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

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Executive Summary

The following is the analysis showing EPA's estimation of the costs and benefits of implementing the phasedown of hydrofluorocarbons (HFCs) required under the AIM Act, as realized by promulgating this rule. The principal component of this rule is establishing the HFC phasedown schedule and a procedure for the allocation of allowances for consuming and producing HFCs.[1] The rule could potentially also have localized impacts on communities living near HFC production facilities that are already disadvantaged and overburdened by pollution due to changes in the toxic feedstocks, catalysts, and byproducts to 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 that regarding disposable cylinders and HFC-23 are expected to have relatively minor impact or no effect on the overall calculation of costs and benefits.

EPA estimates that in 2022 the annual net benefits are $2.6 billion, reflecting abatement costs of $200 million and social benefits of $2.8 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 $17.9 billion. Table ES-1 presents a summary of the annual costs and net benefits of the rule for selected years in the time period 2022-2050, but with the climate benefits discounted at 3%.

[1] The AIM Act states that no HFCs shall be consumed or produced unless allowances are expended. While this rule proposes to establish a framework for the allocation of allowances for the first two years, this analysis assumes that the allowances will always be implemented on time per the Act, and that the alternative scenario is if the Act did not pass at all.

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

Year	Climate Benefits (3% discount rate)	Costs (annual)	Net Benefits
2022	$2.8	$0.2	$2.6
2024	$6.3	-$0.2	$6.5
2029	$10.2	-$0.6	$10.8
2034	$13.5	-$0.9	$14.4
2036	$17.1	-$0.8	$17.9
2045	$25.5	-$0.9	$26.4
2050	$30.2	-$1.1	$31.3

[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 4-20 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, are 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 proposed rule for 2022, 2024, 2029, 2034, 2036, 2045, and 2050.

Table ES-2: Climate Benefits for the Proposed 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	$1.2	$2.8	$3.8	$7.4
2024	$2.7	$6.3	$8.5	$16.7
2029	$4.4	$10.2	$13.5	$27.1
2034	$6.0	$13.5	$17.6	$35.9
2036	$7.7	$17.1	$22.3	$45.7
2045	$12.2	$25.5	$32.6	$68.3
2050	$14.9	$30.2	$38.4	$80.9

[a] 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). 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, are also warranted when discounting intergenerational impacts.

As part of fulfilling analytical guidance with respect to E.O. 12866, EPA presents estimates of the present value (PV) of the benefits and costs over the twenty-nine-year period 2022 to 2050. To calculate the present value of the social net-benefits of the proposed 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 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. 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.

EPA estimates that the net present cumulative benefits evaluated from 2022 through 2050 is $283.9 billion at a 3 percent discount rate.[2] The present value of net benefits are calculated over the 29-year period from 2022–2050, to account for the 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 billion, or $5 billion in savings and the present value of cumulative social benefits is $103.6 billion, both at a 3 percent discount rate. Over the same 15-year period of the phasedown, the present value of cumulative net benefits is $108.2 billion. The EAV over the period 2022-2050 is $14.8 billion when using a 3 percent discount rate and $14.7 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 ES-3. Estimates in the table are presented as rounded values.

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

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 Proposed Rule (billions of 2020$, discounted to 2022)[a,b,c]

Year	Climate Benefits (3% discount rate)[c]	Costs (annual)[d]		Net Benefits	
2022	$2.8	$0.2		$2.6	
2023	$2.9	$0.2		$2.7	
2024	$6.3	-$0.2		$6.5	
2025	$6.5	-$0.2		$6.7	
2026	$6.7	-$0.2		$6.9	
2027	$6.9	-$0.2		$7.1	
2028	$7.1	-$0.2		$7.3	
2029	$10.2	-$0.6		$10.8	
2030	$10.5	-$0.6		$11.1	
2031	$10.8	-$0.6		$11.4	
2032	$11.0	-$0.6		$11.6	
2033	$11.3	-$0.9		$12.2	
2034	$13.5	-$0.9		$14.4	
2035	$13.8	-$0.9		$14.7	
2036	$17.1	-$0.8		$17.9	
2037	$17.5	-$0.8		$18.3	
2038	$17.9	-$0.8		$18.7	
2039	$18.4	-$0.8		$19.2	
2040	$18.8	-$0.8		$19.6	
2041	$19.2	-$0.8		$20.0	
2042	$23.9	-$0.8		$24.7	
2043	$24.4	-$0.9		$25.3	
2044	$24.9	-$0.9		$25.8	
2045	$25.5	-$0.9		$26.4	
2046	$26.0	-$0.9		$26.9	
2047	$28.5	-$0.9		$29.4	
2048	$29.1	-$1.1		$30.2	
2049	$29.7	-$1.1		$30.8	
2050	$30.2	-$1.1		$31.3	
Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**
Present Value	**$272.8**	**-$11.1**	**-$5.8**	**$283.9**	**$278.6**
Equivalent Annualized Value	**$14.2**	**-$0.6**	**-$0.5**	**$14.8**	**$14.7**

[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 social cost of HFCs (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, are also warranted when discounting intergenerational impacts.

[d] The costs presented in this table are consistent with the costs presented in Chapter 3, Table 3-5.

The estimation of $272.8 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 scenario (BAU) 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 HFC to arrive at the monetary value of HFC emission reductions.

EPA estimates the climate benefits for this proposed 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 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.

EPA estimates the total social benefits of HFC emission reductions expected from this proposed rule using HFC-specific SC-HFC estimates. These SC-HFC estimates were developed using methodologies that are consistent with the methodology underlying the interim 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[3] 2021). The interim social cost of greenhouse gas estimates presented in IWG 2021 are interim values developed under Executive Order (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. Thus, EPA considers the HFC estimates used in this analysis as the most appropriate for use in benefit-cost analysis until improved estimates for social cost of other greenhouse gases are developed.

The SC-HFC estimates used in this analysis were developed using methodologies consistent with the methodology underlying the interim estimates of the social cost of other greenhouse gases (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 (IWG) that included the 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

[3] Interagency Working Group

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 Executive Order 13990, which directed the IWG to ensure that the U.S. Government's (USG) estimates of the social cost of carbon and other greenhouse gases 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 proposed 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-12 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 – i.e., the societal harm from one metric ton emitted in

[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.

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 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	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 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	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 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	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 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	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 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	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 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	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 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	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 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	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 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	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

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 benefit populations that may be especially vulnerable to damages associated with climate change. However, how producers transition from high Global Warming Potential (GWP, a measure of the relative climatic impact of a GHG) HFCs will drive changes in future health risks for communities living near HFC production facilities due to the use of feedstock chemicals that have local effects when released into the environment. Given limited information regarding which substitutes will be produced where, it is unclear to what extent health risks from hazardous air toxics for communities living near HFC production facilities are impacted by this proposed 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 as a result of implementing Title VI of the Clean Air Act, incentivizing the creation of newer, non-ozone depleting refrigerants. In addition, the "Exchange Values" listed in the AIM Act are numerically equivalent to the GWPs used in the Kigali Amendment. One key difference between the AIM Act and the Kigali Amendment is that the AIM Act sets aside a mandatory allocation for specific end-uses, although this does not affect the overall cap on HFCs.

The AIM Act directs EPA to allocate the full quantity of allowances necessary, based on projected, current, and historical trends for six applications: (1) propellants in metered dose inhalers (MDIs); (2) defense sprays; (3) structural composite preformed polyurethane foam for marine use and trailer use; (4) the etching of semiconductor material or wafers and the cleaning of chemical vapor deposition (CVD) chambers within the semiconductor manufacturing sector; (5) on board aerospace fire suppression; and (6) mission-critical military end uses, such as armored vehicle engine and shipboard fire suppression systems and systems used in deployable and expeditionary applications.[6] The additional HFCs will likely be used for commercial comfort cooling, cold storage, refrigerated food processing and dispensing equipment, household refrigeration industries, general fire suppression, and application uses such as foam blowing agents, solvents, and aerosols.

[6] EPA estimates this to be less than 6 MMTEVe, compared to the baseline of around 300 (or less than 3%).

The public is invited to provide comment and/or data that would inform various analytic matters (e.g., the speed and cost of transition in various end uses) and uncertainties in the RIA (see chapter 7).

Chapter 1: Introduction and Background

This analysis presents the Environment Protection Agency's (EPA's) estimates of social costs and benefits associated with implementing the phasedown of hydrofluorocarbons (HFCs) as per the American Innovation and Manufacturing Act of 2020 (AIM Act). 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 and the associated transition for sectors and subsectors from using certain HFC-based technology to alternative technologies. In addition, this analysis examines potential localized impacts of implementing the rule in communities surrounding HFC producers.

The Agency estimates that the present cumulative net benefits of phasing down HFCs to be $283.9 billion, discounted at a 3 percent rate. The present value of nets benefits are calculated over the 29-year period from 2022–2050, to account for the 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 are -$5 billion, or $5 billion in savings and the present value of cumulative social benefits is $103.6 billion, both at 3 percent discount rate. Over the same 15-year period of the phasedown, the present value of cumulative net benefits is $108.2 billion. Benefits were calculated out to 2050 and discounted to the present at a 3 percent discount rate. EPA also estimates that while the initial costs for the first two compliance periods (2022–2028) would exceed the cost savings, thereafter for each major time period, the cumulative cost savings exceed costs prior to considering the impact of social 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 solely 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 $15.6 billion in costs to at least $13.9 billion in savings, compared to the Agency's preferred estimate (see Table A-1 for the full sensitivity analysis results).

Note that the results depend heavily on the assumed "business as usual" (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 large-scale adoption of cost-saving technologies by industry; hence, such cost savings not included in the assumed BAU forecast 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.[7] 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, nine states have limited the use of certain HFCs or HFC blends for specific products and seven additional states have indicated an intent to take similar action. These rules are similar to rules EPA promulgated under Clean Air Act (CAA) section 612 that were

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

subsequently partially vacated and remanded to the Agency for further action.[8] None of these state actions phase down overall HFC consumption and production analogous to this rulemaking; however, they do affect availability of HFCs for the restricted applications. States with these use restrictions are California, Colorado, Delaware, Maryland, Massachusetts, New Jersey, New York, Vermont, and Washington. Oher states including Hawaii, Maine, Rhode Island, and Virginia are in the process of also restricting certain 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 a use restriction and a phasedown as well as a lack of available data besides the analysis that accompanied the EPA SNAP regulations that inspired the state actions.[9]

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.

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[8] Under CAA section 612, EPA issued a final rule in July 20, 2015, which, among, other things, changed listings 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*, 866 F.3d 451, 462 (D.C. Cir. 2017); *see also Mexichem Fluor, Inc. v. EPA*, Judgment, Case No. 17-1024 (D.C. Cir., April 5, 2019), 760 Fed. Appx. 6 (Mem).

[9] 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 ($MMTCO_2e$) 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 nine states listed with regulated restrictions would be to apportion by population, or approximately 28.7% of the estimated national emission reductions. (Populations as compiled at https://en.wikipedia.org/wiki/List_of_states_and_territories_of_the_United_States_by_population, accessed March 4, 2021. Original sources: "Population, Population Change, and Estimated Components of Population Change: April 1, 2010 to July 1, 2020 (NST-EST2020-alldata)." United States Census Bureau [https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates.html] and The World Factbook. Central Intelligence Agency [https://www.cia.gov/the-world-factbook/]). It should be noted, however, that the implementation dates for these nine states vary and most often are later than those set under EPA's 2015 and 2016 rules.

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 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 the EPA 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.[10] While past cost analyses of the ODS phaseout provide important context, they also demonstrate that realized costs can be lower.[11,12]

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

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

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

1.1 Statutory Requirement

On December 27, 2020, the AIM Act was enacted and 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. EPA anticipates that there will be future rulemakings including those related to the latter two main areas.

The Act lists 18 saturated HFCs, and their isomers, that are covered by the statute's provisions, referred to as "regulated substances" under the Act.[13] The Act also assigned an "exchange value" 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.

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

[13] 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).

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 tasks the EPA Administrator to ensure the annual quantity of all regulated substances produced or consumed in the United States does not exceed the percentage listed for the applicable production or consumption baseline. The AIM Act provides formulas for how to set a baseline 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.B of the proposed rule.

1.2 Background

1.2.1 Hydrofluorocarbons

HFCs are intentionally produced[14] fluorinated chemicals that have no known natural sources. HFCs are used in the same applications that ODS have historically been used in, such as refrigeration and air conditioning, foam blowing agents, solvents, aerosols, and fire suppression. HFCs are potent greenhouse gases (GHGs) with 100-year GWPs 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 volume of global GHG emissions,[15] their use is growing worldwide due to the global phaseout of ODS under the 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, but global adherence to the Kigali Amendment to the Montreal Protocol would substantially reduce future emissions, leading to a peaking of HFC emissions before 2040.[16] The 18 HFCs listed as regulated substances by the AIM Act include the most commonly used HFCs and have high impacts as measured by the quantity emitted multiplied by their respective GWPs.

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

[14] While the overwhelming majority of HFC production is intentional, EPA is aware that 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), 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.
[16] Ibid.

23 percent from 2012 to 2016. The four most abundant HFCs in the atmosphere 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 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 the Kigali Amendment which outlines a global phasedown of the production and consumption of HFCs. If the Kigali Amendment were to be fully implemented, it is 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 baseline scenario of uncontrolled HFCs.[19]

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 in refrigeration and air-conditioning equipment in homes, commercial buildings, and industrial operations (~75 percent of total HFC use in 2019)

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[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).

and in air conditioning in vehicles and refrigerated transport (~8 percent). HFCs are also used in foam products (~11 percent), aerosols (~4 percent), fire protection systems (~1 percent), and solvents (~1 percent).[20]

EPA considered the emissions reductions from an HFC production and consumption phasedown in the United States and presented the results in the 2016 Biennial Report to the United Nations Framework Climate Change Convention (UNFCCC).[21] At the time, EPA provided an estimate of 113 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) of reduced U.S. HFC emissions 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 certain marked differences from the AIM Act, this analysis provides useful information given they have a similar list of HFCs to be phased down following the same schedule. The Biennial Report included estimates for HFC actions under CAA section 612 modeled in the *2016 Current Measures*.[22] HFC emissions

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[20] 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.

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

[22] Under CAA section 612, EPA issued a final rule in July 20, 2015, which, among, other things, changed listings 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,*

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. The emissions reductions for the Additional Measures were estimated to be 63 $MMTCO_2e$ in 2020 and 113 $MMTCO_2e$ in 2025.

1.2.2 Effect on public health and welfare

Elevated concentrations of GHGs including HFCs have been warming the planet, leading to changes in the Earth's climate including changes in the frequency and intensity of heat waves, precipitation, and extreme weather events, rising seas, and retreating snow and ice. The changes taking place in our atmosphere as a result of the well-documented buildup of GHGs due to human activities are changing the climate at a pace and in a way that threatens human health, society, and the natural environment and these effects may be experienced disproportionately by disadvantaged communities. In particular, communities surrounding HFC producers may be particularly susceptible to localized pollution both for HFC production as well as for its substitutes. These health effects are examined in greater detail in Chapter 6.

Extensive additional information on climate change is available in the scientific assessments and the EPA documents that are briefly described in this section, as well as in the technical and scientific information supporting them. One of those documents is EPA's 2009 Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the CAA (74 FR 66496, December 7, 2009).[23] In the 2009 Endangerment Finding, the

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Inc. v. EPA, 866 F.3d 451, 462 (D.C. Cir. 2017); *see also Mexichem Fluor, Inc. v. EPA*, Judgment, Case No. 17-1024 (D.C. Cir., April 5, 2019), 760 Fed. Appx. 6 (Mem).

[23] In describing these 2009 Findings in this proposal, the EPA is neither reopening nor revisiting them.

Administrator found under section 202(a) of the CAA that elevated atmospheric concentrations of six key well-mixed GHGs – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (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). The 2009 Endangerment Finding, together with the extensive scientific and technical evidence in the supporting record, documented that climate change caused by human emissions of GHGs (including HFCs) threatens the public health of the U.S. population. It explained that by raising average temperatures, climate change increases the likelihood of heat waves, which are associated with increased deaths and illnesses (74 FR 66497). While climate change also increases the likelihood of reductions in cold-related mortality, evidence indicates that the increases in heat mortality will be larger than the decreases in cold mortality in the United States (74 FR 66525). The 2009 Endangerment Finding further explained that compared to a future without climate change, climate change is expected to increase tropospheric ozone pollution over broad areas of the United States, including in the largest metropolitan areas with the worst tropospheric ozone problems, and thereby increase the risk of adverse effects on public health (74 FR 66525). Climate change is also expected to cause more intense hurricanes and more frequent and intense storms of other types and heavy precipitation, with impacts on other areas of public health, such as the potential for increased deaths, injuries, infectious and waterborne diseases, and stress-related disorders (74 FR 66525). Children, the elderly, and the poor are among the most vulnerable to these climate-related health effects (74 FR 66498).

The 2009 Endangerment Finding also documented, together with the extensive scientific and technical evidence in the supporting record, that climate change touches nearly every aspect of public welfare in the United States with resulting economic costs, including: changes in water supply and quality due to changes in drought and extreme rainfall events; increased risk of storm surge and flooding in coastal areas and land loss due to inundation; increases in peak electricity demand and risks to electricity infrastructure; and the potential for significant agricultural disruptions and crop failures (though offset to some extent by carbon fertilization). These impacts are also global and may exacerbate problems outside the United States that raise humanitarian, trade, and national security issues for the United States (74 FR 66530).

In 2016, the Administrator similarly issued Endangerment and Cause or Contribute Findings for greenhouse gas emissions from aircraft under section 231(a)(2)(A) of the CAA (81 FR 54422).[24] In the 2016 Endangerment Finding, the Administrator found that the body of scientific evidence amassed in the record for the 2009 Endangerment Finding compellingly supported a similar endangerment finding under CAA section 231(a)(2)(A), and also found that the science assessments released between the 2009 and the 2016 Findings, "strengthen and further support the judgment that GHGs in the atmosphere may reasonably be anticipated to endanger the public health and welfare of current and future generations." (81 FR 54424).

Since the 2016 Endangerment Finding, the climate has continued to change, with new records being set for several climate indicators such as global average surface temperatures, greenhouse gas concentrations, and sea level rise. Additionally, major scientific assessments continue to be released that further improve our understanding of the climate system and the impacts that GHGs have on public health and welfare both for current and future generations.

[24] In describing these 2016 Findings in this proposal, the EPA is neither reopening nor revisiting them.

These updated observations and projections document the rapid rate of current and future climate change both globally and in the United States.[25,26,27,28]

In addition to the effects HFCs have on health and welfare through their climate impact, there may be direct, localized effects on human health. The HFCs regulated under the AIM Act are not toxic, but some chemicals used in their production have been shown to be acutely toxic, carcinogenic, or otherwise hazardous. While it is not anticipated that this rule will significantly increase or decrease these health risks related to HFC production, and they are not quantified in this analysis, a more thorough discussion of localized health effects can be found in Chapter 6 of this document.

1.3 Regulated Community

The HFC industry is composed of several types of entities. The regulated community analyzed for this proposal 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.[29]

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[25] USGCRP, 2018: *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, 1515 pp. doi: 10.7930/NCA4.2018

[26] IPCC, 2018: 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.)].

[27] National Academies of Sciences, Engineering, and Medicine. 2019. *Climate Change and Ecosystems*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25504.

[28] NOAA National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2020, published online January 2021, retrieved on February 10, 2021 from https://www.ncdc.noaa.gov/sotc/global/202013.

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

The regulated community also includes any of the six applications eligible for an allocation under section (e)(4)(B)(iv) of the AIM Act. There are also users of HFCs, which include, among others, companies in the fields of refrigeration and air conditioning, foam blowing, aerosols, solvents, and fire suppression. These end users are generally not directly regulated by this proposed action. However, the decrease in supply of HFCs will result in transition, which is modeled in this report.

Under section (e)(4)(B)(iv), the AIM Act lists six applications for application-specific allowances including: (1) propellants in metered dose inhalers (MDIs); (2) defense sprays; (3) structural composite preformed polyurethane foam for marine use and trailer use; (4) the etching of semiconductor material or wafers and the cleaning of CVD chambers within the semiconductor manufacturing sector; (5) on board aerospace fire suppression; and (6) 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 section VI.C of the proposed 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 proposed 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. 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 time periods specified in the AIM Act. Although the AIM Act's first compliance period starts in 2020, we have assumed here that compliance would begin in 2022—the earliest possible given the date of enactment. 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 phase down schedule, we look at consumption reductions and associated emission reductions through 2050 by modeling continued abatement with the cap through that time period. The model used to estimate costs, as explained below, only provides output in 5-year intervals (i.e., 2020, 2025, etc.). Due to this limitation, we use years from the cost model as proxies for the years specified in the AIM Act (i.e., 2020 is the proxy for 2022, 2025 for 2024, 2030 for 2029, 2035 for 2034, and 2040 for 2036).

Table 2-1: Phasedown schedule modeled year

Year	Modeled Year
2022–2023	2020
2024–2028	2025
2029–2033	2030
2034–2035	2035
2036	2040
2045*	2045
2050*	2050

*2045 and 2050 are not phasedown years, but are included to facilitate estimation of time lagged emission reductions.

Because emissions generally lag consumption, for example as leaks from equipment which can operate for decades, emission benefits are calculated for the time period of 2020–2050, in 5-year increments. We note that additional benefits of an HFC phasedown would occur even beyond this time 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 withholdings for traded allowances; and requiring industry to shift to using refillable cylinders instead of disposable cylinders.

The effects of the rulemaking on production of HFC-23 as a byproduct of fluorocarbon production were not included in this analysis. EPA is proposing to require that an entity that creates HFC-23 capture the HFC-23 and either 1) expend production and consumption allowances to sell that HFC-23 for uses (e.g., etching) or 2) destroy the captured HFC-23 using a technology approved by the Administrator. EPA proposes that no later than October 1, 2022, as compared to the amount of chemical intentionally produced on a facility line, no more than 0.1% of HFC-23 created as a byproduct on the line may be emitted. Under this proposed provision, the HFC-23 must be destroyed using a technology approved by EPA. EPA has identified less than five facilities affected by this requirement. Those facilities already either meet this standard or have announced their intent to do so by the time the provision takes effect. Therefore, HFC-23 costs and benefits are considered to be included within the business-as-usual scenarios laid out in the analysis. Any costs or benefits realized from this rulemaking are thus considered to be independent of such industry actions.

Chapter 3 provides more detail on the cost of substituting chemicals and related technologies for HFCs, and 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 percent of allowances withheld 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. However, the effect on the total supply is minimal and unlikely to require additional action.

Chapter 3: Abatement Cost Estimates

3.1 Introduction

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

To generate abatement cost estimates for the proposed 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 the EPA's Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation, 2015–2050 report.[30,31] The MACCs describe the supply of abatement available at a given cost in a particular 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 business-as-usual (BAU) forecast of HFC consumption that would occur in absence of the Act. The model tracks the use and emissions

[30] 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.

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

of each of the substances separately for each of the ages or "vintages" of equipment. The Vintaging Model is used to produce the ODS substitute emission estimates 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.[32] 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 over 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).[33,34] 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 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:

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[32] 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.

[33] U.S. EPA, September 2018. EPA Report EPA-400-F-18-001. EPA's Vintaging Model of ODS Substitutes. Available at https://www.epa.gov/sites/production/files/2018-09/documents/epas-vintaging-model-of-ods-substitutes-peer-review-factsheet.pdf.

[34] Appendix D provides detail on the end-uses modeled as part of this RIA.

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 (EIA) Annual Energy Outlook's projection of 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.[35]

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

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 E.[36,37] 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.[38] Market penetration of newer technologies are based on expert judgment and would apply as older HFC-using vintages adopt the new technologies. Abatement option technical applicability, market penetration, reduction efficiency, and technical effectiveness are discussed throughout section 5.2.8.2 of the above referenced methodology documentation.

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:

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

[37] U.S. EPA, September 2013. EPA Report EPA-430-R-13-011. Global Mitigation of Non-CO_2 Greenhouse Gases: 2010–2030. Available online at https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgs-report-2010-2030.

[38] 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).

- 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 expertisef 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.[39] After calculating the break-even price, options can then be ordered from the most cost savings (in terms of dollars per EVe abated) to the

[39] 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.

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 marginal abatement curve (MAC) model described in this document. The applications and the abatement options that produce these cost savings (i.e., that have costs of abatement that 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 of these items (e.g., an HFO generally costs more than an HFC); however, the present value break-even cost for these options are negative, indicating a savings.

Table 3-1: Abatement Options that produce cost savings

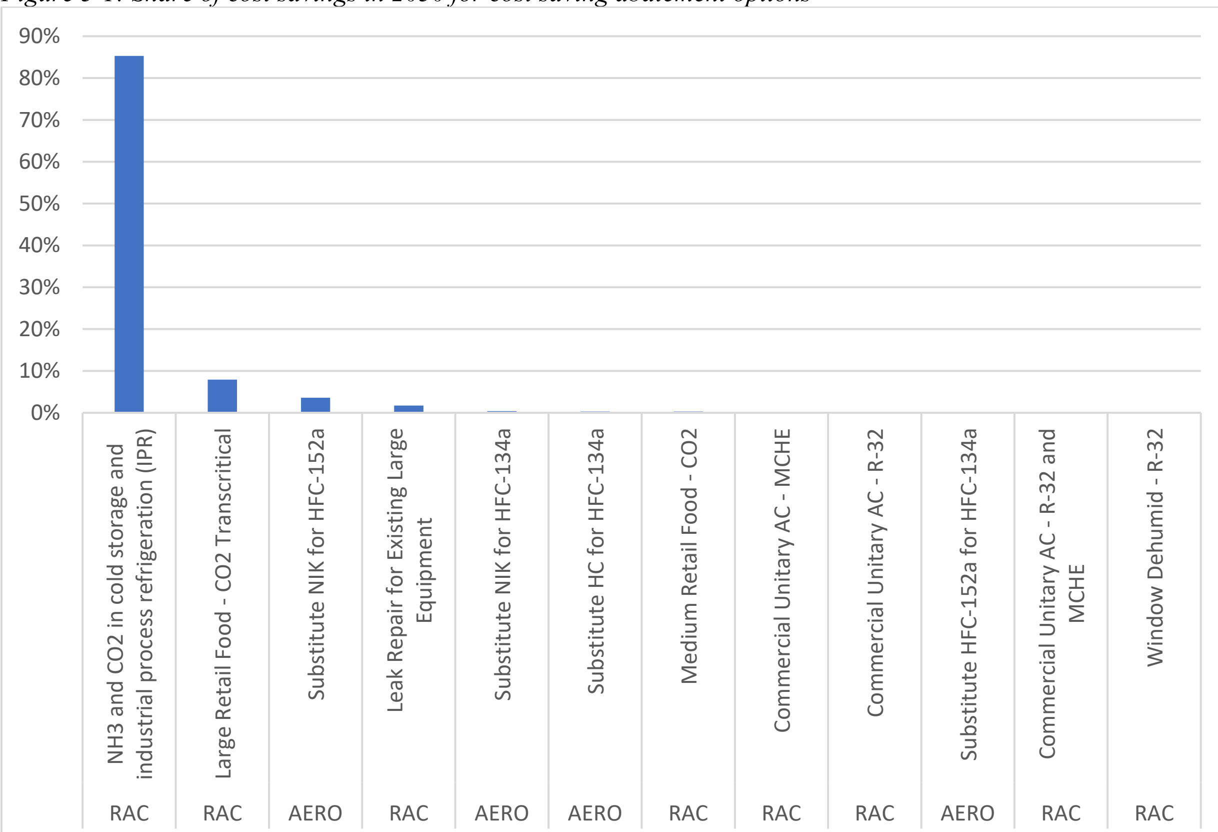
Application	Abatement Option	Technical Applicability (2030)	Market Penetration (2030)	Reduction Efficiency	Energy Consumption Savings	Refrigerants/Gas Cost Savings	Charge and Leakage Cost savings	Capital Costs
New industrial process refrigeration (IPR) and cold storage systems	NH_3 or CO_2	71%	100%	100%	11%	Yes	-	Yes
New large retail food refrigeration systems	DX 407A/407F	2%	34%	50%	13%	-	-	Yes
	DX 407A/407F SLS	3%	33%	50%	13%	-	-	No
	CO_2 transcritical systems	4%	33%	100%	5-10%	-	Yes	Yes
New medium retail food refrigeration systems	CO_2	33%	33%	100%	>0	Yes	-	Neg
New small retail food refrigeration systems	HCs	100%	10%	100%	-	-	-	Yes
New commercial unitary AC equipment	R-32 with microchannel heat exchanger (MCHE)	26%	50%	68%	-	Yes	Yes	Neg
	- R-32	28%	50%	68%	-	Yes	Yes	Neg
	- MCHE	11%	39%	38%	-		Yes	Neg
New window AC and Dehumidifiers	- R-32	51%	50%	68%	-	Yes	Yes	Neg
All existing large equipment (i.e., large retail food, IPR, cold storage, and chillers)	Leak repair	4%	100%	40%	-	-	Yes	Yes
Refrigerated appliances	134a to R-600a	100%	100%	100%	-	-	Yes	Yes
Flooding agents	Inert gas	27%	19%	100%	-	-	-	Yes

	Water mist	4%	3%	100%	-	-	-	Yes
Flexible polyurethane (PU) foam	Integral skin foam	100%	100%	100%	-	-	-	Yes
Extruded Polystyrene (XPS) boardstock foam	134a/CO_2 to Liquid Carbon Dioxide (LCD)/Alcohol	79%	80%	100%	-	-	-	Yes
PU boardstock	245fa Blend to HC	100%	100%	99%	-	-	-	Yes
Domestic Refrigerator and Freezer Insulation	245fa to HCs	0%	50%	99%	-	-	-	Yes
Non-metered dose inhaler (MDI) Aerosols	HFC-134a to HC	13%	20%	100%	-	Yes	-	Yes
	HFC-134a to HFC-152a	6%	10%	91%	-	Yes	-	Yes
	HFC-134a to Not-In-Kind (NIK)	13%	20%	100%	-	Yes	-	Yes
	HFC-152a to NIK	15%	40%	100%	-	Yes	-	Yes

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.

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 cost savings for these first two applications. Much of that discussion could apply to other abatement options but are not explicitly discussed.

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



Source: Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation: 2015–2050

The market penetration is the critical assumption that drives the difference between the business as usual 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 business as usual and policy scenarios for select cost-saving abatement options

Application	Abatement Option	Business as usual market penetration assumptions	Policy market penetration assumptions
New industrial process refrigeration (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 are not included in the market penetration assumptions.
Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016. Annex 3

New industrial process refrigeration (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 $50,200 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 to 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[40] 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 by-product coke ovens or continuous annealing lines.[41] Mokyr (1990) suggests that guilds and trade unions slowed adoption of new technologies during the industrial revolution;[42] and Parente and Prescott (1999) argue that monopoly power in factor supplies gave rise to slow rates of technology adoption.[43] Another area of research argues that that new technologies often trigger purchasing complementary technologies, and this takes longer to coordinate and adopt.[44]

Large retail food systems

The abatement option for large retail food refrigeration systems is replacing current systems with CO_2 transcritical systems, which eliminates the use of HFCs. This system operates

[40] Geroski, P. A. (2000): "Models of Technology Diffusion," Research Policy, 29(45), 603 – 625.
[41] Mansfield, E. (1961): "Technical Change and the Rate of Imitation," Econometrica, 29(4), pp. 741–766. (1989): "The Diffusion of Industrial Robots in Japan and the United States," Research Policy, 43 18(4), 183 – 192.
[42] Mokyr, J., (1990): "Punctuated equilibria and technological progress," The American Economic Review, 80(2), pp.350-354.
[43] Parente, S.L. and Prescott, E.C., (1999): "Monopoly rights: A barrier to riches." American Economic Review, 89(5), pp.1216-1233.
[44] See Rosenberg, N. (1982): Inside the Black Box: Technology and Economics. Cambridge UK: Cambridge University Press.; David Atkin, Azam Chaudhry, Shamyla Chaudry, Amit Khandelwal, Eric Verhoogen (2017): "Organizational Barriers to Technology Adoption: Evidence from Soccer Ball Producers in Pakistan," The Quarterly Journal of Economics, 1101–1164.; and Bresnahan, T. F., and M. Trajtenberg (1995): "General Purpose Technologies: 'Engines of Growth'?," Journal of Econometrics, 65(1), 83 – 108.

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 is less viable in warmer climates. The incremental capital costs for CO_2 transcritical systems is estimated to be $32,000 for a large (60,000 sq. ft.) supermarket, but total annual savings per supermarket is about $13,400 from refrigerant savings due to avoided HFC refrigerant leaks (approximately $1,800) and energy savings due to increased efficiency (approximately $11,600).

The business as usual 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."[45]

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., convenience stores and grocery stores) is so critical to operate successfully, 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

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

technologies rather than new technologies (e.g., working pressure of CO_2, flammability of other options). Firms may decide to go with what their employees prefer in order to minimize disruptions. Some business owners may likewise work exclusively with a limited set of suppliers who 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 standard 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.[46] Estimating better baseline market penetration assumptions cannot be done reliably with the available data and models but will be evaluated in the future.

3.3 Baseline and BAU

3.3.1 Baseline for Allocation of Production and Consumption Allowances

EPA will determine both a production and consumption baseline from which the percentage targets are calculated. The AIM Act provides formulas for how to set a baseline. The equations comprise an HFC component, an HCFC component, and a CFC component. Specifically, EPA is directed to calculate separate production and consumption 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.

To assess the abatement costs, EPA used the best available information currently available to develop a consumption baseline estimate of HFC consumption based on 2011–2013

[46] See Chapter 3 for sensitivity analyses of the savings and costs of abatement options.

data and additional data, already collected under Title VI of the CAA, on CFC and HCFC consumption in 1989. Applying the formula provided in the AIM Act, here we estimate the baseline to be 299 million metric tons of exchange value equivalent (MMTEVe). For brevity, we refer to this in this report as "~300 MMTEVe" and refer to consumption maximums in a similar format (e.g, "~270 MMTEVe" as the 2022 maximum consumption of 90 percent of the baseline). The cost and reductions however use the actual best estimate of the consumption baseline and included the lead option of the offset for traded allowances.

3.3.2 Business as Usual (BAU) Projection of Consumption and Emissions

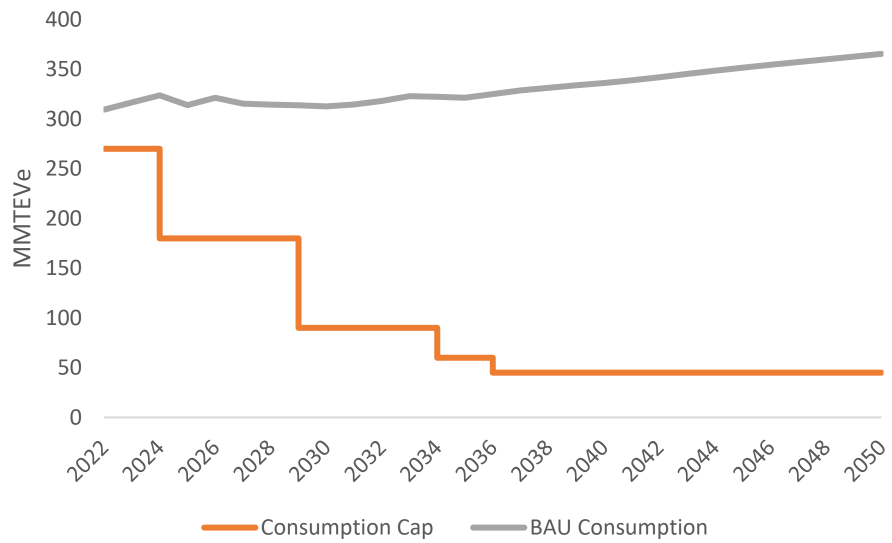
EPA uses the Vintaging Model to project the expected consumption and emissions of HFCs in the absence of the AIM Act. Although many economic analyses will use the term "baseline" to describe such a forecast, here we refer to this projection as a business as usual (BAU) forecast to distinguish it from the baseline describe 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.

Table 3-3: Consumption BAU

Modeled Year	Consumption (MMTEVe)
2020	307.69
2025	314.62
2030	317.01
2035	324.47
2040	336.68

Figure 3-2 shows the BAU consumption scenario as compared to 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 unacceptable for certain end-uses. 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, decisions by the court vacated these rules in part and remanded them to EPA for further consideration. 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 of 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 meet 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 Clean Air Act 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 the CAA and Montreal Protocol also called for those substances to be phased out, and some moved to HFCs. While those uses now in HCFCs began adopting HFCs, more research continued and new, no/low-GWP options were found, and both HCFC and HFC users began adopting them. 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[47] and/or future regulations.

Some examples of such changes from 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)

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

- 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

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 15 percent of the total allowances, including those issued to the six market segments receiving allocations, are traded each year. The 15 percent is based on EPA's experience implementing the phaseout of ODS under Title VI of the CAA. For each allowance trade, EPA proposes a transfer offset of 5 percent. For example, if one party traded away 100 kgEVe, the transfer offset would be 5 kgEVe from the transferring party and would amount to only 95 kgEVe to the receiving company.[48] The net effect of this would be to reduce the allowable consumption by 0.75 percent. For instance, using the 299 MMTEVe baseline, the maximum consumption at the 2022 step of 90 percent of the baseline amounts to a maximum consumption of 267.1 MMTEVe (but is referred to for brevity as ~270 in this report). A transfer offset of 5 percent, assuming 15% of the total allowances are traded annually, would reduce allowances by about 2 MMTEVe each year during the 2022-2023 compliance step.

EPA also examined the effect of choosing a 1 percent or a 10 percent transfer offset. Under the BAU, baseline, and abatement options used for this analysis, the choice of either 1 percent or 10 percent transfer offset does not have any effect compared to the lead option of 5 percent. The reason why this is seen is due to the fact that the MAC curve used is not a smooth

[48] EPA proposed that the offset be 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 than proposed. We expect this difference would be relatively minor compared to the estimated 15% of allowances traded, which is subject to market variability.

line but rather a step function. For these three transfer offsets, at each compliance step (2022, 2024, 2029, 2034, and 2036), the highest-cost abatement option that, combined with all lower-cost abatement options, provides the total reduction needed to meet the cap is the same under each transfer offset analyzed, and no lower-cost abatement option is enough to do so even under the 1 percent transfer offset.

3.5 Costs of abatement

To assess the costs of abatement, the 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 specified in the AIM Act. Table 3-4 shows the phasedown schedule through 2036, the BAU consumption, and the reduction needed to meet each step of the phasedown.

Table 3-4: Estimated Consumption Reductions Required under the Aim Act

AIM Act Compliance Years	Modeled Year	Consumption Cap (% of Consumption Baseline)	Consumption Cap (MMTEVe)	BAU Consumption (MMTEVe)*	Reductions Needed (MMTEVe)
2022–2023	2020	90%	~270	310	40
2024–2028	2025	60%	~180	324	144
2029–2033	2030	30%	~90	317	227
2034–2035	2035	20%	~60	326	266
2036	2040	15%	~45	327	283

*Consumption levels shown are based on the first compliance year. As discussed in section 2.2 above, limitations in the cost model require the use of proxy years to represent the dates specified in the AIM Act.

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: Marginal Abatement Cost Curves by model year

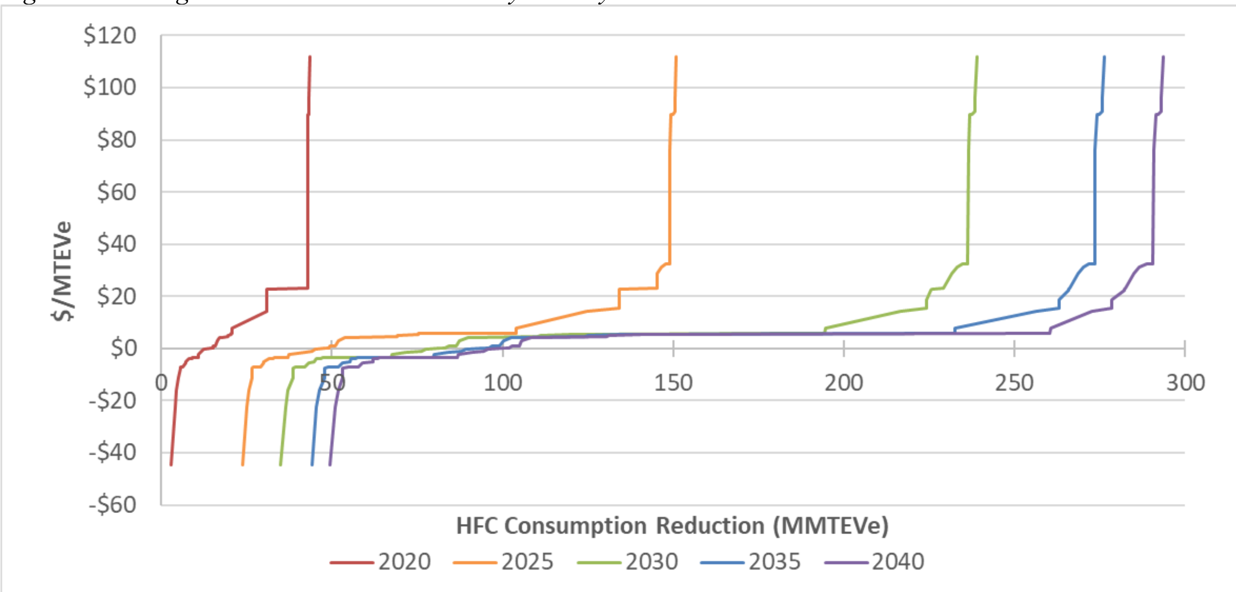


Figure 3-3 depicts the increasing cost ($ per MTEVe) to achieve additional HFC consumption reductions. Moving from left to right on the horizontal axis (i.e., from less abatement to higher abatement), savings decrease and eventually costs are incurred (i.e., moving from bottom to top of the vertical 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 percent discount rate 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 2020, 2025, 2030, 2035, and 2040 (these are the years featured in the MAC model). Recognizing that AIM Act phasedown targets do not all occur on those specific years, we assumed that the costs (or savings) in 2020 and abatement achieved are the same for 2022 through 2023 (to meet the 10 percent phasedown step), the costs (or savings) in 2025 and abatement are the same for 2024–2028 (to meet the 40 percent phasedown step), etc. A year-by-year analysis would be more accurate as 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 costs or savings between 2022–2036 are displayed in Table 3-5 below and the consumption reductions are shown in Table 3-6 below.

Table 3-5: Costs of Abatement (2020$)

AIM Act Compliance Years	Modeled Year	Consumption Cap	Total Annual Savings	Total Annual Costs	Net Annual Cost (Savings)
2022–2023	2020	90% (~270 MMTEVe)	-$0.2B	$0.4B	$0.2B
2024–2028	2025	60% (~180 MMTEVe)	-$1.2B	$1.0B	-$0.2B
2029–2033	2030	30% (~90 MMTEVe)	-$1.8B	$1.1B	-$0.6B
2034–2035	2035	20% (~60 MMTEVe)	-$2.2B	$1.2B	-$0.9B
2036	2040	15% (~45 MMTEVe)	-$2.4B	$1.7B	-$0.8B

Table 3-6: 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% (~270 MMTEVe)	43	43
2024–2028	60% (~180 MMTEVe)	145	231
2029–2033	30% (~90 MMTEVe)	229	1,041
2034–2035	20% (~60 MMTEVe)	266	2,223
2036	15% (~45 MMTEVe)	293	2,781

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 to the analysis presented in the report, which used our estimates for the abatement cost of various options to reduce HFC consumption.

The Marginal Abatement Cost 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 marginal abatement cost 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 estimate abatement cost of as low as -$45 per metric ton of EVe 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 $15.6 billion.

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. Considering the experience with the ODS phaseout and the fact that to comply with State-level requirements the industry is already implementing several options that we examined, we assumed all positive-cost options were only 50 percent the cost of our best estimate, resulting in total savings of $13.9 billion. 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 we only looked at the highest-cost option, there would be no effect on the overall estimated costs.

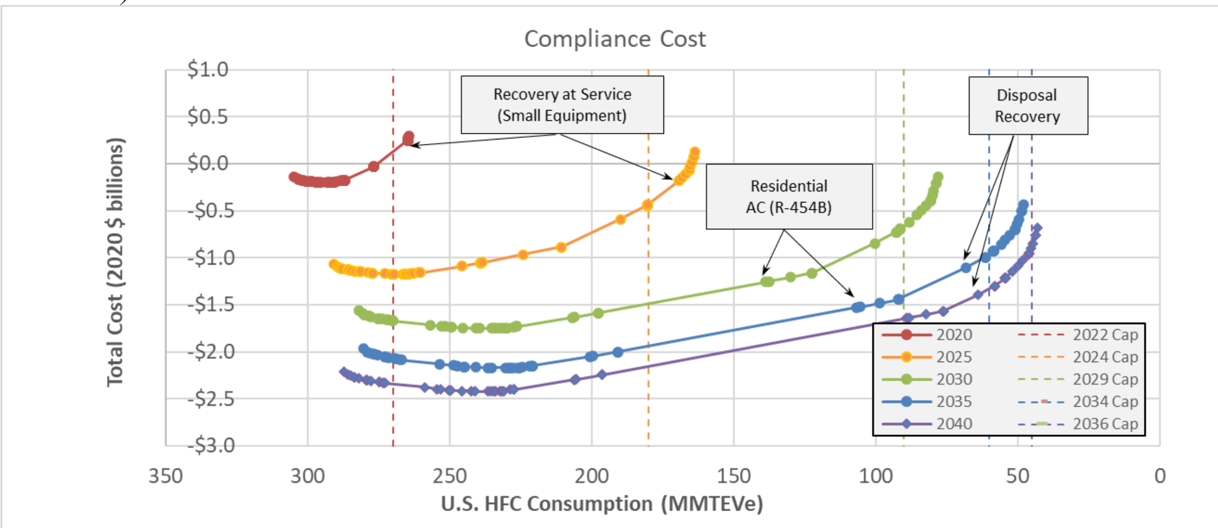
Table 3-7: Estimated Annual and Cumulative Costs of Abatement

Year	Consumption Cap*	Total Net Annual Cost**			Net Cumulative Cost **		
		Estimate	*Lower*	*Higher*	*Estimate*	*Lower*	*Higher*
2020	90% (~270 MMTEVe)	$0.2 B	$0.0 B	$0.4 B	$0.2 B	$0.0 B	$0.4 B
2024	60% (~180 MMTEVe)	($0.2 B)	($0.7 B)	$1.0 B	$0.3 B	($0.6 B)	$1.9 B
2029	30% (~90 MMTEVe)	($0.6 B)	($1.2 B)	$1.1 B	($1.0 B)	($4.5 B)	$7.0 B
2034	20% (~60 MMTEVe)	($0.9 B)	($1.6 B)	$1.2 B	($4.4 B)	($10.8 B)	$12.8 B
2036	15% (~45 MMTEVe)	($0.8 B)	($1.6 B)	$1.7 B	($6.1 B)	($13.9 B)	$15.6 B

*Assumes a baseline of ~300 MMTEVe
** Negative costs, shown in parentheses, indicates cost savings.

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 2025–2040 curves start to the right of the 2020 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): Costs of Abatement (Integrating under the MAC curve)



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 that price change, in addition to whether the assessment of the business-as-usual could be further refined. EPA is seeking information to help improve the BAU forecast (e.g., to incorporate the effect of state actions) and cost estimates.

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 (U.S. EPA, 2010).[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

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

reallocating some resources towards pollution mitigation. Estimates of social costs may be compared to 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 (U.S. EPA, 2010). The advantage of the abatement cost approach is 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. This analysis notes the potential negative health effects of being in close proximity to HFC production and production of HFC substitutes in Chapter 6, 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 proposed 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.

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[50] This section relies on the following references: Berman, E. and L. T. M. Bui. 2001. "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." Journal of Public Economics. 79(2): 265-295; Curtis, E. M. 2018. "Who loses under cap-and-trade programs? The labor market effects of the NOx budget trading program," Review of Economics and Statistics 100 (1): 151–66; Curtis, E.M. 2020. "Reevaluating the ozone nonattainment standards: Evidence from the 2004 expansion," Journal of Environmental Economics and Management, 99: 102261; Deschênes, O. 2018. "Environmental regulations and labor markets," IZA World of Labor: 22: 1-10; Ferris, A. E., R. Shadbegian, A. Wolverton. 2014 "The Effect of Environmental Regulation on Power Sector Employment: Phase I of the Title IV SO2 Trading Program," Journal of the Association of Environmental and Resource Economics 1(4): 521-553; Graff Zivin, J. and M. Neidell. 2018. "Air pollution's hidden impacts". Science. 359(6371). 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): 1175-1219.; Morgenstern, R.D., W.A. Pizer, and J. Shih. 2002. Jobs Versus the Environment: An Industry- Level Perspective. Journal of Environmental Economics and Management 43: 412-436.

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 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: 1) basic chemical manufacturing (NAICS 3251) and 2) other chemical production and preparation manufacturing (NAICS 3259). The chemical manufacturing sector (NAICS 325) employed 850 thousand 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, in February, 2021.[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 thousand employees has increased from 782 thousand employees in February, 2011.

These industries are capital intensive. We rely on three public sources to get a range of estimates of employment per output by sector: the Economic Census (EC), and the Annual Survey of Manufacturers (ASM), both provided by the U.S. Census Bureau, and employment and output by industry provided by U.S. Bureau of Labor Statistics (BLS). The EC is conducted every 5 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

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[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: https://www.bls.gov/iag/tgs/iag325.htm>.

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

employees and the value of shipments at the 6-digit NAICS, which we convert to a ratio in this employment analysis. The BLS data is only provided at the 4-digit NAICS level, which means less sector detail. Table 3-7 shows the sector definitions and the NAICS codes used to estimate the ratios of labor per $1 million value of shipments.

Table 3-8. Relevant Chemical Manufacturing Sectors

Sector Definition	NAICS
Basic chemical manufacturing	3251
Industrial gas manufacturing	325120
All other basic organic chemical manufacturing	325199
Other chemical product and preparation manufacturing	3259
All other miscellaneous chemical product and preparation manufacturing	325998

Tables 3-9 and 3-10 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.

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

Table 3-9: 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 seems to be the most labor-intensive sector across all data sources at the four-digit NAICS.

Table 3-10: 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

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 towards production of lower-cost HFC-substitute chemicals and the phase-out 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 greenhouse-gas-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 proposed regulation may contribute to employment impacts caused from increased international demand for products manufactured by the regulated firms due to those products contributing fewer greenhouse gases.

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 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 proposed process to implement the recordkeeping and reporting requirements of the AIM Act, EPA developed an information collection request (ICR), EPA ICR Number 2685.01, and a Supporting Statement Part A for the ICR, all of which can be found in the docket. 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 36,540 hours per year and the respondent cost will average $4,506,092 per year. This includes $24,100 per year for capital investment and operation and maintenance (O&M) and $4,481,992 per year for labor. The breakdown of the burden per year is provided in Table 3-11.

Table 3-11: 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	3,929	38,176	$4,682,644	$24,100	$4,706,744
Year 2	3,756	27,246	$3,341,970	$24,100	$3,366,070
Year 3	27,306	44,198	$5,421,363	$24,100	$5,445,463
Annual Average	**11,664**	**36,540**	**$4,481,992**	**$24,100**	**$4,506,092**

As detailed in the preamble of the proposed rulemaking and reflected in the ICR Supporting Statement Part A, the total costs in Year 1 are higher than those for Year 2 due to certain proposed one-time recordkeeping or reporting requirements, including but not limited to one-time reports for producers in Year 1. Year 2 includes a one-time inventory reports for HFC suppliers. Year 3 includes one-time registration with entering data into the certification identification system. If the recordkeeping and reporting requirements are finalized as proposed, EPA expects that the total ongoing cost burden for each year past the initial three-year ICR period would closely resemble the average value across the three years (i.e., $4,506,092). The final respondent burden costs may differ from those presented here; specifically, EPA may not finalize all recordkeeping and reporting requirements as proposed, and additionally, there may be additional new burden costs that EPA integrates into the final rulemaking based on comments received during the public comment period.[54]

[54] Two such examples are contained in the discussion of the proposed labeling requirements for bulk regulated substances as described in section VIII.D of the preamble, and in the discussion of the proposed auditing requirements as described in section VIII.E of the preamble.

Chapter 4: Benefits

The benefits of this proposed 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 exchange-value-equivalent metric tons (MTEVe), and although this action regulates production and consumption, but not emissions directly, 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 considered in the MAC model 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 consumption of 2,781 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 emissions of 4,747 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	Modeled Year	Consumption Reductions in Year*
2022–2023	2020	43
2024–2028	2025	145
2029–2033	2030	229
2034–2035	2035	266
2036	2040	293

*As discussed in section 2.2 above, the reductions here are those based on proxy years used for the cost analysis.

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

Year	Emission Reductions in Year[a]
2022	44
2024	94
2029	133
2034	154
2036	187
2045	227
2050	243

[a]See Table 2-1 for a crosswalk of years and modeled years

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

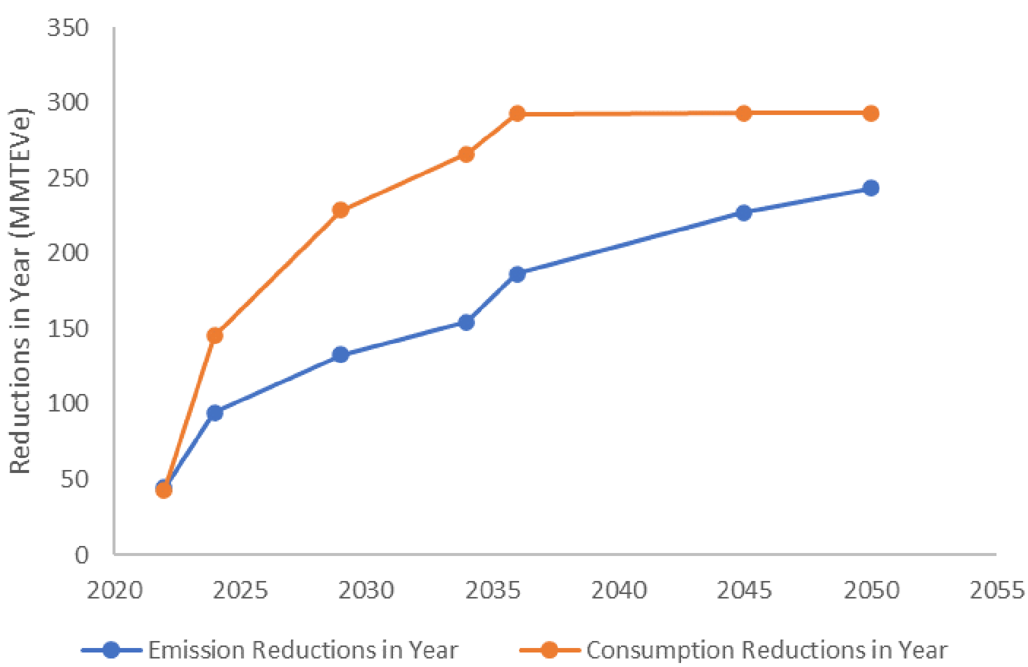


Table 4-3 further disaggregates the emission reductions by metric tons of each gas abated for the same timesteps. It is these values that are used to calculate the climate-related benefits using the SC-HFC values as described in the remainder of this chapter.

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

	2022	2024	2029	2034	2036	2045	2050
HFC-32	4715	11269	12151	8631	11883	12310	12918
HFC-125	5588	14478	20738	25106	30901	39627	41664
HFC-134a	10812	10963	15463	12461	13063	14900	16507
HFC-143a	825	2928	4241	5990	7194	8142	8878
HFC-152a	4119	7822	8132	7937	8260	8595	8945
HFC-227ea	91	170	271	363	334	308	261
HFC-236fa	1	1	0	0	0	0	0
HFC-245fa	654	4520	7506	11999	15154	17826	20749
HFC-43-10mee	536	692	875	1026	1223	1273	1324

[a]See Table 2-1 for a crosswalk of years and modeled years

The monetary value of these benefits is estimated by multiplying the tons of emissions abated of each HFC by the appropriate social cost of that HFC (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 greenhouse gas emitted by humans, it is not the only greenhouse gas with climate impacts. The EPA Endangerment Finding (2009) recognized a basket of six gases, comprising CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (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.[55] We estimate the climate benefits for this proposed rulemaking using a measure of the social cost of each HFC (collectively referred to

[55] 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).

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 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 proposed 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 greenhouse gas estimates presented in IWG (2021) are interim values developed under Executive Order (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 greenhouse gases 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 greenhouse gases (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 the 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 Executive Order 13990, which directed the IWG to ensure that the U.S. Government's (USG) estimates of the social cost of carbon and other greenhouse gases 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.[56]

The SC-HFC estimates used here to estimate the climate benefits for this proposed rulemaking are consistent with the methodologies underlying the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates published in February 2021. 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 greenhouse gases.

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 proposed 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

[56] 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.

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 a 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 Technical Support Document (TSD) did not include direct estimates of the social cost of non-CO_2 GHGs and did not endorse the use of global warming potential (GWP) metrics to approximate the value of non-CO_2 emission changes in regulatory analysis,[57] 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

[57] The potential of non-CO_2 GHGs to change the Earth's climate relative to CO_2 is commonly represented by their 100-year global warming potential (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).

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 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 (Martin 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.[58] 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 to 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 socio-economic-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

[58] 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 towards 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.

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 (TAR) (Ramaswamy et al. 2001) and used in AR4.

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 4-12 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 the 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 proposed 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

There are a number of limitations and uncertainties associated with the SC-HFC estimates presented in Tables 4-4 to 4-12. Some uncertainties are captured within the analysis, while other areas of uncertainty have not yet been quantified in a way that can be modeled.[59] As

[59] 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.

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 4-12 are based on the same methodology underlying the SC-GHG estimates presented in the IWG February 2021 TSD, they 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 integrated assessment models, 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 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007), which was the most current IPCC assessment available at the time when 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 proposed 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 4-12.[60] The results of the monetized benefits calculations by gas and by year are given in Table 4-13 through Table 4-21. Appendix F lists the annual unrounded SC-HFC estimates for the same substances.

Table 4-13: 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	$94	$194	$250	$514
2024	$244	$495	$634	$1,315
2029	$317	$623	$789	$1,659
2034	$272	$516	$646	$1,392
2036	$402	$754	$939	$2,042
2045	$561	$1,000	$1,222	$2,757
2050	$684	$1,189	$1,440	$3,281

[60] 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 occuring 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 proposed rule would yield benefits from climate impacts within U.S. borders of $357 million in 2022, increasing to $3.7 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.

Table 4-14: 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	$499	$1,248	$1,690	$3,281
2024	$1,387	$3,411	$4,597	$9,012
2029	$2,344	$5,565	$7,410	$14,740
2034	$3,332	$7,623	$10,029	$20,297
2036	$4,361	$9,844	$12,894	$26,255
2045	$7,219	$15,394	$19,801	$41,192
2050	$8,636	$17,893	$22,800	$47,599

Table 4-15: 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	$448	$1,004	$1,320	$2,644
2024	$490	$1,081	$1,414	$2,857
2029	$824	$1,761	$2,277	$4,679
2034	$789	$1,629	$2,082	$4,365
2036	$883	$1,801	$2,291	$4,835
2045	$1,313	$2,540	$3,174	$6,820
2050	$1,661	$3,129	$3,875	$8,359

Table 4-16: 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	$84	$232	$325	$612
2024	$319	$867	$1,206	$2,295
2029	$541	$1,415	$1,946	$3,756
2034	$891	$2,241	$3,043	$5,953
2036	$1,135	$2,813	$3,802	$7,473
2045	$1,648	$3,829	$5,075	$10,205
2050	$2,041	$4,594	$6,027	$12,268

Table 4-17: 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	$12	$24	$30	$63
2024	$24	$48	$61	$128
2029	$30	$58	$74	$155
2034	$36	$67	$83	$179
2036	$40	$74	$91	$199
2045	$57	$100	$122	$278
2050	$70	$119	$144	$335

Table 4-18: 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	$7	$19	$25	$49
2024	$14	$37	$50	$96
2029	$27	$66	$89	$175
2034	$43	$100	$133	$266
2036	$42	$97	$127	$257
2045	$49	$108	$140	$286
2050	$48	$101	$130	$268

Table 4-19: 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	$0.2	$0.9	$1	$2
2024	$0.3	$0.9	$1	$2
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 4-20: 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	$20	$43	$56	$113
2024	$152	$316	$407	$837
2029	$303	$610	$777	$1,623
2034	$582	$1,132	$1,425	$3,046
2036	$787	$1,515	$1,897	$4,090
2045	$1,229	$2,246	$2,764	$6,120
2050	$1,649	$2,939	$3,584	$7,999

Table 4-21: 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	$25	$57	$75	$150
2024	$35	$78	$103	$206
2029	$52	$114	$148	$303
2034	$73	$153	$196	$409
2036	$93	$192	$245	$515
2045	$126	$246	$309	$660
2050	$149	$285	$354	$760

Table 4-22 presents the sum of climate benefits across all HFCs reduced for the proposed rule for 2022, 2024, 2029, 2034, 2036, 2045, and 2050.

Table 4-22: Climate Benefits for the Proposed 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	$1.2	$2.8	$3.8	$7.4
2024	$2.7	$6.3	$8.5	$16.7
2029	$4.4	$10.2	$13.5	$27.1
2034	$6.0	$13.5	$17.6	$35.9
2036	$7.7	$17.1	$22.3	$45.7
2045	$12.2	$25.5	$32.6	$68.3
2050	$14.9	$30.2	$38.4	$80.9

[a] 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; 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, are also warranted when discounting intergenerational impacts.

4.2.2 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 Intergovernmental Panel on Climate Change (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 4-23 through 4-25 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)[61] 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 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 4-23: GWP Approximation vs. Direct Estimation, SC-HFC134a

Year	CH_4 GWP-based Approximation 3% Discount Rate	N_2O GWP-based Approximation 3% Discount Rate	SC-HFC134a Direct Estimation 3% Discount Rate	Ratio CH_4 Approx./Direct	Ratio N_2O 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.

Table 4-24: 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
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.

[61] 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, 107–124 (2020). https://doi.org/10.1007/s10584-019-02486-7

Table 4-25: 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 N2O). 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 Chapter 3, the estimated annual abatement costs to implement the rule, as described in this document, are approximately $0.2 billion in 2022 and -$0.8 billion in 2036 (2020$). As described in Section 3.6, this RIA uses abatement costs as a proxy for social costs. 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 5-2.

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 5-1 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%.

Table 5-1: Benefits, Costs, and Net Benefits of the Proposed Rule for 2022–2050 (billions of 2020$)[a,b]

Year	Climate Benefits (3% discount rate)	Costs (annual)	Net Benefits
2022	$2.8	$0.2	$2.6
2024	$6.3	-$0.2	$6.5
2029	$10.2	-$0.6	$10.8
2034	$13.5	-$0.9	$14.4
2036	$17.1	-$0.8	$17.9
2045	$25.5	-$0.9	$26.4
2050	$30.2	-$1.1	$31.3

[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; the additional benefit estimates for the proposed rule range from $1.2 billion to $7.5 billion in 2022, $2.6 billion to $16.7 billion in 2024, $4.4 billion to $27.0 billion in 2029, $6 billion to $35.9 billion in 2034, $7.7 billion to $45.6 billion in 2036, $12.2 billion to $68.3 billion in 2045, and $14.9 billion to $80.9 billion in 2050. Please see Table 4-20 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, are 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 present value (PV) of the benefits and costs over the twenty-nine-year period 2022 to 2050. To calculate the present value of the social net-benefits of the proposed 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 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. 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 twenty-nine-year period of 2022 to 2050, the PV of the net benefits, in 2020$ and discounted to 2022, is $283.9 billion when using a 3 percent discount rate and $278.6 billion when using a 7 percent discount rate. The EAV is $14.8 billion when using a 3 percent discount rate and $14.7 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 5-2. Estimates in the table are presented as rounded values.

Table 5-2: 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 Proposed 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	$2.8	$0.2		$2.6	
2023	$2.9	$0.2		$2.7	
2024	$6.3	-$0.2		$6.5	
2025	$6.5	-$0.2		$6.7	
2026	$6.7	-$0.2		$6.9	
2027	$6.9	-$0.2		$7.1	
2028	$7.1	-$0.2		$7.3	
2029	$10.2	-$0.6		$10.8	
2030	$10.5	-$0.6		$11.1	
2031	$10.8	-$0.6		$11.4	
2032	$11.0	-$0.6		$11.6	
2033	$11.3	-$0.9		$12.2	
2034	$13.5	-$0.9		$14.4	
2035	$13.8	-$0.9		$14.7	
2036	$17.1	-$0.8		$17.9	
2037	$17.5	-$0.8		$18.3	
2038	$17.9	-$0.8		$18.7	
2039	$18.4	-$0.8		$19.2	
2040	$18.8	-$0.8		$19.6	
2041	$19.2	-$0.8		$20.0	
2042	$23.9	-$0.8		$24.7	
2043	$24.4	-$0.9		$25.3	
2044	$24.9	-$0.9		$25.8	
2045	$25.5	-$0.9		$26.4	
2046	$26.0	-$0.9		$26.9	
2047	$28.5	-$0.9		$29.4	
2048	$29.1	-$1.1		$30.2	
2049	$29.7	-$1.1		$30.8	
2050	$30.2	-$1.1		$31.3	
Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**
PV	**$272.8**	**-$11.1**	**-$5.8**	**$283.9**	**$278.6**
EAV	**$14.2**	**-$0.6**	**-$0.5**	**$14.8**	**$14.7**

[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 social cost of HFCs (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, are also warranted when discounting intergenerational impacts.
[d] The costs presented in this table are consistent with the costs presented in Chapter 3, Table 3-5.

Chapter 6: Environmental Justice Analysis

6.1 Background

Executive Order 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.[62] Executive Order 14008 (86 FR 7619; January 27, 2021) also 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

[62] 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.

and health care." EPA also released its "Technical Guidance for Assessing Environmental Justice in Regulatory Analysis" (U.S. EPA, 2016) 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 proposed rule will begin the United States' phasedown of HFC production and consumption, which will mitigate the impacts of climate change by reducing the atmospheric 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 – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (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 human 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 greenhouse gas 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, including the poor, the elderly, the very young, those already in poor health, the disabled, those living alone, and/or indigenous populations dependent on one or a few resources.

More recent assessment reports by the U.S. Global Change Research Program (USGCRP), the Intergovernmental Panel on Climate Change (IPCC), and the National Research

Council (NRC) of the National Academies demonstrate that the potential impacts of climate change raise environmental justice issues. These reports have concluded that poorer communities can be especially vulnerable to climate change impacts (e.g., property damage from extreme weather events such as hurricanes and wildfires; health effects from extreme temperatures) because they tend to have less adaptive capacities due to more limited access to resources and information. They are also more dependent on climate-sensitive resources such as local water and food supplies. In addition, some communities of color, specifically populations defined jointly by both ethnic/racial characteristics and geographic location, may be uniquely vulnerable to climate change health impacts in the United States. The prevalence of many chronic illnesses is higher in minority communities, and climate change can exacerbate these conditions. For example, changes in temperature, wildfires, and pollen seasons may increase risks for people with asthma, and people with diabetes are more susceptible to intense heat waves and can lose access to critical medications during extreme weather events. 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 (USGCRP 2016). 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 2009 Endangerment Finding record also specifically noted that Southwest native cultures are especially vulnerable to water quality and availability impacts. Native Alaskan communities are already experiencing disruptive impacts, including coastal erosion and shifts in the range or abundance of wild species crucial to their livelihoods and well-being.

As previously mentioned, the provisions in this proposed rulemaking will mitigate the impacts of climate change by reducing production and consumption and thus ultimately the emissions of HFCs into the atmosphere. However, there could be distributional effects of the program that may cause potential environmental justice concerns if the rule results in increased concentration of HFC production at certain facilities located within or near disadvantaged communities, which may be historically overburdened, or if facilities within or near such communities reduce HFC production and begin to produce greater volumes of HFC substitutes that could pose greater localized harms. Due to the large degree of uncertainty surrounding what production changes will occur around these communities, EPA is seeking input and/or data that may assist in better characterizing whether there are concerns. The Agency is proposing to issue allowances for only 2022 and 2023, which allows for a more robust review of the early effects of the program, including the uneven distribution of emissions associated with phasing out HFCs and ramping up production of substitutes, prior to issuing allowances for 2024 onwards. Proposed recordkeeping and reporting requirements also will allow EPA to track where and how regulated HFCs and their substitutes are used. The HFC phasedown schedule prescribed by Congress may also reduce the potential for a facility to increase emissions above current levels for a prolonged period.

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 (1) what impacts are associated with reducing emissions of HFCs; (2) whether emissions of HFCs cause localized health or environmental impacts; (3) 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 (4) how localized impacts may be affected as facilities that currently produce HFCs switch to producing substitutes for HFCs or other unrelated chemicals or products. Regarding question 4, EPA is seeking data or analysis to identify whether it is reasonable to expect net increases in emissions; and if so, how we might isolate the impacts of this program (i.e., effects resulting from the phasedown itself, the trading of production allowances, or some other factor) to enable the Agency to conduct a more nuanced analysis of changes in releases associated with chemical feedstocks and byproducts for HFC substitutes, given the inherent uncertainty regarding where, and in what quantities, substitutes will be produced. While EPA's ability to separately evaluate these areas is limited by data and available methods, EPA seeks comment through the proposed rule in sections III and XI on whether these are the right questions to analyze and data or methods available for evaluating them, and whether there are other health and environmental risks associated with the proposed rule that the Agency should assess. EPA is also seeking comment through the proposed rule on whether there are other regulatory tools better suited than adjustments to the HFC program design to address potential increases in emissions in non-HFC feedstocks and byproducts observed at facilities subject to the Congressionally mandated phasedown of HFCs under the AIM Act, if any.

6.2 Analysis of Potential EJ Concerns

As a first step toward evaluating potential EJ concerns, EPA has conducted an analysis to characterize baseline environmental conditions faced by communities living near facilities subject to the proposed rule. The relatively small number of facilities affected by the proposed 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 consumption and production of these HFCs, this analysis mainly focuses on production. HFCs are well-mixed greenhouse gases 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 proposed 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 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).[63] EPA used commercial[64] and internal market reports, facility web pages, and data reported to the GHGRP to determine which of the 14 facilities would be subject to this rule. Based on this information, EPA determined that nine of these facilities produce HFCs or are subject to this proposed rule. (Table 6-1).

[63] 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. EPA has not included the Iofina Chemical facility in this report but intends to do so in future EJ analysis.
[64] "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 proposed rule

Facility name	City	State	FRS ID*	GHGRP ID^	Number of Employees
3M Cordova	Cordova	Illinois	110013886875	1006665	332
Arkema, Inc.	Calvert City	Kentucky	110000380061	1005721	200
Chemours - Corpus Christi Plant	Gregory	Texas	110000746532	1006314	250
Chemours Chambers Works	Deepwater	New Jersey	110007970142	1002618	465
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
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 seven states (Alabama, Arkansas, Illinois, Kentucky, Louisiana, New Jersey, and Texas). Most of these HFC production facilities are located along major waterways and mainly in rural areas (the Chemours Louisville and Daikin America facilities are the only ones 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. 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. Because production facilities emit fluorinated greenhouse gases during HFC production, the emissions of HFCs are correlated with this production. Table 6-2 reports the total quantity of HFCs emitted by each of the nine HFC facilities subject to this rule for the last five years.

Emissions in 2019 ranged widely across facilities, from about 2,600 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; the size of the circles corresponds to the quantity of HFCs emitted in 2019.

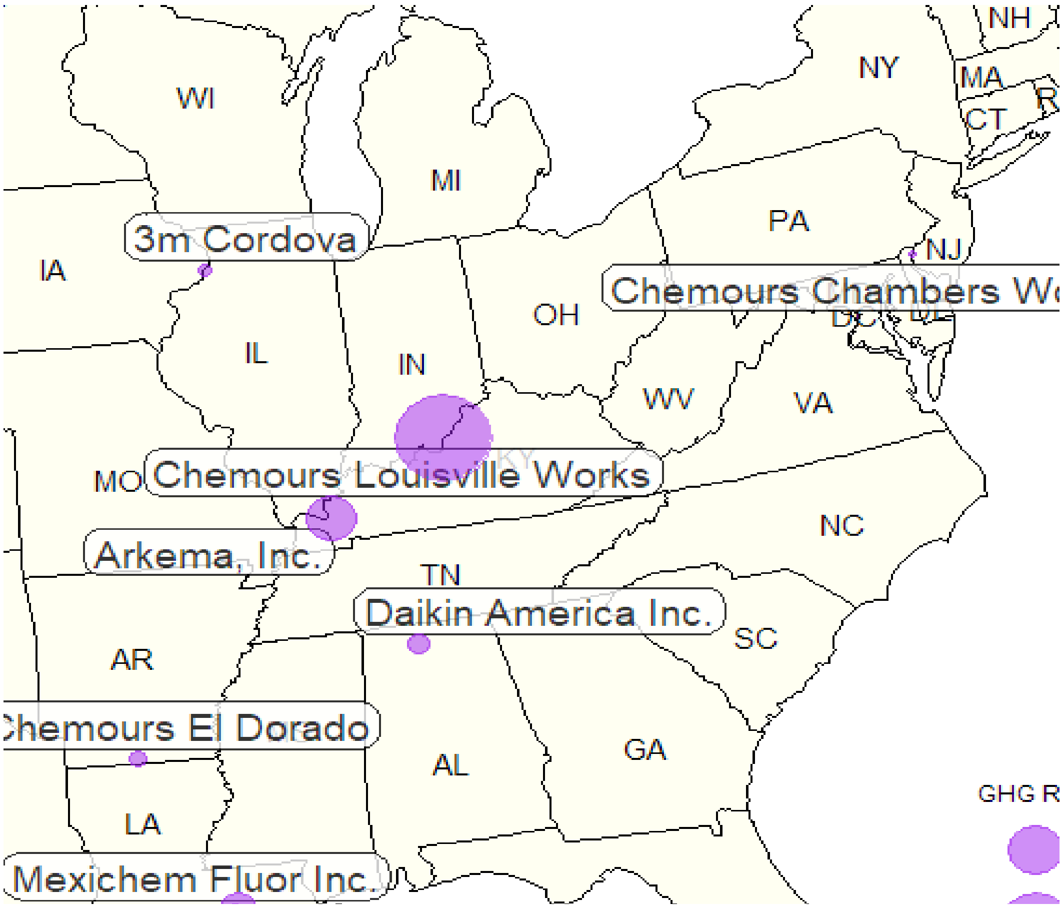
Table 6-2: Quantity of HFCs emitted (Metric Tons CO_2e) by Facility, 2015–2019

Facility Name	2015	2016	2017	2018	2019
3M Cordova	57,228	27,383	19,749	31,986	29,487
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 Chambers Works	484,802	3,933	2,681	3,509	2,619
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
Mexichem Fluor Inc.	23,407	20,089	15,794	18,626	18,331

Source: Greenhouse Gas Reporting Inventory

*The Chemours Chamber Works facility manufactures products made from HCFC-22, which generates HFC-23, a high global warming potential GHG. One hypothesis for the large decrease in HFC emissions between 2015 and 2016 is that the HFC-23 was vented as an unwanted byproduct in 2015 (and prior years), but after 2015 it was instead destroyed.

Figure 6-1: Emissions of HFCs (Metric Tons CO_2e) subject to this proposed 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 are 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 (HF) 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 amount or location of destruction of HFCs due to this proposed rule might be associated with local health risks. Facilities are already destroying HFCs as a portion of the other materials they destroy, and with the exception of HFC-23,[65] this rule does not require destruction of HFCs. As a result, this rule is not expected to affect local emissions at off-site destruction facilities. Additionally, 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.

The HFCs regulated under this proposed 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 a Group B2, probable human carcinogen (EPA IRIS assessment 2010). 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 (ATSDR 2003).

[65] One off-site facility may destroy a significant quantity of HFC-23. EPA intends to investigate this further between the proposed rule and final rule. On-site destruction of HFC-23 also occurs at the same facilities that produce HFCs. We anticipate that the majority of the chemicals produced on-site would already be captured by the list of TRI chemicals.

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

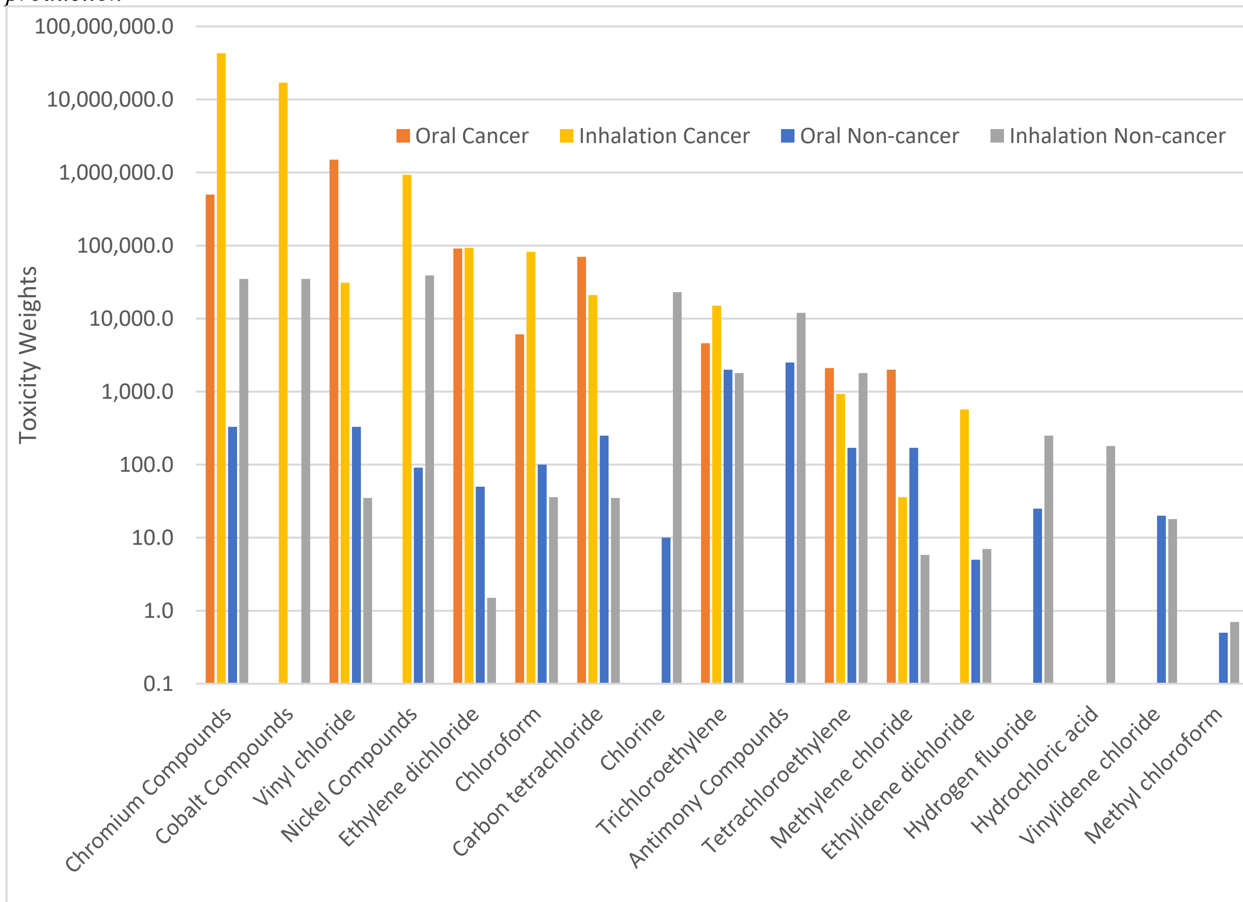
Chemical Name	Health Effects[66]
Antimony Compounds*	Metabolic, Other Systemic
Carbon tetrachloride	Cancer, Developmental, Hepatic, Reproductive
Chlorine	Ocular, Respiratory
Chloroform	Cancer, Developmental, Hepatic, Renal, Respiratory
Chromium Compounds*	Cancer, Gastrointestinal, Hematological, Respiratory
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 on the inhalation route for air releases, .

[66] 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 transfered offsite for disposal by HFC facilities in 2019 (transfers offsite for other purposes such as recycling, reuse, or energy recovery are not shown). Facilities varied widely in terms of the magnitude of their releases. For instance, total air releases ranged from about 22,000 pounds to more than 243,000 pounds. Water releases varied even more widely, with three plants reporting no water releases of toxic chemicals and one reporting over 530,000 pounds. Land disposal of toxic chemicals was a very small proportion (less than 5%) of the total releases. For two facilities, 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 Toxic Releases into Air, Water, and Land and Disposed of Offsite by Production Facility (in pounds)

Facility	Location	Air Releases	Water Releases	Land Disposal	Off-Site Transfers
3M Cordova	Cordova, IL	52,142	4,464		32,590
Arkema, Inc.	Calvert City, KY	243,194	896	5,845	501
Chemours - Corpus Christi	Gregory, TX	61,295			
Chemours Chambers Works	Deepwater, NJ	21,896	532,865	11,419	5,924
Chemours El Dorado	El Dorado, AR	26,038			
Chemours Louisville	Louisville, KY	657,191			196
Daikin America	Decatur, AL	169,339	18,607		30
Honeywell - Geismar Complex	Geismar, LA	122,651	4,722	12,786	158,858
Mexichem Fluor Inc.	Saint Gabriel, LA	22,593	40		73

Source: Toxic Releases Inventory

Given the sizeable 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 transfered offsite for disposal for the subset of chemicals that are used as feedstocks or catalysts or are produced as byproducts of HFC production. Note that releases from a given facility are not only associated with 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 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 chemicals used in HFC production ranged from 3 pounds to almost 64,000 pounds in 2019 and represented between 0 percent (Chemours Chamber Works) 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 total reported air releases. For the Chemours Chamber Works facility, which had very high reported total water releases, none are associated with HFC production.

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

Facility	Air releases for HFC production chemicals	Ratio of HFC-related to total air releases	Water releases for HFC production chemicals	Ratio of HFC-related to total water releases	Offsite transfers of HFC production chemicals	Ratio of HFC-related to total offsite transfers
3M Cordova	5,700	0.11	163	0.04	32,590	1.00
Arkema, Inc.	58,043	0.24	456	0.51	501	1.00
Chemours - Corpus Christi	34,876	0.57				
Chemours Chambers Works	3	0	0	0.00	0	0.00
Chemours El Dorado	9,868	0.38				
Chemours Louisville	3,724	0.01			196	1.00
Daikin America	3,313	0.02	22	0.00	30	1.00
Honeywell - Geismar Complex	51,282	0.42	499	0.11	62,543	0.39
Mexichem Fluor Inc.	4,369	0.19	28	0.70	73	1.00

Source: Toxic Releases Inventory

The quantity of chemicals associated with HFC production that are taken for offsite disposal are presented in columns 6 and 7. In the case of the 3M Cordova facility, all 32,590 pounds are nickel compounds. The Honeywell facility also 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 6-3 and the descriptions of the health risks described in Table 6-2. 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. 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 estimate 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 (Hu et al. 2016). 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.

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

Chemical	Maximum RSEI toxicity weight*	3M Cordova	Arkema, Inc.	Chemours - Corpus Christi	Chemours Chambers Works	Chemours El Dorado	Chemours Louisville	Daikin America	Honeywell - Geismar Complex	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	5,700	8,004	5,760		6,237	506	772	23,138	3,095
Hydrochloric acid	180		39,717	6,437	3		2,703	624	12,970	1,267
Vinylidene chloride	20									
Methyl chloroform	0.7		2,327							
Total for HFC-Related Subset		**5,700**	**58,043**	**34,876**	**3**	**9,868**	**3,724**	**3,313**	**51,282**	**4,369**

* 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.

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 reports non-production releases for HAP chemicals used in HFC production from 2010–2019; into which media is not specified. Four of the nine facilities report non-zero nonproduction releases. Notably, 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 6-7: 2010–2019 TRI Nonproduction Releases (lbs.) for Chemicals used in HFC Production

Chemical	Maximum RSEI toxicity weight*	3M Cordova	Arkema, Inc.	Chemours - Corpus Christi	Chemours Chambers Works	Chemours El Dorado	Chemours Louisville	Daikin America	Honeywell - Geismar Complex	Mexichem Fluor Inc.
Chromium Compounds	43,000,000								0.001	
Cobalt Compounds	17,000,000									
Vinyl chloride	1,500,000						112			
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		3		236		6,078	
Hydrochloric acid	180		2,954		11		847		1,177	
Vinylidene chloride	20									
Methyl chloroform	0.7		837							
Total for HFC-Related Subset		**0**	**4,994**	**0**	**14**	**0**	**1,208**	**0**	**7,370**	**0**

It is also possible that feedstock chemicals pose a risk to workers from more direct exposure pathways. Under the Toxic Substances Control Act (TSCA), as amended in 2016, EPA is required to evaluate potential risks from new and existing chemicals, with clear and enforceable deadlines, and to address any unreasonable risks those chemicals may have on human health and the environment. EPA announced the first 10 chemicals to undergo risk evaluations in December 2016 and an additional 20 chemicals were listed in December 2019 as a high priority for risk evaluation. Six chemicals used in the production of HFCs (listed in Table 6-7) are in this initial list of 30 chemicals prioritized for risk evaluation under TSCA, and are listed in Table 6-8 below. This risk evaluation can provide some information on the type of risks faced by workers from direct exposure. In the future, additional chemicals used in the production of HFCs may be evaluated as EPA moves through the list of prioritized chemicals. In the TSCA chemical prioritization process, preference is given to chemicals that are known human carcinogens or have high acute or chronic toxicity.

Four of the chemicals in Table 6-8 were part of the first 10 evaluated by EPA and have a completed risk assessment. Three of those chemicals (carbon tetrachloride, perchloroethylene, and trichloroethylene) are known to present an unreasonable risk of injury to the health of workers or occupational non-users in processing as a reactant or intermediate in industrial gas manufacturing. The fourth chemical (methylene chloride) was found to not pose an unreasonable risk to workers for this condition of use, but it is subject to an Occupational Safety and Health Administration (OSHA) eight-hour time-weighted average permissible exposure limit (PEL). This is an upper limit of the airborne concentration to which an employee may be exposed.[67]

[67] Another chemical in Table 6-5, vinyl chloride, is also subject to an OSHA PEL, but has not yet been listed for risk evaluation under TSCA.

Two of the chemicals listed in Table 6-8 (1,1-dichloroethane and 1,2-dichloroethane) do not yet have a risk determination but are in the final scoping stage for an evaluation by EPA under the amended TSCA evaluation process.

Table 6-8: TCSA risk evaluation for workers and occupational non-users of chemicals used in the production of HFCs

Chemical Name	TSCA Risk Determination in processing as a reactant/intermediate in industrial gas manufacturing
Carbon tetrachloride	Presents an unreasonable risk of injury to health of workers and occupational non-users
Tetrachloroethylene (Perchloroethylene)	Presents an unreasonable risk of injury to health of workers and occupational non-users
Trichloroethylene	Presents an unreasonable risk of injury to health of workers and occupational non-users
Dichloromethane (Methylene Chloride)	Does not present an unreasonable risk of injury to health of workers and occupational non-users
1,1-Dichloroethane	No evaluation (Final scope stage)
1,2-Dichloroethane	No evaluation (Final scope stage)

Source: EPA, Chemicals Undergoing Risk Evaluation under TSCA

6.3 Aggregate Average Characteristics of Communities with HFC Production Facilities

A key issue relevant to evaluating the potential for EJ concerns is the extent to which an individual might be exposed to feedstock, catalyst, or byproduct emissions from HFC production. EPA has not undertaken an analysis of how the emissions of various HFC feedstocks, catalysts, and byproducts 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 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 feedstocks, catalysts, or byproducts while those living further away are less likely to be exposed to these releases. 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. Socioeconomic and demographic data from the American Community Survey 5-year data release for 2019 (the most recent year available) is used to examine whether a greater percentage of population groups of concern live within 1 or 3 miles of an HFC production facility compared to the national average. The national average for rural areas is also presented since seven of the nine HFC production facilities subject to the proposed rule are classified as rural (Daikin America and Chemours Louisville are not).[68] In addition, National Air Toxic Assessment (NATA) data from 2014 (the most recent year available) for census tracts within and outside of a 1 and 3 mile distance are used to approximate the cumulative baseline cancer and respiratory risk due to air toxics exposure for communities near an HFC production facility. 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 production facility. Industrial activity is often concentrated (i.e., multiple plants located within the same geographic area).

[68] The US 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 40 people per square mile to 306 people per square mile for each of the seven facilities in rural areas. For the 3-mile radius, population density near a facility ranges from 46 people per square mile to 1,262 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.

Table 6-9 presents the density of TRI facilities (nearby facilities that could contribute to the cumulative NATA cancer and respiratory risk in HFC production communities) located within 1- and 3-mile radii of the nine HFC production facilities. Eight of the nine facilities have fewer than 5 neighboring TRI facilities within a 1-mile radius. Chemours Louisville, which is in an urban area - is an outlier with 14 neighboring TRI facilities. Expanding the radius to a 3-mile radius increases the number of neighboring TRI facilities substantially for four of the nine HFC facilities: Arkema (3 neighboring TRI facilities up to 11), Daikin America (3 neighboring TRI facilities up to 16), Mexichem Flour (5 neighboring TRI facilities up to 17), and Honeywell International (5 neighboring TRI facilities up to 20).

Table 6-9: Total Number of TRI Facilities within 1 and 3 miles of HFC Production Facilities

Facility	**Location**	**Neighboring TRI Facilities within a 1-Mile Radius**	**Neighboring TRI Facilities within a 3-Mile Radius**
3M Cordova	Cordova, IL	1	1
Arkema, Inc.	Calvert City, KY	3	11
Chemours - Corpus Christi	Gregory, TX	2	4
Chemours Chambers Works	Deepwater, NJ	2	4
Chemours El Dorado	El Dorado, AR	2	2
Chemours Louisville	Louisville, KY	14	19
Daikin America	Decatur, AL	3	16
Honeywell - Geismar Complex	Geismar, LA	5	20
Mexichem Fluor Inc.	Saint Gabriel, LA	5	17

Source: Toxic Releases Inventory (2019)

Summary statistics presented earlier in this section 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 for the proposal, though they may be worthy of further investigation.

Table 6-9 presents summary information for averaged across the nine communities near HFC production facilities compared to the overall and rural national average. The values in the last two columns reflect population-weighted averages across the Census block groups within the radius distance (i.e., 1 or 3 miles) of the facility. While it is not possible to disaggregate the risk information from NATA by race, ethnicity or income, the overall cancer and respiratory risk in communities within 1 or 3 miles of an HFC production facility is markedly greater than either the overall or rural national average.

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**
% White (race)	72	84	76	56
% Black or African American (race)	13	7.5	20	39
% Other (race)	15	8.2	4.4	5.4
% Hispanic (ethnic origin)	18	10	9.9	9.2
Median Household Income (1k 2019$)	71	67	63	52
% Below Poverty Line	7.3	6.8	6.8	10
% Below Half the Poverty Line	5.8	5.1	6.6	7.7
Total Cancer Risk (per million)	32	28	59	54
Total Respiratory Risk (hazard quotient)	0.44	0.38	0.71	0.58

Notes: Demographic definitions are as described in the 2019 American Community Survey (US 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 noncancer effects are unlikely and, thus, can be considered to have negligible hazard. For HQs 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).

Results by race and ethnicity are often sensitive to how the comparison group (i.e., overall versus rural national average) and the distance to an HFC production facility are defined. Since most of the facilities are located in areas clearly classified by Census as rural for both the 1-and 3-mile distance radii, the rural national average is likely the more relevant comparison. However, in addition to the two facilities that fall outside the rural designation (Daikin America, Chemours Louisville), two others (Chemours Corpus Christi and Chemours Chamber Works) have some census blocks that are adjacent to an urban area and therefore fall within the Census urban classification. While currently designated as rural, identifying the appropriate radii for approximating exposure to air toxics is worthy of further exploration, particularly if toxics travel longer distances and use of a larger radii results in a reclassification of some facilities from rural to urban.

Looking across all nine facilities (Table 6-10), a notably higher percentage of Black or African American individuals live within 1 or 3 miles of an HFC production facility (20 percent within 1 mile and 39 percent within 3 miles) compared to the rural and overall national averages (7.5 percent and 13 percent, respectively). A lower or similar percentage of White and Hispanic individuals live near an HFC production facility. Median income is lower for households living near an HFC facility compared to either national average. It is worth noting that the averages reported in Table 6-9 may obfuscate potentially large differences in the community characteristics surrounding individual production facilities. It is important, therefore, to examine the socioeconomic and demographic community characteristics for each facility separately, using the appropriate applicable national- and state-level averages for comparison.

6.4 Characteristics of Communities with HFC Production Facilities by Facility

Tables 6-11 through 6-19 present information about race, ethnicity, income, and exposure risks in nearby communities by individual HFC production facility compared to the applicable national and state level averages (i.e., rural or overall). Facilities vary in their race, ethnicity, and income characteristics from one facility to the next, but generally have larger cancer and respiratory exposure risks than their comparison populations.

Communities near two of the HFC production facilities (3M Cordova and Chemours Corpus Christi) have similar cancer and respiratory risks from air toxics to the state and national rural averages. These facilities have a higher percent of White individuals and lower percent of Black or African American individuals living nearby. While fewer individuals of Hispanic origin live near the 3M Cordova facility, a higher number of Hispanic individuals live near the Chemours Corpus Christi facility relative to the national and state rural averages. Fewer households are living below the poverty line near these facilities compared to the state and national rural averages, though the proportion of households in extreme poverty (below half of the poverty line) varies. While the communities surrounding Arkema Inc. and Chemours El Dorado (Tables 6-12 and 6-15) have substantially increased risk for one of the two indicators (for Arkema, respiratory risk is 4.5 to 5.5 times that of the relevant comparison population; see also Figure 6-4), they are qualitatively similar to the communities surrounding the 3M Cordova and Chemours Corpus Christi facilities when comparing race and ethnicity to the state and national rural averages: they have higher percentages of White individuals, and lower percentages of Black or African American and Hispanic individuals. How the income and poverty variables compare to the state and national averages depends on the distance used.

Communities around three HFC production facilities (Chemours Chambers Works, Chemours Louisville, and Daikin America) have noticeably higher risks from air toxics than the applicable state and national averages – depending on the distance to the facility used to define the nearby community. However, the socioeconomic characteristics of the surrounding communities differ. How the race and ethnicity of individuals living near Chemours Chamber

Works – in terms of ethnicity, and income – compare to the national or state average is sensitive to the distance used as well as which average is used as the basis of comparison (see Table 6-14). Median household income near the facility is consistently lower than average, while poverty rates are consistently higher regardless of which distance measure or average is used. The communities living near the Chemours Louisville and Daikin America facilities are both characterized by lower percentages of White individuals, higher percentages of Black or African American individuals, lower median household incomes, and higher percentages in poverty compared to state and national averages (see Tables 6-16 and 6-17). The percentage Hispanic is sensitive to the distance and basis of comparison.

Characteristics around the two facilities in Louisiana (Honeywell Geismar Complex and Mexichem Fluor) demonstrate very high baseline risks from air toxics (2.5 to 6 times the cancer risk – Figure 6-3 – and 1.3 to 2.4 times the respiratory risk – Figure 6-4 – relative to the state and national rural averages). These facilities are 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 to the state and national rural average (see Tables 6-18 and 6-19). 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 proposed action are important for understanding how these communities might be affected.

Table 6-11: Community Profiles and NATA Risks for 3M Cordova - Cordova, IL

	Rural Areas National Average	Rural Areas State Average	Within 1 mile of HFC production facility	Within 3 miles of HFC production facility
% White (race)	84	91	98	98
% Black or African American (race)	7.5	3.9	0.45	0.17
% Other (race)	8.2	4.9	1.8	1.8
% Hispanic (ethic origin)	10	5.5	0	2.1
Median Household Income (1k 2019$)	67	72	70	57
% Below Poverty Line	6.8	5.3	3.4	4.5
% Below Half the Poverty Line	5.1	4.2	4.5	2.4
Total Cancer Risk (per million)	28	25	22	22
Total Respiratory Risk (hazard quotient)	0.38	0.32	0.29	0.29

Table 6-12: 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
% White (race)	84	94	99	99
% Black or African American (race)	7.5	3.2	0.0	0.36
% Other (race)	8.2	3.2	0.85	1.0
% Hispanic (ethic origin)	10	2.4	1.8	3.1
Median Household Income (1k 2019$)	67	51	53	55
% Below Poverty Line	6.8	10	5.7	4.7
% Below Half the Poverty Line	5.1	7.7	8.2	7.2
Total Cancer Risk (per million)	28	30	34	33
Total Respiratory Risk (hazard quotient)	0.38	0.42	2.2	1.9

Table 6-13: Community Profiles and NATA Risks for Chemours Corpus Christi Plant – Gregory, TX

	Rural Areas National Average	Rural Areas State Average	Within 1 mile of HFC production facility	Within 3 miles of HFC production facility
% White (race)	84	82	95	91
% Black or African American (race)	7.5	7.9	1.6	2.3
% Other (race)	8.2	9.8	3.6	6.3
% Hispanic (ethic origin)	10	32	40	41
Median Household Income (1k 2019$)	67	70	78	79
% Below Poverty Line	6.8	7.1	1.4	4.1
% Below Half the Poverty Line	5.1	5.4	1.0	2.8
Total Cancer Risk (per million)	28	32	18	18
Total Respiratory Risk (hazard quotient)	0.38	0.39	0.22	0.22

Table 6-14: Community Profiles and NATA Risks for Chemours Chambers Works – Deepwater, NJ

	Rural Areas National Average	Rural Areas State Average	Within 1 mile of HFC production facility	Within 3 miles of HFC production facility
% White (race)	84	84	87	70
% Black or African American (race)	7.5	5.8	6.6	20
% Other (race)	8.2	10	6.6	10
% Hispanic (ethic origin)	10	8.1	9.6	12
Median Household Income (1k 2019$)	67	100	62	57
% Below Poverty Line	6.8	3.2	6.2	10
% Below Half the Poverty Line	5.1	2.8	2.9	5.8
Total Cancer Risk (per million)	28	27	40	52
Total Respiratory Risk (hazard quotient)	0.38	0.35	0.46	0.42

Table 6-15: 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
% White (race)	84	83	94	94
% Black or African American (race)	7.5	11	1.4	1.4
% Other (race)	8.2	5.9	4.7	4.7
% Hispanic (ethic origin)	10	5.3	2.4	2.4
Median Household Income (1k 2019$)	67	51	66	66
% Below Poverty Line	6.8	9.6	8.0	8.0
% Below Half the Poverty Line	5.1	6.2	5.2	5.2
Total Cancer Risk (per million)	28	35	54	54
Total Respiratory Risk (hazard quotient)	0.38	0.5	0.68	0.68

Table 6-16: 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
% White (race)	72	87	59	30
% Black or African American (race)	13	8.1	37	64
% Other (race)	15	5.0	4.7	4.2
% Hispanic (ethic origin)	18	3.7	4	5.3
Median Household Income (1k 2019$)	71	55	40	35
% Below Poverty Line	7.3	9.5	13	15
% Below Half the Poverty Line	5.8	7.3	12	11
Total Cancer Risk (per million)	32	31	36	37
Total Respiratory Risk (hazard quotient)	0.44	0.43	0.46	0.49

Table 6-17: 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**
% White (race)	72	68	35	53
% Black or African American (race)	13	27	59	39
% Other (race)	15	5.3	18	14
% Hispanic (ethic origin)	18	4.3	5.7	8.3
Median Household Income (1k 2019$)	71	55	36	42
% Below Poverty Line	7.3	9.1	21	17
% Below Half the Poverty Line	5.8	7.2	13	8.1
Total Cancer Risk (per million)	32	43	52	45
Total Respiratory Risk (hazard quotient)	0.44	0.65	0.69	0.62

Table 6-18: 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**
% White (race)	84	70	57	63
% Black or African American (race)	7.5	26	38	34
% Other (race)	8.2	4.7	5.4	2.5
% Hispanic (ethic origin)	10	3.6	3.8	2.7
Median Household Income (1k 2019$)	67	52	79	84
% Below Poverty Line	6.8	9.9	2.3	2.5
% Below Half the Poverty Line	5.1	7.9	7.2	5.0
Total Cancer Risk (per million)	28	49	130	140
Total Respiratory Risk (hazard quotient)	0.38	0.59	0.77	0.79

Table 6-19: 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
% White (race)	84	70	25	55
% Black or African American (race)	7.5	26	75	42
% Other (race)	8.2	4.7	0.24	2.6
% Hispanic (ethic origin)	10	3.6	4.6	2.6
Median Household Income (1k 2019$)	67	52	31	65
% Below Poverty Line	6.8	9.9	4.6	3.3
% Below Half the Poverty Line	5.1	7.9	35	4.4
Total Cancer Risk (per million)	28	49	180	140
Total Respiratory Risk (hazard quotient)	0.38	0.59	0.94	0.83

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

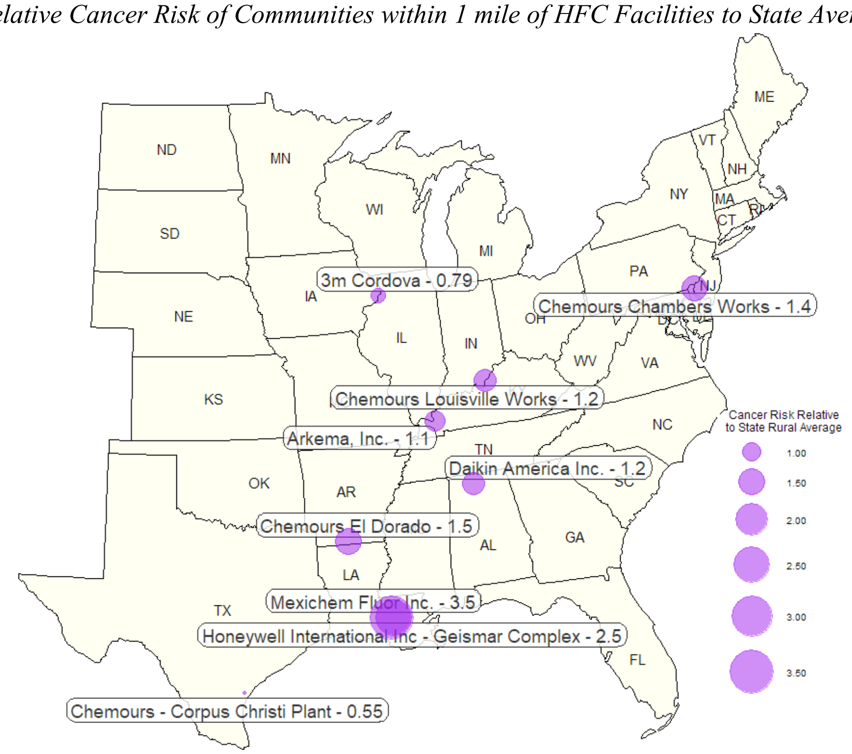
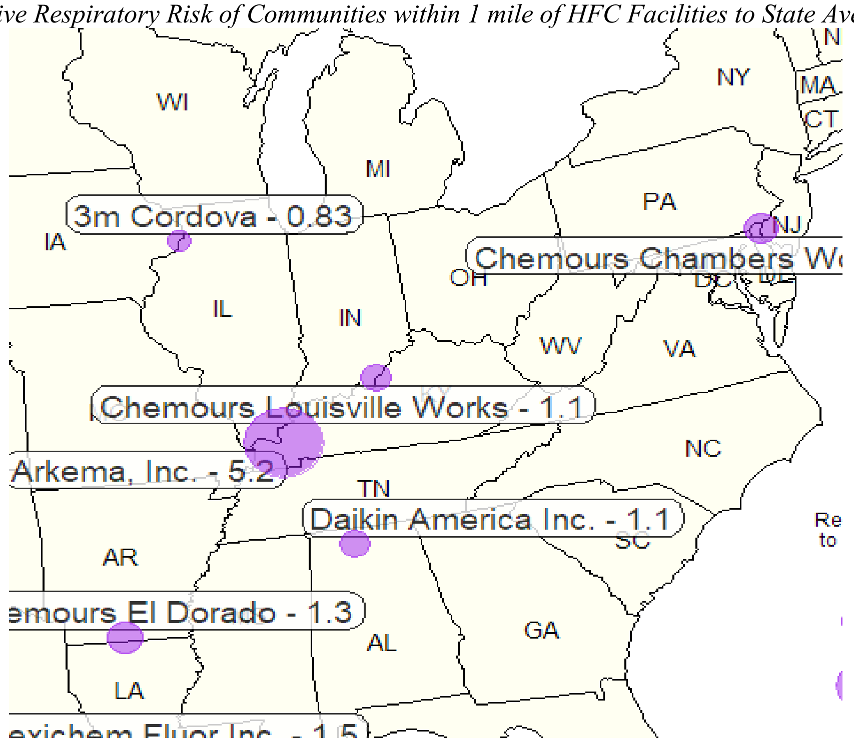


Figure 6-4: Relative Respiratory Risk of Communities within 1 mile of HFC Facilities to State Averages



6.5 Previous Violations and Enforcement Actions

Tables 6-20 and 6-21 present the number of informal and formal enforcement actions and quarters of non-compliance for each of the nine HFC production facilities under the major statutes for air (Clean Air Act - CAA), hazardous waste (Resource Recovery and Conservation Act - RCRA), water (Clean Water Act - CWA), and drinking water (Safe Drinking Water Act - SDWA). Note that these enforcement actions are not necessarily specific to the HFC production process. Most of the facilities have between zero and four enforcement actions, with the exception of Chemours Chamber Works, with seven informal and seven formal actions under the RCRA and 57 informal and 1 formal action under the SDWA. For RCRA, these actions represent 4 percent and 7 percent of all informal and formal enforcement actions, respectively, taken against facilities in New Jersey in 2019. For SDWA, the actions taken against Chemours Chamber Works represent 5 percent and 6 percent of all informal and formal enforcement actions in New Jersey, respectively. Two of the three HFC production facilities that have similar cumulative risk profiles for nearby communities, 3M Cordova and Chemours – Corpus Christi Plant, compared to the national and state level rural averages have had no enforcement actions under any of these environmental statutes in the last five years.

Table 6-20: Number of Informal and Formal Enforcement Actions in Last Five Years

	RCRA		**CAA**		**SDWA**		**CWA**	
Facility Name	**Informal**	**Formal**	**Informal**	**Formal**	**Informal**	**Formal**	**Informal**	**Formal**
3M Cordova								
Arkema, Inc.			2					
Chemours Chambers Works	7	7		2	57	1		
Chemours El Dorado	3	2	1	1				
Chemours Corpus Christi Plant								
Chemours Louisville	2						2	
Daikin America			2				1	
Honeywell - Geismar Complex	1			2				
Mexichem Fluor Inc.			1					

Source: EPA's Enforcement and Compliance History Online (ECHO).

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

Table 6-21: Quarters of Non-Compliance (Out of 12)

Facility Name	Location	RCRA	CAA	SDWA	CWA
3M Cordova	Cordova, IL	12			3
Arkema, Inc.	Calvert City, KY		1		
Chemours - Chambers Works	Deepwater, NJ	12		6	12
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
Mexichem Fluor Inc.	Saint Gabriel, LA				

Source: EPA's Enforcement and Compliance History Online (ECHO)

6.6 Proposed option and trading

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 (U.S. EPA. 2015, Banzhaf et al. 2019, Hernandez-Cortes and Meng 2020, Mansur and Sherrif 2021). The potential for trading to increase pollution, or at least deliver fewer emission reductions, in some communities compared to others has distributional implications. For example, if facilities 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., if more modern and efficient facilities with lower marginal abatement costs). EPA also notes that this rule affects a small number of entities through a distinct allocation program, and that these entities manufacture a wide variety of products and are subject to a number of distinct market and regulatory forces independent of this HFC program. As such, the issues identified here and possible remedies may not be broadly applicable or practicable in other rulemakings.

This proposed rule under the AIM Act phases down the production and consumption of the regulated HFCs identified in Table 1-1. Because multiple HFCs are allowed to be traded[69] within the same market, trading ratios - referred to here as exchange values - are used to adjust for their differential effects on global warming. 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,

[69] The proposed regulation to phase down HFCs uses the term "transfer," but the general meaning as presented in this section of the RIA is the same.

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 proposed rule.

Table 6-22 lists the anticipated substitutes for each of the HFCs subject to the proposed rule and their respective exchange values. Which substitutes are likely to be used to replace a particular HFC or HFC blend depends 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.[70] Both of these aspects of the program further complicate predictions of which and for how long different substitutes will be produced.

[70] 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 6-22: Possible substitutes for HFCs produced in the US and subject to the proposed rule

HFC Subject to the Proposed Rule	Exchange Value	Substitutes †
HFC-134a	1430	HFO-1234yf, HFO-1234ze
HFC-125	3500	HFC-32, HFO-1234yf, NH_3
HFC-32	675	HC, CO_2
HFC-152a	124	HFO-1234yf, HC, HFO-1234ze, HC
HFC-245fa	1030	Cyclopentane, HCFO-1233zd(*E*)
HFC-143a	4470	HFC-32, HFC-134a, HFO-1234yf, HFO-1234ze, CO_2, NH_3
HFC-236fa	9810	C6-perfluoroketone, dry chemical, 2-BTP (in aircraft only)
HFC-227ea	3220	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. 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.[71]

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.[72]

[71] 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 (https://www.fluorocarbons.org/wp-content/uploads/2020/07/2020_07_27_Fluorocarbon-Molecules-environmental-properties-and-main-applications-2020-July.pdf)
[72] 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.

Production of HFOs use toxic chemicals as feedstocks or catalysts and produces toxic chemicals as byproducts. Table 6-23 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 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 6-23: 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[73]
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 HFC 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

[73] Chemical health effects information comes from the Occupational Safety and Health Administration (OSHA) Carcinogen List and the TRI-CHIP datasets.

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 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 could drive changes in potential risk for communities living near HFC and HFC substitute production facilities due to the use of feedstock chemicals that could have local effects if released into the environment. The EJ 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 within 1–3 miles of an HFC production facility;

- Higher percentages of low income and Black or African American individuals live near HFC production facilities compared to 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, some of which have toxic profiles for the chemicals used as feedstocks in their production.

Given limited information regarding which substitutes will be produced where, it is unclear to what extent this proposed rule will impact baseline risks from hazardous air toxics for communities living near HFC and HFC substitute production facilities. EPA is seeking information to help better characterize these changes and their implications for nearby communities for analysis of the final rule.[74] See section III and XI of the proposed rule for more information on the questions on which EPA is seeking input.

[74] 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 and costs of this rulemaking and to address uncertainty, also sensitivity analysis to show other plausible though less likely values for benefits, costs, and net 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.[75] 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 cost elements associated with the proposal to prohibit the use of non-refillable cylinders in a separate document. That document 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 HFC (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 to current practices. More

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

discussion on the costs of this proposal is included in the preamble (section VIII.D) and the technical support document included in the docket, "Refillable and Non-refillable Cylinders: Analysis of Use, Emissions, Disposal, and Distribution of Refrigerants."

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. It 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 which 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 III of the proposed rule.

The second area relates to the safety of certain alternative technologies that may replace HFCs. EPA evaluates substitutes using a comparative risk framework. 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. 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 expects to consider risks and where appropriate the mitigation of risks in implementing subsections (h) and (i). Under subsection (h), Management of Regulated Substances, Congress directed EPA to promulgate regulations "for the 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), Technology Transitions, EPA is directed to "evaluate substitutes for regulated substances in a sector or subsector, taking into account technological achievability, commercial demands, *safety*, overall economic costs and environmental impacts, and other relevant factors [and to] make the evaluation … available to the public, including the factors associated with the *safety* of those substitutes," (emphasis added). In addition, in carrying out rulemakings under (i) and making a determination to grant or deny a petition submitted under subsection (i)(3), subsection (i)(4) provides that EPA "shall, to the extent practicable, factor in" a number of considerations, including "the availability of substitutes for use of the regulated substance … in a sector or subsector, taking into account … *safety,*" (emphasis added). EPA's assessment of transitions associated with the AIM Act's phase down is based on the availability alternatives and their safe use. Throughout the phaseout of ozone-depleting substitutes under Clean Air Act Title VI, EPA has addressed 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 must pose less 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. Consistent with its comparative risk approach for alternatives, EPA expects that it will continue to consider safety in implementing these aspects 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-HFC estimates. In particular, there are uncertainties surrounding the discount rate and the parameters set by model developers in the Integrated Assessment Models. More discussion of these uncertainties can be found in Chapter 4 and Appendix A.

Chapter 8: Appendix

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) (USG 2010, USG 2013, USG 2016a, USG 2016b, USG 2021). 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 (USG 2021). Tables A-1 through A-9 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

Appendix B: State Level Actions

One aspect that may affect the economic baseline (business-as-usual) projections used by EPA is the actions undertaken by several states to adopt regulations similar to EPA's previous regulations promulgated in 2015 and 2016 (SNAP program's Rules 20 and 21). These state rules restrict the use of certain HFCs in specific end-uses[76].

To date, 16 states have indicated intent to take action on HFCs and of the 16 states, nine states have finalized regulations, as shown in Table B-1 below. While some of the nine states may also be considering additional HFC restrictions, no states are pursuing a statewide phasedown in HFCs analogous to the phasedown described in this RIA.

Table B-1: States that indicated intent to restrict use of certain HFCs in specific end-uses

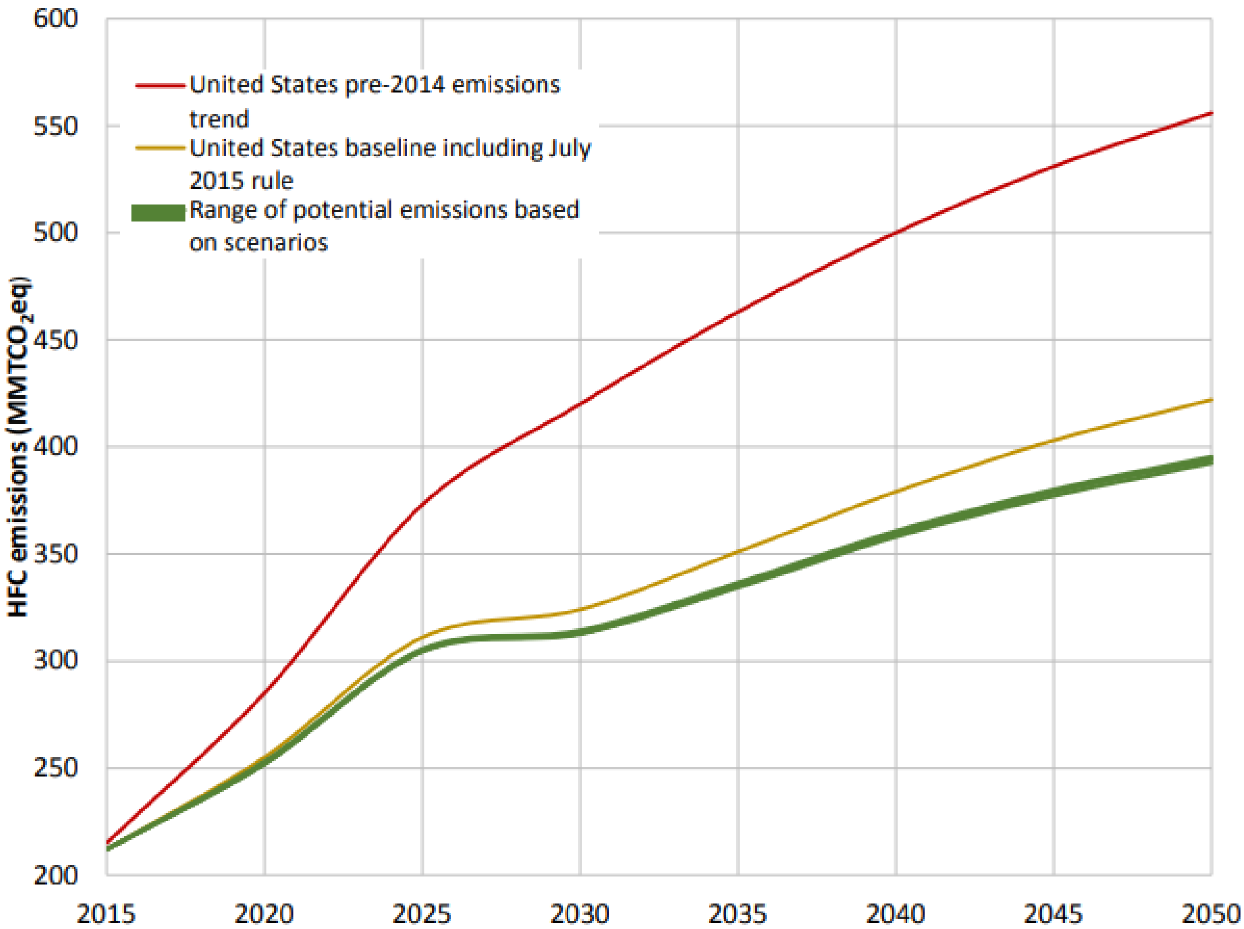
State	Year regulations issue
California	2019
Colorado	2021
Connecticut	*N/A*
Delaware	2021
Hawaii	*N/A*
Maine	*N/A*
Maryland	2021
Massachusetts	2021
New Jersey	2020
New York	2021
Pennsylvania	*N/A*
Oregon	*N/A*
Rhode Island	*N/A*
Vermont	2021
Virginia	*N/A*
Washington	2021

[76] Under CAA section 612, EPA issued a final rule in July 20, 2015, which, among, other things, changed listings 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*, 866 F.3d 451, 462 (D.C. Cir. 2017); *see also Mexichem Fluor, Inc. v. EPA*, Judgment, Case No. 17-1024 (D.C. Cir., April 5, 2019), 760 Fed. Appx. 6 (Mem).

Where it concerns the regulated use of HFCs, SNAP Rules 20 and 21 were considerably narrower in scope compared to phasedown of HFCs under the AIM Act. Also, shown in Table B-1, the state regulations on HFC were promulgated several years after the SNAP rules and in some cases have later compliance dates for various end-use restrictions which would further limit how the regulations affect the economic BAU.

When analyzing the benefits of the SNAP rules, EPA estimated the likely effects the rules would have on HFC emissions for the entire United States including territories and all 50 states. Under these scenarios, the trajectory of HFC emissions is clearly dampened, but are still increasing. Figure B-1 shows the emissions scenarios and HFC baseline as calculated for SNAP Rules 20 and 21.

Figure B-1: Emissions scenarios from SNAP Rules 20 and 21



Note that the above figure represents emissions scenarios for the entire United States, including territories and all 50 states, originating in 2015, whereas the present reality is that only nine states have adopted these laws and at a much later date, and another seven states have indicated their intention to adopt similar laws.

Collectively, the states that have enacted regulations to limit the use of HFCs comprise a significant proportion of the U.S. population (~29 percent). However, a direct link to market share of the regulated chemicals would be misleading, as regional differences in HFC equipment and product usage (owing to building codes and sizes, weather patterns, and other factors) can greatly skew the overall HFC usage. Furthermore, it is possible that through these regulations, HFC usage could shift to states without regulations or to other unregulated end-uses. For analytical purposes, EPA lacks state-level data of HFC usage to accurately capture the effect of state regulations in the economic baseline. While EPA believes it is reasonable to assume that the state actions would have some effect on estimating a BAU economic baseline (i.e., in absence of the passage of the AIM Act, the U.S. would not consume quite as much HFCs as the BAU demonstrates), their impact, for the purposes of this nation-wide regulation of greater scope, are 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 phase-down schedule.

2022, 2024, 2029

- IPR CS - NH_3/CO_2
- non-MDI Aerosols HFC-152a to NIK
- Large Retail Food - DX 407A/407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - 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 - 134a to R-600a
- non-MDI Aerosols HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - 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) - 134a to HCs
- Leak Repair for Large Equipment
- Window Dehumid - R-32
- Large Retail Food - 407A/407F SLS
- Medium Retail Food - DX 407A/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) - 134a to HCs
- non-MDI Aerosols HFC-152a to HC
- Flooding Agents - 5-K-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - 245fa to 1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - 245fa/CO_2 to 1233zd(*E*)

- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to 1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze
- 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
- Screw Chillers - 410&407 replaced w/ 1235
- Reciprocating Chillers - 410&407 replaced w/ 1235
- PU Rigid: One Component Foam - 134a to HFO-1234ze
- Recovery at Disposal for ALL Equipment
- Scroll Chillers - 410&407 replaced w/ 4522
- Vending Machines - 4503
- 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

2034

- IPR CS - NH_3/CO_2
- non-MDI Aerosols HFC-152a to NIK
- Large Retail Food - DX 407A/407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - 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 - 134a to R-600a
- non-MDI Aerosols HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - 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) - 134a to HCs

- Leak Repair for Large Equipment
- Window Dehumid - R-32
- Large Retail Food - 407A/407F SLS
- Medium Retail Food - DX 407A/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) - 134a to HCs
- non-MDI Aerosols HFC-152a to HC
- Flooding Agents - 5-K-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - 245fa to 1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - 245fa/CO_2 to 1233zd(*E*)
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to 1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zd(*E*)
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze
- 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
- Screw Chillers - 410&407 replaced w/ 1235
- Reciprocating Chillers - 410&407 replaced w/ 1235
- PU Rigid: One Component Foam - 134a to HFO-1234ze
- Recovery at Disposal for ALL Equipment
- Scroll Chillers - 410&407 replaced w/ 4522
- Vending Machines - 4503
- Transport - R-452A

2036

- IPR CS - NH_3/CO_2
- non-MDI Aerosols HFC-152a to NIK
- Large Retail Food - DX 407A/407F
- Large Retail Food - CO_2 Transcritical
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to HCs
- Flooding Agents - Inert Gas
- PU and PIR Rigid: Boardstock - 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 - 134a to R-600a
- non-MDI Aerosols HFC-134a to HFC-152a
- Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - 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) - 134a to HCs
- Leak Repair for Large Equipment
- Window Dehumid - R-32
- Large Retail Food - 407A/407F SLS
- Medium Retail Food - DX 407A/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) - 134a to HCs
- non-MDI Aerosols HFC-152a to HC
- Flooding Agents - 5-K-12
- Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - 245fa to 1233zd(*E*)
- Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - 245fa/CO_2 to 1233zd(*E*)
- Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - 245fa to 1233zd(*E*)
- PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zdE
- HP - R-32/R-452B
- PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze
- 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
- Screw Chillers - 410&407 replaced w/ 1235
- Reciprocating Chillers - 410&407 replaced w/ 1235
- PU Rigid: One Component Foam - 134a to HFO-1234ze
- Recovery at Disposal for ALL Equipment
- Scroll Chillers - 410&407 replaced w/ 4522
- Vending Machines - 4503
- 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 – 134a replaced w/ 4503
- CFC-11 Centrifugal Chillers – 134a replaced w/ 4503
- CFC-12 Centrifugal Chillers – 134a replaced w/ 4503
- R-500 Chillers – 134a replaced w/ 4503
- Electronic Cleaning applications - retrofitted Not-in-kind Aqueous
- Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous
- CFC-12 Centrifugal Chillers - 245 replaced w/ 1233
- R-500 Chillers - 245 replaced w/ 1233
- CFC-11 Centrifugal Chillers - 245 replaced w/ 1233

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 - 5-K-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) - 245fa to 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) - 134a to HCs	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock - 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) - 245fa to 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) - 245fa to HCs	25	50%	50%	50%	50%	50%	50%	50%
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam - 134a to HFO-1234ze	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) - 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) - 245fa/CO_2 to 1233zd(*E*)	25	33%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zd(*E*)	25	12%	70%	70%	70%	70%	70%	70%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze	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%	0%	80%	80%	80%	80%	80%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – 134a replaced w/ 4503	25	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers - 245 replaced w/ 1233	25	20%	100%	100%	100%	100%	100%	100%

Refrigeration & A/C	Chillers	CFC-114 Chillers – 134a replaced w/ 4503	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers - 134 replaced w/ 4503	27	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers - 245 replaced w/ 1233	27	20%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	R-500 Chillers - 134 replaced w/ 4503	27	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Chillers	R-500 Chillers - 245 replaced w/ 1233	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	IPR CS - NH_3/CO_2	25	17%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Large Retail Food	Large Retail Food - 407A/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 407A/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 407A/407F	20	67%	67%	67%	67%	67%	67%	67%
Refrigeration & A/C	PD Chillers	Reciprocating Chillers - 410&407 replaced w/ 1235	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Screw Chillers - 410&407 replaced w/ 1235	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Scroll Chillers - 410&407 replaced w/ 4522	20	0%	100%	100%	100%	100%	100%	100%
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances - 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%	0%	100%	100%	100%	100%	100%
Refrigeration & A/C	Service	Recovery at Service for Small Equipment	7	100%	100%	100%	100%	100%	100%	100%
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 – 4503	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 Dehumids	Window Dehumid - 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 - 5-K-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) - 245fa to 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) - 134a to HCs	100%	33%	100%	100%	100%	100%	100%	100%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock - 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) - 245fa to 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) - 245fa to HCs	99%	17%	0%	0%	0%	0%	0%	0%
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam - 134a to HFO-1234ze	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) - 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) - 245fa/CO_2 to 1233zd(*E*)	99%	14%	41%	41%	41%	41%	41%	41%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zdE	99%	12%	69%	69%	69%	69%	69%	69%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze	99%	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	100%	0%	0%	79%	79%	79%	79%	79%

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-11 Centrifugal Chillers – 134a replaced w/ 4503	57%	0%	48%	55%	64%	67%	93%	45%
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers - 245 replaced w/ 1233	99%	6%	31%	34%	38%	38%	45%	20%
Refrigeration & A/C	Chillers	CFC-114 Chillers – 134a replaced w/ 4503	57%	0%	0%	100%	100%	100%	57%	57%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers - 134 replaced w/ 4503	57%	0%	54%	61%	70%	77%	85%	74%
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers - 245 replaced w/ 1233	99%	3%	19%	20%	23%	24%	26%	15%
Refrigeration & A/C	Chillers	R-500 Chillers – 134a replaced w/ 4503	57%	0%	54%	61%	71%	77%	85%	74%
Refrigeration & A/C	Chillers	R-500 Chillers - 245 replaced w/ 1233	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 - 407A/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 407A/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 407A/407F	50%	20%	25%	34%	38%	33%	33%	33%
Refrigeration & A/C	PD Chillers	Reciprocating Chillers - 410&407 replaced w/ 1235	100%	0%	87%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Screw Chillers - 410&407 replaced w/ 1235	100%	0%	92%	100%	100%	100%	100%	100%
Refrigeration & A/C	PD Chillers	Scroll Chillers - 410&407 replaced w/ 4522	64%	0%	62%	100%	100%	100%	63%	63%
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances - 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%	0%	57%	80%	100%	86%	86%
Refrigeration & A/C	Service	Recovery at Service for Small Equipment	95%	9%	9%	3%	0%	0%	0%	0%
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 - 4503	63%	29%	87%	80%	70%	70%	70%	70%

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	Vending Machines	Vending Machines - R-290	100%	10%	29%	27%	23%	23%	23%	23%
Refrigeration & A/C	Window Dehumids	Window Dehumid - 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%
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 (mtCO₂e)	Breakeven Cost (2015 USD / mtCO₂e)
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	$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	$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 - 5-K-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) - 245fa to 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) - 134a to HCs	$405,000	$135,000	$0	42,705.0	($2.13)
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock - 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) - 245fa to 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) - 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 - 134a to HFO-1234ze	$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) - 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) - 245fa/CO_2 to 1233zd(*E*)	$0	$0	$1,812,000	463,419.0	$3.91
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) - 245fa and 245fa/CO_2 blend to Solstice-1233zdE	$250,000	$0	$230,124	58,854.2	$4.37
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) - 245fa and 245fa/CO_2 to HFO-1234ze	$550,000	$0	$230,124	58,911.7	$4.92
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - 134a/CO_2 to LCD/Alcohol	$5,856,000	$4,770,000	$915,000	1,007,942.4	($3.19)

Sector	End Use	Abatement Option	Capital Cost (2015 USD)	Annual Revenue (2015 USD)	Annual O&M Costs (2015 USD)	Abatement Amount ($mtCO_2e$)	Breakeven Cost (2015 USD / $mtCO_2e$)
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers – 134a replaced w/ 4503	$12,695	$0	$762	74.2	$28.84
Refrigeration & A/C	Chillers	CFC-11 Centrifugal Chillers - 245 replaced w/ 1233	$53,800	$0	$168	71.8	$83.62
Refrigeration & A/C	Chillers	CFC-114 Chillers – 134a replaced w/ 4503	$16,793	$0	$1,008	111.3	$26.53
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers – 134a replaced w/ 4503	$13,057	$0	$783	73.2	$29.70
Refrigeration & A/C	Chillers	CFC-12 Centrifugal Chillers - 245 replaced w/ 1233	$53,880	$0	$173	71.7	$82.51
Refrigeration & A/C	Chillers	R-500 Chillers - 134 replaced w/ 4503	$13,057	$0	$783	73.2	$29.70
Refrigeration & A/C	Chillers	R-500 Chillers - 245 replaced w/ 1233	$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 - 407A/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 407A/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 407A/407F	$0	$0	$0	5.2	$0.00
Refrigeration & A/C	PD Chillers	Reciprocating Chillers - 410&407 replaced w/ 1235	$2,048	$0	$123	66.8	$5.39
Refrigeration & A/C	PD Chillers	Screw Chillers - 410&407 replaced w/ 1235	$1,950	$0	$117	63.6	$5.39
Refrigeration & A/C	PD Chillers	Scroll Chillers - 410&407 replaced w/ 4522	$3,334	$0	$200	40.9	$14.33
Refrigeration & A/C	Refrigerated Appliances	CFC-12 Refrigerated Appliances - 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 - 4503	$5	$0	$0	0.1	$17.31

Sector	End Use	Abatement Option	Capital Cost (2015 USD)	Annual Revenue (2015 USD)	Annual O&M Costs (2015 USD)	Abatement Amount ($mtCO_2e$)	Breakeven Cost (2015 USD / $mtCO_2e$)
Refrigeration & A/C	Vending Machines	Vending Machines - R-290	$305,950	$191	$0	554.0	$88.76
Refrigeration & A/C	Window Dehumids	Window Dehumid - 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$)

	Discount rate and statistic			
Year	**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$)

Year	Discount rate and statistic 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

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 may also be potentially affected by this proposal 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

NAICS Code	NAICS Industry Description
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing
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

NAICS Code	NAICS Industry Description
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
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.