089.64	506009.35	73736.77
2021	272110.248	198595.466	521308.516	76559.579
2022	278864.004	204101.296	536607.681	79382.390
2023	285617.761	209607.126	551906.846	82205.201
2024	292371.518	215112.956	567206.011	85028.012
2025	299125.275	220618.786	582505.176	87850.823
2026	306344.044	226530.215	598382.520	90917.832
2027	313562.813	232441.643	614259.863	93984.842
2028	320781.582	238353.072	630137.207	97051.852
2029	328000.351	244264.500	646014.550	100118.861
2030	335219.120	250175.928	661891.893	103185.871
2031	342806.814	256528.702	679511.654	106723.214
2032	350394.508	262881.476	697131.415	110260.557
2033	357982.202	269234.249	714751.177	113797.900
2034	365569.896	275587.023	732370.938	117335.243
2035	373157.590	281939.796	749990.699	120872.586
2036	381305.447	288757.900	768267.650	124675.878
2037	389453.303	295576.004	786544.602	128479.170
2038	397601.160	302394.107	804821.553	132282.462
2039	405749.017	309212.211	823098.505	136085.755
2040	413896.874	316030.314	841375.456	139889.047
2041	421916.693	322894.341	858948.745	144016.673
2042	429936.512	329758.368	876522.034	148144.299
2043	437956.331	336622.395	894095.323	152271.926
2044	445976.150	343486.421	911668.612	156399.552
2045	453995.969	350350.448	929241.901	160527.178
2046	462537.979	357669.454	948617.279	164934.047
2047	471079.989	364988.461	967992.657	169340.916
2048	479621.999	372307.467	987368.035	173747.785
2049	488164.010	379626.473	1006743.413	178154.654
2050	496706.020	386945.480	1026118.791	182561.522

Table E-7: SC-HFC-236fa (2020$)

	Discount rate and statistic			
Year	2.5%	3%	3% 95th Percentile	5%
2020	971911.32	635691.68	1671593.41	182719.62
2021	990966.334	650225.941	1712939.154	189003.615
2022	1010021.351	664760.197	1754284.899	195287.611
2023	1029076.368	679294.453	1795630.645	201571.608
2024	1048131.384	693828.709	1836976.391	207855.604
2025	1067186.401	708362.965	1878322.137	214139.600
2026	1087374.004	723836.127	1920231.244	220906.135
2027	1107561.607	739309.289	1962140.352	227672.670
2028	1127749.210	754782.450	2004049.460	234439.205
2029	1147936.813	770255.612	2045958.567	241205.740
2030	1168124.416	785728.774	2087867.675	247972.275
2031	1189329.895	802305.367	2136403.703	255826.244
2032	1210535.374	818881.960	2184939.731	263680.213
2033	1231740.853	835458.553	2233475.759	271534.182
2034	1252946.332	852035.146	2282011.786	279388.152
2035	1274151.811	868611.739	2330547.814	287242.121
2036	1296438.782	886109.188	2381068.457	295594.550
2037	1318725.754	903606.638	2431589.100	303946.979
2038	1341012.726	921104.088	2482109.743	312299.409
2039	1363299.698	938601.538	2532630.386	320651.838
2040	1385586.670	956098.988	2583151.028	329004.267
2041	1408441.699	974359.583	2635485.726	338463.005
2042	1431296.727	992620.177	2687820.423	347921.743
2043	1454151.756	1010880.772	2740155.121	357380.481
2044	1477006.785	1029141.366	2792489.818	366839.219
2045	1499861.814	1047401.961	2844824.516	376297.957
2046	1523747.327	1066577.257	2898382.352	386286.778
2047	1547632.840	1085752.553	2951940.189	396275.599
2048	1571518.353	1104927.849	3005498.026	406264.421
2049	1595403.866	1124103.145	3059055.863	416253.242
2050	1619289.379	1143278.441	3112613.700	426242.064

Table E-8: SC-HFC-245fa (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	79920.92	61300.90	161390.69	28587.55
2021	82459.557	63446.648	167363.131	29847.970
2022	84998.191	65592.394	173335.569	31108.389
2023	87536.826	67738.140	179308.007	32368.807
2024	90075.460	69883.886	185280.445	33629.226
2025	92614.095	72029.632	191252.883	34889.645
2026	95356.029	74354.956	197500.284	36269.117
2027	98097.963	76680.280	203747.684	37648.589
2028	100839.897	79005.603	209995.085	39028.061
2029	103581.831	81330.927	216242.485	40407.533
2030	106323.765	83656.250	222489.886	41787.005
2031	109426.575	86333.922	230330.054	43460.060
2032	112529.385	89011.593	238170.222	45133.114
2033	115632.195	91689.265	246010.390	46806.169
2034	118735.005	94366.936	253850.558	48479.224
2035	121837.815	97044.608	261690.726	50152.278
2036	125196.978	99939.251	269867.222	51961.200
2037	128556.141	102833.894	278043.717	53770.121
2038	131915.305	105728.538	286220.213	55579.043
2039	135274.468	108623.181	294396.709	57387.965
2040	138633.631	111517.824	302573.204	59196.886
2041	141916.845	114417.253	310725.593	61151.160
2042	145200.059	117316.683	318877.982	63105.433
2043	148483.273	120216.112	327030.370	65059.707
2044	151766.487	123115.542	335182.759	67013.980
2045	155049.701	126014.971	343335.148	68968.254
2046	158589.120	129137.145	351770.865	71067.545
2047	162128.539	132259.319	360206.582	73166.836
2048	165667.957	135381.493	368642.300	75266.127
2049	169207.376	138503.667	377078.017	77365.418
2050	172746.795	141625.840	385513.735	79464.709

Table E-9: SC-HFC-43-10mee (2020$)

	Discount rate and statistic			
Year	**2.5%**	**3%**	**3% 95th Percentile**	**5%**
2020	132976.19	100136.12	262542.58	43232.49
2021	136842.827	103357.628	271504.098	45019.695
2022	140709.459	106579.132	280465.619	46806.902
2023	144576.092	109800.636	289427.140	48594.110
2024	148442.724	113022.139	298388.661	50381.318
2025	152309.357	116243.643	307350.182	52168.526
2026	156513.011	119747.938	317037.761	54124.231
2027	160716.666	123252.233	326725.339	56079.936
2028	164920.320	126756.528	336412.918	58035.642
2029	169123.975	130260.823	346100.496	59991.347
2030	173327.629	133765.118	355788.075	61947.052
2031	177841.943	137606.700	366655.119	64229.658
2032	182356.257	141448.282	377522.163	66512.263
2033	186870.571	145289.863	388389.206	68794.869
2034	191384.885	149131.445	399256.250	71077.474
2035	195899.199	152973.026	410123.294	73360.080
2036	200701.567	157076.690	421305.310	75819.959
2037	205503.935	161180.355	432487.326	78279.838
2038	210306.303	165284.019	443669.342	80739.717
2039	215108.671	169387.683	454851.358	83199.596
2040	219911.039	173491.347	466033.374	85659.475
2041	224514.092	177516.883	476545.962	88252.826
2042	229117.145	181542.419	487058.550	90846.177
2043	233720.198	185567.956	497571.138	93439.528
2044	238323.251	189593.492	508083.726	96032.878
2045	242926.304	193619.028	518596.314	98626.229
2046	247831.642	197913.424	529594.395	101398.496
2047	252736.980	202207.819	540592.477	104170.763
2048	257642.319	206502.215	551590.559	106943.030
2049	262547.657	210796.610	562588.641	109715.298
2050	267452.996	215091.006	573586.723	112487.565

Table E-10: SC-HFC-23 (2020$)

Year	2.5%	3%	3% 95th Percentile	5%
	Discount rate and statistic			
2020	1483435.899	965975.482	2566380.066	274829.362
2021	1512334.175	987952.030	2628461.987	284263.718
2022	1541232.452	1009928.578	2690543.907	293698.075
2023	1570130.728	1031905.126	2752625.827	303132.431
2024	1599029.004	1053881.674	2814707.747	312566.788
2025	1627927.280	1075858.222	2876789.667	322001.145
2026	1658460.740	1099209.337	2940999.970	332155.387
2027	1688994.199	1122560.453	3005210.272	342309.629
2028	1719527.659	1145911.568	3069420.575	352463.871
2029	1750061.118	1169262.683	3133630.877	362618.114
2030	1780594.578	1192613.798	3197841.180	372772.356
2031	1812698.086	1217652.379	3271609.673	384571.571
2032	1844801.595	1242690.960	3345378.166	396370.786
2033	1876905.104	1267729.541	3419146.660	408170.001
2034	1909008.612	1292768.122	3492915.153	419969.216
2035	1941112.121	1317806.703	3566683.647	431768.431
2036	1974899.788	1344277.188	3642377.730	444342.072
2037	2008687.454	1370747.673	3718071.814	456915.713
2038	2042475.121	1397218.159	3793765.897	469489.354
2039	2076262.788	1423688.644	3869459.981	482062.995
2040	2110050.455	1450159.130	3945154.065	494636.636
2041	2144715.499	1477788.348	4026205.523	508872.690
2042	2179380.542	1505417.566	4107256.982	523108.744
2043	2214045.586	1533046.785	4188308.441	537344.798
2044	2248710.630	1560676.003	4269359.899	551580.852
2045	2283375.674	1588305.221	4350411.358	565816.905
2046	2319595.263	1617298.516	4433292.967	580829.914
2047	2355814.853	1646291.811	4516174.575	595842.922
2048	2392034.442	1675285.106	4599056.184	610855.931
2049	2428254.032	1704278.401	4681937.793	625868.939
2050	2464473.621	1733271.696	4764819.401	640881.948

Appendix F: Industries Potentially Affected by the AIM Act

Industries that may be potentially affected by this rule are those that produce, import, export, destroy, use as a feedstock, reclaim, or otherwise distribute HFCs. Companies that may also be potentially affected by this rule include those that use HFCs to manufacture products, such as refrigeration and air conditioning systems, foams, aerosols, and fire suppression systems, and the six applications eligible for an allocation under section (e)(4)(B)(iv) of the AIM Act. Potentially affected categories, NAICS codes, and examples of potentially regulated entities are included in Table F-1.

Table F-1: NAICS Classification of Potentially Regulated Entities

NAICS Code	NAICS Industry Description
211120	Crude Petroleum Extraction
221210	Natural Gas Distribution
236118	Residential Remodelers
236220	Commercial and Institutional Building Construction
238220	Plumbing, Heating, and Air-Conditioning Contractors
238990	All Other Specialty Trade Contractors
311351	Chocolate and Confectionery Manufacturing from Cacao Beans
322299	All Other Converted Paper Product Manufacturing
325120	Industrial Gas Manufacturing
325180	Other Basic Inorganic Chemical Manufacturing
325199	All Other Basic Organic Chemical Manufacturing
325211	Plastics Material and Resin Manufacturing
325320	Pesticide and Other Agricultural Chemical Manufacturing
325412*	Pharmaceutical Preparation Manufacturing
325414*	Biological Product (except Diagnostic) Manufacturing
325992	Photographic Film, Paper, Plate and Chemical Manufacturing
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing
326150*	Urethane and Other Foam Product
331420	Copper Rolling, Drawing, Extruding, and Alloying
332312	Fabricated Structural Metal Manufacturing
332313	Plate Work Manufacturing
333132	Oil and Gas Field Machinery and Equipment Manufacturing
333314	Optical Instrument and Lens Manufacturing
333316	Photographic and Photocopying Equipment Manufacturing
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing

NAICS Code	NAICS Industry Description
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333611	Turbine and Turbine Generator Set Unit Manufacturing
333996	Fluid Power Pump and Motor Manufacturing
334413*	Semiconductor and Related Device Manufacturing
334419*	Other Electronic Component Manufacturing
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
334516	Analytical Laboratory Instrument Manufacturing
334613	Blank Magnetic and Optical Recording Media Manufacturing
336212*	Truck Trailer Manufacturing
336214*	Travel Trailer and Camper Manufacturing
336411*	Aircraft Manufacturing
336510	Railroad Rolling Stock Manufacturing
336611*	Ship Building and Repairing
336612*	Boat Building
336992*	Military Armored Vehicle, Tank, and Tank Component Manufacturing
339999*	All Other Miscellaneous Manufacturing
SIC 373102*	Military Ships, Building, and Repairing
423120	Motor Vehicle Supplies and New Parts Merchant Wholesalers
423450	Medical, Dental, and Hospital Equipment and Supplies Merchant Wholesalers
423460	Ophthalmic Goods Merchant Wholesalers
423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers
423740	Refrigeration Equipment and Supplies Merchant Wholesalers
423830	Industrial Machinery and Equipment Merchant Wholesalers
423860*	Transportation Equipment and Supplies (except Motor Vehicle) Merchant Wholesalers
423990*	Other Miscellaneous Durable Goods Merchant Wholesalers
424210	Drugs and Druggists' Sundries Merchant Wholesalers
424410	General Line Grocery Merchant Wholesalers
424610	Plastics Materials and Basic Forms and Shapes Merchant Wholesalers
424690	Other Chemical and Allied Products Merchant Wholesalers
424910	Farm Supplies Merchant Wholesalers
441310	Automotive Parts and Accessories Stores
443141	Household Appliance Stores
443142	Electronics Stores
444130	Hardware Stores
446191	Food (Health) Supplement Stores
452311	Warehouse Clubs and Supercenters
453998	All Other Miscellaneous Store Retailers (except Tobacco Stores)
454110	Electronic Shopping and Mail-Order Houses

NAICS Code	NAICS Industry Description
481111	Scheduled Passenger Air Transportation
482111	Line-Haul Railroads
488510	Freight Transportation Arrangement
493110	General Warehousing and Storage
522293	International Trade Financing
523130	Commodity Contracts Dealing
531110	Lessors of Residential Buildings and Dwellings
531120	Lessors of Nonresidential Buildings (except Miniwarehouses)
532420	Office Machinery and Equipment Rental and Leasing
541330	Engineering Services
541519	Other Computer Related Services
541715	Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology)
561210	Facilities Support Services
561910	Packaging and Labeling Services
561990	All Other Support Services
562920	Recovery and Reclamation
722511	Full-Service Restaurants
811219	Other Electronic and Precision Equipment Repair and Maintenance
811412	Appliance Repair and Maintenance
922160*	Fire Protection

*Codes marked with an asterisk may apply to sectors that receive application-specific allowances under the AIM Act.

Appendix G: Provisions Related to Controlling Emissions of HFC-23

This section presents information associated with the requirement to control, capture, and destroy HFC-23 that would otherwise be emitted.

G.1 HFC-23

With its long atmospheric lifetime and high radiative efficiency, HFC-23 is a very potent GHG and has an exchange value of 14,800. HFC-23 is produced during the manufacture of certain other chemicals including certain HFCs and ODS (in particular HCFC-22). While some HFC-23 is recovered, purified, and sold for applications including fire suppression, very low-temperature refrigeration, and semiconductor manufacturing, the majority of HFC-23 produced, unless controlled or captured and destroyed, is vented to the atmosphere.

G.2 Regulated Community

The regulated community analyzed includes entities that manufacture HFCs and HCFCs and that have byproduct emissions of HFC-23. Using data made publicly available through the GHGRP, we analyzed four plants that would be affected by the rule. The four plants are currently manufacturing either HCFC-22 for transformation under an exception to the HCFC phaseout under the CAA and its implementing regulations or facilities are currently manufacturing HFCs. Three of the plants are already capturing and controlling HFC-23 to a level that is expected to be below the emissions standard finalized in the rule this analysis accompanies. The other plant has made public commitments to install equipment in 2022 that will capture at least 99 percent of HFC-23 process emissions from the site.[162]

[162] The Chemours Company. "Chemours Announces Project to Reduce HFC-23 Emissions." *PR Newswire,* 8 March 2021, https://www.prnewswire. Available in the rulemaking docket (EPA-HQ-OAR-2021-0044).

G.3 Abatement Option Modeled

To generate abatement cost estimates, EPA used components of the cost estimates developed for and presented in EPA's *Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation, 2015–2050* report, supplemented with HCFC-22 production-specific studies.[163,164,165,166] The HFC-23 abatement option evaluated for this analysis is capture with offsite thermal destruction. The abatement option cost and reduction efficiency were used to estimate the abatement cost and associated HFC-23 emission reductions stemming from the rule. For the abatement option, EPA used the literature cited above and technical expertise to estimate:

- capital cost (e.g., to install new HFC-23 capture technology)
- annual costs (e.g., the ongoing cost of capturing, transporting, and destroying HFC-23)
- reduction efficiency and net amount of HFC-23 emissions abated at a model facility undertaking the abatement option.

Table G-1 describes the cost and reduction efficiency components of the modeled abatement option.

[163] U.S. EPA, September 2019a. EPA Report EPA-430-R-19-012. Global Non-CO_2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation. Available at https://www.epa.gov/sites/production/files/2019-09/documents/nonco2_methodology_report.pdf.
[164] U.S. EPA, September 2019b. EPA Report EPA-430-R-19-010. Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation: 2015–2050. Available at https://www.epa.gov/sites/production/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf.
[165] UN Environment Programme. Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol. Key Aspects Related to HFC-23 By-Product Control Technologies (Decision 78/5). Bangkok, 3-7 July 2017. Available at http://www.multilateralfund.org/79/English/1/7948.pdf
[166] McCulloch, A.: Incineration of HFC-23 Waste Streams for Abatement of Emissions from HCFC-22 Production: A Review of Scientific, Technical and Economic Aspects, commissioned by the UNFCCC secretariat to facilitate the work of the Methodologies Panel of the CDM Executive Board, Available at http://cdm.unfccc.int/methodologies/Background_240305.pdf, 2004.

Table G-1: Abatement Option Cost and Reduction Efficiency Parameters

Abatement Option	Reduction Efficiency	Option Lifetime (years)	Capital Cost for Capture Technology (2020$)	Annual Revenue (2020$)	Annual O&M costs (2020$)	Transportation to Destruction Facility ($/kg HFC-23)	Abatement Potential (kg HFC-23)
Capture with offsite thermal destruction	95%*	20	$2.6 million	$0	$212,602	$0.25/kg	260,000

*While the technology's destruction efficiency can be greater than 99.99%, 95% reduction efficiency takes into account thermal oxidation unit downtime for various reasons (e.g., maintenance).[163]

Table G-2 describes the components of the total cost of the modeled abatement option, including the present value of the capital cost, the annual ongoing costs, and the cost of transportation, all expressed as cost per kg of HFC-23 abated.

Table G-2: Annualized Abatement Option Cost

Abatement Option	Capital Cost ($/kg HFC-23)	Annual O&M Costs ($/kg HFC-23)	Transportation to Destruction Facility ($/kg HFC-23)	Total Option Cost ($/kg HFC-23)
Capture with offsite thermal destruction	$1.18	$0.83	$0.25	$2.26

G.4 Historical and Projected Emissions

We analyzed four plants that would be affected by the standard: a Chemours-owned plant in Louisville, KY, a Daikin-owned plant in Decatur, AL, a Honeywell-owned plant in Geismar, LA, and an Arkema-owned facility in Calvert City, KY.

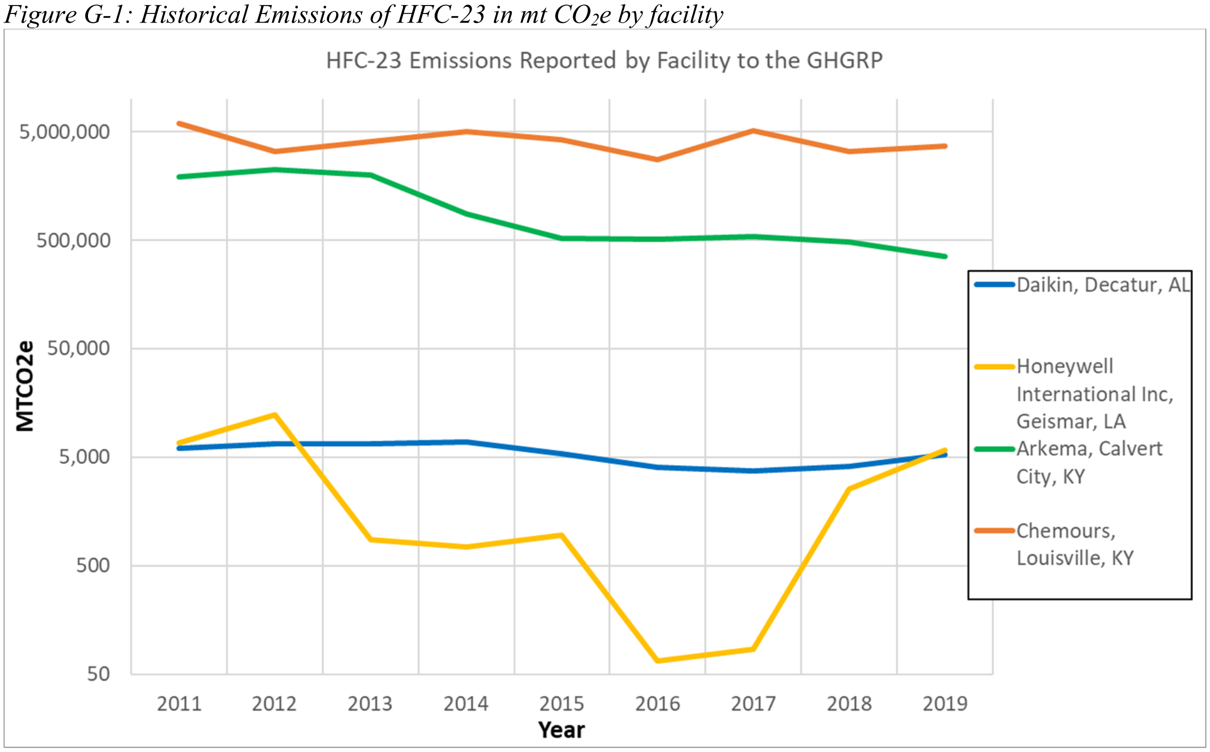
Table G-3 and Figure G-1 show historical emissions of HFC-23 in metric tons (mt) CO_2e from each facility for the period 2011–2019 as reported to Subpart O of the GHGRP.

*Table G-3: Historical Emissions of HFC-23 in mt CO_2e from Chemours in Louisville, KY, and Daikin in Decatur, AL**

Year	Arkema, Calvert City, KY	Chemours, Louisville, KY	Daikin, Decatur, AL	Honeywell International Inc, Geismar, LA
2011	1,939,096	5,958,835	6,083	6,793
2012	2,262,624	3,315,200	6,704	12,432
2013	1,985,272	4,087,464	6,704	875
2014	878,084	5,022,854	6,883	746
2015	523,476	4,258,715	5,372	955
2016	512,657	2,792,553	4,014	67
2017	543,780	5,156,202	3,755	86
2018	484,195	3,276,291	4,156	2,569
2019	355,558	3,707,770	5,297	5,809

*Historical emissions of HFC-23 from these two facilities as reported to Subpart O of the GHGRP

Figure G-1: Historical Emissions of HFC-23 in mt CO_2e by facility



The four facilities are already controlling or have made public commitments to control their HFC-23 emissions. Using data that are publicly available, we are aware that the Daikin plant, Honeywell plant, and Arkema plant are destroying HFC-23 onsite.[167] In March 2021,

[167] Information related to emissions of HFC-23 for the two facilities is in the document titled "Facilities with HFC-23 Emissions," which is available in the docket for the rule (EPA-HQ-OAR-2021-0044).

Chemours publicly announced that it was planning to install proprietary technology to capture at least 99 percent of HFC-23 process emissions from the site in 2022.[168] The HFC-23 would be transported and destroyed at Chemours Washington Works in West Virginia.[169] The 2021 announcement by Chemours was preceded by a 2015 commitment by the company that stated, in part, that it agreed to eliminate byproduct emissions of HFC-23 at its production facilities in North America to the extent feasible.[170] Because the other facilities are already destroying HFC-23 onsite and this facility has not yet installed the equipment, EPA focused its estimated cost of control and benefits on the Chemours facility in Louisville, KY.

To construct a BAU projection, EPA looked at abatement and emissions indicated by the historical record from all four facilities and only included facility-level abatement currently occurring. As shown in Figure G-1, the historical controlled and uncontrolled emissions of byproduct HFC-23 indicate some variability across the period of data available, but generally indicate flat to slightly decreasing emissions over time. To capture the variability of emissions over the last decade EPA used a nine-period moving average to project emissions through the entire period of analysis (2022–2050). Table G-4 shows the projected BAU emissions of HFC-23 starting in 2022 through 2050 for the Chemours facility in Louisville, KY.

Table G-4: Projected Emissions of HFC-23 in MMTEVe from Chemours in Louisville, KY

Year	Chemours, Louisville, KY
2022	4,100,000
2025	3,900,000
2030	4,000,000
2035	4,000,000
2040	4,000,000
2045	4,000,000
2050	4,000,000

[168] The Chemours Company. "Chemours Announces Project to Reduce HFC-23 Emissions." *PR Newswire,* 8 March 2021, https://www.prnewswire. Available in the docket to the rule (EPA-HQ-OAR-2021-0044).
[169] Information related to emissions of HFC-23 for the two facilities is in the document titled "Facilities with HFC-23 Emissions," which is available in the docket for the rule (EPA-HQ-OAR-2021-0044).
[170] https://obamawhitehouse.archives.gov/the-press-office/2015/10/15/fact-sheet-obama-administration-and-private-sector-leaders-announce.

G.5 Estimation of Costs and Benefits

The cost of abatement was calculated using the projected emissions in Table G-4 and the mitigation option and costs outlined in Tables G-1 and G-2 and is included in the total yearly abatement cost shown in Table 5-1. Likewise, the benefits of reducing HFC-23 were monetized as described in Chapter 4 and as shown in Table 4-23 and 4-24.

Appendix H: Refillable Cylinders

H.1 Emission Estimates for Cylinders During Transport and Storage

This section presents the results of an analysis of total annual emissions from refrigerant losses during cylinder transport and storage conducted by Stratus.[171,172] It includes a description of the methodology used to calculate these impacts and resulting emissions. These emission estimates were updated for 2020 to reflect an updated distribution of refrigerants sold annually in 30-pound cylinders.

Methodology

The following steps explain how the total annual emissions from refrigerant losses during cylinder transport and storage were calculated. More information on the variables identified in these steps can be found in Table H-1 and a. Assumes all refrigerant is lost, minus the heel. The heel is estimated to be approximately 4 percent (see list of assumptions below).

c. The likelihood of these types of losses occurring is considered negligible. We use 0.01 percent as the smallest likelihood of a loss occurring. See list of assumptions below

[171] See note 56.

[172] Other factors in evaluating the comparative advantages and disadvantages of the two types of cylinders include the amount of resources consumed in their manufacture and potential waste due to improper disposal. One argument for using refillable cylinders is to reduce the amount of recyclable metal that is landfilled. Another differentiating factor is the implications of the cylinders' differences in size and weight for the amount of energy required to transport them (CARB 2011). These considerations are outside the scope of this analysis.

Table H-2.

1. For each type of cylinder, the total number of cylinder "trips" (i.e., times traveling from refrigerant manufacturer to end use) in a year was calculated as the product of:
   a. The number of cylinders of that type manufactured in the United States each year; and
   b. The average number of times per year that a cylinder is filled (only once for disposable cylinders).
2. For each type of cylinder and for each type of refrigerant loss that a cylinder could experience, the total amount of refrigerant emitted each year was calculated as the product of:
   a. The total number of cylinder trips per year (result from Step 1);
   b. The percentage of cylinders transported and stored that experience the specific type of refrigerant loss ;
   c. The average amount of refrigerant in a full cylinder; and
   d. The percentage of the refrigerant in the cylinder that is emitted due to the type of loss.
3. The resultant products for each cylinder/refrigerant loss type combination (from Step 2) were then summed to produce the total annual emissions (in pounds) resulting from refrigerant losses during cylinder transport and storage.
4. The total annual emissions resulting from refrigerant losses during cylinder transport and storage (from Step 3) were then converted into GWP-weighted emissions.

The values used for several of the variables identified above are based on the information presented in sections 2 and 3 and are presented in

Table H-1. Table H-2 presents values for several other key inputs used in the analysis, indicating the corresponding step in the above process.

Table H-1: Summary of information on types of refrigerant loss from transported and stored cylinders

Type of refrigerant loss	% of refrigerant in cylinder that is emitted due to this type of loss	% of cylinders that experience this type of loss
Disposable Cylinders		
Mechanical damage to valve	96%[a]	0.01%[b]
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	100%	0.01%[b]
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	96%[a]	0.01%[b]
Refillable Cylinders		
Mechanical damage to valve	96%[a]	0.02%
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	100%	0.01%[b]
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	Up to 20%	0.01%[b]

a. Assumes all refrigerant is lost, minus the heel. The heel is estimated to be approximately 4 percent (see list of assumptions below).

c. The likelihood of these types of losses occurring is considered negligible. We use 0.01 percent as the smallest likelihood of a loss occurring. See list of assumptions below

Table H-2: Key variables used in calculations

Step	Variable	Value	Source/notes
1	Total number of 30-pound cylinders of HFCs sold in the United States each year	4.5 million	A-Gas 2021; Fluorofusion 2021
1	% of 30-pound cylinders that are refillable	1%	A-Gas 2021; Fluorofusion 2021; National Refrigerants 2021
1	Total number of 30-pound cylinders of each type manufactured in the United States each year	Disposable cylinders: 4,455,000 Refillable cylinders: 45,000	Derived from total number of 30-pound cylinders sold and percentage of 30-pound cylinders that are refillable
1	Average number of times per year that a cylinder is filled	Disposable cylinders: 1 Refillable cylinders: 1	CARB 2011; Refrigerant Services 2012
2	Total number of cylinder "trips" per year	Disposable cylinders: 4,455,000 Refillable cylinders: 45,000	Derived from Step 1 calculations
2	Average amount of refrigerant in a "full" cylinder	24 lbs[a]	See assumptions in notes below
2	Types of refrigerant losses	See Table H-1	N/A
2	% of refrigerant in cylinder that is emitted due to each type of loss	See Table H-1	N/A
2	% of cylinders that experience each type of loss	See Table H-1	N/A
2	% of cylinders containing each type of HFC refrigerant	R-134a: 22% R-410A: 51% R-407C: 3% R-404A: 12% R-507A: 2% R-407A: 9%	EPA 2020
4	GWP	As reported in The Montreal Protocol on Substances that Deplete the Ozone Layer	Ozone Secretariat 1987

[a] Assuming cylinder is filled to 80 percent capacity, and full capacity is 30 lbs. (see assumptions below).

Assumptions

Stratus made several assumptions to estimate the total annual emissions resulting from refrigerant losses during cylinder transport and storage:

- Analysis only includes emissions from 30-pound cylinders. As noted above, 30-pound cylinders are the most commonly used cylinders for transporting refrigerant in the United States. For simplicity, this analysis does not include emissions from transport and storage of cylinders of other sizes.
- Analysis only considers emissions from "outbound" cylinder trips. Cylinders returning from service technicians to wholesalers and then to reclaimers, disposers, and refrigerant

manufacturers (the actual life cycle will depend on the type of cylinder) are not considered.

- Every type of refrigerant loss is assumed to occur in at least 0.01 percent of all cylinders. Based on input from experts contacted for this analysis, the likelihood of certain types of refrigerant losses occurring in cylinders is negligible. For this analysis, every type of refrigerant loss is assumed to occur in at least 0.01 percent of all cylinders.
- All cylinders have a maximum capacity of 30 lbs. and are filled to 80 percent capacity, unless overfilled. This assumption is made to simplify the analysis. The cylinder capacity will vary depending on the cylinder manufacturer, because every cylinder has slight differences in size.
- Refrigerant heels remain in cylinders that lose refrigerant due to defects in or damage to valves. The heel is assumed to equal approximately 5 percent of the original refrigerant charge. It is assumed that cylinders that experience a rupture will lose the refrigerant heel, and cylinders that experience a safety-valve refrigerant release will retain the heel.

Results

Emissions from transport and storage of cylinders for 2020 are presented in terms of absolute pounds and in terms of their impact on climate (using MTEVe) and the ozone layer (using ODP metric tons).

Disposable cylinders

Table H-3: presents the estimated pounds of emissions resulting from each type of refrigerant loss that disposable cylinders might experience. The table shows that refrigerant losses from disposable cylinders result in emissions of approximately 31,200 pounds of refrigerant per year.

Table H-3: Emissions from disposable cylinder transport and storage – pounds emitted

Type of loss	Total number of cylinder trips per year	Average amount of refrigerant in full cylinder	% of refrigerant in cylinder that is emitted due to this type of loss	% of cylinders that experience this type of loss	Pounds emitted
Mechanical damage to valve	4,455,000	24	96%	0.01%	10,264
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	4,455,000	24	100%	0.01%	10,692
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	4,455,000	24	96%	0.01%	10,264
Total	**N/A**	**N/A**	**N/A**	**N/A**	**31,221**

Table H-4: presents the estimated MTEVe of emissions resulting from refrigerant losses from disposable cylinders, based on the breakdown of HFC refrigerants transported and stored in 30-pound cylinders. As the table shows, emissions from disposable cylinders account for approximately 31,025 MTEVe per year.

Table H-4: Emissions from disposable cylinder transport and storage – MTEVe emitted

Refrigerant	% of all refrigerants in cylinders	Pounds emitted (using total pounds emitted from Table H-3:)	Metric tons emitted	MTEVe
R-134a	22%	6,898	3.13	4,474
R-410A	51%	15,973	7.25	15,128
R-407C	3%	1,089	0.49	876
R-404A	12%	3,630	1.65	6,458
R-507A	2%	726	0.33	1,312
R-407A	9%	2,904	1.32	2,776
Total (All)	**100%**	**31,221**	**14.2**	**31,025**

Note: Totals might not sum due to rounding.

Refillable Cylinders

Table H-5 presents the estimated pounds of emissions resulting from each type of refrigerant loss that refillable cylinders might experience. The table shows that refrigerant losses from refillable cylinders result in emissions of approximately 340 pounds of refrigerant per year. This amount is considerably smaller than the amount emitted from disposable cylinders. This discrepancy is logical, considering the estimation that refillable cylinders account for only 1 percent of all 30-pound cylinders in use.

Table H-5: Emissions from refillable cylinder transport and storage – pounds emitted

Type of Loss	Total Number of Cylinder Trips per Year	Average Amount of Refrigerant in Full Cylinder	% of Refrigerant in Cylinder that is Emitted due to This Type of Loss	% of Cylinders that Experience This Type of Loss	Pounds Emitted
Mechanical damage to valve	45,500	24	95%	0.02%	207
Overfilled cylinder with defective safety-relief valve ruptures (e.g., due to extreme heat or blunt contact)	45,500	24	100%	0.01%	108
Overfilled cylinder with effective safety-relief valve releases overfilled amount (e.g., due to extreme heat or blunt contact)	45,500	24	20%	0.01%	22
Total	**N/A**	**N/A**	**N/A**	**N/A**	**337**

Table H-6 presents the estimated MTEVe of emissions resulting from HFC refrigerant losses from refillable cylinders, based on the breakdown of refrigerants transported and stored in 30-pound cylinders. As the table shows, HFC emissions from refillable cylinders account for approximately 335 MTEVe per year. Again, the discrepancy between these figures and those indicated for disposable cylinders (Table H-4:) is due to the very small percentage of 30-pound cylinders that are refillable compared with those that are disposable.

Table H-6: Emissions from refillable cylinder transport and storage – MTEVe emitted

Refrigerant	% of all refrigerants in cylinders	Pounds emitted (using total pounds emitted from Table H-5:)	Metric tons emitted	$MTCO_2e$
R-134a	22%	74	0.03	48
R-410A	51%	172	0.08	163
R-407C	3%	12	0.01	9
R-404A	12%	39	0.02	70
R-507A	2%	8	0.00	14
R-407A	9%	31	0.01	30
Total (All)	**100%**	**337**	**0.15**	**335**

Note: Totals might not sum due to rounding.

H.2. Estimate of Emissions from Heels (Theoretical and Empirical) in Disposable Cylinders

Theoretical Estimates of Amount of Refrigerant Remaining in Disposable Cylinders

This section describes the approach used by Stratus[173] to estimate theoretical heels in disposable cylinders under different field servicing and recovery conditions.

Refrigerants studied

Based on input from EPA technical experts and industry sources, as well as a review of available literature, six refrigerants were included in the theoretical study. Table H-8: lists the refrigerants that were selected for inclusion, along with information about the cylinder sizes they are typically sold in and the use for which they are commonly purchased. These refrigerants include HCFC-22 (HCFC-22) and HFC-134a (R-134a) and blended refrigerants R-410A, R-407C, R-404A, and R-507A.

[173] See note 57.

Table H-7 presents the estimated heel amounts for each of the six refrigerants for three applications (air conditioning, mid-temperature refrigeration, and low-temperature refrigeration) assuming that no vapor recovery process was used following field servicing. Average estimated heel amounts ranged between 0.31 lbs. and 0.70 lbs.

It is important to note that the four blends comprise different measures of multiple pure refrigerants. Aside from R-134a, which was included in the study, refrigerants that are combined to create the mixtures were not considered individually, and for the purposes of this study these refrigerants are included only insofar as they determine the characteristics of the refrigerant blends of interest.

Table H-7 shows the typical quantities of refrigerant contained in a 13.5-L disposable cylinder for each refrigerant studied. As shown, the amount of refrigerant in a 13.5-L cylinder is 30 lbs. for pure refrigerants (HCFC-22 and R-134a) and 24 lbs. to 25 lbs. for refrigerant blends. The difference between refrigerant charge sizes for pure and blended refrigerants is due to the potential fractioning of the refrigerant mixtures, which could selectively vaporize the low boiling temperature constituent of the mixture.

Table H-7: Typical refrigerant mass in a 13.5-L disposable cylinder

	HCFC-22	**R-134a**	**R-410A**	**R-407C**	**R-404A**	**R-507A**
Mass (lb)	30	30	25	25	24	25

Source: National Refrigerants. Product Specifications. Available: http://www.refrigerants.com/product. Accessed 9/13/2009.

Model used and simulated operating conditions

Xprops™, a refrigerant property analysis software developed by Thermal Analysis Partners (TAP), was used to estimate heel amounts for the six refrigerants. This model can generate theoretical heel amounts and other outputs based on inputs that simulate operating conditions. AHRI Standard 540-2004 was used to determine typical operating conditions of air-conditioning and refrigeration systems. The AHRI standard provided information on the suction dew point temperature, discharge dew point temperature, and the return gas temperature. Based on the suction dew point temperature that corresponds with different uses of refrigerant (e.g., air conditioning, mid-temperature refrigeration, and low-temperature refrigeration), the suction pressure of the six targeted refrigerants was calculated using Xprops.

Heel estimation

The estimated theoretical heel amount that would remain in a typical cylinder was estimated considering two different scenarios. In the first scenario, the cylinder is assumed to have been emptied in the field and disposed of without a vapor recovery process. When the liquid phase refrigerant is being charged, the pressure in the cylinder approaches the system suction pressure.

This causes the moisture in the air to condense on the cylinder surface. As the last of the liquid refrigerant is removed from the cylinder, the refrigerant is in the vapor phase. As heat is transferred from the high-temperature ambient air to the low-temperature cylinder, the refrigerant in the cylinder becomes superheated vapor. During this process, the cylinder pressure decreases and ultimately reaches the system suction pressure.

Using the calculated system suction pressure ($P_{suction}$) and the assumption that the typical ambient temperature (T_{amb}) is 24°C, the density of the refrigerant vapor ($\rho_{vapor, cylinder}$) can be calculated for each of the refrigerants based on the following function by using the Xprops software:

$$\rho_{vapor,cylinder} = f(P_{suction}, T_{amb})$$

Once the density of the refrigerant vapor and the internal volume ($V_{internal}$) of the cylinder are known, the mass of the heel (m_{heel}) can be calculated as follows:

$$m_{heel} = \rho_{vapor,cylinder}\ x\ V_{internal}$$

In the second scenario, the cylinder is assumed to have been used in the field and then subjected to a vapor recovery process. In the vapor recovery process, the cylinder ultimately reaches a final recovery pressure. Two final recovery pressures were explored: vapor recovery to a certain final pressure based on AHRI Standard 740-1998, and vapor recovery to several specific vacuum pressures.

Recovery to AHRI Standard

To estimate the heel in a cylinder that has undergone vapor recovery based on AHRI Standard 740-1998, the following assumptions were made:

- Cylinder is at ambient temperature (T_{amb}) 24°C;
- Initial recovery pressure ($P_{recovery, initial}$) is at the system suction pressure ($P_{suction}$); and
- Final recovery pressure ($P_{recovery, final}$) is 10 percent of the initial cylinder pressure.

Given these assumptions, the density of the refrigerant vapor in the cylinder was calculated using Xprops for each of the six refrigerants. Given the cylinder's internal volume and the previously calculated density of the refrigerant vapor, the masses of the refrigerant heels and the percentage of the total that the heel accounts for were calculated.

Recovery to Specific Pressure

To estimate the heel in a cylinder that has undergone vapor recovery based on several specific vacuum pressures, the following assumptions were made:

- Cylinder is at ambient temperature (T_{amb}) 24ºC; and
- Final recovery pressure is below the atmospheric pressure [measured at 0, 5, 10, 15, 20, 25, and 29 inches of mercury (inHg) vacuum].

As in the process to estimate the heel in a cylinder that has followed the AHRI standard for refrigerant recovery (Standard 740-1998), once the final recovery pressure and the ambient temperature were known, the density of the refrigerant vapor was calculated for each of the six refrigerants.

The estimate of the mass of the heel and the percentage of the initial volume remaining are calculated based on the density of refrigerant vapors.

Results

This section presents the results of the theoretical study, including the estimated theoretical heel amounts resulting from the three refrigerant recovery conditions. Table H-8: presents the estimated heel amounts for each of the six refrigerants for three applications (air conditioning, mid-temperature refrigeration, and low-temperature refrigeration) assuming that no vapor recovery process was used following field servicing. Average estimated heel amounts ranged between 0.31 pounds and 0.70 pounds.

Table H-8: Suction dew heel amounts (lbs.) assuming no vapor recovery at $P_{suction}$ and $T_{ambient}$

Application	point temp. (°C)	HCFC-22	R-134a	R-410A	R-407C	R-404A	R-507A
Air conditioning	7.2	0.72	0.50	1.02	0.66	1.03	1.08
Mid-temp. refrigeration	-6.7	0.44	0.29	0.61	0.39	0.62	0.66
Low-temp. refrigeration	-23.3	0.23	0.15	0.32	0.20	0.33	0.35
Average	**NA**	**0.46**	**0.31**	**0.65**	**0.42**	**0.66**	**0.70**

Note: Figures have been rounded to two decimal points

Table H-9: provides the estimated heel amounts for each of the six refrigerants for three applications (air conditioning, mid-temperature refrigeration, and low-temperature refrigeration) assuming a vapor recovery process based on the AHRI standard for refrigerant recovery (Standard 740-1998) was used following field servicing. Average estimates ranged between 0.03 lbs. and 0.06 lbs.

Table H-9: Heel amounts (lbs.) assuming vapor recovery to AHRI standards

Application	point temp. (°C)	HCFC-22	R-134a	R-410A	R-407C	R-404A	R-507A
Air conditioning	7.2	0.07	0.05	0.09	0.06	0.09	0.09
Mid-temp. refrigeration	-6.7	0.04	0.03	0.06	0.04	0.06	0.06
Low-temp. refrigeration	-23.3	0.02	0.01	0.03	0.02	0.03	0.03
Average	**NA**	**0.04**	**0.03**	**0.06**	**0.04**	**0.06**	**0.06**

Note: Figures have been rounded to two decimal points.

Table H-10 provides the estimated heel amounts for each of the six refrigerants at different vacuum pressures assuming a vapor recovery process following field servicing. Average estimates ranged between 0.04 lbs. and 0.06 lbs. The range of heel amounts indicated in Table H-10 corresponds to heel ratios of between 0.01 percent to 0.51 percent, across all refrigerants and at vacuum recovery pressures ranging from 0 inHg to 29 inHg. These ratios are consistent with the results of a study conducted by AHRI[174] that considered the effects of different recovery pressures on heel ratios. The results of this study showed that under pressures ranging from system suction pressure to 20 inHg, the ratios decline from system suction pressure (ratios between 1.5 percent and 3 percent for different refrigerants) to less than 0.5 percent at 0 psig for all refrigerants and close to 0.1 percent at 20 inHg for all refrigerants. Table H-10 illustrates the declining heel amounts at higher vacuum pressures for each of the refrigerants.

Table H-10: Heel amounts (lbs.) assuming vapor recovery to various vacuum pressures

InHg vacuum	Psig vacuum	Kpa abs.	HCFC-22	R-134a	R-410A	R-407C	R-404A	R-507A
0	0.00	101.35	0.11	0.13	0.09	0.11	0.12	0.12
5	2.46	84.42	0.09	0.11	0.07	0.09	0.10	0.10
10	4.91	67.49	0.07	0.08	0.06	0.07	0.08	0.08
15	7.37	50.56	0.05	0.06	0.04	0.05	0.06	0.06

[174] See note 89.

Empirical Study of Amounts of Refrigerant Remaining in Disposable Cylinders

Stratus[175] collected data by measuring quantities of refrigerant remaining in disposable cylinders after being used to service stationary air-conditioning and refrigeration equipment in the field. A refrigerant recovery, measurement, and recording framework was designed to facilitate collection and analysis of the data obtained with a Phoenix, Arizona refrigerant distributor. This section describes the methodology employed for collecting the data and the results produced.

Methodology

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

Results

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

[175] See note 57.

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

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

The cylinders collected for this study contained the following refrigerants: HCFC-22, R-404A, R-408A, R-410A, and R-507. Table H-11 provides the distribution of the cylinders by refrigerant type and application.

Table H-11: Summary of cylinders collected by refrigerant and application

Application	**HCFC-22**	**R-404A**	**R-408A**	**R-410A**	**R-507**	**Total**
	30 lb cylinder	**24 lb cylinder**	**24 lb cylinder**	**25 lb cylinder**	**25 lb cylinder**	
Appliance servicing	2	0	0	0	0	2
Residential A/C	32	0	0	0	0	32
Commercial refrigeration	24	12	0	2	5	43
Chillers	26	5	2	0	0	33
Total	**84**	**17**	**2**	**2**	**5**	**110**

Source: Communication with Joe Ward, American Refrigeration Supplies. October 2009.

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

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

Of the latter two types, it is unknown whether refrigerant was recovered by the source or if the refrigerant was vented. Of the 63 cylinders that remained under pressure (i.e., had measurable amounts of refrigerant remaining), most contained HCFC-22 and came from the residential air-conditioning sector. Table H-12 provides a summary of cylinders with pressure by refrigerant and source.

Table H-12: Summary of cylinders collected with pressure by refrigerant and application

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

Of the cylinders that remained under pressure, the amounts of refrigerant remaining varied, with a mean of 1.08 lbs. Table H-13 and H-14 provide summary statistics of the amounts by refrigerant and application.

Table H-13: Mean and median amounts of refrigerant remaining (lbs.), by refrigerant

Refrigerant	Number of cylinders	Mean amount	Median amount	Standard deviation	Minimum	Maximum
R-404a	12	1.40	0.96	0.91	0.42	2.91
R-410A	2	0.96	0.96	0.09	0.89	1.02
R-507	2	0.53	0.53	0.03	0.51	0.55
Total	**63**	**1.08**	**0.70**	**0.79**	**0.28**	**3.69**

Table H-14: Mean and median amounts of refrigerant remaining (lbs.), by application

Application	Number of cylinders	Mean amount	Median amount	Standard deviation	Minimum	Maximum
Appliance servicing	1	0.64	0.64	N/A	N/A	N/A

Residential A/C	28	1.02	0.68	0.80	0.28	3.69
Commercial refrigeration	19	1.13	0.87	0.78	0.33	2.91
Chillers	15	1.15	0.68	0.84	0.47	3.26
Total	**63**	**1.08**	**0.70**	**0.79**	**0.28**	**3.69**

H.3. Estimation of Emissions Under Various Recovery Scenarios for Disposable Cylinders During Disposal

A five-step process was implemented to estimate the quantity of annual emissions resulting from disposal of disposable cylinders. These steps include estimating or identifying the following:

1. Number of disposable cylinders used per year;
2. Percentage of cylinders containing different refrigerants;
3. Amount of refrigerant remaining in typical 30-pound disposable cylinders after use;
4. GWP of the refrigerants in question; and
5. Total amount of GHG emissions resulting from disposal of disposable cylinders with refrigerant remaining under varying assumptions about venting.

The information used to complete each of these steps was collected through a review of available information in previous studies and input from industry sources. Detailed explanations of each step of the approach are provided below.

Estimate the number of non-refillable cylinders used per year

Based on input from industry sources, it is estimated that there are between 4 million and 5 million 30-pound cylinders used to charge stationary air-conditioning and refrigeration systems annually, including both disposable and refillable cylinders (Airgas 2021a; Fluorofusion 2021). For this study, it is assumed that there are 4.5 million HFC cylinders (disposable and refillable) used to service stationary air-conditioning and refrigeration systems annually.

In addition, based on conversations with those familiar with the stationary air and refrigeration servicing industry, it is estimated that refillable cylinders account for between less than 1 percent and 10 percent of all 30-pound cylinders used, with a general assumption that the quantity of refillable cylinders as a percentage of all 30-pound cylinders used is closer to 1 percent (Airgas 2021b; Fluorofusion 2021; National Refrigerants 2021). For this study, it is assumed that the percentage of refillable cylinders is 1 percent, meaning that the total number of disposable cylinders would be or 4.46 million (99 percent of 4.5 million).

Estimate the percentage of cylinders containing different refrigerants

Table 3-14 H-15 presents the estimated distribution of disposable cylinders sold annually for servicing stationary air conditioning and refrigeration systems, by type of refrigerant. For this study, the distribution of refrigerant types assumed to be sold in 30-pound cylinders in the United States in 2020 was based on refrigerant demand for servicing and charging equipment estimated by EPA's Vintaging Model (EPA 2020).

Table H-15: Breakdown of cylinders by refrigerant type

Refrigerant	Distribution of Cylinders
HFC-134a	22%
R-410A	51%
R-407C	3%
R-404A	12%
R-507A	2%
R-407A	9%
Total	**100%**

Estimate the total amount of refrigerant remaining annually in typical 30-pound non-refillable cylinders after use

The total annual amount of refrigerant emitted each year from disposing of disposable 30-pound cylinders was estimated based on (i) the typical amount of refrigerant remaining in a disposable 30-pound cylinder; (ii) the total number of disposable cylinders used per year (estimated in Step 1 to be 4.46 million); and (iii) the distribution of the total number of cylinders used by type of refrigerant.

Four scenarios were developed based on different assumptions of the amount of refrigerant remaining in cylinders at the time of disposal, as follows:

Scenario 1: 0.5 lbs. of refrigerant remaining per cylinder;

Scenario 2: 1.0 lbs. of refrigerant remaining per cylinder;

Scenario 3: 1.25 lbs. of refrigerant remaining per cylinder;

Scenario 4: 1.5 lbs. of refrigerant remaining per cylinder; and

Scenario 5: 2.0 lbs. of refrigerant remaining per cylinder.

For each scenario, the total volume of refrigerant remaining was calculated by multiplying the appropriate amount of refrigerant remaining per cylinder times the estimated number of cylinders (i.e., 4.5 million cylinders distributed across the six refrigerants). Table H-16 shows the estimated volume of refrigerant remaining under each scenario, for each type of refrigerant and in total. If all cylinders are disposed of while still containing 1 pound of refrigerant, an estimated that 4.4 million pounds of refrigerant would be vented.

Table H-16: Total Amount of Refrigerant Emitted by Scenario and Refrigerant

Refrigerant	Pounds per cylinder	Number of cylinders	Total pounds
Scenario 1 0.5 lbs. of refrigerant remaining			
R-134a	0.5	984,741	492,371
R-410A	0.5	2,280,453	1,140,227
R-407C	0.5	155,485	77,743
R-404A	0.5	518,285	259,142
R-507A	0.5	103,657	51,828
R-407A	0.5	414,628	207,314
Total (All)		**4,457,250**	**2,228,625**
Scenario 2 – 1.0 lbs. of refrigerant remaining			
R-134a	1.0	984,741	984,741
R-410A	1.0	2,280,453	2,280,453
R-407C	1.0	155,485	155,485

Refrigerant	Pounds per cylinder	Number of cylinders	Total pounds
R-404A	1.0	518,285	518,285
R-507A	1.0	103,657	103,657
R-407A	1.0	414,628	414,628
Total (All)		**4,457,250**	**4,457,250**
Scenario 3 – 1.25 lbs. of refrigerant remaining			
R-134a	1.25	984,741	1,230,927
R-410A	1.25	2,280,453	2,850,567
R-407C	1.25	155,485	194,357
R-404A	1.25	518,285	647,856
R-507A	1.25	103,657	129,571
R-407A	1.25	414,628	476,822
Total (All)		**4,457,250**	**5,530,100**
Scenario 4 – 1.5 lbs. of refrigerant remaining			
R-134a	1.5	984,741	1,477,112
R-410A	1.5	2,280,453	3,420,680
R-407C	1.5	155,485	233,228
R-404A	1.5	518,285	777,427
R-507A	1.5	103,657	155,485
R-407A	1.5	414,628	621,942
Total (All)		**4,457,250**	**6,685,875**
Scenario 5 – 2.0 lbs. of refrigerant remaining			
R-134a	2.0	984,741	1,969,483
R-410A	2.0	2,280,453	4,560,907
R-407C	2.0	155,485	310,971
R-404A	2.0	518,285	1,036,570
R-507A	2.0	103,657	207,314
R-407A	2.0	414,628	829,256
Total (All)		**4,457,250**	**8,914,500**

Note: For the purposes of this table, it is assumed under each scenario that every cylinder is disposed with the same amount of refrigerant being emitted.

Estimate the total amount of GHG emissions resulting from disposal of cylinders with refrigerant remaining in them. The total amount of emissions resulting from each of the four scenarios was calculated based on (1) the total estimated amount of refrigerant remaining in cylinders by type of refrigerant and (2) the percentage of cylinders that are vented.

Table H-17 provides the resulting estimates. For example, under Scenario 2 (1.0 pounds refrigerant remaining), assuming 100 percent of cylinders are vented, it is estimated that the disposal of disposable cylinders would result in GHG emissions of approximately 4.4 MMTEVe. Because it is unlikely that all cylinders will be vented, emissions for each refrigerant were also estimated based on varying assumptions about the percentage of cylinders that are vented. For example, under Scenario 2, if 95 percent of cylinders is vented (with the remaining 5 percent of cylinders disposed of properly), the resultant estimated emissions of GHGs would be equivalent to approximately 4.2 MMTEVe.

Table H-17: Refrigerant emissions under cylinder recovery scenarios, distributed by percent of cylinders vented (MMTEVe)

Percent of cylinders vented	Scenario 1 (0.5 lbs. Heel)	Scenario 2 (1.0 lbs. Heel)	Scenario 3 (1.25 lbs. Heel)	Scenario 4 (1.5 lbs. Heel)	Scenario 5 (2.0 lbs. Heel)
10	0.22	0.44	0.55	0.66	0.89
20	0.44	0.89	1.10	1.33	1.77
30	0.66	1.33	1.65	1.99	2.66
40	0.89	1.77	2.20	2.66	3.54
50	1.11	2.21	2.75	3.32	4.43
60	1.33	2.66	3.30	3.99	5.32
70	1.55	3.10	3.85	4.65	6.20
80	1.77	3.54	4.40	5.32	7.09
90	1.99	3.99	4.95	5.98	7.97
100	2.10	4.21	5.22	6.31	8.42

H.4 Estimation of Annual Emission Changes from Replacing Disposable Cylinders with Refillable Cylinders

The annual emission changes between the BAU scenario with both refillable and disposable and the most likely, low, and high scenarios with all cylinders replaced with refillable cylinders and the average refrigerant GWP applied reflecting the change in mixture of HFCs and other alternatives resulting from mitigation options applied in EPA (2021a) are shown in Table H-18.

Table H-18: Estimated Annual Emission Changes Compared with BAU, 2022–2050

Year	Average HFC GWP	Emission Changes Relative to BAU (MMTEVe)		
		Most Likely	**Low**	**High**
2022	1,694	-0.6	-2.0	0.8
2023	1,583	-1.1	-2.2	-0.1
2024	1,473	-1.6	-2.3	-0.9
2025	1,358	-2.0	-2.3	-1.5
2026	1,246	-2.3	-2.4	-2.1
2027	1,126	-2.1	-2.1	-1.9
2028	999	-1.8	-1.9	-1.6
2029	866	-1.6	-1.6	-1.4
2030	720	-1.3	-1.4	-1.2
2031	681	-1.3	-1.3	-1.1
2032	644	-1.2	-1.2	-1.1
2033	609	-1.1	-1.2	-1.0
2034	572	-1.1	-1.1	-0.9
2035	537	-1.0	-1.0	-0.9
2036	502	-0.9	-1.0	-0.8
2037	467	-0.9	-0.9	-0.8
2038	433	-0.8	-0.8	-0.7
2039	400	-0.7	-0.8	-0.7
2040	367	-0.7	-0.7	-0.6
2041	340	-0.6	-0.6	-0.6
2042	318	-0.6	-0.6	-0.5
2043	301	-0.6	-0.6	-0.5
2044	290	-0.5	-0.5	-0.5
2045	285	-0.5	-0.5	-0.5
2046	281	-0.5	-0.5	-0.5
2047	278	-0.5	-0.5	-0.5
2048	276	-0.5	-0.5	-0.5
2049	274	-0.5	-0.5	-0.5
2050	274	-0.5	-0.5	-0.5
Total		**-29**	**-34**	**-23**

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