Regulatory Impact Analysis Addendum: Impact of the Technology Transitions Rule

September 2023

United States Environmental Protection Agency

Contents

Executive Summary

ES.1 Introduction

This Regulatory Impact Analysis (RIA) addendum provides an assessment of the costs and benefits of the rule *Phasedown of Hydrofluorocarbons: Restrictions on the Use of Certain Hydrofluorocarbons under Subsection (i) of the American Innovation and Manufacturing Act of 2020* (also referred to in this document as the Technology Transitions Rule). The rule furthers the implementation of the American Innovation and Manufacturing (AIM) Act, including through restricting the use of certain hydrofluorocarbons (HFCs) above a certain global warming potential (GWP) whether neat or used in a blend,[1] or restricting certain HFCs and certain blends containing HFCs, in specific sectors or subsectors where HFCs are used. This rule establishes restrictions for the aerosols, foam blowing, and refrigeration, air conditioning, and heat pump sectors and applies to both domestically manufactured and imported products. This analysis is intended to provide the public with information on the relevant costs and benefits of this rulemaking and to comply with executive orders. While significant, the estimated benefits detailed in this document are considered incidental and secondary to the rule's statutory objective of facilitating the transition to next-generation technologies by restricting use of HFCs in the sectors or subsectors in which they are used.

This rulemaking follows an already finalized rule issued separately under the AIM Act, *Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program Under the American Innovation and Manufacturing Act* (Allocation Framework Rule, 86 FR 55116, October 5, 2021), as well as an update to that rule, *Phasedown of Hydrofluorocarbons: Allowance Allocation Methodology for 2024 and Later Years* (88 FR 46836, July 20, 2023).[2] The analysis presented in the sections below provides estimated economic costs and environmental impacts of the provisions of the Technology Transitions Rule. The analysis also provides a comparison of these costs and benefits with those assessed for the Allocation Rules to provide the public with an understanding of any potential changes in economic and environmental impacts relative to prior estimates. In addition, for the purposes of identifying potential environmental justice issues, the analysis presents EPA's assessment of the characteristics of

---

[1] Under the GWP limit approach, for HFCs used in a blend in the sector or subsector, compliance with the GWP limit would be determined based on the GWP of the blend. Blends containing an HFC with GWPs at or above the GWP limit would be prohibited from use in that sector or subsector.

[2] Throughout this document, we use "Allocation Framework RIA" and "2024 Allocation Rule RIA Addendum" to refer to the analyses of these rules. We use "Allocation Rules" and "Allocation Rules RIA" to refer to combined or cumulative effect of those two rules; i.e., the Allocation Framework RIA as updated by the 2024 Allocation Rule RIA Addendum.

communities near facilities producing predominant HFC substitutes that are expected to be affected by the rule.

The methodology used to examine the economic costs and environmental impacts of the rule closely follows that used in the Allocation Framework RIA[3] as well as the addendum to that RIA prepared for the 2024 Allocation Rule (collectively, "Allocation Rules"). Results and methods from these analyses are referenced throughout this document. As with the 2024 Allocation Rule analysis, this document is presented as an addendum to the original Allocation Framework RIA.

The Technology Transitions Rule includes restrictions on the use of a regulated substance in the sector or subsector in which the regulated substance is used. The intent of this rule is to facilitate transitions to innovative technologies as HFCs are phased down. This rule responds to petitions covering approximately 40 sectors or subsectors. The restrictions take the form of GWP limits or a list of prohibited HFCs or HFC blends used in those sectors or subsectors. The additional benefits anticipated from the Technology Transitions Rule that are presented in this analysis are non-trivial but also represent a relatively small increase above the total benefits already accounted for in the Allocation Rules RIA.[4]

ES.2 Relationship to Allocation Framework Rule and 2024 Allocation Rule RIA Results

Results from this analysis indicate that the restrictions in the Technology Transitions Rule will reduce HFC consumption and emissions at a level on par with that estimated for the Allocation Framework Rule and the 2024 Allocation Rule for many sectors and subsectors, while requiring more rapid, deeper transitions in others, resulting in potential additional reductions and associated climate benefits beyond those estimated for the Allocation Rules. However, the schedule for the production and consumption phasedown is not made more stringent than the schedule under subsection (e)(2)(C) of the AIM Act (i.e., the production and consumption caps contained in the Allocation Rules are unchanged). In terms of net compliance costs, transitions required to meet the restrictions also result in additional cost savings over time beyond those projected in the Allocation Rules. These additional savings stem largely from a more rapid and comprehensive transition to lower-GWP, energy-saving technologies than is otherwise assumed in the compliance pathway evaluated for the Allocation Rules.

[3] Available at *www.regulations.gov* under Docket ID EPA-HQ-OAR-2021-0044-0227.
[4] The Allocation Rule Reference Case projects the present value of climate-related benefits from 2025 through 2050 to be $253.2 billion (2020$, 3% discount rate, discounted to 2022). The Technology Transitions Rule base case projects incremental climate-related benefits over the same time period to be $3.1 billion, equivalent to 1% of those projected for the Allocation Rule Reference Case. (Table 5-14).

The incremental environmental impact of the Technology Transitions Rule depends in part upon the specific set of transitions made to comply with the rule restrictions together with the set of transitions projected for the already established Allocation Rules. This rule contains sector- and subsector-specific restrictions covering a large share of HFC uses. Industry is already making many of these transitions and we expect that achieving the allowance cap step-downs will require many of the same subsector-specific technology transitions that are also required by this rule. However, the rule may in some cases require regulated entities to further accelerate transitions in specific subsectors, relative to what EPA previously assumed in its analysis of the Allocation Rules. Conversely, for a discrete set of subsectors not covered by this rule, HFC consumption reductions could conceivably decrease in response to this rule (i.e., consumption would increase compared to the levels projected in the Allocation Rules analysis). This could occur to the extent that additional consumption allowances are "freed up" as a result of greater consumption reductions in subsectors covered by the rule, so long as overall domestic consumption and production remains within the AIM Act HFC phasedown cap for a given year.

Ultimately, the extent of these potential offsetting effects is uncertain. To account for this uncertainty, this analysis provides two scenarios to illustrate the range of potential incremental environmental impacts: a "base case" and a "high additionality case." In our base case scenario for the Technology Transitions Rule, we conservatively estimate that abatement does not occur in subsectors not covered by the rule—even if abatement in those same subsectors was previously assumed in the Allocation Rules' RIAs—since we find that abatement from the Technology Transitions Rule's restrictions would on its own be sufficient to achieve the AIM Act HFC phasedown cap. In other words, these consumption and emissions reducing opportunities are assumed to be forgone in the Technology Transitions base case. By contrast, the "high additionality" case is a less conservative scenario and assumes that HFC consumption reduction activities not covered by the rule remain consistent with the Allocation Rule Reference Case (*i.e.*, neither increase nor decrease in response to this rule).

The two scenarios are meant to provide a lower and upper bound of the incremental benefits from this rule. Previous regulatory programs to reduce chemical use in the affected industries show that regulated entities do not limit their response to the required compliance level; rather, regulated entities may take additional actions that transform industry practices for other reasons, including the anticipation of future restrictions, strengthening their competitive position, and supporting overall environmental goals. For example, U.S. production and consumption of ozone-depleting substances (ODS) during their phaseout was consistently below the limits established under the Montreal Protocol. Moreover, the existing HFC phasedown regulations are likely to drive industry transitions in the coming years regardless of whether they are covered by the restrictions contained in the Technology Transitions Rule. While the Technology

Transitions Rule has compliance starting in 2025 for some subsectors, industry transitions to meet compliance with the 2024 phasedown step under the Allocation Rules will be well underway by this time. This may include transitions in subsectors not explicitly covered by this rule that are likely to continue even after the Technology Transitions Rule is promulgated. In addition, actions beyond those assumed to occur under the Allocation Rules may reduce HFC consumption further as industry meets the Technology Transition Rule requirements. For these reasons, EPA expects that industry transitions will ultimately result in greater reductions than those projected in the base case, albeit lower than the upper bound high additionality scenario.

Table ES-1 below presents the incremental consumption reductions of this rule relative to those estimated for the Allocation Rules. Values are presented in both the base case and high additionality case, illustrating the range in incremental impacts. Notably, emissions are generally assumed to lag consumption, for example as leaks from equipment that can operate for decades. Due to this dynamic, estimated annual consumption reductions may not correspond to estimates of annual emission reductions and associated benefits occurring in the same year that are presented elsewhere in this RIA addendum.

Table ES-1: Incremental Consumption Reductions Compared to the Allocation Rule Reference Case[5] for the Technology Transitions Base Case and the Technology Transitions High Additionality Case

Year	***Technology Transitions Base Case Incremental Consumption Reductions (MMTEVe[6])***	***Technology Transitions High Additionality Case Incremental Consumption Reductions (MMTEVe)***
2025	-5*	30
2029	24	51
2034	32	47
2036	33	41
2040	22	30
2045	37	45
2050	39	47
Total (Cumulative)	**720**	**1,113**

**Negative values occur in years where the modeled set of transitions for the Technology Transitions compliance pathway yields slightly lower consumption reductions than the previously modeled Allocation Rule Reference Case. Overall, the Technology Transitions compliance pathway yields significant positive incremental consumption reductions on a cumulate basis in both the base case and high additionality case.*

[5] Throughout this document, "Allocation Rule Reference Case" refers to the estimated climate and economic impacts of the Allocation Rules, specifically as presented in the updated 2024 Allocation Rule RIA Addendum. These values represent the status quo from which incremental impacts of the Technology Transitions Rule are evaluated.

[6] In this document, units for consumption and emission reductions are presented in Million Metric Tons Exchange Value Equivalent (MMTEVe) or Metric Tons Exchange Value Equivalent (MTEVe). As explained in the Allocation Framework Rule, a metric ton of exchange value equivalent (MTEVe) is numerically equal to a metric ton of carbon dioxide equivalent ($MTCO_2e$) and we use these terms interchangeably throughout this document.

ES.3 Climate Benefits

Climate benefits of the Technology Transitions Rule are realized through the reduction of emissions of greenhouse gases (GHGs), specifically HFCs. GHG emissions reductions in turn contribute to reduction in damages from climate change. A primary aim of the Technology Transitions Rule is to facilitate transitions away from higher-GWP HFCs through sector- and subsector-specific restrictions. These restrictions may in-turn contribute to climate benefits previously quantified by EPA in relation to the Allocation Rules and may yield additional benefits insofar as transitions progress beyond those that would occur through implementation of the Allocation Rules alone. Table ES-2 shows the projected incremental emission reductions by year corresponding to the Technology Transitions Rule compliance scenario in the base case and high additionality case, relative to the Allocation Rule Reference Scenario. These benefits of avoided climate damages are monetized using previously established social cost of HFCs (SC-HFCs) estimates and are presented in Table ES-3.

Both the base case and high additionality case results show a net reduction in consumption and emissions on a cumulative basis through 2050. Emissions under the Technology Transitions Rule decrease compared to business-as-usual (BAU) estimates (described in more detail in Chapter 3), however they do not decrease as much as under the Allocation Rule Reference Case for certain modeled years. For these years, incremental emission reductions are therefore shown as negative numbers in the table. This reflects differences in the mix of technological solutions assumed for compliance with each rule and how EPA accounts for the corresponding changes in emissions over time. Specifically, the base case excludes actions not required by this rule, such as improved leak reduction and enhanced recovery of HFCs, which are assumed to otherwise yield relatively rapid emission reductions. Since the Allocation Rule Reference Case includes those actions, incremental emission reductions in the base case accrue more slowly (and therefore are negative in certain years) but are positive on a cumulative basis. Finally, we note that values in the Technology Transitions base case represent a conservative estimate of incremental climate benefits from the rule and there are a range of potential incremental benefits depending on the ultimate transition pathway chosen by industry.

Table ES-2: Incremental Emission Reductions in the Technology Transitions Compliance Base Case and High Additionality Case Compared to the Allocation Rule Reference Case

Year	***Technology Transitions Base Case Incremental Emission Reductions (MMTEVe)***	***Technology Transitions High Additionality Case Incremental Emission Reductions (MMTEVe)***
2025	-54	7
2029	-17	31
2034	-1	41
2036	-6	34

2040	25	38
2045	28	37
2050	32	40
Total (cumulative)	83	876

Table ES-3: Annual Incremental Climate Benefits in the Technology Transitions Compliance Base Case and High Additionality Case Compared to the Allocation Rule Reference Case [a,b,c]

Year	*Technology Transitions Base Case Incremental Climate Benefits (millions 2020$)*[7]	*Technology Transitions High Additionality Case Incremental Climate Benefits (millions 2020$)*
2025	$(3,730)	$486
2029	$(1,253)	$2,451
2034	$(73)	$3,636
2036	$(613)	$3,121
2040	$2,448	$3,831
2045	$3,080	$4,164
2050	$3,869	$4,938

[a] Incremental climate benefits from the rule in the base case are net negative in the initial model years, but on a cumulative basis through 2050 are net positive. This is due to differences in the assumed transition pathways and the timing of corresponding emission reductions. EPA's Vintaging Model is based on stock-turnover, with some emission reductions occurring faster than others depending on the abatement option. More details on these assumptions can be found in Chapter 5 of this RIA addendum and the accompanying annexes.

[b] Benefits include only those related to climate. Climate benefits are based on changes 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. See Tables 5-3 through 5-12 for the full range of SC-HFC estimates. As discussed in Chapter 5, a consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

[c] These estimates are year-specific estimates.

ES.4 Compliance Costs

Compliance costs in this analysis stem largely from the assumed industry transitions required to meet the sector-based and subsector-based restrictions in the rule. This analysis finds that for some sectors and subsectors, the transitions will result in net positive costs due to required investments in new lower-GWP technologies and refrigerants. For other cases, these costs are outweighed by assumed energy savings from the deployment of new technologies, lower-cost refrigerants, and other factors, resulting in net-

[7] For consistency and comparability with the Allocation Framework Rule RIA, throughout this analysis estimates are presented in 2020 dollars.

negative compliance costs (i.e., cost savings). On the whole, we find that meeting the GWP limits and HFC restrictions established by the rule will result in net negative compliance costs.

There are also costs associated with recordkeeping, reporting, and labeling requirements, as detailed in the preamble to the rule and Section 4.6 of this RIA addendum. Annual incremental net compliance costs, reflecting these additional costs as well as industry transitions, are shown in Table ES-4 below for select model years.

Table ES-4: Annual Incremental Net Compliance Costs/Savings in the Technology Transitions Compliance Base Case and High Additionality Case Compared to the Allocation Rule Reference Case*

**Note: Values in parenthesis represent net cost savings*

Year	***Technology Transitions Base Case Incremental Compliance Costs/Savings (millions 2020$)***	***Technology Transitions High Additionality Case Incremental Compliance Costs/Savings (millions 2020$)***
2025	$73	$532
2029	$208	$498
2034	($28)	$98
2036	($424)	($381)
2040	($677)	($618)
2045	($587)	($523)
2050	($619)	($549)

ES.5 Net Costs/Benefits

Total net benefits in this analysis stem from both the projected compliance costs (or savings) and monetized climate benefits. As part of fulfilling analytical guidance with respect to Executive Order 12866, EPA presents estimates of the present value (PV) of the benefits and costs over the 29-year period 2022 to 2050. To calculate the PV of the net benefits of the rule, annual costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4. Climate benefits are discounted at 3 percent as described in Section 5.3 and consistent with the Final Regulatory Impact Analysis for the Allocation Framework Rule.[8] EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2025 to 2050, would yield a sum equivalent to the PV, discounted at 3 percent and 7 percent. The EAV represents the value of a constant cost or net benefit for each year of the analysis, in contrast to the year-specific estimates mentioned earlier in this document.

[8] Available at www.regulations.gov under docket ID EPA-HQ-OAR-2021-0044, or see 86 FR 55116 (October 5, 2021).

EPA estimated net benefits in the same manner for the HFC Allocation Rules, and those previous estimates represent the status quo from which incremental net benefits of this rule are calculated. EPA estimates that the range of PV of cumulative net incremental benefits evaluated from 2025 through 2050 is $7.56 billion to $52 billion at a 3 percent discount rate for the base case and high additionality case respectively. The range of incremental EAV over the same period 2025 through 2050 is $0.46 billion and $3.2 billion when using a 3 percent discount rate for the base case and high additionality case respectively. The comparison of benefits and costs in PV and EAV terms for the base case and high additionality case can be found in Table ES-5. Estimates in the table are presented as rounded values.

Table ES-5 – Summary of Annual Incremental Climate Benefits, Costs, and Net Benefits of the Technology Transitions Rule Base Case and High Additionality Case Scenarios for the 2025–2050 Timeframe (millions of 2020$, discounted to 2022) [a,b,c,d]

	Base Case			***High Additionality Case***		
Year	***Incre-mental Climate Benefits (3%)***	***Annual Costs (savings)***	***Net Benefits (3% Benefits, 3% or 7% Costs)*** [e]	***Incre-mental Climate Benefits (3%)***	***Annual Costs (savings)***	***Net Benefits (3% Benefits, 3% or 7% Costs)*** [e]
2025	($3,730)	$73	($3,803)	$486	$532	($46)
2026	($3,347)	($179)	($3,168)	$771	$204	$567
2027	($3,406)	($255)	($3,151)	$1,073	$135	$938
2028	($3,218)	($275)	($2,943)	$1,339	$87	$1,252
2029	($1,253)	$208	($1,461)	$2,451	$498	$1,953
2030	($1,171)	$136	($1,307)	$2,652	$429	$2,223
2031	($1,000)	$102	($1,102)	$2,893	$399	$2,494
2032	($687)	$85	($772)	$3,148	$336	$2,812
2033	($345)	$114	($459)	$3,416	$301	$3,115
2034	($73)	($28)	($45)	$3,636	$98	$3,538
2035	$297	($1)	$298	$3,924	$66	$3,858
2036	($613)	($424)	($190)	$3,121	($381)	$3,501
2037	$293	($466)	$759	$3,469	($432)	$3,901
2038	$1,106	($525)	$1,631	$3,747	($494)	$4,240
2039	$1,797	($615)	$2,412	$3,876	($519)	$4,395
2040	$2,448	($677)	$3,125	$3,831	($618)	$4,449
2041	$2,378	($579)	$2,956	$3,710	($519)	$4,229
2042	$2,463	($573)	$3,037	$3,721	($514)	$4,235
2043	$2,628	($574)	$3,202	$3,829	($514)	$4,343
2044	$2,845	($581)	$3,426	$4,027	($516)	$4,543
2045	$3,080	($587)	$3,667	$4,164	($523)	$4,687
2046	$3,265	($589)	$3,854	$4,338	($523)	$4,862
2047	$3,424	($591)	$4,015	$4,489	($525)	$5,013
2048	$3,587	($594)	$4,181	$4,648	($526)	$5,173

2049	$3,711	($603)		$4,314		$4,772	($534)		$5,306	
2050	$3,869	($619)		$4,488		$4,938	($549)		$5,488	
Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**	**3%**	**3%**	**7%**	**3%**	**7%**
PV	$3,013	($4,549)	($2,073)	$7,561	$5,086	$50,406	($1,601)	$1	$52,007	$50,405
EAV	$184	($278)	($215)	$462	$399	$3,081	($98)	$0	$3,179	$3,081

[a] Benefits include only those related to climate. Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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 5, a consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[b] Rows may not appear to add correctly due to rounding.
[c] The annualized present value of costs and benefits are calculated as if they occur over a 26-year period from 2025 to 2050.
[d] The costs presented in this table are annual estimates.
[e] The PV for the 7% net benefits column is found by taking the difference between the PV of climate benefits at 3% and the PV of costs discounted at 7%. Due to the intergenerational nature of climate impacts the social rate of return to capital, estimated to be 7 percent in OMB's Circular A-4, is not appropriate for use in calculating PV of climate benefits.

Chapter 1: Introduction and Background

1.1 Statutory Requirement

This RIA addendum evaluates the impact associated with the Final Rulemaking referred to as the "Technology Transitions" rule. Subsection (i) of the AIM Act provides EPA the authority to "restrict, fully, partially, or on a graduated schedule, the use of a regulated substance in the sector or subsector in which the regulated substance is used." Persons may petition EPA to act on this authority, and EPA must make the petition available to the public within 30 days, and grant or deny the petition within 180 days of receipt. If a petition is granted, EPA must promulgate a final rule no later than two years after such granting. Any restriction finalized by such a rule may take effect no sooner than one year after that rule is promulgated. For a complete description of the statutory requirements, see Section II.B of the rule.

Fulfilling a separate statutory requirement of the AIM Act, EPA has previously published the Allocation Framework Rule establishing a baseline and phasedown schedule for the consumption and production of HFCs, along with an accompanying RIA detailing the costs and benefits of the HFC phasedown.[9] In July 2023, EPA also finalized an update to that rule to provide the methodology for distributing allowances for the years 2024 through 2028, referred to as the 2024 Allocation Rule. The Technology Transitions Rule is being promulgated under a separate statutory requirement and is expected to have a complementary effect on meeting the HFC phasedown schedule by facilitating necessary transitions to lower-GWP substitutes.

1.2 Background

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

HFC use and emissions have been growing worldwide due to the global phaseout of ODS under the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol), and the increasing use of refrigeration and air conditioning equipment globally.[10] HFC emissions had previously been projected to increase substantially over the next several decades. In 2016, in Kigali, Rwanda, countries

[9] Available at *www.regulations.gov* under Docket ID EPA-HQ-OAR-2021-0044, or see 86 FR 55116 (October 5, 2021).
[10] World Meteorological Organization (WMO), Scientific Assessment of Ozone Depletion: 2018, World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 58, 588 pp., Geneva, Switzerland, 2018. Available at *https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf*.

agreed to adopt an amendment to the Montreal Protocol, known as the Kigali Amendment, which provides for a global phasedown of the production and consumption of HFCs. Global adherence to the Kigali Amendment would substantially reduce future emissions, leading to a peaking of HFC emissions before 2040.[11,12]

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 of each substance 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. For a more detailed background on HFCs, see Section III of the rule.

1.3 Regulated Community

The HFC industry is composed of several types of entities. As noted in the RIA for the Allocation Framework Rule, entities potentially affected by this previous action include those that produce, import, export, destroy, use as a feedstock, reclaim, package, or otherwise distribute bulk HFCs. This analysis—which serves as an addendum to the above-mentioned Allocation Framework RIA—assesses a final rule under subsection (i) of the AIM Act that restricts the use of HFCs in the following industries: air conditioning, refrigeration, and heat pumps; foam blowing; and aerosols (including aerosol solvents). This rule affects those who manufacture, import, sell, distribute, or install products and equipment that use or are intended to use HFCs in these sectors. Entities who supply bulk HFCs to these manufacturers, such as producers, bulk importers, and reclaimers, could be affected tangentially because the restrictions affect subsectors into which they market and sell HFCs with uses restricted by the rule. However, entities marketing or supplying lower-GWP HFCs or substitutes that meet the criteria established by the rule may be unaffected or see increased market share.

1.4 Summary of Petitions Addressed and Restrictions

In the Technology Transitions Rule, EPA is addressing a number of petitions received pursuant to subsection (i) of the AIM Act.[13] On October 7, 2021, EPA granted 10 petitions and partially granted one petition (86 FR 57141).[14] Two additional petitions were submitted in 2022. These 13 petitions are addressed in the Technology Transitions Rule and are available in the associated docket. For purposes of

[11] WMO, 2018.
[12] Guus J.M. Velders et al. Projections of hydrofluorocarbon (HFC) emissions and the resulting global warming based on recent trends in observed abundances and current policies. Atmos. Chem. Phys., 22, 6087–6101, 2022. Available at *https://doi.org/10.5194/acp-22-6087-2022*.
[13] These petitions can be found at *https://www.epa.gov/climate-hfcs-reduction/technology-transition-petitions-under-aim-act*.
[14] *https://www.federalregister.gov/documents/2021/10/14/2021-22318/notice-of-determination-to-grant-or-partially-grant-certain-petitions-submitted-under-subsection-i.*

this RIA addendum, we also consider all 16 petitions. A list of the petitioners, topics of the petitions, and date received is shown in Table 1-1.

Table 1-1 – Summary of Petitions

Petitioner	***Receipt Date***	***Topic***
International Institute of Ammonia Refrigeration (IIAR), *et al.*	May 23, 2022	Restrict the Use of HFCs in Certain Refrigeration End-Uses
Air-Conditioning, Heating, and Refrigeration Institute (AHRI), *et al.*	March 24, 2022	Restrict the Use of HFCs in Certain Commercial Refrigeration Equipment
California Air Resources Board (CARB), *et al.*	July 15, 2021	Replicate HFC Prohibitions from SNAP Rules 20 & 21 and Issue Additional Federal Standards
Household & Commercial Products Association (HCPA) and National Aerosol Association (NAA)	July 6, 2021	Replicate SNAP Rules 20 and 21 HFC prohibitions for Aerosol Propellants
International Institute of Ammonia Refrigeration (IIAR), *et al.*	June 3, 2021	Restrict the Use of HFCs in Certain Refrigeration End-Uses
American Chemistry Council's Center for the Polyurethanes Industry (CPI)	May 26, 2021	Replicate SNAP Rules 20 and 21 HFC Prohibitions for the Polyurethane Industry
DuPont	May 10, 2021	Replicate SNAP Rule 20 with Regard to the Phase-out of HFC-134a in Extruded Polystyrene Boardstock and Billet (XPS) End-use
DuPont	May 10, 2021	Replicate SNAP Rule 21 with Regard to Rigid Polyurethane Low-pressure Two-component Spray Foam (2K-LP SPF) End-use
Association of Home Appliance Manufacturers (AHAM)	April 13, 2021	Restrict the Use of HFCs in Certain Air Conditioners and Dehumidifiers
Air-Conditioning, Heating, and Refrigeration Institute (AHRI), *et al.*[15]	April 13, 2021	Restrict the Use of HFCs in Certain Commercial Refrigeration Equipment
Air-Conditioning, Heating, and Refrigeration Institute (AHRI), *et al.*	April 13, 2021	Restrict the Use of HFCs in Residential and Light Commercial Air Conditioners
Environmental Investigation Agency (EIA), *et al.*	April 13, 2021	Restrict the Use of HFCs in Certain Stationary Refrigeration and Air Conditioning End-uses
Natural Resources Defense Council (NRDC), *et al.*	April 13, 2021	Replicate HFC Prohibitions from SNAP Rules 20 & 21

The petitions cover approximately 40 sectors and subsectors. Sectors covered are aerosols, foam blowing, and refrigeration, air conditioning and heat pumps. Within each of these, several subsectors are addressed in the petitions and the Technology Transitions Rule. Table 1-2 provides the sector and subsectors, GWP limits or prohibited substances, and compliance dates established in the final rule.

[15] AHRI submitted two additional petitions on August 19, 2021, and October 12, 2021. EPA is treating these two AHRI petitions as addenda to their October 7, 2021, granted petition, and not as separate petitions, since the subsectors listed in these petitions are contained in the granted AHRI petition and AHRI refers to these as further steps in the transition for these uses.

Table 1-2 – Restrictions and compliance dates by sector and subsector

Sectors and Subsectors	***GWP Limit or Prohibited Substance***	***Compliance Date***
Refrigeration, Air Conditioning, and Heat Pump		
Industrial process refrigeration systems where the temperature of the refrigerant entering the evaporator is less than -22 ºF/-30 ºC and greater than or equal to -58 ºF/-50 Cº *	700	January 1, 2028
Industrial process refrigeration systems (excluding the high temperature side of a cascade system) where the temperature of the refrigerant entering the evaporator is equal to or greater than -22 ºF/-30 ºC with refrigerant charge capacities of 200 pounds or greater*	150	January 1, 2026
Industrial process refrigeration systems where the temperature of the refrigerant entering the evaporator is equal to or greater than -22 ºF/-30 ºC with refrigerant charge capacities less than 200 pounds	300	January 1, 2026
Industrial process refrigeration, high temperature side of cascade systems and temperature of the refrigerant entering the evaporator is equal to or above -22 ºF/-30 ºC	300	January 1, 2026
Data Center, Information Technology Equipment Facility, and Computer Room Cooling	700	January 1, 2027
Retail food refrigeration – stand-alone units	150	January 1, 2025
Retail food refrigeration – self-contained refrigerated food processing and dispensing equipment with capacities of 500 grams of refrigerant or less and outside the scope of UL Standard 621, edition 7	150	January 1, 2027
Retail food refrigeration – self-contained refrigerated food processing and dispensing equipment with capacities of more than 500 grams of refrigerant and outside the scope of UL Standard 621, edition 7	R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-407F, R-407H, R-408A, R-410A, R-410B, R-411A, R-411B, R-417A, R-417C, R-420A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-427A, R-428A, R-434A, R-437A, R-438A, R-507A, HFC-134a, HFC-227ea, R-125/290/134a/600a (55/1/42.5/1.5), RB-276, RS-24 (2002 formulation), RS-44 (2003 formulation), GHG-X5, or Freeze 12	January 1, 2027

Retail food refrigeration – ice cream makers within the scope of UL 621, edition 7	R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-407F, R-407H, R-408A, R-410A, R-410B, R-411A, R-411B, R-417A, R-417C, R-420A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-427A, R-428A, R-434A, R-437A, R-438A, R-507A, HFC-134a, HFC-227ea, R-125/290/134a/600a (55/1/42.5/1.5), RB-276, RS-24 (2002 formulation), RS-44 (2003 formulation), GHG-X5, or Freeze 12	January 1, 2028
Retail food refrigeration – remote	R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-407F, R-407H, R-408A, R-410A, R-410B, R-411A, R-411B, R-417A, R-417C, R-420A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-427A, R-428A, R-434A, R-437A, R-438A, R-507A, HFC-134a, HFC-227ea, R-125/290/134a/600a (55/1/42.5/1.5), RB-276, RS-24 (2002 formulation), RS-44 (2003 formulation), GHG-X5, or Freeze 12	January 1, 2027
Retail food refrigeration – supermarket systems with refrigerant charge capacities of 200 pounds or greater (excluding high temperature side of cascade systems)	150	January 1, 2027
Retail food refrigeration – supermarket systems with refrigerant charge capacities less than 200 pounds charge	300	January 1, 2027
Retail food refrigeration – supermarket systems, high temperature side of cascade system	300	January 1, 2027
Retail food refrigeration – remote condensing units with refrigerant charge capacities of 200 pounds or greater (excluding high temperature side of cascade systems)	150	January 1, 2026
Retail food refrigeration – remote condensing units with refrigerant charge capacities less than 200 pounds	300	January 1, 2026
Retail food refrigeration – remote condensing units – high temperature side of cascade system	300	January 1, 2026

Vending machines	150	January 1, 2025
Cold storage warehouse systems with refrigerant charge capacities of 200 pounds or greater (excluding high temperature side of cascade systems)	150	January 1, 2026
Cold storage warehouse systems with refrigerant charge capacities less than 200 pounds	300	January 1, 2026
Cold storage warehouse – high temperature side of cascade system	300	January 1, 2026
Ice rinks	700	January 1, 2025
Automatic commercial ice machines – self-contained batch type with a harvest rate less than or equal to 1,000 pounds of ice per 24 hours	150	January 1, 2026
Automatic commercial ice machines – self-contained continuous type with a harvest rate less than or equal to 1,200 pounds of ice per 24 hours	150	January 1, 2026
Automatic commercial ice machines – self-contained with a harvest rate greater than 1,000 or 1,200 pounds of ice per 24 hours (batch type and continuous type, respectively)	R-402A, R-402B, R-404A, R-407A, R-407B, R-407C, R-407F, R-408A, R-410A, R-410B, R-411A, R-411B, R-417A, R-417C, R-420A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-442A, R-507A, HFC-134a, R-125/290/134a/600a (55/1/42.5/1.5), RB-276, RS-24 (2002 formulation), RS-44 (2003 formulation), GHG-X5, G2018C, or Freeze 12	January 1, 2027
Automatic commercial ice machines – remote	R-402A, R-402B, R-404A, R-407B, R-408A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-438A, R-507A, R-125/290/134a/600a (55/1/42.5/1.5), RS-44 (2003 formulation), GHG-X5	January 1, 2027
Transport refrigeration – intermodal containers*	700	January 1, 2025
Transport refrigeration – road	R-402A, R-402B, R-404A, R-407B, R-408A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-438A, R-507A, R-125/290/134a/600a	January 1, 2025

	(55/1/42.5/1.5), RS-44 (2003 formulation), GHG-X5	
Transport refrigeration – marine	R-402A, R-402B, R-404A, R-407B, R-408A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-438A, R-507A, R-125/290/134a/600a (55/1/42.5/1.5), RS-44 (2003 formulation), GHG-X5	January 1, 2025
Household refrigerators and freezers	150	January 1, 2025
Chillers – industrial process refrigeration (exiting fluid temperature less than -22 ºF/-30 ºC and greater than -58 ºF/-50 ºC)*	700	January 1, 2028
Chillers – industrial process refrigeration (exiting fluid temperature equal to or greater than -22 ºF/-30 ºC)	700	January 1, 2026
Chillers – comfort cooling	700	January 1, 2025
Residential and light commercial air conditioning and heat pump systems – variable refrigerant flow systems	700	January 1, 2026
Residential and light commercial air conditioning and heat pump systems – all others	700	January 1, 2025
Residential dehumidifiers	700	January 1, 2025
Motor vehicle air conditioning – light-duty Passenger Vehicles**	150	Model year 2025
Motor vehicle air conditioning – medium-duty passenger vehicles	150	Model year 2028
Motor vehicle air conditioning – heavy-duty pick-up trucks	150	Model year 2028
Motor vehicle air conditioning – Complete heavy-duty vans	150	Model year 2028
Motor vehicle air conditioning – Certain Nonroad vehicles (agricultural tractors greater than 40 horsepower; self-propelled agricultural machinery; compact equipment; construction, forestry, and mining equipment; and commercial utility vehicles)	150	January 1, 2028
Foam blowing		
Polystyrene – extruded boardstock and billet and extruded sheet	150	January 1, 2025
Polyisocyanurate laminated boardstock	150	January 1, 2025

Polyurethane (Rigid, Flexible, Integral skin, Laminated boardstock)***	150	January 1, 2025
Polyolefin	150	January 1, 2025
Phenolic insulation board and bunstock	150	January 1, 2025
Aerosols		
Consumer aerosol products	150	January 1, 2025
Technical aerosol products	150	January 1, 2028

*Industrial process refrigeration systems and self-contained refrigerated transport intermodal containers where the refrigerant temperature entering the evaporator is less than -50 ºC (-58 ºF) are not restricted. Industrial process refrigeration chillers and remote refrigerated transport intermodal containers where the temperature of the fluid leaving the chiller is less than -50 ºC (-58 ºF) are not restricted.

**MY 2025 vehicles manufactured before one year after publication of a final rule are not restricted.

***Includes blown foam, products incorporating blown foam, and pre-blended polyol products. Excludes composite structural preformed polyurethane foam for trailer use and for marine use.

Chapter 2: Overview of the Analysis

2.1 Introduction

This analysis identifies the principal costs and benefits of implementing this rulemaking. Costs and benefits presented in this analysis include compliance costs, climate benefits, and combined net benefits. While significant, the estimated benefits detailed in this document are considered secondary to the rule's statutory objective of facilitating the transition to next-generation technologies by restricting use of HFCs in the sectors or subsectors in which they are used.

Given that the rule places restrictions on HFCs, which are subject to the overall phasedown of production and consumption under the AIM Act, EPA relied on previous analyses conducted for the Allocation Framework Rule (86 FR 55116; October 5, 2021) and the 2024 Allocation Rule (88 FR 46836; July 20, 2023) as a starting point for the assessment of costs and benefits of this rule. We then evaluated how certain sectors and subsectors could respond to the restrictions in the form of GWP limits or prohibitions on specifically listed HFCs and HFC blends while the overall phasedown cap also remains in place to determine potential incremental impacts.

A separate analysis included in this document evaluates the environmental justice impacts of the rule. As with the costs/benefits analysis, this assessment builds on an initial environmental justice analysis conducted for the Allocation Framework Rule and expands on the previous approach to provide additional insight into the demographic characteristics and baseline exposure of the communities near facilities producing predominant HFC substitutes.

Finally, this analysis includes an assessment of the impact of restrictions on imports of products containing HFCs, as this rule restricts imported and domestically manufactured products on an equal basis.

2.2 Organization of the Analysis

The analysis contained in the RIA addendum is organized as follows:

Chapter 3 summarizes the Allocation Framework RIA and specifically the results of the 2024 Allocation Rule RIA Addendum. These values are used as a starting point for this analysis, and effectively serve as the primary reference case against which incremental impacts of the rule are evaluated. This chapter also discusses the potential for higher or lower incremental benefits from the Technology Transitions Rule, depending on whether additional transitions in subsectors covered by the rule are offset by forgone transitions elsewhere.

Chapter 4 provides an assessment of the net costs of compliance (excluding climate benefits), based on the GWP limits and specific restrictions in this rule. As with the Allocation Framework RIA, this assessment follows a Marginal Abatement Cost (MAC) approach, whereby the total costs and savings associated with abatement options or "transitions" needed to meet compliance are calculated using EPA's Vintaging Model (described below).[16] This chapter also provides details on the general modeling approach to modeling abatement and costs, as well as the specific market transition assumptions made in order to estimate the impact of the restrictions in the rule.

Chapter 5 discusses the climate benefits associated with the compliance pathway presented in Chapter 4. The use restrictions in the rule have an ancillary effect of leading to reduced consumption of HFCs, which in turn reduces HFC emissions. The reduction in emissions of these greenhouse gases (GHGs) yields social benefits by reducing climate impacts. These climate benefits are monetized by multiplying the change in emissions of each regulated HFC by estimates of the social cost of HFCs (SC-HFC) for that chemical. The methodology for calculating the SC-HFCs is described in detail in Section 4.1 of the Allocation Framework RIA, and the SC-HFC values are given in Section 5.3.2 of this document.

Chapter 6 combines the compliance costs and climate benefit estimates from the preceding chapters to provide an assessment of total net benefits associated with the rule.

Chapter 7 provides a sensitivity analysis of costs and benefits under alternative compliance scenarios with either higher or lower subsector-specific GWP limits than those contained in the rule. This supplementary analysis is provided for illustrative purposes, and we note that economic costs and benefits are only one factor of several used to determine the limits contained in the rule.

Chapter 8 covers the environmental justice analysis conducted for the rule. This analysis builds on the environmental justice analysis conducted for the Allocation Framework Rule and evaluates the demographic characteristics and baseline exposure of the communities near facilities producing predominant HFC substitutes.

Annex A provides a summary of the mitigation technologies applied to the subsectors affected by this rule as a means to model the costs and benefits of the restrictions.

Annex B provides annual emission reductions by gas for the Technology Transitions Rule base case.

Annex C lists the industries that might be affected by this rule.

Annex D provides an assessment of the impact specifically of import restrictions. The Allocation Framework Rule and 2024 Allocation Rule do not require expenditure of allowances for importing

[16] For additional information on the development and use of MAC curves, see Section 3.2 of the Allocation Framework RIA.

products containing HFCs; however, as explained in that annex, the analysis performed for those rules was agnostic as to where products were manufactured, including both domestic consumption of HFCs and imports of products containing HFCs. When projecting the U.S. demand for products containing HFCs, the Vintaging Model and MAC curves do not distinguish between products manufactured in the United States and those that are imported from other countries. Hence, some portion of the HFC consumption reduction estimated in the RIA for the Allocation Rules reflects the adoption of lower-GWP alternatives in products imported from other countries, although the adoption of lower-GWP substances in imported products would not be the direct result of compliance with the Allocation Rules. The Technology Transitions Rule establishes GWP limits and specific restrictions for both imported and domestically produced equipment; therefore, a scoping analysis estimates the effects of such restrictions on imported products containing HFCs. To the extent that the Allocation Rules' analyses include reductions due to imported products containing HFCs, those analyses may underestimate the domestic adoption of abatement options required to meet the AIM Act consumption caps. This, in turn, may result in an overestimate of the subsequent availability of options for the abatement in domestically produced equipment to comply with the lower-GWP requirements of this rule.

Annex E provides a demonstration analysis using a geospatially disaggregated "microsimulation" model to assess communities near facilities identified as producing predominant HFC substitutes. The tool used is an example of microsimulation approaches using recent advancements in data science, and which can offer insight into the characteristics of communities by statistically representing "synthetic populations." These techniques show promise for improving analysis for many issues, including environmental justice. We include the demonstration analysis, which identifies communities for which further environmental justice analysis may be warranted.

2.3 Years of Analysis

This analysis estimates the costs for technology transitions that meet the HFC restrictions. The earliest required compliance year is 2025; however, we assume some "early actors" will begin certain transitions sooner, consistent with assumptions made in the Allocation Framework RIA. We have assumed here that full compliance will be reached within each subsector no later than the associated compliance date.

2.4 Factors Analyzed

This RIA addendum takes into consideration the costs of technology transition options to meet the restrictions and the environmental benefits of the consequent reduction in HFC emissions and the associated avoided global warming. As explained in the Allocation Framework RIA, specific factors evaluated in this assessment include capital costs, operations and maintenance (O&M) costs, and anticipated energy savings resulting from transitions to lower-GWP technologies. This analysis does not take into account certain factors that could potentially further reduce compliance costs, such as potential decreases in costs over time resulting from economies of scale or the energy savings from reduced cooling demand as a result of avoided global warming. We also did not take into account costs associated with the three-year sell-through allowed for products. While we recognize there will still be costs to establishing a sell-through limitation, we expect that the three-year timeframe will mitigate the costs of stranded inventory, storage, and disposal of noncompliant product that remain after the sell-through expires. As such we do not quantify these costs in this RIA addendum.

2.5 Vintaging Model

EPA uses the Vintaging Model to forecast the use and emissions of HFCs and other substances, by sector and subsector, under a BAU scenario and under various policy compliance scenarios. This analysis uses a version of the model intended to represent compliance with the AIM Act HFC Phasedown as a starting point and makes adjustments in various subsectors as needed to align with the available abatement options for the GWP limits. The resulting consumption and emissions are compared against the analysis developed for the Allocation Rules to evaluate incremental impacts.

The model tracks the use and emissions of each of the substances separately for each generation or "vintage" of equipment. The Vintaging Model is used to produce the estimates of GHG emissions in the official U.S. GHG Inventory and is updated and enhanced annually. Information on the version of the model used for this analysis, the various assumptions used, and HFC emissions may be found in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014*.[17] A more detailed explanation of the Vintaging Model is also found in Section 3.2.1 of the Allocation Framework RIA.

As explained in Section 3.3.2 of the Allocation Framework RIA, the Vintaging Model assumes some transition to lower-GWP substances is occurring in the baseline, not as a response to the AIM Act. Some of these baseline market transitions meet the requirements in the Technology Transitions Rule, avoiding the need to model technology transition options to reach compliance.

Due to the nature and limitations of the Vintaging Model, the MAC analysis from the Allocation Framework RIA, the 2024 Allocation Rule RIA Addendum, and this RIA addendum cover the projected impact of compliance for the full U.S. market in aggregate. This includes both domestically produced (or installed) and imported products utilizing HFCs. Since the model on its own does not distinguish between domestic consumption of regulated HFCs versus imported products containing regulated HFCs, a separate

[17] U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014. April 2016. EPA Report EPA-430-R-16-002. Available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014.

Annex to this RIA addendum evaluates the impact of the import restrictions specifically. As mentioned in that Annex, the impacts of the import restrictions are a subset of—rather than additional to—the benefits presented in this analysis.

2.6 Regulatory Option

As noted in the Technology Transitions rule, EPA is using two approaches to restrict HFCs under the authority of AIM Act subsection (i). They are: (1) to set GWP limits for HFCs used within a sector or one or more subsectors, whether neat or used in a blend; and (2) to restrict specific HFCs or specific blends containing HFCs by sector or one or more subsectors. The rule uses the approach of setting GWP limits for all but a few subsectors. These restrictions have been modeled accordingly, by sector and subsector, to estimate the impact of the Rule. For additional details, see *Abatement Options Modeled* in Chapter 4.

The primary costs/benefits analysis conducted for this RIA addendum is based on assumed transitions to HFC substitutes based on the subsector-specific GWP limits in the rule. As a bounding exercise, we have also included in this RIA addendum an analysis of potential costs and benefits of this rule under alternative regulatory scenarios, one where GWP limits are 50% lower than finalized, and one where they are 50% higher. This supplementary analysis helps illustrate the extent to which costs and benefits may shift under more or less restrictive limits, while also demonstrating that in many cases impacts would be essentially unchanged. Importantly, this supplementary analysis is conducted for illustrative purposes only. We note that EPA has set the specific GWP limits set for the subsectors covered by the rule based on a number of factors besides overall economic cost, including best available data, availability of substitutes (taking into account factors such as technological achievability, commercial demands, affordability for residential and small business consumers, safety, consumer costs, building codes, appliance efficiency standards, and contractor training costs), and environmental benefits. More detail on this analysis can be found in Chapter 7 of this RIA addendum.

Chapter 3: HFC Allocation Framework Rule Baseline

3.1 Introduction

This chapter discusses the HFC consumption baseline established by the Allocation Rules, 40 CFR 84, subpart A, and the estimated costs and benefits of the HFC phasedown as detailed in the Allocation Framework RIA. These values represent the status quo from which incremental costs and benefits of the Technology Transitions Rule are calculated.

For the purposes of this analysis, we specifically rely on the estimates from the 2024 Allocation Rule RIA Addendum, which are a revision to the estimates from the original Allocation Framework RIA. The revision reflects updated costs and benefits resulting from a lowered HFC consumption baseline as well as an adjustment to an abatement option based on information from industry stakeholders. These estimates are therefore the most up-to-date and relevant reference point from which to quantify additional impacts. More details on these updates can be found in sections 1.3 and 2.4 of the 2024 Allocation Rule RIA Addendum.

3.2 Baseline for Allocation of Consumption Allowances

Through the Allocation Framework Rule issued under the AIM Act, 40 CFR Part 84, Subpart A, EPA has established a consumption baseline for the phasedown of HFCs. The consumption baseline was established using the average annual quantity of all regulated substances consumed in the United States from January 1, 2011, through December 31, 2013, and additional quantities of past chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) consumption. More details on the methodology used to establish this baseline can be found in the Allocation Framework Rule.[18] The baseline serves as the starting point from which statutorily mandated percentage reductions are taken to implement the AIM Act HFC phasedown.

As detailed in the 2024 Allocation Rule RIA Addendum, EPA has updated the consumption baseline to correct for data that had previously been inaccurately reported. The change would lead to a revision of the consumption baseline from 303,887,017 MTEVe[19] to 302,538,316 MTEVe and associated revisions to the total consumption cap in each year after the revision takes effect, as the phasedown schedule is determined as a percentage of the baseline under subsection (e)(2)(C) of the AIM Act, which EPA

[18] *https://www.federalregister.gov/documents/2021/10/05/2021-21030/phasedown-of-hydrofluorocarbons-establishing-the-allowance-allocation-and-trading-program-under-the*.

[19] As explained in the Allocation Framework Rule, a metric ton of exchange value equivalent (MTEVe) is numerically equal to a metric ton of carbon dioxide equivalent ($MTCO_2e$).

codified at 40 CFR 84.7(a). It is this updated consumption baseline that is used as a reference point in this analysis and the associated revisions to total consumption are shown in figures below.

Table 3-1: Consumption Caps of the HFC Phasedown

Year	***Revised Total Consumption (MTEVe)***	***Percentage of Starting Baseline***
2024–2028	181,522,990	60%
2029–2033	90,761,495	30%
2034–2035	60,507,663	20%
2036 and thereafter	45,380,747	15%

3.3 HFC Consumption under BAU Projection and Allocation Rule Reference Case

The Allocation Framework RIA and 2024 Allocation Rule RIA Addendum estimate reductions in HFC consumption and resulting benefits relative to a "Business as Usual" (BAU) scenario of expected consumption and emissions of HFCs in the absence of regulations promulgated under the AIM Act, derived from EPA's Vintaging Model. Although many economic analyses will use the term "baseline" to describe such a forecast, for the purposes of these previous analyses we referred to the projection as a BAU forecast to distinguish it from the baselines described above from which maximum HFC production and consumption levels are to be calculated under the AIM Act.

For this analysis, the Allocation Framework Rule with the adjustments in the 2024 Allocation Rule is the relevant point of comparison and effectively serves as the "BAU" to determine incremental impacts, given its precedence as existing policy. As a disambiguation, throughout this document we refer to the Allocation Framework Rule estimates as the "Allocation Rule Reference Case" rather than "BAU," to avoid confusion with the BAU scenario included in the Allocation Framework RIA.

Table 3-2 below shows the consumption based BAU originally used to quantify benefits in the Allocation Framework Rule analysis and the 2024 Allocation Rule analysis, as well as estimated consumption under the Allocation Rule Reference Case. The latter is used to quantify incremental benefits in this analysis.

Table 3-2: HFC Consumption under the Original BAU and the Allocation Rule Reference Case (MMTEVe)

Year	***HFC Consumption under BAU (i.e., no AIM Act)***	***HFC Consumption under Allocation Rule Reference Case (i.e., with AIM Act cap)***
2024	324.43	179.10
2029	316.55	86.99
2034	326.44	59.29
2036	326.98	44.65

2045	352.14	67.08
2050	365.93	72.73

The BAU scenario used to quantify benefits under the Allocation Framework Rule does not include certain transitions that may otherwise have occurred either as a result of separate regulations at the state or federal level or due to market forces. For a more detailed description of transitions included and not included in the BAU, as well as a sensitivity analysis including alternative BAUs, see sections 3.3.2 and Appendix B, respectively, of the Allocation Framework RIA.

3.4 Approach to Evaluating Incremental Benefits of the Technology Transitions Rule

The cost/benefit analysis contained in this document considers the incremental benefits resulting from the Technology Transitions Rule. In practice, this means only counting additional emission reductions from BAU beyond those previously quantified in in the Allocation Framework RIA and updated 2024 addendum (i.e., incremental to the Allocation Rule Reference Case).

As discussed above, the Allocation Framework Rule establishes a pool of allowances which decrease over time in accordance with the overall phasedown schedule. These allowances are to a degree interchangeable, meaning that additional abatement stemming from the restrictions in the Technology Transitions Rule could conceivably be offset by corresponding increases in HFC consumption in subsectors not covered by the rule, so long as the overall HFC phasedown compliance caps are still met. To deal with the inherent uncertainty, we modeled two scenarios. EPA assumed the price of HFCs to be constant in both scenarios.

1) A “base case” where all subsectors covered by restrictions contained in the rule are assumed to make transitions needed to meet those restrictions, but consumption reduction activities in subsectors not covered by the Technology Transitions Rule are excluded, even if previously assumed in the Allocation Rule Reference Case. This scenario effectively represents a conservative representation of the additionality of this rule.
2) A “high additionality case” where any transitions and resulting abatement assumed in the Allocation Rule Reference Case is retained in the Technology Transitions scenario, even in subsectors not technically covered by this rule. This effectively represents an upper bound of the potential incremental benefits of the rule.

The two scenarios are meant to provide a lower and upper bound of the incremental benefits from this rule. Previous regulatory programs to reduce chemical use in the affected industries show that regulated entities do not limit their response to the required compliance level; rather, regulated entities may take additional actions that transform industry practices for other reasons, including the anticipation of future restrictions, strengthening their competitive position, and supporting overall environmental goals. For example, U.S. production and consumption of ozone-depleting substances (ODS) during their phaseout was consistently below the limits established under the Montreal Protocol.[20] Moreover, the existing HFC phasedown regulations are likely to drive industry transitions in the coming years regardless of whether they are covered by the restrictions contained in the Technology Transitions Rule. While the Technology Transitions Rule has compliance starting in 2025 for some subsectors, industry transitions to meet compliance with the 2024 phasedown step under the Allocation Rules will be well underway by this time. This may include transitions in subsectors not explicitly covered by this rule that are likely to continue even after the Technology Transitions Rule is promulgated. In addition, actions beyond those assumed to occur under the Allocation Rules may reduce HFC consumption further as industry meets the Technology Transition Rule requirements. For these reasons, EPA expects that industry transitions will ultimately result in greater reductions than those projected in the base case, albeit lower than the upper bound high additionality scenario.

Annex Table A-3 provides details on transitions assumed in various subsectors in both the Allocation Rule Reference Case and the Technology Transitions Base Case. The high additionality case retains abatement options from the Allocation Rule Reference Case even if they are not covered by the Technology Transitions Rule. These include actions taken in the fire protection subsector, and improved leak repair, additional recovery at disposal, and enhanced recovery at servicing for RACHP equipment.

As discussed in the presentation of results later in this document, both the base case and high additionality case meet compliance with the phasedown cap and yield additional consumption reductions relative to the Allocation Rule Reference Case. However, the high additionality case ultimately yields the greatest incremental benefits in terms of reduced consumption and emissions.

Finally, we note that the primary purpose of the Technology Transitions Rule is not to capture additional emissions benefits or savings, but to facilitate smooth transitions to lower GWP substitutes by restricting the use of HFCs in certain sectors and subsectors. To the extent that additional benefits are captured, these can be considered ancillary.

[20] From 2004 through 2015, total U.S. consumption of HCFCs was at least 30% below annual limits under the Montreal Protocol limit for Annex C controlled substances (i.e., HCFCs). https://ozone.unep.org/countries/data-table

Chapter 4: Compliance Costs

4.1 Introduction

This RIA addendum estimates the technology transition costs associated with meeting the GWP limits, as well as the costs associated with the recordkeeping, reporting, and labeling requirements of the Technology Transitions 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 analysis. The technology transition costs associated with the rule and the methodology for modeling costs are described in this chapter.

4.2 Modeling Method for Technology Transition Costs

To generate cost estimates for the technology transitions in the rule, EPA relied on a methodology consistent with the approach used in the Allocation Framework RIA (see Section 3.2 of the Allocation Framework RIA). As before, abatement options—or in this case transitions that comply with the restrictions in this rule—were used to estimate the consumption and emission reductions, the costs, and the societal benefits associated with compliance. The reductions achieved through implementing these options are evaluated against both (1) the same "business as usual" (BAU) forecast of HFC consumption and emissions, generated from EPA's Vintaging Model, used in the Allocation Framework RIA, and (2) "incremental" benefits beyond those already assessed in the Allocation Framework RIA as amended by the 2024 Allocation Rule (i.e., the Allocation Rule Reference Case). An evaluation against the BAU is required because the analytic period for the Allocation Rules and this Technology Transitions Rule overlap. Some of the technology transitions assumed in the Allocation Rules will no longer be valid given the GWP-limits and subsector-specific restrictions.

Thus, a key methodological distinction between the method applied for this analysis and the Allocation Rule's RIAs is that only abatement options meeting the Technology Transitions Rule restrictions for each subsector are modeled. For example, because the restrictions for the large retail food subsector require transitions to technology utilizing substances below a GWP threshold of 150 to 300, depending on charge size, in year 2027, then only options below this threshold that we have modeled to date (e.g., transitioning to CO_2-based refrigerant systems) are assumed to be viable compliance options once the restriction takes effect. This differs from the approach in the Allocation Framework Rule, where additional, potentially higher-GWP options that exceed the GWP limits in this rule may have been assumed to be available as compliance options so long as the overall cap was still met.

As a further point of clarification, many of the transitions required by the Technology Transitions Rule and included in this analysis are expected to take place regardless of the rule, since they would be likely to occur given the AIM Act HFC phasedown and other state and local laws and regulations.[21] The AIM Act HFC phasedown does not prescribe specific transitions and it is not clear if absent the Technology Transitions Rule the same transitions would be made at the same time. This analysis therefore may not accurately predict transition paths but provides an assessment stemming from the restrictions in the Technology Transitions Rule to more closely evaluate the projected costs and benefits.

4.3 Abatement Options Modeled

As discussed above, this analysis relies on the version of the Vintaging Model used to evaluate the impact of the Allocation Framework Rule as updated by the 2024 Allocation Rule. Assumptions for various sectors and subsectors are then modified, with some additional transitions added or—in cases where they do not meet the restrictions—removed to conform with the Technology Transitions Rule requirements.

The two regulatory options discussed in Section 2.6 of either GWP- or compound-specific restrictions do not affect the modeling approach. Where a GWP limit is established for a subsector, we modeled transitions to alternatives that comply with that GWP limit. For the few cases where specific HFCs and specific blends containing HFCs are restricted, the GWP of the restricted HFC or blend with the lowest GWP is modeled as the de facto GWP limit.

Table 4-1 below shows the Technology Transitions Rule requirements by sector/subsector and the transitions assumed to model compliance. The transitions listed in the table represent a "best guess" of expected technological changes at the time this analysis was conducted and should by no means be interpreted as a prescriptive list.[22]

Table 4-1: Restrictions and Transitions Assumed

Subsector	***GWP Limit***	***Compliance Year***	***Assumed Transition(s) Included in Model***
Centrifugal Chillers (comfort cooling)	700	2025	HFC-134a replaced w/ R-450A/R-513A; HFC-245fa replaced w/ HCFO-1233zd(E)
Screw Chillers (comfort cooling)	700	2025	HFO-1234ze(E)
Scroll Chillers (comfort cooling)	700	2025	R-452B

[21] For example, several states have implemented restrictions, or will implement such restrictions before this rule's compliance dates for stand-alone retail food refrigeration and household refrigerator-freezers. The states include California, Colorado, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, Virginia, Vermont, and Washington. Additionally, California has adopted, and Washington has proposed, restrictions for residential and variable refrigerant flow systems in light commercial air conditioning units and heat pumps.

[22] Certain restrictions in the Technology Transitions Rule are not shown here and are not assumed to undergo a future transition, because a transition of the entire market to a substitute compliant with the restrictions was assumed in the baseline model, and/or because the model used does not break out a specific subsector in the manner addressed in the rule.

Reciprocating Chillers (comfort cooling)	700	2025	HFO-1234ze(E)
Industrial Process Refrigeration without chillers, refrigerant temperature entering the evaporator >-22°F (-30°C)** (>=200 lb charge size)	150	2026	NH_3/CO_2
Industrial Process Refrigeration without chillers, refrigerant temperature entering the evaporator >-22°F (-30°C)** (<200 lb charge size or high side of a cascade system)	300	2026	NH_3/CO_2
Industrial Process Refrigeration without chillers, refrigerant temperature entering the evaporator < -22°F (-30°C)**	700	2028	NH_3/CO_2
Industrial Process Refrigeration with chillers, exiting fluid temperature >-22°F (-30°C)**	700	2026	NH_3/CO_2
Industrial Process Refrigeration with chillers, exiting fluid temperature <-22°F (-30°C)**	700	2028	NH_3/CO_2
Data Center and IT Equipment Cooling	700	2027	R-454B
Ice Rinks	700	2025	R-454B
Cold Storage (>=200 lb charge size)	150	2026	NH_3/CO_2
Cold Storage (<200 lb charge size or high side of a cascade system)	300	2026	NH_3/CO_2
Large Retail Food (>=200 lb charge size)	150	2027	CO_2 Transcritical
Large Retail Food (<200 lb charge size or high side of a cascade system)	300	2027	CO_2 Transcritical
Medium Retail Food (>=200 lb charge size)	150	2026	CO_2
Medium Retail Food (<200 lb charge size)	300	2026	CO_2
Small Retail Food	150	2025	HCs
Refrigerated Food Processing and Dispensing Equipment, Remote	1,425*	2027	R-448A/R-449A/R-449B
Refrigerated Food Processing and Dispensing Equipment (ice-cream makers within the scope of UL 621, edition 7)	1,425*	2028	R-448A/R-449A/R-449B
Refrigerated Food Processing and Dispensing Equipment, Self-Contained (>500 gram charge size)	1,425*	2027	R-448A/R-449A/R-449B
Refrigerated Food Processing and Dispensing Equipment, Self-Contained (<=500 gram charge size)	150	2027	R-290
Vending Machines	150	2025	R-290
Ice Machines, Self-Contained batch type with harvest rate <=1,000 pounds of ice per 24 hours	150	2026	R-290
Ice Machines, Self-Contained continuous type with harvest rate <=1,200 pounds of ice per 24 hours	150	2026	R-290
Ice Machines, Self-Contained (batch type harvest rate >1,000 pounds of ice per 24 hours; continuous type harvest rate >1,200 pounds of ice per 24 hours)	1,425*	2027	R-448A/R-449A

Ice Machines, Remote	2,200*	2027	R-448A/R-449A
Refrigerated Transport—Intermodal Containers**	700	2025	R-450A/R-513A
Refrigerated Transport—Marine and Road	2,200*	2025	R-452A
Household Refrigerator-Freezers	150	2025	R-600a
Residential Dehumidifiers	700	2025	R-32
Window A/C Units	700	2025	R-32
Residential Unitary A/C	700	2025	R-454B
Small Commercial Unitary A/C	700	2025	R-32
Large Commercial Unitary A/C	700	2025	R-32
Variable Refrigerant Flow A/C	700	2026	R-32
Water & Ground Source HP	700	2025	R-32/R-452B
PTAC/PTHP	700	2025	R-32/R-452B
Non-MDI Consumer Aerosols	150	2025	HFC-152a to HCs; HFC-134a/HFC-152a to Not-in-kind (NIK)
Non-MDI Technical Aerosols	150	2028	HFC-134a to HFC-152a, HCs; HFC-134a/HFC-152a to HFO-1234ze(E)
Aerosol Solvents (Consumer/Technical)	150	2025/2028	NIK Aqueous and Semi-aqueous clean
Rigid Polyurethane (PU) Appliance Foam	150	2025	HFC-245fa to HCs, HCFO-1233zd(E)
Rigid PU Commercial Refrigeration Foam	150	2025	HFC-245fa to HCFO-1233zd(E)
Rigid PU Sandwich Panels	150	2025	HFC-134a to HCs; HFC-245fa/CO_2 to HCFO-1233zd(E)
Polystyrene Extruded Boardstock and Billet Foam	150	2025	HFC-134a/CO_2 to HFO-1234ze(E)/HCFO-1233zd(E)
Integral Skin PU Foam	150	2025	HFC-134a to HCs
Rigid PU and Polyisocyanurate Laminated Boardstock	150	2025	HFC-245fa Blend to HCs
Rigid PU One Component and Spray Foam	150	2025	HFC-134a to HFO-1234ze(E); HFC-245fa to HCFO-1233zd(E), HFO-1234ze(E)

*Subsectors for which EPA is restricting specific blends containing HFCs are modeled as having an effective GWP limit of either 2,200 or 1,425, depending on the specific list finalized, as a result.
** Chillers used in IPR with a leaving fluid temperature, and Refrigerated Transport Intermodal Containers and IPR systems not using a chiller with refrigerant temperature entering the evaporator, below -58°F (-50°C) are not restricted.

4.4 Costs of Transition

To quantify compliance costs, EPA used estimates of the assumed cost of each transition (including capital and operations and maintenance costs), by sector and subsector, calculated on the basis of each ton of avoided consumption. Costs of a particular transition may be either net positive or net negative in cases where a particular transition results in savings (e.g., due to energy efficiency) that outweigh expected costs. The result is an estimate of the costs to U.S. companies to implement transitions that align with the restrictions contained in the rule.

EPA calculated how much consumption would be reduced in the Technology Transitions scenarios (base case and high additionality case) by evaluating what options would be needed to achieve compliance within each sector and subsector, how much of the market those transitions would capture, and how quickly they would happen. While compliance years for specific restrictions do not start until 2025 at the earliest, EPA assumed a ramp-up period for certain transitions in the years leading up to the compliance dates in anticipation of the rule.

Table 4-2 below shows a subset of subsectors where there are notable differences between the Allocation Rule Reference Case and the Technology Transitions base case. The table illustrates how the two analyses differ in terms of assumed transitions depending on the subsector EPA evaluated. For example, for the Heat Pumps subsector, both scenarios include the same transition option (conversion to R-452B). However, whereas the market penetration rate of this transition in the base case increases to 100% by 2025 to align with restrictions in the Technology Transitions Rule, a similar transition does not begin until later years (2026 in this example) and impacts a smaller portion of the market (50% in this example) in the Allocation Rule Reference Case. This leads to higher compliance costs in the Technology Transitions base case given the earlier and more comprehensive transition required for that subsector. As another example, in the retail food sector, the set of abatement options from the Allocation Rule Reference Case is narrowed exclusively to transitions that meet the required GWP limit of the rule—in this case the conversion to CO_2-based refrigeration systems[23]—which have a markedly higher reduction efficiency (i.e., abatement potential). This conversion is assumed to be net negative in terms of costs to industry due to energy efficiency gains and the lower cost of the refrigerant being used.

Finally, there are multiple subsectors where no transition or abatement is assumed in the Technology Transitions base case even though options are included in the Allocation Rule Reference Case, such as the fire suppression subsectors. These “forgone” abatement options are excluded because they are not covered by the Technology Transitions Rule. Despite the forgone abatement, we note that the Technology Transitions base case would be sufficient to meet the AIM Act HFC phasedown schedule without their inclusion due to consumption reductions in other subsectors. As discussed in Section 3.3 of this document, the Technology Transitions Rule may have greater or less incremental abatement and costs in a given sector or subsector relative to the Allocation Rule Reference Case depending on whether such

[23] Note: modeling assumptions regarding the alternatives available within a certain GWP limit are based on expert judgement and EPA analysis. However, these assumptions should not be interpreted as the only options actually available or technically feasible for a given appliance or end use.

abatement options are assumed to be undertaken or not. To deal with this uncertainty, we separately provide a “high additionality” case where these transitions are not assumed to “backslide” in the Technology Transitions scenario and are included.

Table 4-2: Assumed Transitions in the Allocation Rule Reference Case and Technology Transitions Base Case, Reduction Efficiency, and Market Penetration[24]

Note: This table provides details on a subset of transition assumptions with notable differences between the Allocation Rule Reference Case and Technology Transitions base case scenario. A table listing all transitions assumed for each scenario is included in Annex Table A-3.

	Allocation Rule Reference Case				***Technology Transitions (Base Case)***			
Subsector	***Transition/ Substitute***	***Reduction Efficiency***	***MP (2026)***	***Cost ($/ton)***	***Transition/ Substitute***	***Reduction Efficiency***	***MP (2026)***	***Cost ($/ton)***
Disposal recovery	RACHP subsectors	85%	100%	$14	Not included*			
Electronics Cleaning (Aerosols) ††	NIK Aqueous	100%	5%	$36	NIK Aqueous	100%	2.5%	$36
	NIK Semi-aqueous	100%	5%	$76	NIK Semi-aqueous	100%	2.5%	$76
Electronics Cleaning (Other)	NIK Aqueous	100%	5%	$36	Not included*			
	NIK Semi-aqueous	100%	5%	$76	Not included*			
	HFE-7100/ HFE-7200	85%	56%	$0	Not included in base case (alternative not used as an aerosol solvent for electronics)*			
Flooding Agents	Inert Gas	100%	11%	$(7)	Not included*			
	Water Mist	100%	2%	$(7)	Not included*			
	FK- 5-1-12	100%	35%	$3	Not included*			
Heat Pumps	R-32/R-452B	67%	10%	$5	R-32/R-452B	67%	100%	$5
Ice Machines	R-290	100%	25%	$1	R-290	100%	50%	$1
	Not included†				R-448A/R-449A	58%	40%	$6
Industrial Process Refrigeration (Data Centers)	NH3/CO2 ††	100%	100%	$(45)	R-454B	88%	2%	$8
Industrial Process Refrigeration (Ice Rinks)					R-454B	88%	2%	$8
Industrial Process Refrigeration (Lower Temperature)					NH3/CO2	100%	21%	$(45)
Industrial Process					NH3/CO2	100%	54%	$(45)

23 Market Penetration (MP) represents share of total new demand for a given vintage of equipment within a subsector or for a given subsector in aggregate. For example, an MP of 100% in the Large Retail Food subsector for “404A/507A to CO_2 Transcritical” indicates that 100% of new systems that in the baseline would have used 404A/507A in the specified year are assumed to transition to transcritical CO_2.

Refrigeration (Other)								
Large Retail Food	DX 407A/407F	50%	34%	$(16)	Not included**			
	CO_2 Transcritical	100%	33%	$(11)	404A/507A to CO_2 Transcritical	100%	83%	$(11)
	407A/407F SLS	50%	33%	$(0)	Not included**			
	Not included[†]				407A to CO_2 Transcritical	100%	33%	$(20)
Leak Recovery	RACHP subsectors	40%	100%	$(1)	Not included*			
Medium Retail Food (Large Condensing Units) [††]	CO_2	100%	33%	$(3)	CO_2	100%	100%	$(3)
	DX 407A/407F	50%	67%	$(0)	Not included**			
Medium Retail Food (Small Condensing Units) [††]	CO_2	100%	33%	$(3)	CO_2	100%	95%	$(3)
	DX 407A/407F	50%	67%	$(0)	448A/449A/ 449B	65%	4%	$6
Non-MDI Aerosols	HFC-134a to HCs	100%	20%	$(3)	HFC-134a to HCs	100%	23%	$(3)
	HFC-134a to NIK	100%	20%	$(5)	HFC-134a to NIK	100%	25%	$(5)
	HFC-134a to HFC-152a	91%	10%	$(4)	HFC-134a to HFC-152a	91%	11%	$(4)
	Not included [†]				HFC-152a to HFO-1234ze(E)	95%	16%	$112
Precision Cleaning (Aerosols) [††]	NIK Aqueous	100%	5%	$36	NIK Aqueous	100%	2.5%	$36
	NIK Semi-aqueous	100%	5%	$76	NIK Semi-aqueous	100%	2.5%	$76
Precision Cleaning (Other) [††]	NIK Aqueous	100%	5%	$36	NIK Aqueous	100%	2.5%	$36
	NIK Semi-aqueous	100%	5%	$76	NIK Semi-aqueous	100%	2.5%	$76
	Retrofitted HFC to HFE	85%	76%	$0	Not included**			
PU Rigid: One Component Foam	134a to HFO-1234ze	100%	30%	$8	134a to HFO-1234ze	100%	100%	$8
Servicing recovery	RACHP subsectors	95%	40%	$23	Not included *			
Small Retail Food (RFPDE)	HCs[††]	100%	10%	$(7)	R-290	100%	0%	$(7)
Small Retail Food (Other)					HCs	100%	88%	$(7)
Small Retail Food (RFPDE)	R-448A/R-449A[††]	65%	70%	$5	R-448A/R-449A	58%	4%	$7
Small Retail Food (Other)					Not included**			

Small Retail Food (Other)	R-450A/R-513A	57%	20%	$23	Not included**			
Vending Machines	R-450A/R-513A	63%	100%	$19	Not included**			
	Not included †				R-290	100%	100%	$96
Window Units/ Dehumidifiers	R-32	68%	32%	$(1)	R-32	68%	100%	$(1)
XPS: Boardstock Foam	134a/CO_2 to 1234ze(E)/1233zd(E)	100%	68%	$8	134a/CO_2 to 1234ze/1233zdE	100%	100%	$8

†Transition not assumed in Allocation Rule Reference Case, due to assumed transition to less expensive and/or more commercially established options.
†† Transition was assumed in Allocation Rule Reference Case as part of the broader subsector. For the final rule, specific uses within the subsector have been explicitly included in this model version
**Transition not assumed in Technology Transitions base case because subsector is not covered by the rule, despite inclusion in Allocation Rule Reference Case. These subsectors are included in the Technology Transitions high additionality case (see Section 3.3 of this RIA addendum for discussion of alternative scenarios of incremental benefits).*
*** Transition is not assumed in Technology Transitions Rule base case scenario nor the high additionality case because it is above the subsector GWP limit in the rule.*

After evaluations of the full set of transitions required to meet compliance with the Technology Transitions Rule, as with the Allocation Framework RIA, total compliance costs were analyzed based on total abatement associated with each transition for each year, and the assumed cost of each transition. Costs reflect capital (one-time) cost, revenue, and operating and maintenance costs (annual), and are calculated on a per MTEVe (in avoided consumption) basis. They are present value in 2020 dollars, utilizing a 9.8 percent opportunity cost of capital and 0 percent tax rate. Transitions and costs are also calculated on a year-by-year basis, which accounts for the fact that most options require time for stock turnover to fully implement.

Total annual net costs (or savings) associated with both the Allocation Rule Reference Case and Technology Transitions compliance scenarios are shown in Table 4-3.

Table 4-3: Costs of Compliance[a,b] by Year (billions of 2020$) in Allocation Rule Reference Case and Technology Transitions Scenarios

	Allocation Rule Reference Case	***Technology Transitions Base Case***		***Technology Transitions High Additionality Case***	
Year	***Costs/Savings***	***Costs/Savings***	***Incremental Costs/Savings***	***Costs/Savings***	***Incremental Costs/Savings***
2025	$0.14	$0.21	$0.07	$0.66	$0.53
2030	$(0.59)	$(0.46)	$0.13	$(0.17)	$0.42
2035	$(0.87)	$(0.87)	$(0.01)	$(0.81)	$0.06

2040	$(0.61)	$(1.29)	$(0.68)	$(1.23)	$(0.62)
2045	$(0.74)	$(1.33)	$(0.59)	$(1.27)	$(0.53)
2050	$(0.91)	$(1.54)	$(0.63)	$(1.47)	$(0.56)

[a]*Values in parenthesis represent net negative costs, i.e., savings*
[b] *Abatement costs presented in this table do not include recordkeeping and reporting costs*

The cost curves below present rolling total compliance costs and U.S. HFC consumption in a given year as transition options are applied from lowest- to highest-cost options (left to right). The curves help to show the relationship between total abatement and costs and how these factors shift over time. In the Technology Transitions scenarios (Figures 4-1 and 4-2), total savings and total abatement build over time. Two subsectors highlighted in the figure, Large Retail Food and Residential AC, both contribute to significant amounts of abatement, the former at a net negative cost and the latter at a net positive cost. A similar dynamic occurs with Allocation Framework Rule compliance pathway (Figure 4-3), although certain subsectors are not assumed to transition as rapidly or completely, in some cases resulting in forgone cost savings (e.g., in the Large Retail Food subsector). All three graphs represent all options assumed to be undertaken to meet compliance, so the right-most data point shows the resulting consumption and total cost in a given year (i.e., the rightmost points represent final consumption and net costs in each year after all required options are applied).

Figure 4-1 – Technology Transition Base Case Cost Curve

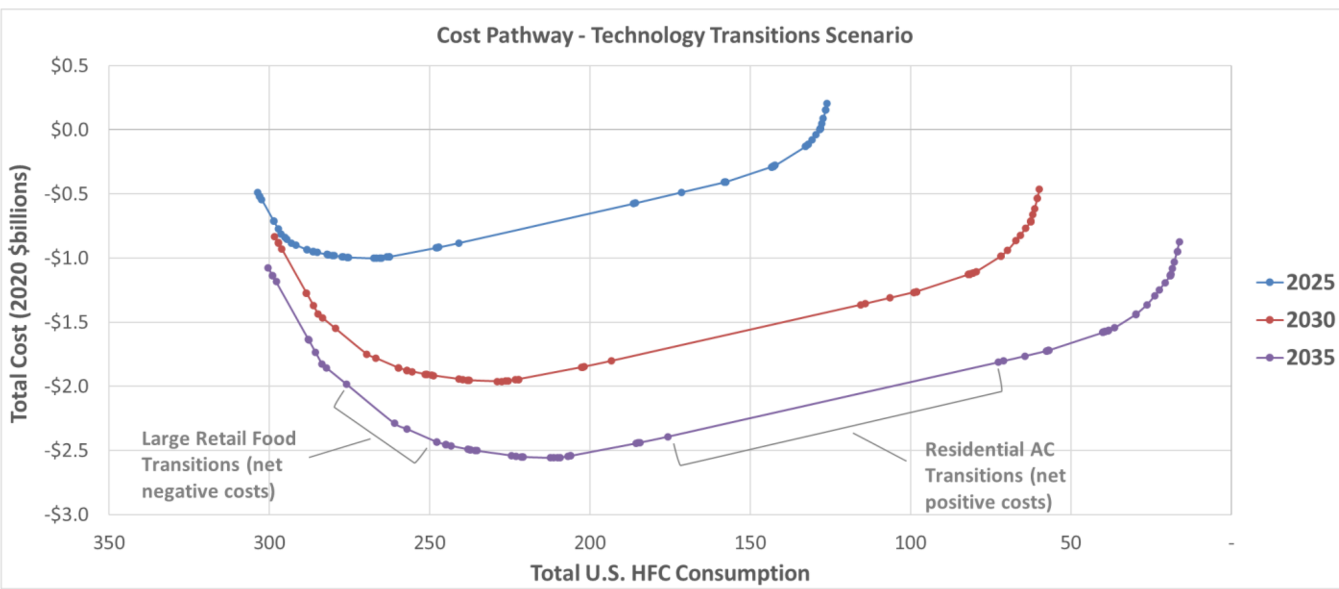


Figure 4-2 – Technology Transitions High Additionality Case Cost Curve

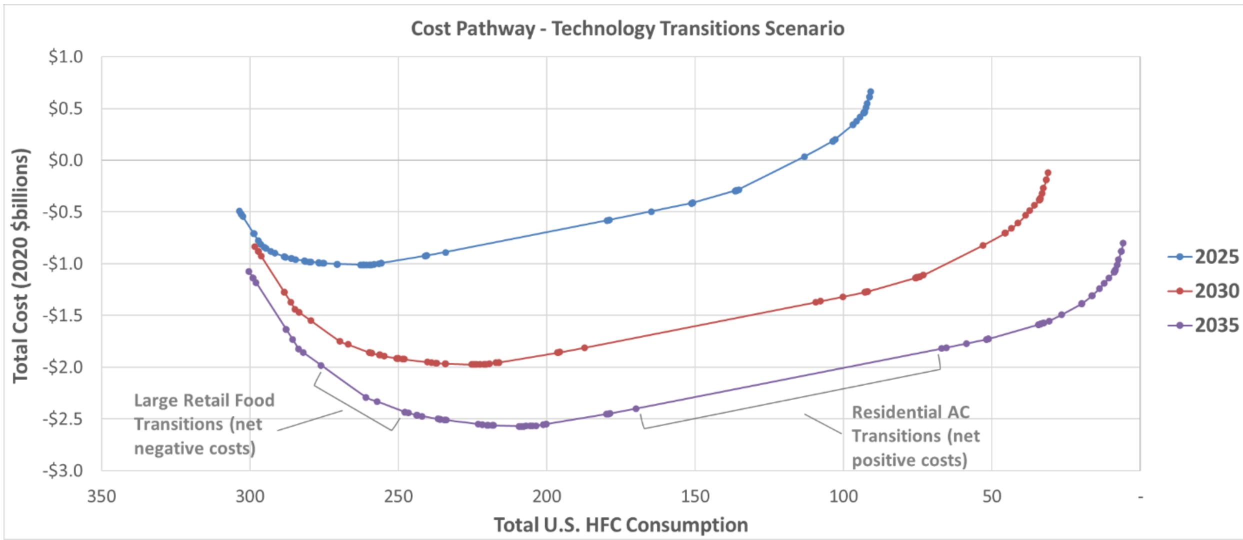


Figure 4-3 – Allocation Rule Reference Case Cost Curve

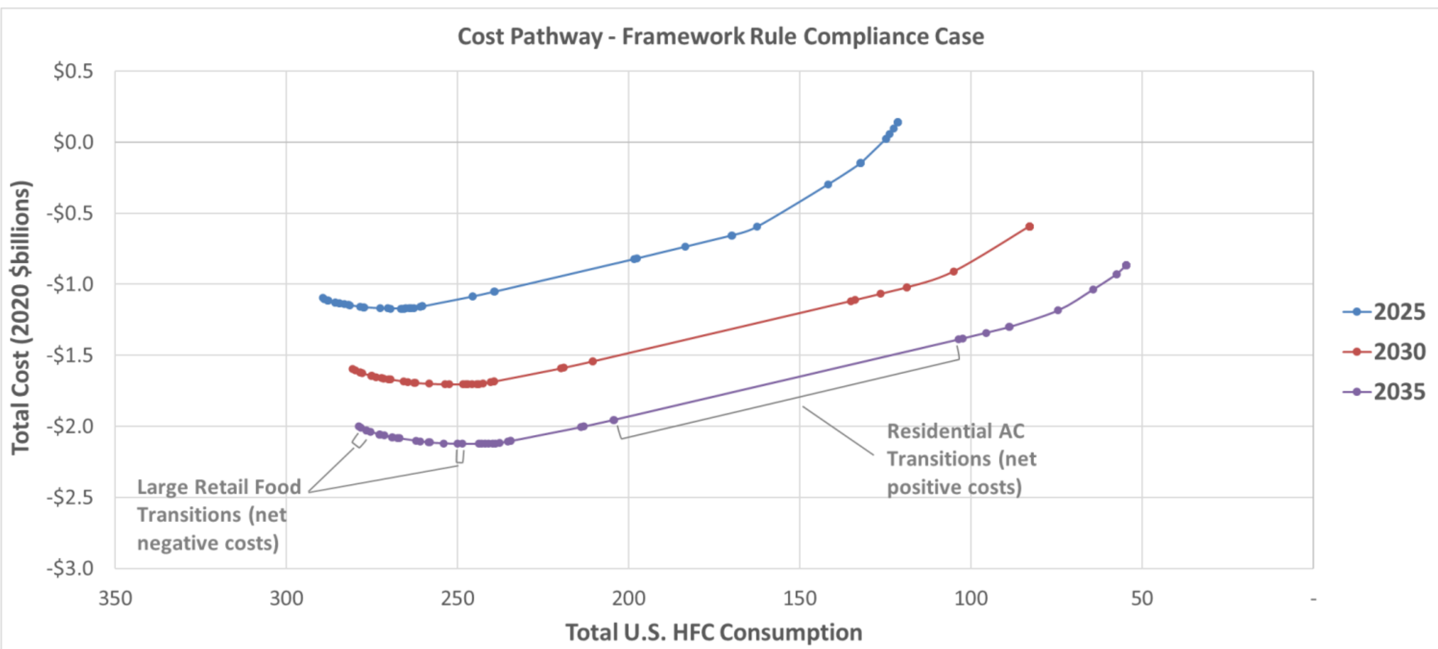


Figure Description: Each curve in Figures 4-1 through 4-3 starts with total costs incurred with the cheapest (or most cost-effective) transition applied, with more expensive options added as the curve moves left to right. Points to the left of the low point on each curve represent transitions with assumed net negative costs (or cost savings), while points to the right of the low point on each curve represent transitions with assumed net positive costs. The rightmost point on each curve for a given year in each figure represents the final total net cost with all required transitions being applied. Two transitions that result in significant levels of abatement in the Technology Transitions scenario, one at a net negative cost (large retail food) and one at a net positive cost (residential AC), are highlighted in the figures.

These results indicate that the Technology Transitions Rule will not result in significant additional compliance costs relative to the Allocation Rules, and in fact may yield additional abatement over time. In other words, it would result in additional abatement while reducing compliance costs. In some respects, this finding could be viewed as counterintuitive. Whereas the Allocation Rules analysis assumes a "least cost" pathway to compliance based on available abatement options, the Technology Transitions pathway applies sector-based restrictions regardless of transition costs. It follows then that such restrictions could be expected to result in added costs.

That the Technology Transitions scenario instead shows additional net savings in both the base case and high additionality case stems largely from the more rapid and more comprehensive transition to cost-saving, lower-GWP technologies in particular sectors and subsectors required by the rule. A similarly comprehensive transition is not assumed to be an "available" abatement option in the Allocation Rules analysis, since it assumed that the market penetration rates of newer technologies will face more industry inertia and shift less rapidly without an explicit regulation in place, regardless of potential energy savings or other benefits over time. While the rate of such industry transitions is ultimately uncertain, a significant body of literature indicates that in many cases market actors will favor existing technologies and discount energy savings without incentives or regulations, as discussed in Section 3.2.2 of the Allocation Framework RIA.

An example of how these assumptions impact the modeled results is highlighted in the above figures, where abatement and cost savings in the Large Retail Food subsector is assumed to be significantly deeper in the Technology Transitions scenarios vis-a-vis the Allocation Rule Reference Case. By contrast, the transitions for the Residential AC subsector are similar in both scenarios, as the GWP limits contained in the rule would not require a substantially different transition than was previously modeled in the Allocation Rule Reference Case. For a detailed breakdown of incremental abatement and costs by subsector, see annex Table A-4 of this document.

Since costs are ultimately a reflection of the full suite of transitions assumed in the compliance pathway, changes in assumed technology costs, rates of adoption, or abatement options assumed to be "available" in a particular scenario can significantly impact results. The model is sensitive to assumed transition costs, particularly those which result in high levels of abatement and/or which are high-cost or high-saving. The Allocation Framework RIA contains a sensitivity analysis showing costs of compliance for the phasedown rule ranging from a lower bound estimate of $15.7 billion in cumulative savings to an upper bound estimate of $15.3 billion in cumulative costs through 2036. These sensitivity results are indicative of the uncertainty associated with the Technology Transitions Rule results as well, given the similar methodology and transition assumptions used for both.

4.5 Labor Impacts

An assessment of labor impacts is included in the Allocation Framework RIA. That analysis, which includes details on the baseline employment characteristics for regulated industries, potential employment impacts, and potential impacts on downstream production processes, can be found in Section 3.7 of the Allocation Framework RIA.

Overall, we assess the Technology Transitions Rule as unlikely to have substantial labor impacts differing from those discussed in this previous analysis. EPA has therefore not endeavored to conduct an additional assessment of labor impacts. As with the Allocation Framework Rule, we expect the industry transitions required by the rule to result in small changes to costs, both positive and negative, for HFC producers, importers, and downstream sectors (including Air Conditioning, Foams, Aerosols, and Solvents) that use lower GHG-emitting manufactured products. We also note that on the whole these regulatory costs may represent only a small fraction of total costs at regulated firms. Also as noted in the previous RIA, 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, and labor impacts may further be muted due to the low labor intensity of production in the chemical manufacturing sector in general.

4.6 Recordkeeping, Reporting, and Labeling Costs

EPA has prepared an information collection request (ICR), ICR Number 2742.01, and a Supporting Statement. The information collection requirements for recordkeeping, reporting, and labeling are not enforceable until OMB approves them. Among other things, EPA calculated the estimated time and financial burden over a three-year period (ICRs generally cover three-year time periods) for respondents to implement labeling practices and to electronically report data to the Agency on an annual basis. A key summary of the respondent burden estimates follows.

For the three years covered in the ICR, the total respondent burden associated with information collection will average 17,938 hours per year and the respondent cost will average $6,944,962 per year. This includes $5,137,952 for capital investment and operation and maintenance (O&M) and $1,807,010 per year for labor. The breakdown of the burden per year is provided in Table 4-4a in 2022 dollars and in Table 4-4b in 2020 dollars to align with other analyses in this document.

The ICR will be subject to renewal after the three-year time period is over. For purposes of analysis, we assume the on-going costs will be equivalent to the year 2 and year 3 costs of $6,832,015 per year.

Table 4-4a: Total Respondent Burden Costs Over the Three-year ICR Period (2022$s)

Year	***Total Responses***	***Total Hours***	***Total Labor Costs (2022$)***	***Total O&M Costs (2022$)***	***Total Costs (2022$)***
Year 1 (2025)	51,209,894	19,715	$2,032,904	$5,137,952	$7,170,856
Year 2 (2026)	51,209,698	17,050	$1,694,063	$5,137,952	$6,832,015
Year 3 (2027)	51,209,698	17,050	$1,694,063	$5,137,952	$6,832,015
3yr ICR Annual Average	51,209,764	17,938	$1,807,010	$5,137,952	$6,944,962
Year 4 (2028) and beyond	51,209,698	17,050	$1,694,063	$5,137,952	$6,832,015

Table 4-4b: Total Respondent Burden Costs Over the Three-year ICR Period (2020$s)

Year	***Total Responses***	***Total Hours***	***Total Labor Costs (2020$)***	***Total O&M Costs (2020$)***	***Total Costs (2020$)***
Year 1 (2025)	51,209,894	19,715	$1,871,229	$4,729,335	$6,600,564
Year 2 (2026)	51,209,698	17,050	$1,559,336	$4,729,335	$6,288,671
Year 3 (2027)	51,209,698	17,050	$1,559,336	$4,729,335	$6,288,671
3yr ICR Annual Average	51,209,764	17,938	$1,663,300	$4,729,335	$6,392,635
Year 4 (2028) and beyond	51,209,698	17,050	$1,559,336	$4,729,335	$6,288,671

When combined with the compliance costs associated with the industry transitions necessary to meet the GWP restrictions of the rule, as shown in Table 4-3 in the previous section, these costs add to the total expected incremental compliance costs of the rule and therefore reduce total expected cost savings.

Table 4-5 below shows the combined net compliance costs—including transition costs as well as recordkeeping, reporting, and labeling costs—associated with the Technology Transitions Rule compared to compliance costs previously estimated for the Allocation Rules. Incremental costs reflect the additional costs (or savings) associated with the transitions necessary to meet the rule’s subsector-based GWP restrictions, plus the full recordkeeping, reporting, and labeling costs shown above, which are assumed to be entirely additional.

Table 4-5: Annual Compliance Costs/Savings from the Allocation Rule Reference Case, the Technology Transitions Rule, and Resulting Incremental Benefits (billions of 2020$)*

	Allocation Rule Reference Case	***Technology Transitions Base Case***	***Technology Transitions High Additionality Case***

Year	*Costs/Savings*	*Costs/Savings*	*Incremental Costs/Savings*	*Costs/Savings*	*Incremental Costs/Savings*
2025	$0.14	$0.21	$0.07	$0.67	$0.53
2029	$(0.47)	$(0.26)	$0.21	$0.03	$0.50
2034	$(0.77)	$(0.80)	$(0.03)	$(0.67)	$0.10
2036	$(0.53)	$(0.95)	$(0.42)	$(0.91)	$(0.38)
2040	$(0.61)	$(1.28)	$(0.68)	$(1.22)	$(0.62)
2045	$(0.74)	$(1.32)	$(0.59)	$(1.26)	$(0.52)
2050	$(0.91)	$(1.53)	$(0.62)	$(1.46)	$(0.55)

**Note: Values in parenthesis represent net cost savings*

Chapter 5: Climate Benefits

5.1 Introduction

The benefits of this rule derive mostly from preventing the emissions of HFCs with higher GWPs, thus reducing the damage from climate change that would have been induced by those emissions. Results from this analysis indicate that the restrictions will in some cases lead to more rapid and deeper transitions to lower-GWP substitutes, with the potential ancillary effect of reducing consumption of HFCs, although the schedule for the production and consumption phasedown would not be made more stringent than the schedule under subsection (e)(2)(C) of the AIM Act. These HFC consumption reductions are expected to lead to HFC emissions reductions since it is assumed that all HFCs produced or consumed would be emitted eventually, either from their direct release (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 their servicing or disposal.

In addition to climate benefits, additional or reduced energy use of transition technologies could result in both negative or positive emissions benefits due to the marginal change in energy use. However, these potential benefits or disbenefits are not accounted for in this analysis.

5.2 Consumption and Emission Reductions

EPA's Vintaging Model is used to estimate both consumption and emissions for each regulated substance for each generation or "vintage" of equipment in the Technology Transitions compliance scenarios. Reductions in consumption (in units of MMTEVe) are calculated for a given year by summing the total tons avoided resulting from transitions in each sector or subsector. Emission reductions are similarly calculated by summing total emissions avoided across sectors/subsectors; however, these benefits typically lag corresponding reductions in consumption since they often occur over the course of equipment lifetime or during servicing and disposal.

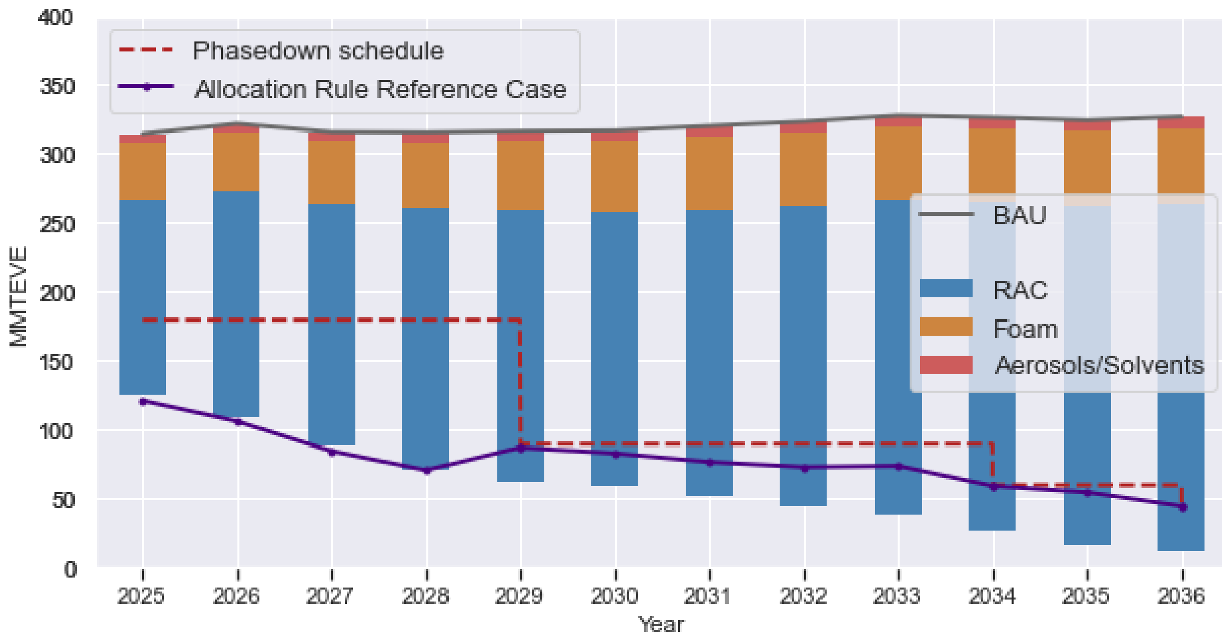
Table 5-1 below shows the consumption reductions by year corresponding to the Technology Transitions Rule compliance scenario in the base case and high additionality case, which are compared to the Allocation Rule Reference Case to evaluate potential incremental reductions.

Table 5-1: Annual Consumption Reductions in Allocation Rule Reference Case and Technology Transitions Compliance Scenarios

	Allocation Rule Reference Case	***Technology Transitions Base Case***		***Technology Transitions High Additionality Case***	
Year	***Consumption Reduction (MMTEVe)***	***Consumption Reduction (MMTEVe)***	***Incremental Consumption Reduction (MMTEVe)***	***Consumption Reduction (MMTEVe)***	***Incremental Consumption Reduction (MMTEVe)***
2025	193	189	-5	224	30
2026	216	212	-4	242	27
2027	231	227	-4	258	27
2028	245	245	0	275	30
2029	230	254	24	281	51
2030	234	257	23	284	50
2031	244	269	25	296	52
2032	251	279	29	303	52
2033	254	289	35	308	54
2034	267	299	32	314	47
2035	270	308	38	319	49
2036	282	315	33	323	41
2037	283	315	32	322	39
2038	285	320	36	326	42
2039	287	317	30	328	41
2040	287	309	22	317	30
2041	278	312	34	320	42
2042	280	315	35	323	43
2043	283	319	36	327	44
2044	286	322	36	330	45
2045	285	322	37	331	45
2046	288	325	38	334	46
2047	290	328	38	336	46
2048	291	330	39	338	47
2049	292	331	39	340	47
2050	293	333	39	341	47
Total	**6,924**	**7,643**	**720**	**8,037**	**1,113**

The mitigation charts below (Figures 5-1 and 5-2) show the estimated avoided consumption resulting from the Technology Transitions Rule restrictions for each year modeled, by sector. As shown, the anticipated amount of abatement overshoots (dips below) the relevant AIM Act consumption cap (the maximum annual domestic consumption allowed under the phasedown schedule) from 2025, the first compliance year for the restrictions, through 2036, the final step-down year of the phasedown schedule. In the high additionality case, additional reductions stem from the assumption that consumption and emissions reducing op17portunities included in the Allocation Rule Reference Case are retained in the Technology Transitions case—even if not covered by the Technology Transitions Rule—rather than assuming these opportunities are forgone. Total consumption reductions from the Allocation Rule Reference Case are also included as a reference line in both figures. The reductions in both figures reflect abatement in both domestically manufactured products and imported products.[25]

Figure 5-1 – Consumption Mitigation by Year under Technology Transitions Scenario (base case)



[25] Due to limitations in the tools used for this analysis, consumption reductions as modeled are agnostic as to whether the avoided HFCs would have been HFC consumption in the United States (i.e., produced in or imported to the United States) or are HFCs contained in imported products. The AIM Act consumption cap only applies to domestic HFCs consumption. The import of bulk HFCs placed in domestically manufactured products would therefore require expenditure of allowances under the Allocation Framework Rule whereas the import of HFCs contained in imported products do not require such an expenditure of allowances.

Figure 5-2 – Consumption Mitigation by Year under the Technology Transitions Scenario (high additionality case)

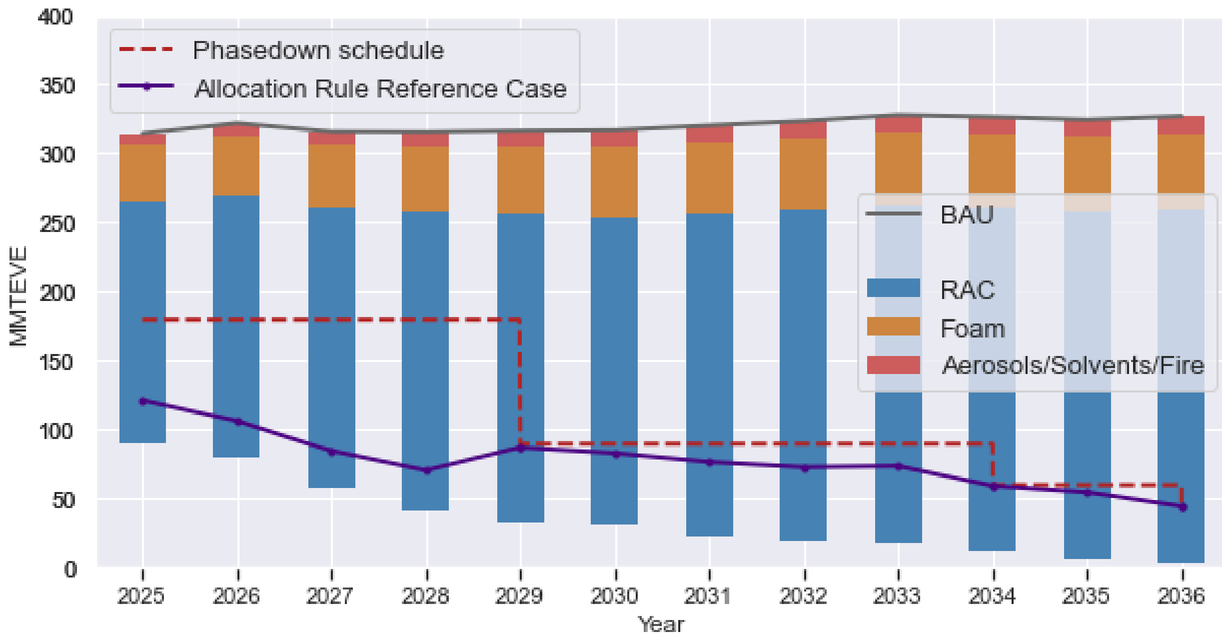
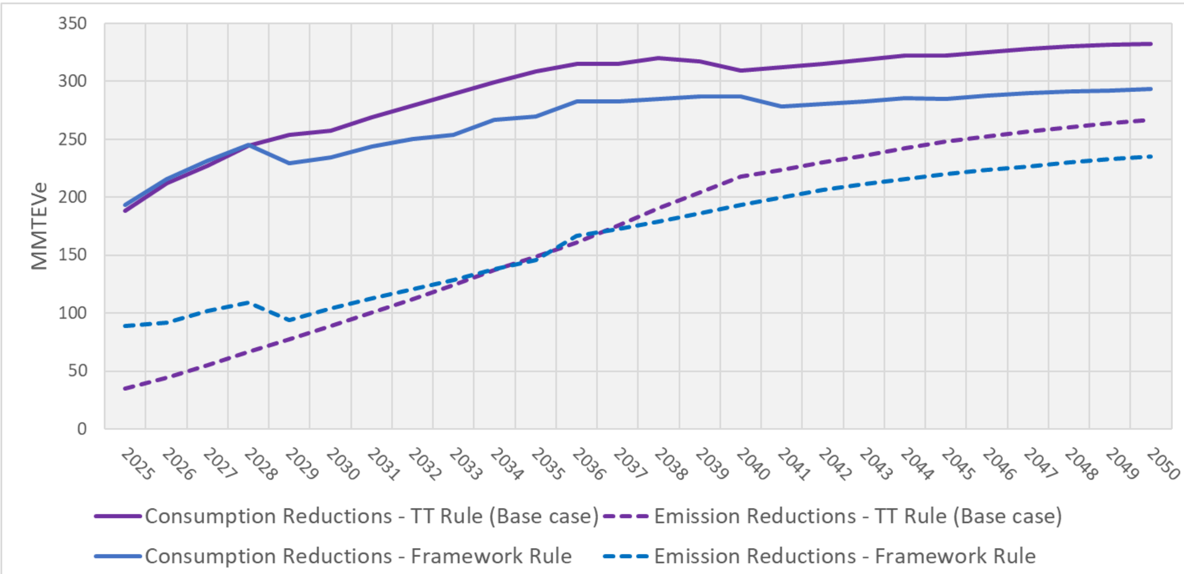


Table 5-2 below shows the emission reductions by year corresponding to the Technology Tran sitions compliance scenarios. Again, these results are compared to the Allocation Rule Reference Case to determine incremental reductions. Notably, these results indicate that in the base case, the Technology Transitions Rule only leads to incremental emission reductions in later years (after 2035), despite the more immediate incremental consumption reductions shown above. This is due to the fact that nearly all subsectors covered by the Technology Transitions Rule are ones where emission reductions lag behind consumption reductions, and they are modeled as occurring gradually over the course of equipment lifetime. By contrast, the Allocation Rule Reference Case assumes implementation of additional abatement options not covered by the Technology Transitions Rule—namely leak recovery, disposal, and equipment servicing—which apply immediately rather than gradually. The exclusion of these abatement options from the Technology Transitions base case compliance scenario means that emission reductions are delayed vis-a-vis the Allocation Rule Reference Case. The one subsector covered by the Technology Transitions Rule that does see near-immediate emission reductions equal to the consumption reductions is aerosols, based on the assumed lifetime of one year. However, the restrictions analyzed here are equivalent to the abatement options assumed in the Allocation Framework RIA, and hence there are no incremental benefits from that subsector. These differences in the timing of emission reductions notwithstanding, the results of this analysis indicate that the Technology Transitions Rule base case ultimately yields incremental emission reductions on a cumulative basis.

This dynamic of emission reductions lagging behind consumption reductions is further illustrated by Figure 5-3 below, which shows annual consumption and emission reductions in the Technology Transitions Rule base case scenario and Allocation Rule Reference Case over time. The difference within each set of reductions (i.e., purple line minus blue line) represents the incremental environmental impacts from this rule as compared to the Allocation Rule Reference Case.

Figure 5-3 – Consumption and Emission Reductions in Technology Transitions Compliance Scenario and Allocation Rule Reference Scenario



In contrast with the base case, the high additionality case for the Technology Transitions Rule yields immediate incremental emission reductions, beginning in the first compliance year (2025) and continuing for all years modeled. This is because the high additionality case assumes that all transitions occurring in the Allocation Rule Reference Case, if valid under the Technology Transitions Rule, remain selected even if not covered by the Technology Transitions Rule's restrictions (including those abatement options that would lead to immediate emission reductions). The high additionality case is representative of the upper bound of incremental benefits of the rule, illustrating the range of incremental benefits depending on the ultimate transition pathway.

Table 5-2 below shows the emission reductions by year corresponding to the Technology Transitions Rule compliance scenario in the base case and high additionality case, which are compared to the Allocation Rule Reference Scenario to evaluate incremental reductions.

Table 5-2: Annual Emission Reductions in the Allocation Rule Reference Case and Technology Transitions Compliance Base Case and High Additionality Case[a]

	Allocation Rule Reference Case	***Technology Transitions Base Case***		***Technology Transitions High Additionality Case***	
Year	***Emission Reductions (MMTEVe)***	***Emission Reductions (MMTEVe)***	***Incremental Emission Reductions (MMTEVe)***	***Emission Reductions (MMTEVe)***	***Incremental Emission Reductions (MMTEVe)***
2025	93	38	-54	99	7
2026	96	48	-47	106	11
2027	106	59	-47	120	15
2028	113	70	-43	131	18
2029	98	81	-17	129	31
2030	108	93	-15	141	33
2031	117	104	-13	152	35
2032	124	116	-9	162	38
2033	132	128	-4	172	40
2034	142	141	-1	183	41
2035	150	153	3	193	44
2036	171	164	-6	205	34
2037	176	179	3	213	37
2038	183	194	11	222	39
2039	190	208	18	229	39
2040	197	221	25	235	38
2041	204	228	24	240	37
2042	210	234	24	246	36
2043	215	240	25	251	36
2044	220	246	26	256	37
2045	224	252	28	261	37
2046	227	256	29	265	38
2047	231	260	30	269	38
2048	234	264	31	272	39
2049	236	267	31	276	39
2050	239	271	32	279	40
Total	**4,435**	**4,516**	**83**	**5,309**	**876**

[a] Rows may not appear to add correctly due to rounding.

Annex B further disaggregates the emission reductions by metric tons of each gas abated. It is these values that are used to calculate the climate-related benefits using the SC-HFC values described in the remainder of this chapter.

5.3 The Social Cost of HFC Emissions

5.3.1 Methodology overview

This analysis relies on the same methodology for calculating the social cost of HFC emissions as previous regulatory impact analyses conducted by EPA for AIM Act regulations.[26] While CO_2 is the most prevalent GHG emitted by humans, it is not the only GHG with climate impacts. The EPA Endangerment Finding (2009) recognized a basket of six gases, comprising CO_2, methane (CH_4), nitrous oxide (N_2O), HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The climate impact of the emission of a molecule of each of these gases is generally a function of their lifetime in the atmosphere and the radiative efficiency of that molecule.[27] We estimate the climate benefits for this rulemaking using a measure of the social cost of each HFC (collectively referred to as SC-HFC) that is affected by the rule. The SC-HFC is the monetary value of the net harm to society associated with a marginal increase in HFC emissions in a given year or the benefit of avoiding that increase. In principle, SC-HFC includes the value of all climate change impacts, including (but not limited to) changes in net agricultural 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.

The gas-specific SC-HFC estimates used in this analysis were developed using methodologies that are consistent with the methodology underlying estimates of the social cost of other GHGs (carbon dioxide [SC-CO_2], methane [SC-CH_4], and nitrous oxide [SC-N_2O]), collectively referred to as SC-GHG, presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* published in February 2021 by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) (IWG 2021). As a member of the IWG involved in the development of the February 2021 SC-GHG Technical Support Document (TSD), EPA agrees that the TSD represents the most appropriate methodology for estimating the social cost of greenhouse gases until revised estimates have been developed reflecting the latest, peer-reviewed science. Therefore, EPA views the SC-HFC estimates used in analysis to be appropriate for use in benefit-cost analysis until improved estimates of the social cost of other GHGs are developed.

---

[26] Available at www.regulations.gov under Docket ID EPA-HQ-OAR-2021-0044.

[27] 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).

The SC-GHG estimates were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, in 2009, an interagency working group (IWG) that included EPA and other executive branch agencies and offices was established to ensure that agencies had access to the best available information when quantifying the benefits of reducing CO_2 emissions in benefit-cost analyses. The IWG published SC-CO_2 estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set of input assumptions in each model for future population, economic, and CO_2 emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. These estimates were updated in 2013 based on new versions of each IAM.[28] In August 2016 the IWG published estimates of the social costs 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. The modeling approach that extends the IWG SC-CO_2 methodology to non-CO_2 GHGs has undergone multiple stages of peer review. The SC-CH_4 and SC-N_2O estimates were developed by Marten, Kopits, Griffiths, Newbold, and Wolverton (2015) and underwent a standard double-blind peer review process prior to journal publication. These estimates were applied in regulatory impact analyses of EPA proposed rulemakings with CH_4 and N_2O emissions impacts.[29] EPA also sought additional external peer review of technical issues associated with its application to regulatory analysis. Following the completion of the independent external peer review of the application of the Marten et al. (2015) estimates, EPA began using the estimates in the primary benefit-cost analysis calculations and tables for a number of proposed rulemakings in 2015 (EPA 2015b, 2015c). EPA considered and responded to public comments received for the proposed rulemakings before using the estimates in final regulatory analyses in 2016.[30] 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*

[28] Dynamic Integrated Climate and Economy (DICE) 2010 (Nordhaus, 2010), Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) 3.8 (Anthoff & Tol, 2013a, 2013b), and Policy Analysis of the Greenhouse Gas Effect (PAGE) 2009 (Hope, 2013).

[29] The SC-CH_4 and SC-N_2O estimates were first used in sensitivity analysis for the Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2 (U.S. EPA, 2015).

[30] See IWG (2016b) for more discussion of the SC-CH_4 and SC-N_2O and the peer review and public comment processes accompanying their development.

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). Shortly thereafter, in March 2017, President Trump issued Executive Order 13783, which disbanded the IWG, withdrew the previous TSDs, and directed agencies to ensure SC-GHG estimates used in regulatory analyses are consistent with the guidance contained in OMB's Circular A-4, "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (Executive Order 13783, Section 5(c)). Benefit-cost analyses following Executive Order 13783 used SC-GHG estimates that attempted to focus on the U.S.-specific share of climate change damages as estimated by the models (and so did not reflect many pathways by which physical impacts outside the United States affect the welfare of U.S. citizens and residents) and were calculated using two default discount rates recommended by Circular A-4, 3 percent and 7 percent.[31] All other methodological decisions and model versions used in the SC-GHG calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued Executive Order 13990, which re-established the IWG and directed it to develop a comprehensive update of the SC-GHG estimates that reflect the best available science and the recommendations of National Academies (2017). In February 2021, the IWG recommended the interim use of the most recent SC-GHG estimates developed by the IWG prior to the group being disbanded in 2017 (IWG, 2021). As discussed in the February 2021 TSD, the IWG's selection of these interim estimates reflected the immediate need to have SC-GHG estimates available for agencies to use in regulatory benefit-cost analyses and other applications that were developed using a transparent process, peer reviewed methodologies, and the science available at the time of that process. The February 2021 update also recognized the limitations of the interim estimates and encouraged agencies to use their best judgment in, for example, considering sensitivity analyses using lower discount rates. The IWG published a Federal Register notice on May 7, 2021, soliciting comment on the February 2021 TSD and on how best to incorporate the latest peer-reviewed scientific literature in order to develop an updated set of SC-GHG estimates. The EPA has applied the IWG's interim SC-GHG estimates in regulatory analyses published since the release of the February 2021 TSD.

---

[31] EPA regulatory analyses under Executive Order 13783 included sensitivity analyses based on global SC-GHG values and using a lower discount rate of 2.5%. OMB Circular A-4 (OMB, 2003) recognizes that special considerations arise when applying discount rates if intergenerational effects are important. In the IWG's 2015 *Response to Comments*, OMB—as a co-chair of the IWG—made clear that "Circular A-4 is a living document," that "the use of 7 percent is not considered appropriate for intergenerational discounting," and that "[t]here is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself." OMB, as part of the IWG, similarly repeatedly confirmed that "a focus on global SCC estimates in [regulatory impact analyses] is appropriate" (IWG 2015).

The SC-HFC estimates used in this analysis were developed using methodologies consistent with the methodologies underlying the interim estimates of the SC-GHG published in February 2021 by the IWG. As such, we first summarize the general findings of the IWG review and interim update, and then provide more discussion of the modeling decisions specific to the estimation of the social cost of non-CO_2 GHGs.

The February 2021 SC-GHG TSD provides a complete discussion of the IWG's initial review conducted under Executive Order 13990. In particular, the IWG found that the SC-GHG estimates used under Executive Order 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG concluded that those estimates fail to capture many climate impacts that can affect the welfare of U.S. citizens and residents. Examples of affected interests include direct effects on U.S. citizens and assets located abroad, international trade, tourism, and spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns. Those impacts are better captured within global measures of the social cost of greenhouse gases.

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. A wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions. Using a global estimate of damages in U.S. analyses of regulatory actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to take significant steps to reduce emissions. The only way to achieve an efficient allocation of resources for emission reductions on a global basis — and so benefit the U.S. and its citizens — is for all countries to base their policies on global estimates of damages.

As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, EPA agrees with this assessment and, therefore, in this rule the 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. A robust estimate of climate damages to U.S. citizens and residents that accounts for the myriad of ways that global climate change reduces the net welfare of U.S. populations does not currently exist in the literature. As explained in the February 2021 TSD, existing estimates are both incomplete and an underestimate of total damages that accrue to the citizens and residents of the U.S. because they do not fully capture the regional interactions and spillovers discussed above, nor do they include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature, as discussed further below. The EPA, as a member of the IWG, will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various damages to U.S. populations from climate impacts and reciprocal international mitigation activities, and explore ways to better inform the public of the full range of carbon impacts.

Second, the IWG concluded 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 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.[32] Furthermore, the damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms, and so an application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG. As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, the EPA agrees with this assessment and will continue to follow developments in the literature pertaining to this issue. EPA also notes that while OMB Circular A-4, as published in 2003, recommends using 3 percent and 7 percent discount rates as “default” values, Circular A-4 also reminds agencies that “different regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues and the sensitivity of the benefit and cost estimates to the key assumptions.” On discounting, Circular A-4 recognizes that “special ethical considerations arise when comparing benefits and costs across generations,” and Circular A-4 acknowledges that analyses may appropriately “discount future costs and consumption benefits…at a lower rate than for intragenerational analysis.” In the 2015 Response to Comments on the Social Cost of Carbon for Regulatory Impact Analysis, OMB, EPA, and the other IWG members recognized that “Circular A-4 is a living document” and “the use of 7 percent is not considered appropriate for intergenerational discounting. There is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself.” Thus, EPA concludes that a 7 percent discount rate is not appropriate to apply to value the social cost of greenhouse gases in this analysis. To calculate the present and annualized values of climate benefits in this analysis, EPA uses the same discount rate as the rate used to discount the value of damages from future GHG emissions, for internal consistency. That

[32] GHG emissions are stock pollutants, with damages associated with what has accumulated in the atmosphere over time, and they are long lived such that subsequent damages resulting from emissions today occur over many decades or centuries depending on the specific greenhouse gas under consideration. In calculating the SC-GHG, the stream of future damages to agriculture, human health, and other market and non-market sectors from an additional unit of emissions are estimated in terms of reduced consumption (or consumption equivalents). Then that stream of future damages is discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages.

approach to discounting follows the same approach that the February 2021 SC-GHG TSD recommends "to ensure internal consistency—i.e., future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate." EPA has also consulted the National Academies' 2017 recommendations on how SC-GHG estimates can "be combined in RIAs with other cost and benefits estimates that may use different discount rates." The National Academies reviewed "several options," including "presenting all discount rate combinations of other costs and benefits with [SC-GHG] estimates."

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 recommended 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 SC-GHG TSD, the IWG has concluded 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 SC-GHG TSD, and EPA agrees, this update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013. Since the original 2010 SC-CO_2 TSD did not include direct estimates of the social cost of non-CO_2 GHGs and did not endorse the use of GWP metrics to approximate the value of non-CO_2 emission changes in regulatory analysis,[33] more work was needed

[33] The potential of non-CO_2 GHGs to change the Earth's climate relative to CO_2 is commonly represented by their 100-year GWP. GWPs measure the contribution to warming of the Earth's atmosphere resulting from emissions of a given gas (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. As such, GWPs are often used to convert emissions of non-CO_2 GHGs to CO_2 equivalents to facilitate comparison of policies and inventories involving different GHGs. While GWPs allow for some useful comparisons across gases on a physical basis, using the social cost of carbon dioxide (SC-CO_2) to value the damages associated with changes in CO_2-equivalent emissions is not optimal. This is because non-CO_2 GHGs differ not just in their potential to absorb infrared radiation over a given time frame, but also in the temporal pathway of their impact on radiative forcing, which is relevant for estimating their social cost but not reflected in the GWP. Physical impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike CH_4

following 2010 to link non-CO_2 GHG emission changes to economic impacts. The IWG calculated the SC-CH_4 and SC-N_2O estimates following the approach used in Marten et al. (2015). In order to develop SC-CH_4 and SC-N_2O estimates consistent with the methodology underlying the SC-CO_2 estimates, Marten et al. (2015) needed to minimally augment the IWG modeling framework in two respects: (1) augment the climate model of two of the IAMs to explicitly consider the path of additional radiative forcing from a CH_4 or N_2O perturbation, and (2) add more specificity to the 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 mirrors that of the peer-reviewed SC-CH_4 and SC-N_2O estimates (Marten et al. 2015, IWG 2016a, IWG 2016b), 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.[34] Therefore, to estimate the SC-HFC, we applied a one-box atmospheric gas cycle model to explicitly consider the path of additional radiative forcing from the HFC perturbation, which is then added to the exogenous non-CO_2 radiative forcing projection to estimate the incremental damages compared with the baseline. The one-box atmospheric gas cycle model appended to DICE and PAGE used exponential decay functions to project atmospheric HFC concentrations from the HFC emissions projections, respectively, in the five socioeconomic emissions scenarios. Consistent with the SC-CH_4 and SC-N_2O, the average lifetime of each HFC follow the findings of the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) (Forster et al. 2007). The direct radiative forcing associated with the atmospheric HFC concentration was estimated using the functional relationships for each gas presented in the IPCC's Third Assessment Report (Ramaswamy et al. 2001) and used in AR4.

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

---

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).

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

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.

5.3.2 SC-HFC estimates

Tables 5-3 through 5-12 summarize the SC-HFC estimates for the years 2020 through 2050 in five-year increments. 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 full range of annual unrounded estimates are available in Appendix E of the Allocation Framework Rule RIA.[35] For purposes of capturing uncertainty around the SC-HFC estimates in analyses, we emphasize the importance of considering all four values for each HFC affected by the rule. The SC-HFC increases over time within the models—i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025—because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 5-3: Social Cost of HFC-32, 2020–2050 (in 2020 dollars per metric ton HFC-32)

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

	Discount Rate and Statistic			
Year	***5% Average***	***3% Average***	***2.5% Average***	***3% 95th Pct.***
2020	83000	210000	290000	550000
2025	99000	240000	330000	640000

[35] Available at www.regulations.gov under Docket ID EPA-HQ-OAR-2021-0044.

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 5-5: Social Cost of HFC-134a, 2020–2050 (in 2020 dollars per metric ton HFC-134a)

	Discount Rate and Statistic			
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 5-6: Social Cost of HFC-143a, 2020–2050 (in 2020 dollars per metric ton HFC-143a)

	Discount Rate and Statistic			
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 5-7: Social Cost of HFC-152a, 2020–2050 (in 2020 dollars per metric ton HFC-152a)

	Discount Rate and Statistic			
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 5-8: Social Cost of HFC-227ea, 2020–2050 (in 2020 dollars per metric ton HFC-227ea)

	Discount Rate and Statistic			
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 5-9: Social Cost of HFC-236fa, 2020–2050 (in 2020 dollars per metric ton HFC-236fa)

	Discount Rate and Statistic			
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 5-10: Social Cost of HFC-245fa, 2020–2050 (in 2020 dollars per metric ton HFC-245fa)

	Discount Rate and Statistic			
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 5-11: Social Cost of HFC-43-10mee, 2020–2050 (in 2020 dollars per metric ton HFC-43-10mee)

	Discount Rate and Statistic			
Year	***5% Average***	***3% Average***	***2.5% Average***	***3% 95th Pct.***
2020	43000	100000	130000	260000
2025	52000	120000	150000	310000
2030	62000	130000	170000	360000
2035	73000	150000	200000	410000

2040	86000	170000	220000	470000
2045	99000	190000	240000	520000
2050	110000	220000	270000	570000

Table 5-12: Social Cost of HFC-23, 2020–2050 (in 2020 dollars per metric ton HFC-23)

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

Since the SC-HFC estimates presented in Tables 5-3 to 5-12 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 interim 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-GHG estimates. However, the IWG has recommended that, taken together, the limitations suggest that the interim SC-GHG estimates used in this rule 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 the National Academies of Sciences, Engineering, and Medicine (National Academies, 2017, 2019).The modeling limitations do not all work in the same direction in terms of their influence on the SC-GHG estimates. However, the IWG has recommended that, taken together, the limitations suggest that the interim SC-GHG estimates used in this rule 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 the National Academies of Sciences, Engineering, and Medicine (National Academies, 2017, 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). EPA has reviewed and considered the limitations of the models used to estimate the interim SC-GHG estimates and concurs with the February 2021 SC-GHG TSD's assessment that, taken together, the limitations suggest that the interim SC-GHG estimates likely underestimate the damages from GHG emissions. The February 2021 SC-GHG 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.

5.4 Monetized Climate Benefits Results

To monetize the climate benefits resulting from the Technology Transitions Rule, the HFC emission reductions in each year (Table 5-2) are multiplied by the corresponding SC-HFC for that HFC in that year

(Tables 5-3 through 5-12). Table 5-13 presents the incremental climate benefits for the Technology Transitions Final Rule base case for select years from 2025-2050, evaluated from the Allocation Rule Reference Case.[36] The incremental climate benefits shown here represent the additional benefits (positive numbers) achieved from the Technology Transitions Rule base case and high additionality case.

Table 5-13: Incremental Climate Benefits for the Final Rule for select years from 2025-2050 (Base Case scenario – Billions of 2020$)[a,b]

	Incremental climate benefits by discount rate and statistic			
Year	***5% (average)***	***3% (average)***	***2.5% (average)***	***3% (95th percentile)***
2025	-1.6	-3.7	-5.0	-9.9
2029	-0.5	-1.3	-1.7	-3.3
2034	0.0	-0.1	-0.1	-0.2
2036	-0.5	-0.6	-0.7	-1.7
2040	1.0	2.4	3.2	6.5
2045	1.4	3.1	4.0	8.2
2050	1.8	3.9	5.0	10.2

[a] Benefits include only those related to climate
[a] Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; and 95th percentile at 3 percent discount rate). The IWG emphasized, and EPA agrees with, 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.

Table 5-14 presents the undiscounted monetized incremental climate benefits from all regulated HFCs under the Technology Transitions Rule base case and high additionality case, evaluated from the Allocation Rule Reference Case. When the base case benefits are discounted to 2022 using a discount rate of 3 percent, the present value of the incremental benefits of this rule from 2025–2050 are estimated to be $3.0 billion in 2020 dollars (Table 5-14). This is equivalent to an annual incremental benefit of $184 million per year over that timeframe. Similarly, the present value of the incremental benefits of the high additionality case from 2025–2050 are estimated to be $50 billion in 2020 dollars, discounting to 2022 using a discount rate of 3 percent, with an annual incremental benefit of $3 billion per year over that timeframe.[37] Table 5-14 shows discounted monetized incremental climate benefits and the PV and EAV for the 2025–2050 time period using a 3 percent discount rate for the Technology Transitions Rule base

[36] This includes the 2024 Allocation Rule including the lower baseline and changes to one of the abatement options.
[37] The Allocation Rule Reference Case projects the present value of climate-related benefits from 2025 through 2050 to be $253.2 billion (2020$, 3% discount rate, discounted to 2022). The Technology Transitions Rule base case projects climate-related benefits over the same time period to be $5 billion, equivalent to 2% of those projected for the Allocation Rule Reference Case. The high additionality case projects climate-related benefits over the same time period to be $79 billion, equivalent to 31% of those projected for the Allocation Rule Reference Case. (Table 5-14).

case and high additionality case. The future benefits in each column are discounted back to 2022 to produce the present value estimate.

Table 5-14: Discounted Monetized Climate Benefits of the Technology Transitions Rule 2025–2050 (millions of 2020$)[a,b,c]

Year	Technology Transitions Base Case Incremental Climate Benefits (millions 2020$)	Technology Transitions High Additionality Case Incremental Climate Benefits (millions 2020$)
2025	($3,730)	$486
2026	($3,347)	$771
2027	($3,406)	$1,073
2028	($3,218)	$1,339
2029	($1,253)	$2,451
2030	($1,171)	$2,652
2031	($1,000)	$2,893
2032	($687)	$3,148
2033	($345)	$3,416
2034	($73)	$3,636
2035	$297	$3,924
2036	($613)	$3,121
2037	$293	$3,469
2038	$1,106	$3,747
2039	$1,797	$3,876
2040	$2,448	$3,831
2041	$2,378	$3,710
2042	$2,463	$3,721
2043	$2,628	$3,829
2044	$2,845	$4,027
2045	$3,080	$4,164
2046	$3,265	$4,338
2047	$3,424	$4,489
2048	$3,587	$4,648
2049	$3,711	$4,772
2050	$3,869	$4,938
PV (3% d.r.)	$3,013	$50,406
EAV (3% d.r.)	$184	$3,081

[a] Rows may not appear to add correctly due to rounding.
[b] The equivalent annual values of benefits are calculated over a 26-year period from 2025 to 2050.
[c] Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show effects 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. A consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

Chapter 6: Comparison of Benefits and Costs

This section summarizes the total incremental compliance costs (or savings) and the monetized incremental environmental benefits detailed in the sections above to provide an assessment of the total net incremental costs/benefits of the rule. The rule's abatement costs are estimated using the Vintaging Model and an evaluation of marginal abatement cost curves. This analysis uses abatement costs as a proxy for social costs. As shown in Section 4.4, Table 4-3, the base case estimated that the total annual abatement costs to implement the Technology Transitions Rule are approximately $0.21 billion in 2025 and -$1.54 billion in 2050 (2020$), while the incremental annual abatement costs are $0.07 billion in 2025 and -$0.63 billion in 2050 (2020$). As shown in Section 4.6, Table 4-4, the recordkeeping, reporting, and labeling costs are approximately $6.6 million in 2025 and $6.3 million in 2026 and beyond (2020$). The base case total costs inclusive of abatement costs and recordkeeping, reporting, and labeling costs are approximately $0.21 billion in 2025 and -$1.5 billion in 2050 (2020$). The base case incremental compliance costs are $0.07 billion in 2025 and -$0.6 billion in 2050 (2020$). The high additionality case total costs inclusive of abatement costs and recordkeeping, reporting, and labeling costs are approximately $0.67 billion in 2025 and -$1.46 billion in 2050 (2020$). The high additionality case incremental compliance costs are $0.53 billion in 2025 and -$0.55 billion in 2050 (2020$). Table 6-1 summarizes the annual abatement, annual recordkeeping, reporting, and labeling, and total annual costs for selected years for both the base case and high additionality case.

Table 6-1: Summary of Cost Components of Base Case and High Additionality Case Scenarios for Selected Years, 2025–2050 (millions of 2020$)

Year	Allocation Rule Reference Case Costs (Savings)	Technology Transitions Rule						
			Base Case			High Additionality Case		
		Record-keeping, Reporting, & Labeling Costs	MAC Model Net Abatement Costs (Savings)	Total Costs (Savings) (Abatement + R&R)	Total Incremental Costs (Savings)	MAC Model Net Abatement Costs (Savings)	Total Costs (Savings) (Abatement + R&R)	Total Incremental Costs (Savings)
2025	$139	$6.6	$205	$212	$73	$664	$671	$532
2029	($471)	$6.3	($270)	($263)	$208	$20	$26	$498
2034	($768)	$6.3	($802)	($796)	($28)	($676)	($670)	$98
2036	($530)	$6.3	($960)	($953)	($424)	($917)	($911)	($381)
2040	($606)	$6.3	($1,289)	($1,283)	($677)	($1,230)	($1,224)	($618)
2045	($738)	$6.3	($1,331)	($1,325)	($587)	($1,266)	($1,260)	($523)
2050	($909)	$6.3	($1,535)	($1,529)	($619)	($1,465)	($1,459)	($549)

As shown in Chapter 5, the estimated base case monetized incremental climate benefits from implementation of the rule are approximately $-3.7 billion in 2025 (2020$, using a 3 percent discount rate). For 2050, the estimated base case monetized annual incremental climate benefits from implementation of the rule are approximately $3.8 billion (using a 3 percent discount rate). The estimated high additionality case monetized annual incremental climate benefits from implementation of the rule are approximately $0.5 billion in 2025 (2020$, using a 3 percent discount rate) and $4.9 billion (using a 3 percent discount rate) in 2050.

EPA calculates the incremental net benefits of the rule by subtracting the estimated incremental abatement costs from the estimated incremental benefits. The benefits include those to climate. The annual base case incremental net benefits of the rule in 2025 (in 2020$) are approximately -$3.8 billion. The annual high additionality case incremental net benefits of the rule in 2025 (in 2020$) are approximately -$0.46 billion. The annual base case incremental net benefits of the rule in 2029 are approximately -$1.4 billion, while the annual high additionality case incremental net benefits are $1.9 billion. The annual base case incremental net benefits of the rule in 2034 are approximately -$45 million, while the annual high additionality case incremental net benefits are $3.5 billion. The annual base case incremental net benefits of the rule in 2036 are approximately -$190 million, while the annual high additionality case incremental net benefits are $3.5 billion. The annual base case incremental net benefits of the rule in 2045 are approximately $3.6 billion, while the annual high additionality case incremental net benefits are $4.7 billion. The annual base case incremental net benefits of the rule in 2050 are approximately $4.5 billion, while the annual high additionality case incremental net benefits are $5.5 billion. Table 6-2 presents annual costs and net benefits of the rule for the time period of 2025–2050.

As part of fulfilling analytical guidance with respect to Executive Order 12866, EPA presents estimates of the present value (PV) of the benefits and costs over the 29-year period 2022 to 2050. To calculate the PV of the net benefits of the rule, annual costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4. Climate benefits are discounted at 3 percent as described in Section 5.3 and consistent with the Final Regulatory Impact Analysis for the Allocation Framework Rule.[38] EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2025 to 2050, would yield a sum equivalent to the PV, discounted at 3 percent and 7 percent. The EAV represents the value of a constant cost or net benefit for each year of the analysis, in contrast to the year-specific estimates mentioned earlier in this document.

[38] Available at *www.regulations.gov* under Docket ID EPA-HQ-OAR-2021-0044, or see 86 FR 55116 (October 5, 2021).

EPA estimates that the range of PV of cumulative net incremental benefits evaluated from 2025 through 2050 is $7.6 billion to $52 billion at a 3 percent discount rate for the base case and high additionality case respectively. The range of incremental EAV over the period 2025–2050 is $0.46 billion and $3.1 billion when using a 3 percent discount rate for the base case and high additionality case respectively. The comparison of benefits and costs in PV and EAV terms for the base case and high additionality case can be found in Table 6-2. Estimates in the table are presented as rounded values.

Table 6-2 – Summary of Annual Incremental Climate Benefits, Costs, and Net Benefits of the Technology Transitions Rule Base Case and High Additionality Case Scenarios for the 2025–2050 Timeframe (millions of 2020$, discounted to 2022)[a,b,c,d]

	Base Case			***High Additionality Case***		
Year	***Incre-mental Climate Benefits (3%)***	***Annual Costs (savings)***	***Net Benefits (3% Benefits, 3% or 7% Costs)*** [e]	***Incre-mental Climate Benefits (3%)***	***Annual Costs (savings)***	***Net Benefits (3% Benefits, 3% or 7% Costs)*** [e]
2025	($3,730)	$73	($3,803)	$486	$532	($46)
2026	($3,347)	($179)	($3,168)	$771	$204	$567
2027	($3,406)	($255)	($3,151)	$1,073	$135	$938
2028	($3,218)	($275)	($2,943)	$1,339	$87	$1,252
2029	($1,253)	$208	($1,461)	$2,451	$498	$1,953
2030	($1,171)	$136	($1,307)	$2,652	$429	$2,223
2031	($1,000)	$102	($1,102)	$2,893	$399	$2,494
2032	($687)	$85	($772)	$3,148	$336	$2,812
2033	($345)	$114	($459)	$3,416	$301	$3,115
2034	($73)	($28)	($45)	$3,636	$98	$3,538
2035	$297	($1)	$298	$3,924	$66	$3,858
2036	($613)	($424)	($190)	$3,121	($381)	$3,501
2037	$293	($466)	$759	$3,469	($432)	$3,901
2038	$1,106	($525)	$1,631	$3,747	($494)	$4,240
2039	$1,797	($615)	$2,412	$3,876	($519)	$4,395
2040	$2,448	($677)	$3,125	$3,831	($618)	$4,449
2041	$2,378	($579)	$2,956	$3,710	($519)	$4,229
2042	$2,463	($573)	$3,037	$3,721	($514)	$4,235
2043	$2,628	($574)	$3,202	$3,829	($514)	$4,343
2044	$2,845	($581)	$3,426	$4,027	($516)	$4,543
2045	$3,080	($587)	$3,667	$4,164	($523)	$4,687
2046	$3,265	($589)	$3,854	$4,338	($523)	$4,862
2047	$3,424	($591)	$4,015	$4,489	($525)	$5,013
2048	$3,587	($594)	$4,181	$4,648	($526)	$5,173
2049	$3,711	($603)	$4,314	$4,772	($534)	$5,306
2050	$3,869	($619)	$4,488	$4,938	($549)	$5,488

Discount rate	3%	3%	7%	3%	7%	3%	3%	7%	3%	7%
PV	$3,013	($4,549)	($2,073)	$7,561	$5,086	$50,406	($1,601)	$1	$52,007	$50,405
EAV	$184	($278)	($215)	$462	$399	$3,081	($98)	$0	$3,179	$3,081

[a] Benefits include only those related to climate. Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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. A consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[b] Rows may not appear to add correctly due to rounding.
[c] The annualized present value of costs and benefits are calculated as if they occur over a 26-year period from 2025 to 2050.
[d] The costs presented in this table are annual estimates.
[e] The PV for the 7% net benefits column is found by taking the difference between the PV of climate benefits at 3% and the PV of costs discounted at 7%. Due to the intergenerational nature of climate impacts the social rate of return to capital, estimated to be 7% in OMB's Circular A-4, is not appropriate for use in calculating PV of climate benefits.

Chapter 7: Supplementary Analysis of Alternative GWP Restriction Scenarios

7.1 Introduction

This chapter contains a supplementary assessment of economic costs and benefits under alternative compliance scenarios with either higher or lower GWP limits than those contained in the rule. This supplementary analysis helps illustrate the extent to which costs and benefits may shift under more or less restrictive limits, while also demonstrating that in many cases impacts would be essentially unchanged. Importantly, this supplementary analysis is conducted for illustrative purposes only.

7.2 Description of Scenarios

We modeled two alternative scenarios in order to evaluate potential differences in costs and benefits compared to the final rule base case: one with GWP limits for all subsectors set 50% higher, and one with GWP limits for all subsectors set 50% lower. In making assumptions about the HFC substitutes and technologies that would be used in the base case for the rule as well as the higher and lower bound scenarios, our approach relies on industry data of already commercially established or near-commercially established substitutes for HFCs. We acknowledge this as a modeling limitation, since ultimately industry is expected to innovate and develop new lower-GWP substitutes that are as yet undeveloped or for which data on expected costs do not exist. This means these scenarios are indicative of potential future costs and benefits, but not meant as prescriptive or fully predictive.

Table 7-1 below details the GWP limits assumed for the base, upper, and lower bound scenarios as well as the corresponding assumed technological transitions for each subsector. As shown in the table, even under the higher and lower GWP limit scenarios, for many subsectors the assumed transitions remain unchanged. This stems from fact that there are a finite number of known substitutes for any given subsector. Therefore, additional options may not necessarily be available even if the GWP limits are loosened, and by the same token many GWP transitions made in the base case scenario—particularly those that are already zero or near-zero GWP substances—would still be in compliance even if the GWP is lowered further.

Table 7-1: GWP Limits and Transition Assumption for the Technology Transitions Base Case, Lower Scenario, and Higher Scenario

	Technology Transitions Base Case Scenario		***50% Lower Scenario***		***50% Higher Scenario***	
Subsector	***GWP Limit***	***Transition Assumptions***	***GWP Limit***	***Transition Assumptions***	***GWP Limit***	***Transition Assumptions***

Centrifugal Chillers	700	HFC-134a replaced w/ R-450A/R-513A; HFC-245fa replaced w/ HCFO-1233zd(E)	350	Transition to HCFO-1233zd(E)	1,050	No change (no known additional likely alternative)
Screw Chillers	700	R-410A & R-407C replaced w/ HFO-1234ze(E)	350	No change (base case complies with limit)	1,050	No change (no known additional likely alternative)
Scroll Chillers	700	R-410A & R-407C replaced w/ HFO-1234ze(E)	350	No change (base case complies with limit)	1,050	No change (no known additional alternative)
Reciprocating Chillers	700	R-410A & R-407C replaced w/ R-452B	350	Transition to HFO-1234ze(E)	1,050	No change (no known additional likely alternative)
Industrial Process Refrigeration (<200 lb charge)	300	NH_3/CO_2	150	No change (base case complies with limit)	450	No change (no known additional likely alternative)
Industrial Process Refrigeration (>=200 lb charge)	150	NH_3/CO_2	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Data Centers, Computer Room Air Conditioning, and Information Technology Equipment Cooling	700	R-454B	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
Ice Rinks	700	R-454B	350	Transition to HFO-1234ze(E)	1,050	No change (no known additional likely alternative)
Cold Storage (<200 lb charge)	300	NH_3/CO_2	150	No change (base case complies with limit)	450	No change (no known additional likely alternative)
Cold Storage (>=200 lb charge)	150	NH_3/CO_2	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Large Retail Food (<200 lb charge)	300	R-407A to CO_2 Transcritical; R-404A/R-507A to CO_2 Transcritical	150	No change (base case complies with limit)	450	R-454A is an available option
Large Retail Food (>=200 lb charge)	150	R-407A to CO_2 Transcritical; R-404A/R-507A to CO_2 Transcritical	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Medium Retail Food (<200 lb charge)	300	CO_2	150	No change (base case complies with limit)	450	R-454A is an available option
Medium Retail Food (>=200 lb charge)	150	CO_2	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Small Retail Food	150	HCs	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Refrigerated Food Processing and	1,425**	R-448A/R-449A/R-449B	712.5	Transition to HFC-32	2,137.5	R-452A is an available option

Dispensing Equipment (within the scope of UL 621)						
Refrigerated Food Processing and Dispensing Equipment, Self-Contained (<=500 gram charge; not within the scope of UL 621)	150	HCs	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Refrigerated Food Processing and Dispensing Equipment (>500 gram charge; not within the scope of UL 621)	1,425**	R-448A/R-449A/R-449B	712.5	Transition to HFC-32	2,137.5	R-452A is an available option
Refrigerated Food Processing and Dispensing Equipment (remote; not within the scope of UL 621)	1,425**	R-448A/R-449A/R-449B	712.5	Transition to HFC-32	2,137.5	R-452A is an available option
Vending Machines	150	R-290	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Ice Machines Self-Contained batch type (harvest rate <=1,000 pounds ice per 24 hours	150	R-290	350	No change (base case complies with limit)	1,050	R-32 or R-454B are available options
Ice Machines Self-Contained continuous type (harvest rate <=1,200 pounds ice per 24 hours)	150	R-290	350	No change (base case complies with limit)	1,050	R-32 or R-454B are available options
Ice Machines, Self-Contained (harvest rate >1,000 pounds ice per 24 hours (batch) or >1,2000 pounds ice per 24 hours (continuous))	1,425**	R-448A/R-449A	712.5	No change (base case complies with limit)	2,137.5	R-452A is an available option
Ice Machines, Remote	2,200*	R-448A/R-449A	1,100	Transition to R-290	3,300	R-452A is an available option
Refrigerated Transport—	700	R-450A/R-513A	350	Transition to R-454A	1050	No change (no known additional likely alternative)

Intermodal Containers						
Refrigerated Transport—Marine and Road	2,200*	R-452A	1,100	Transition to R-450A/R-513A	3,300	No change (no known additional likely alternative)
Household Refrigerator-Freezers	150	HFC-134a to R-600a	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Residential Dehumidifiers	700	R-32	350	Transition to R-290	1,050	No change (no known additional likely alternative)
Window A/C Units	700	R-32	350	Transition to R-290	1,050	No change (no known additional likely alternative)
Residential Unitary A/C	700	R-454B	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
Small Commercial Unitary A/C	700	R-32	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
Large Commercial Unitary A/C	700	R-32	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
Water & Ground Source HP	700	R-32/R-452B	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
PTAC/PTHP	700	R-32/R-452B	350	Transition to R-454A	1,050	No change (no known additional likely alternative)
Non-MDI Aerosols	150	HFC-134a to HFC-152a; HFC-134a/HFC-152a to Not-in-kind (NIK), HCs, HFO-1234ze(E)	75	Transitions to NIK, HC, HFO-1234ze(E)	225	No change (no known additional likely alternative)
Rigid Polyurethane (PU) Appliance Foam	150	HCs, HCFO-1233zd(E)	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Rigid PU Commercial Refrigeration Foam	150	HFC-245fa to HCFO-1233zd(E)	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Rigid PU Sandwich Panels	150	HFC-134a to HCs; HFC-245fa/CO_2 to HCFO-1233ze(E)	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Polystyrene Extruded Boardstock and Billet Foam	150	HFC-134a/CO_2 to HFO-1234ze(E)/HCFO-1233zd(E)	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Integral Skin PU Foam	150	HCs	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)
Rigid PU and Polyisocyanurate Laminated Boardstock	150	HCs	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)

Spray Foam	150	HFC-134a to HFO-1234ze(E); HFC-245fa to HCFO-1233zd(E), HFO-1234ze(E)	75	No change (base case complies with limit)	225	No change (no known additional likely alternative)

* No specific GWP limit is set for remote ice machines, refrigerated transport—road, or refrigerated transport—marine. Based on the specific HFCs and specific blends containing HFCs prohibited, these subsectors are modeled as a GWP limit of 2,200.

** No specific GWP limit is set for self-contained batch type ice machines with a harvest rate greater than 1,000 pounds of ice per 24 hours, self-contained continuous type ice machines with a harvest rate greater than 1,200 pounds of ice per 24 hours, or refrigerated food processing and dispensing equipment with charge sizes greater than 500 grams. Based on the specific HFCs and specific blends containing HFCs prohibited, these subsectors are modeled as a GWP limit of 1,425.

7.3 Results

Results of this exercise are shown in Tables 7-2 and 7-3 below. In terms of avoided HFC consumption, the results are generally aligned with expectations and indicate that a raising or lowering of the GWP limits in the rule would have the effect of producing corresponding increases or decreases, respectively, in HFC consumption and emissions. However, it is notable that the change is modest in both cases. In the high-GWP case, with limits 50% higher than those in the rule, annual HFC consumption reductions are approximately 1.7% lower on average relative to the base case, for a cumulative difference of approximately -130 MMTEVe through 2050. In the low-GWP case, with limits set 50% lower, annual HFC consumption reductions are approximately 3.5% higher on average relative to the base case, for a cumulative difference of approximately +263 MMTEVe through 2050. While modest relative to total consumption reductions resulting from this rule and the Allocation Rules, it is notable that these increases are more significant relative to the incremental impact of the Technology Transitions Rule alone. In the low-GWP case, the change would increase the average annual incremental consumption reductions relative to the Allocation Rules by approximately 37%. In the high-GWP case, the change would represent a roughly 17% decrease in average annual incremental consumption reductions.

Several factors contribute to the somewhat muted HFC consumption impacts stemming from alternative GWP limits in these scenarios. The first being that, as shown in Table 7-1 above, many of the subsectors retain their base case transition assumptions and thus are unchanged in this analysis even with the higher or lower assumed GWP limits in place. In addition, many of the subsectors where we do assume a change in transitions are small in terms of their HFC consumption relative to the total affected by this rule. Finally, even for subsectors that represent a relatively large share of consumption, the difference between the GWP of the transition assumed in the base case versus that assumed in the high- or low-GWP case may be relatively small. For example, we assume that in the residential AC subsector, units would transition to a lower-GWP HFC blend, R-454A (GWP of 236, or 88.7% below the original HFC blend R-

410A used in this subsector), in the low-GWP case as opposed to the base case transition to R-454B (GWP of 465, or 77.7% below the original HFC blend). This yields additional average annual consumption reductions of approximately 2.2 MMTEVe through 2050 which—while not trivial—are small in comparison to total annual consumption reductions across all subsectors relative to business as usual.

In contrast with the HFC consumption results, in both the high- and low-GWP case, the changes to compliance costs are significant. In the high-GWP case, average annual abatement costs are $0.8 billion higher than in the base case, and cumulative abatement costs come to approximately $4.7 billion through 2050. In the low-GWP case, average annual abatement costs are approximately $3 billion higher than in the base case, and cumulative abatement costs come to approximately $64.1 billion through 2050. By contrast, cumulative costs in the base case come to a net savings of -$28 billion through 2050.

The higher abatement costs in both the high- and low-GWP case stem from differences in assumed transition costs in a small subset of subsectors with relatively large shares of HFC consumption and available abatement. For example, in the high-GWP case, the Large Retail Food subsector transitions partially to an HFC blend (R-454A) that would be available under the revised GWP limit, and which has an assumed net positive transition cost of approximately $10-20 per ton of abatement as opposed to the base case transition to CO_2-based systems that are assumed to yield a net savings due to their superior efficiency and the lower cost of refrigerants. In the low-GWP case, the transition to a lower GWP blend in the residential AC subsector yields a modest improvement in avoided consumption, as mentioned above, but a much steeper increase in costs to approximately $28 per ton of abatement as opposed to $5.60 in the base case. Each of these subsectors represents a substantial share of the HFC market (e.g., Residential AC accounts for over 100 MMTEVe in annual HFC consumption, or roughly one-third of the total market across all sectors in the model's BAU), meaning that changes to assumed transitions costs will have significant impacts on results.

These findings further illustrate the decoupled nature of abatement and costs in the model; a transition to a lower-GWP substitute may yield additional abatement at a lower cost if the transition is assumed have a net cost savings, and transitions to higher-GWP substitute do not necessarily reduce costs if these substitutes are more expensive to produce and use. Results of this exercise also underscore that the model is sensitive to the cost assumptions of transitions, particularly for subsectors that consume a large share of HFCs. Tables 7-2, 7-3, and 7-4 show the annual consumption reductions, emission reductions, and costs, respectively, from these two scenarios and incremental changes relative to the Technology Transitions Rule base case.

Table 7-2 - Annual Consumption Reductions in Technology Transitions Rule Base Case and High/Low GWP Scenarios

	Technology Transitions Rule Base Case	***Technology Transitions Rule Low GWP Case***		***Technology Transitions Rule High GWP Case***	
Year	***Consumption Reductions (MMTEVe)***	***Consumption Reductions (MMTEVe)***	***Change in Consumption Reductions (MMTEVe)***	***Consumption Reductions (MMTEVe)***	***Change in Consumption Reductions (MMTEVe)***
2025	189	196	7	183	-5
2026	212	216	4	205	-8
2027	227	235	9	222	-5
2028	245	254	9	239	-6
2029	254	261	7	248	-6
2030	257	263	6	251	-6
2031	269	275	6	263	-6
2032	279	286	7	273	-6
2033	289	297	7	284	-6
2034	299	307	8	293	-6
2035	308	315	7	302	-6
2036	315	320	5	308	-7
2037	315	322	7	308	-7
2038	320	328	8	313	-7
2039	317	329	11	312	-5
2040	309	321	12	306	-4
2041	312	324	12	310	-2
2042	315	327	12	315	0
2043	319	331	12	319	1
2044	322	334	12	321	0
2045	322	337	14	319	-4
2046	325	340	14	319	-6
2047	328	343	15	322	-6
2048	330	346	16	324	-6
2049	331	349	17	326	-5
2050	333	351	18	328	-5
Total	**7,643**	**7,906**	**263**	**7,514**	**-130**

Table 7-3: Annual Emission Reductions in Technology Transitions Rule Base Case and High/Low GWP Scenarios [a]

	Technology Transitions Rule Base Case	***Technology Transitions Rule Low GWP Case***		***Technology Transitions Rule High GWP Case***	
Year	***Emission Reductions (MMTEVe)***	***Emission Reductions (MMTEVe)***	***Change in Emission Reductions (MMTEVe)***	***Emission Reductions (MMTEVe)***	***Change in Emission Reductions (MMTEVe)***
2025	92	39	-53	37	-55
2026	95	50	-46	47	-49
2027	106	61	-44	57	-48
2028	113	73	-40	68	-45
2029	98	85	-13	79	-19
2030	108	97	-11	90	-18
2031	117	108	-8	101	-16
2032	124	121	-3	112	-12
2033	132	134	1	124	-9
2034	142	147	5	136	-6
2035	150	160	10	147	-2
2036	171	172	2	159	-12
2037	176	189	13	173	-3
2038	183	205	22	188	5
2039	190	219	29	202	12
2040	197	233	36	214	17
2041	204	239	36	220	16
2042	210	246	36	226	16
2043	215	252	37	232	17
2044	220	259	39	237	18
2045	224	265	41	243	19
2046	227	269	42	247	20
2047	231	274	43	251	21
2048	234	278	44	255	21
2049	236	282	45	258	22
2050	239	285	46	262	23
Total	4433	4743	310	4366	-67

[a] Rows may not appear to add correctly due to rounding.

Table 7-4 - Costs of Compliance by Year (billions of 2020$) in Technology Transitions Base Case and High/Low GWP Scenarios*

	Technology Transitions Rule Base Case	***Technology Transitions Rule Low GWP Case***		***Technology Transitions Rule High GWP Case***	
Year	***Net Compliance Costs***	***Net Compliance Costs***	***Change in Costs/Savings***	***Net Compliance Costs***	***Change in Costs/Savings***
2025	$0.14	$2.20	$2.07	$0.26	$0.13
2026	$0.13	$2.21	$2.08	$0.23	$0.10
2027	$0.12	$2.33	$2.22	$0.29	$0.18
2028	$0.12	$2.54	$2.43	$0.35	$0.23
2029	$(0.47)	$2.54	$3.01	$0.33	$0.80
2030	$(0.59)	$2.41	$3.01	$0.22	$0.81
2031	$(0.65)	$2.51	$3.16	$0.22	$0.87
2032	$(0.72)	$2.59	$3.30	$0.22	$0.94
2033	$(0.83)	$2.66	$3.49	$0.22	$1.05
2034	$(0.77)	$2.74	$3.51	$0.22	$0.99
2035	$(0.87)	$2.79	$3.65	$0.22	$1.09
2036	$(0.53)	$2.73	$3.26	$0.21	$0.74
2037	$(0.59)	$2.66	$3.25	$0.18	$0.78
2038	$(0.63)	$2.62	$3.25	$0.16	$0.79
2039	$(0.61)	$2.52	$3.13	$0.13	$0.74
2040	$(0.61)	$2.23	$2.83	$0.11	$0.72
2041	$(0.71)	$2.24	$2.94	$0.15	$0.86
2042	$(0.72)	$2.27	$2.99	$0.19	$0.90
2043	$(0.71)	$2.31	$3.02	$0.23	$0.94
2044	$(0.70)	$2.36	$3.07	$0.22	$0.92
2045	$(0.74)	$2.38	$3.12	$0.11	$0.85
2046	$(0.74)	$2.41	$3.14	$0.08	$0.81
2047	$(0.76)	$2.43	$3.19	$0.07	$0.83
2048	$(0.80)	$2.45	$3.25	$0.05	$0.85
2049	$(0.86)	$2.47	$3.33	$0.02	$0.88
2050	$(0.91)	$2.48	$3.39	$(0.02)	$0.89

**Values in parenthesis represent net negative costs, i.e., savings*

To monetize the climate benefits resulting from the Technology Transitions Rule low and high GWP scenarios, the HFC emission reductions in each year (Table 7-3) are multiplied by the corresponding SC-HFC for that HFC in that year (Tables 5-3 through 5-12). Table 7-5 presents the undiscounted monetized incremental climate benefits from all regulated HFCs under the Allocation Rule Reference Case,[39] the Technology Transitions Rule high additionality case, the low GWP scenario, and the high GWP scenario.

[39] This includes the 2024 Allocation Rule including the lower baseline and changes to one of the abatement options.

The incremental climate benefits shown here represent the additional benefits (positive numbers) achieved from these four scenarios over the Allocation Rule Reference Case.

Table 7-5: Undiscounted Monetized Climate Benefits of the Technology Transitions Rule Low and High GWP Case Scenarios 2025–2050 (3% model average SC-GHG estimates, millions of 2020$, discounted to 2022)[a]

Year	***Technology Transitions Base Case Incremental Climate Benefits***	***Technology Transitions Low GWP Case Incremental Climate Benefits***	***Technology Transitions High GWP Case Incremental Climate Benefits***
2025	$(3,730)	$(3,680)	$(3,816)
2029	$(1,253)	$(1,001)	$(1,458)
2034	$(73)	$475	$(516)
2036	$(613)	$94	$(1,168)
2040	$2,448	$3,615	$1,653
2045	$3,080	$4,559	$1,951
2050	$3,869	$5,731	$2,539

[a] Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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. A consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

As in Table 6-3 EPA presents estimates of the present value (PV) of the incremental benefits and costs of the low and high GWP scenarios over the 26-year period 2025 to 2050. To calculate the PV of the net benefits annual costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed by OMB's Circular A-4. Climate benefits are discounted at 3 percent as described in Section 5.3 and consistent with the Final Regulatory Impact Analysis for the Allocation Framework Rule.[40] EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2025 to 2050, would yield a sum equivalent to the PV, discounted at 3 percent and 7 percent.

EPA estimates that the range of PV of cumulative net incremental benefits evaluated from 2025 through 2050 is -$33 billion to -$18 billion at a 3 percent discount rate for the low GWP and high GWP case respectively. The range of incremental EAV over the period 2025–2050 is -$2 billion and -$1.1 billion when using a 3 percent discount rate for the low GWP and high GWP case respectively. The comparison

[40] Available at www.regulations.gov under Docket ID EPA-HQ-OAR-2021-0044, or see 86 FR 55116 (October 5, 2021).

of benefits and costs in PV and EAV terms for the low and high GWP scenarios can be found in Tables 7-6 and 7-7. Estimates in the table are presented as rounded values.

Table 7-6 – Summary of Annual Incremental Climate Benefits, Costs, and Net Benefits of the Technology Transitions Rule Low GWP Case Scenario for the 2025–2050 Timeframe (millions of 2020$, discounted to 2022)[a,b,c,d]

	Low GWP Case Scenario				
Year	***Incremental Climate Benefits (3%)***	***Annual Costs (savings)***		***Net Benefits (3% Benefits, 3% or 7% Costs)***[e]	
2025	($3,680)	$2,066		($5,746)	
2026	($3,252)	$2,079		($5,332)	
2027	($3,265)	$2,215		($5,480)	
2028	($3,006)	$2,427		($5,432)	
2029	($1,001)	$3,012		($4,012)	
2030	($885)	$3,007		($3,892)	
2031	($658)	$3,158		($3,815)	
2032	($280)	$3,303		($3,583)	
2033	$130	$3,492		($3,361)	
2034	$475	$3,508		($3,033)	
2035	$917	$3,653		($2,736)	
2036	$94	$3,262		($3,168)	
2037	$1,216	$3,252		($2,035)	
2038	$2,109	$3,247		($1,138)	
2039	$2,878	$3,133		($256)	
2040	$3,615	$2,835		$780	
2041	$3,602	$2,945		$658	
2042	$3,750	$2,987		$763	
2043	$3,975	$3,023		$952	
2044	$4,253	$3,067		$1,187	
2045	$4,559	$3,117		$1,442	
2046	$4,809	$3,143		$1,665	
2047	$5,037	$3,191		$1,846	
2048	$5,270	$3,253		$2,016	
2049	$5,508	$3,331		$2,177	
2050	$5,731	$3,389		$2,342	
Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**
PV	$15,780	$48,909	$28,109	($33,129)	($12,329)
EAV	$965	$2,990	$2,912	($2,025)	($1,947)

[a] Benefits include only those related to climate. Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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. A consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[b] Rows may not appear to add correctly due to rounding.
[c] The annualized present value of costs and benefits are calculated as if they occur over a 26-year period from 2025 to 2050.
[d] The costs presented in this table are annual estimates.
[e] The PV for the 7% net benefits column is found by taking the difference between the PV of climate benefits at 3% and the PV of costs discounted at 7%. Due to the intergenerational nature of climate impacts the social rate of return to capital, estimated to be 7% in OMB's Circular A-4, is not appropriate for use in calculating PV of climate benefits.

Table 7-7 – Summary of Annual Incremental Climate Benefits, Costs, and Net Benefits of the Technology Transitions Rule High GWP Case Scenario for the 2025–2050 Timeframe (millions of 2020$, discounted to 2022)[a,b,c,d]

	High GWP Case Scenario		
Year	***Incremental Climate Benefits (3%)***	***Annual Costs (savings)***	***Net Benefits (3% Benefits, 3% or 7% Costs)[e]***
2025	($3,816)	$126	($3,942)
2026	($3,446)	$95	($3,541)
2027	($3,538)	$176	($3,714)
2028	($3,385)	$231	($3,616)
2029	($1,458)	$800	($2,258)
2030	($1,416)	$815	($2,231)
2031	($1,290)	$869	($2,159)
2032	($1,025)	$937	($1,962)
2033	($735)	$1,052	($1,786)
2034	($516)	$988	($1,504)
2035	($204)	$1,091	($1,295)
2036	($1,168)	$744	($1,912)
2037	($318)	$776	($1,094)
2038	$436	$785	($349)
2039	$1,066	$739	$328
2040	$1,653	$718	$935
2041	$1,515	$858	$657
2042	$1,531	$904	$627
2043	$1,623	$935	$687
2044	$1,768	$919	$849
2045	$1,951	$848	$1,103
2046	$2,094	$815	$1,279
2047	$2,214	$831	$1,384
2048	$2,338	$854	$1,484
2049	$2,421	$882	$1,539
2050	$2,539	$885	$1,653

Discount rate	**3%**	**3%**	**7%**	**3%**	**7%**
PV	($6,554)	$11,770	$6,418	($18,324)	($12,972)
EAV	($401)	$719	$665	($1,120)	($1,065)

[a] Benefits include only those related to climate. Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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. A consideration of climate effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.
[b] Rows may not appear to add correctly due to rounding.
[c] The annualized present value of costs and benefits are calculated as if they occur over a 26-year period from 2025 to 2050.
[d] The costs presented in this table are annual estimates.
[e] The PV for the 7% net benefits column is found by taking the difference between the PV of climate benefits at 3% and the PV of costs discounted at 7%. Due to the intergenerational nature of climate impacts the social rate of return to capital, estimated to be 7% in OMB's Circular A-4, is not appropriate for use in calculating PV of climate benefits.

Chapter 8: Environmental Justice Analysis

8.1 Introduction and Background

This environmental justice analysis was developed to support the Technology Transitions Rule. The environmental justice analysis that was conducted as part of the Allocation Framework RIA addressed issues associated with the impacts of changes in the production of HFCs on communities near facilities identified as producers of these chemicals. EPA could not identify specific effects of the phasedown on individual communities, but the Agency did identify eight facilities with emissions likely to be affected by the Allocation Framework Rule. EPA was also able to analyze demographic characteristics of the fence-line communities in the Census Block Groups within 1-, 3-, 5-, and 10-mile radii of the affected facilities. Chapter 6 – the environmental justice analysis – of the Allocation Framework RIA concluded, in part, that:

- *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;*
- *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 rule will impact baseline risks from hazardous air toxics for communities living near HFC and HFC substitute production facilities.*

Many of the environmental justice implications of the Technology Transitions Rule are similar to those addressed at length in the Allocation Framework RIA. This rule has the effect of providing incremental additional reductions in HFC consumption beyond those specified in the Allocation Framework Rule. These reductions in emissions are expected to further improve future climate conditions to the benefit, particularly, of vulnerable populations. The Agency is not quantifying these benefits at this time.

8.2 Environmental Justice at EPA

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, disproportionate 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.[41] 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 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.

As noted in the Allocation Framework RIA, the production and consumption of HFCs is expected to result in the emission of chemicals which burden communities surrounding the production facilities. Because of the limited information regarding where substitutes will be produced and what other factors might affect production and emissions at those locations, it is unclear to what extent this rule may affect baseline risks from hazardous air toxics for communities living near facilities producing HFC substitutes. We do understand that communities neighboring facilities that currently produce HFCs and those that are likely to produce HFC substitutes are often overburdened and disadvantaged. The Agency has a strong interest in mitigating undue burden on these overburdened communities.

EPA stated its intention in the Allocation Framework Rule to "continue to monitor the impacts of this program on HFC and substitute production, and emissions in neighboring communities, as we move forward to implement this rule," (see 86 FR 55129). EPA will continue to work to address environmental justice and equity concerns for the communities near the facilities identified in this analysis.

In addition to the Technology Transitions Rule and other rules which address emissions under the Clean Air Act, the Agency continues to evaluate chemicals under the Toxic Substances Control Act (TSCA). For certain chemicals for which risk evaluations are complete that are used in the manufacture of HFCs

[41] 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 environmental justice 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 HFC substitutes, including carbon tetrachloride, methylene chloride, tetrachloroethylene (perchloroethylene), and trichloroethylene, EPA under Section 6 of TSCA will be addressing the unreasonable risks identified.

8.3 Environmental Justice Analysis for the HFC Allocation Rule

In the Allocation Framework Rule, EPA summarized the public health and welfare effects of GHG emissions (including HFCs), including findings that certain parts of the population may be especially vulnerable to climate change risks 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 limited resources due to factors including but not limited to geography, access, and mobility (86 FR 55124-55125). Potential impacts of climate change raise environmental justice issues. Low-income communities can be especially vulnerable to climate change impacts because they tend to have more limited capacity to bear the costs of adaptation and are more dependent on climate-sensitive resources such as local water and food supplies. In corollary, 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.

As discussed in more detail in the Allocation Framework RIA, the environmental justice benefits of reducing climate change are significant. The HFCs themselves are not a local pollutant and have low toxicity to humans. However, chemicals used as feedstocks or catalysts in the production of HFCs or produced as byproducts may have localized effects if released into the environment, and these may have environmental justice implications. The HFCs regulated under the HFC Allocation Program 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. More information on these chemicals, their toxicities, and their health effects can be found in the Allocation Framework RIA.

Similar to the Allocation Framework Rule, EPA expects that this rule will reduce GHG emissions, which will benefit populations that may be especially vulnerable to damages associated with climate change. We also expect that the restriction on use of certain HFCs will increase the production of HFC substitutes. For the purposes of the Technology Transitions Rule, EPA assessed the characteristics of communities near facilities producing predominant HFC substitutes. EPA used data from the Toxics Release Inventory

(TRI),[42] Greenhouse Gas Reporting Program (GHGRP),[43] Chemical Data Reporting (CDR) Program,[44] and information provided by industry stakeholders to identify the facilities producing HFC substitutes. Once production locations were identified, EPA retrieved the Facility Registry Service (FRS) IDs for each production facility using the Agency's FRS national dataset.[45] This step was conducted to facilitate extracting 1) an environmental profile and 2) demographic information within 1, 3, 5 and 10 miles for each facility using EPA's Enforcement and Compliance History Online (ECHO) database.[46]

EPA identified 12 facilities producing predominant non-fluorinated substitutes for HFCs such as hydrocarbons, ammonia (R-717), and CO_2 (R-744), and two additional facilities producing hydrofluoroolefins (HFOs), for a total of 14 sites that may be impacted by this rule and where production changes may impact nearby communities.

As discussed in the Allocation Framework RIA, there are many toxic and potentially toxic chemicals involved in the manufacturing processes that may be impacted by this rule, and fenceline communities are impacted by emissions from facilities of the type identified here. That analysis details the reported emissions and assessments of the risks that some of the substances may pose, but it also notes several limits to our ability to assess the impact this rule on the exposure that specific communities may face:

- These facilities generally produce several chemical products, individual facilities use different production methods with differing emissions characteristics, and processes and feedstocks may change. It is unknown how emissions and risks may change as a result of the Allocation Framework Rule, and this uncertainty extends to the potential emission impacts of this rule
- Many of the emissions resulting from production are poorly understood given a lack of data on the choices that producers of impacted chemicals will make in the future in response to the Allocation Framework Rule and this rule.

[42] TRI tracks the management of certain toxic chemicals that may pose a threat to human health and the environment. U.S. facilities in different industry sectors must report annually how much of each chemical is released to the environment and/or managed through recycling, energy recovery and treatment. Facilities submit a TRI Form R for each TRI-listed chemical it manufactures, processes, or otherwise uses in quantities above the reporting threshold.

[43] The GHGRP requires reporting of greenhouse gas data and other relevant information from large GHG emission sources, fuel and industrial gas suppliers, and CO_2 injection sites in the United States. The program generally requires reporting when emissions from covered sources are greater than 25,000 pounds of CO_2e per year.[43] Publicly available information[43] includes facility names, addresses, and lat/long information.

[44] The CDR program, under the Toxic Substances Control Act, requires manufacturers (including importers) to provide EPA with information on the production and use of chemicals in commerce. Under the CDR rule, EPA collects information on the types, quantities, and uses of chemical substances produced domestically and imported into the United States. The information is collected every four years from manufacturers of certain chemicals in commerce generally when production volumes are 25,000 pounds or greater for a specific reporting year.[44] Publicly available information[44] includes facility name, addresses, lat/long information on production facilities, and additional information about the chemicals and downstream uses.

[45] FRS National Data Set available at *https://www.epa.gov/frs/epa-frs-facilities-state-single-file-csv-download*

[46] *https://echo.epa.gov/.*

- Many of the communities near the facilities expected to be affected by the Allocation Framework Rule and this rule are also near other sources of toxic emissions which contribute to environmental justice concerns.
- Some companies with multiple production facilities may choose to consolidate production of regulated substances at a subset of facilities as the phasedown continues, which could lead to an increase in regulated substance production at a single facility, despite the overall phasedown.

Due to the limitations of the current data, we cannot make conclusions about the impact of this rule on individuals or specific communities. For the purposes of identifying environmental justice issues, however, it is important to understand the characteristics of the communities surrounding these facilities to better ensure that future actions, as more information becomes available, can improve outcomes. Following the format used for the Allocation Framework RIA, this analysis focuses on information that is available on the demographics and baseline exposure of the communities near these facilities.

8.4 Aggregate Average Characteristics of Communities Near Potentially Affected Production Facilities

The RIA for the Allocation Framework Rule notes that a key issue for evaluating potential for environmental justice concerns is the extent to which an individual might be exposed to feedstock, catalyst, or byproduct emissions from the production of HFCs or HFC substitutes. As described earlier, as part of risk evaluations conducted under Section 6 of TSCA, EPA has evaluated risks to workers and occupational non-users for several chemicals used as feedstocks for HFCs or HFC substitutes (e.g., carbon tetrachloride, methylene chloride, tetrachloroethylene (perchloroethylene), and trichloroethylene). These risks are characterized in the 2020 risk evaluations for each chemical.[47] The rulemakings under TSCA to address unreasonable risks for each chemical aim to incorporate reasonably available information on demographics of workers at these facilities to identify potential environmental justice concerns.

EPA has not undertaken an analysis of how the emissions of various HFC or HFC substitute feedstocks, catalysts, and byproducts affect nearby communities (e.g., through use of a fate and transport model or the modeling of main exposure pathways). However, a proximity-based approach can identify correlations between the location of these identified production facilities and potential effects on nearby communities. Specifically, this approach assumes that individuals living within a specific distance of an HFC

[47] The risks evaluations for these chemicals can be found in the following dockets: EPA-HQ-OPPT-2019-0499 (carbon tetrachloride); EPA-HQ-OPPT-2019-0437 and EPA-HQ-OPPT-2016-0742 (methylene chloride); EPA-HQ-OPPT-2019-0502 and EPA-HQ-OPPT-2016-0732 (tetrachloroethylene (perchloroethylene)); EPA-HQ-OPPT-2016-0737 and EPA-HQ-OPPT-2019-0500E (trichloroethylene).

production facility are more likely to be exposed to releases from feedstocks, catalysts, or byproducts. Those living further away are less likely to be exposed to these releases. Census block groups that are located within 1, 3, 5, and 10 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) are used to examine whether a greater percentage of population groups of concern live within a specific distance from a production facility compared to the national average. The national average for rural areas is also presented since 9 of the 14 production facilities expected to be impacted by the rule are classified as rural.[48]

In addition, Air Toxics Screening Assessment (AirToxScreen, formerly National Air Toxic Assessment (NATA)) data from 2019 for census tracts within and outside of a 1-, 3-, 5- and 10-mile distance are used to approximate the cumulative baseline cancer and respiratory risk due to air toxics exposure for communities near these production facilities. 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 the chemicals evaluated in the AirToxScreen database. Note that these risks are not necessarily only associated with a specific HFC substitute production facility. Industrial activity is often concentrated (i.e., multiple plants located within the same geographic area).

Table 8-1 presents the density of TRI facilities (nearby facilities that could contribute to the cumulative AirToxScreen cancer and respiratory risk in communities) located within 1-, 3-, 5-, and 10-mile radii of the nine facilities. 11 of the 14 facilities have fewer than five neighboring TRI facilities within a 1-mile radius. Expanding the radius to 3 miles increases the number of neighboring TRI facilities substantially for seven of the facilities. Expanding the radii to 5 and 10 miles generally increases the number of neighboring facilities even further. There are only three facilities within ten miles of the KSP plant in Tad, WV, and analysis shows there are no TRI facilities within ten miles of the Aeropress facility in Sibley, LA.

[48] 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 8-1: Total Number of Neighboring TRI Facilities within 1, 3, 5 and 10 miles of Identified Facilities

Facility	***Location***	***TRI Facilities within a 1-Mile Radius***	***TRI Facilities within a 3-Mile Radius***	***TRI Facilities within a 5-Mile Radius***	***TRI Facilities within a 10-Mile Radius***
Chemours-Corpus Christi	Gregory, TX	2	4	6	6
Chemours El Dorado	El Dorado, AR	2	2	2	12
Honeywell-Geismar	Geismar, LA	4	21	31	36
Aeropress Corp. San Dimas Plant	San Dimas, CA	1	1	4	34
CF Industries Nitrogen LLC-Port Neal	Sergeant Bluff, IA	2	6	7	21
Linde, Inc - Whiting	East Chicago, IN	5	27	35	71
Air Products and Chemicals Geismar SMR	Geismar, LA	3	13	18	42
Haltermann Carless Manvel Inc	Manvel, TX	1	1	2	10
Air Products and Chemicals Port Arthur	Port Arthur, TX	2	15	15	31
Diversified Gas and Oil KSP CO_2 Plant	Tad, WV	0	0	0	3
Linde, Inc – Decatur	Decatur, AL	3	11	23	29
CALAMCO	Stockton, CA	5	7	14	22
Diversified CPC International	Channahon, IL	5	6	9	24
Aeropres Corp -Sibley	Sibley, LA	0	0	0	0

Source: Toxic Releases Inventory (2019)

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

Table 8-2 presents summary information for the demographic data and AirToxScreen risks averaged across the 14 communities near the identified production facilities compared to the overall and rural national average. This table is analogous to one presented in the Allocation Framework RIA for these facilities, but it uses the updated AirToxScreen data.

The values in the last four columns reflect population-weighted averages across the Census block groups within the specified distance of the facility. While it is not possible to disaggregate the risk information from AirToxScreen by race, ethnicity, or income the overall cancer and respiratory risk in communities within 1, 3, 5, or 10 miles of an identified production facility is markedly greater than either the overall or rural national average.

Table 8-2: Overall Community Profile and AirToxScreen Risks for Communities Near Identified Facilities

	Overall National Average	***Rural Areas National Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	84	61	60	58	54
% Black or African American (race)	13	7.6	19	15	15	19
% Other (race)	15	8.2	20	25	26	27
% Hispanic (ethnic origin)	18	10	32	37	39	34
Median Household Income (1k 2019$)	71	67	63	66	65	70
% Below Poverty Line	7.3	6.8	8.2	8.5	8.5	7.6
% Below Half the Poverty Line	5.8	5.1	8.0	7.0	6.8	6.1
Total Cancer Risk (per million)	26	23	34	31	31	31
Total Respiratory Risk (hazard quotient)	0.31	0.27	0.36	0.35	0.35	0.36

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 Air Toxics Screening Assessment (AirToxScreen, 2021).

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 substitute production facility are defined. Looking across all 14 facilities (Table 8-2), a higher percentage of Black or African American individuals live in the communities near HFC substitute production facilities compared to the national average or the rural areas national average. In these communities, the percentage of White residents is lower than either the national average or the rural national average at all distances analyzed. There is a higher percentage of Black or African American individuals near these locations, compared to the averages, and higher percentages of people of other racial minorities or persons of Hispanic Ethnicity. Median income is lower for the communities near these facilities compared to the national average or rural national average, except that within 10 miles, the median income of $70,000 is higher than the rural national average of $67,000. There is a higher percentage of households with low and very low incomes at all analyzed distances from these facilities. The national percentage of rural households with incomes less than half of the poverty line is 5.1%, and the overall national average is 5.8%. Within 1 mile of these specific facilities, the average percentage of rural households with incomes less than half of the poverty line is 8.0%. The percentage of households with incomes less than half of the poverty level declines with distance from the facilities, but, at 6.1%, the number at the 10-mile radius is still higher than the national or rural national average.

For this analysis, we use 2019 AirToxScreen data for total cancer risk and total respiratory risk. Comparing the data for the whole country to the 2014 data (that were available at the time the Allocation Framework RIA was written) it is important to note that total cancer and total respiratory risk have dropped for both rural and national average areas. The overall national average and rural areas average total cancer risk using the 2019 data are shown to have dropped to 26 and 23 per million, respectively, from 32 and 29 per million, compared to the 2014 data averages. A similar drop for total respiratory risk to 0.31 and 0.27 per million for the overall national average and rural areas national average respectively, from 0.44 and 0.38 per million.

Proximity analysis to the identified facilities generally shows higher risks at all analyzed distances, on average, for these 14 facilities. The analysis shows that the risks are higher for those within the 1-mile average radius and generally decrease at the 3-, 5-, and 10-mile radii. It is worth noting that the averages reported in Table 8-2 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.[49]

8.5 Characteristics of Communities Near Identified Individual Facilities

For three of the 14 facilities identified here, the demographic data is identical to that published in the Allocation Framework RIA in September of 2021. The racial, ethnic, and income figures for these eight communities within 1, 3, 5, and 10 miles of the respective facilities are drawn from the most recent American Communities Survey data, which is the 2019 dataset. The facility-by-facility discussion in the Allocation Framework RIA used the 2014 NATA Database. This analysis uses the 2019 AirToxScreen Database. For the Chemours Corpus Christi, Chemours El Dorado, and Honeywell Geismar facilities, the AirToxScreen 2019 analysis indicates that total cancer risk and total respiratory risk declined since the 2014 report, and two of these facilities are in communities identified as having higher risks than either their respective state or national averages.

[49] The relatively small number of facilities affected by this rule enabled EPA to assemble a uniquely granular assessment of the characteristics of these facilities and the communities where they are located.

Table 8-3: Community Profiles and AirToxScreen Risks for Chemours Corpus Christi – Gregory, TX

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	74	95	91	92	91
% Black or African American (race)	13	12	1.6	2.3	2.2	2.1
% Other (race)	15	14	3.6	6.3	6.2	7.1
% Hispanic (ethnic origin)	18	39	40	41	44	40
Median Household Income (1k 2019$)	71	69	78	79	69	61
% Below Poverty Line	7.3	8.2	1.4	4.1	3.4	6.0
% Below Half the Poverty Line	5.8	6.2	1.0	2.8	3.7	4.9
Total Cancer Risk (per million)	26	28	17	19	19	19
Total Respiratory Risk (hazard quotient)	0.31	0.30	0.20	0.20	0.19	0.18

Table 8-4: Community Profiles and AirToxScreen Risks for Chemours El Dorado – El Dorado, AR

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	83	94	94	82	62
% Black or African American (race)	7.6	11	1.4	1.4	15	35
% Other (race)	8.2	5.9	4.7	4.7	2.9	3.4
% Hispanic (ethnic origin)	10	5.3	2.4	2.4	3.4	4.5
Median Household Income (1k 2019$)	67	51	66	66	54	45
% Below Poverty Line	6.8	9.7	8	8	11	13
% Below Half the Poverty Line	5.1	6.2	5.2	5.2	4.2	7.7
Total Cancer Risk (per million)	23	29	50	50	47	51
Total Respiratory Risk (hazard quotient)	0.27	0.36	0.50	0.50	0.50	0.51

Table 8-5: Community Profiles and AirToxScreen Risks for Honeywell Geismar Complex – Geismar, LA

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	70	57	63	62	66
% Black or African American (race)	7.6	25	38	34	36	27
% Other (race)	8.2	4.7	5.4	2.5	3	7.1
% Hispanic (ethnic origin)	10	3.6	3.8	2.7	2.9	5.1
Median Household Income (1k 2019$)	67	53	79	84	80	79

% Below Poverty Line	6.8	9.8	2.3	2.5	2.8	5.7
% Below Half the Poverty Line	5.1	7.8	7.2	5	5.5	4.9
Total Cancer Risk (per million)	23	33	67	67	65	54
Total Respiratory Risk (hazard quotient)	0.27	0.27	0.42	0.43	0.43	0.42

Of the other 11 facilities, nine are in communities in which either the AirToxScreen 2019 data show elevated Total Cancer Risk and/or Total Respiratory Risk are generally above the national and state averages. The Air Products and Chemicals Geismar, LA facility (near the Honeywell Geismar Complex noted above) has higher risks than the state or national averages. The CF Industries facility in Sergeant Bluff, IA and the Diversified CPC International facility in Channahon, IL are located in areas where the Total Cancer Risk and Total Respiratory Risk are generally lower than the state and national average risks (although the Total Cancer Risk within one mile of the Diversified CPC facility is 30 per million – slightly higher than the 29 per million risks for the overall national average and Illinois overall average risk).

Ten of the 14 facilities are situated in communities that are generally more diverse than the national or state average. Four of the facilities are in communities (San Dimas, CA; Stockton, CA; East Chicago, IL; and Decatur, AL) are home to more residents who identify as having Hispanic Ethnicity than the state or national averages. Five communities (East Chicago, IL; Geismar, LA; Port Arthur, TX; Decatur, AL, and Sibley, LA) have higher proportions of residents who identify as Black or African American than the averages. For some facilities, such as the Chemours El Dorado, HC Manvel, Aeropress-Sibley and CF Industries Port Neal plants, there are relatively high percentages of households that identify as White in close proximity, but become more diverse at the 5 and 10 mile distances.

For six of the 14 facilities, median household incomes in surrounding communities are consistently lower than the state or national averages and percentages of low and very low-income households are high. In many cases, the incomes are lowest and poverty rates highest close to the plants. On the other hand, for Chemours Corpus Christi, Chemours El Dorado, Diversified CPC Channahon, and Aeropress San Dimas, median income is relatively high close to the facility, and percentages of households below the poverty line and half the poverty line are low. In these communities, analysis shows that median incomes decrease and poverty rates increase with distance from the facilities. Finally, the communities near the Honeywell and Aeropress facilities in Geismar, LA, the Diversified CPC facility in Channahon, IL, and the Haltermann Carless facility in Manvel, TX have higher median incomes and lower percentages of households with low incomes than the averages.

Table 8-6: Community Profiles and AirToxScreen Risks for Aeropress Inc. – San Dimas, CA

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	60	73	65	58	49
% Black or African American (race)	13	5.8	2.1	3	3.9	3.6
% Other (race)	15	35	25	32	39	47
% Hispanic (ethnic origin)	18	39	36	44	50	55
Median Household Income (1k 2019$)	71	83	88	88	83	80
% Below Poverty Line	7.3	7.3	3.5	4.8	6	6.5
% Below Half the Poverty Line	5.8	5.8	5.6	4.1	5	4.6
Total Cancer Risk (per million)	26	27	30	30	30	31
Total Respiratory Risk (hazard quotient)	0.31	0.34	0.40	0.40	0.40	0.41

Table 8-7: Community Profiles and AirToxScreen Risks for CF Industries Inc – Nitrogen Port Neal, Sergeant Bluff, IA

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	94	94	90	79	79
% Black or African American (race)	7.6	1.6	0.13	0.07	0.25	3.0
% Other (race)	8.2	4.4	5.7	9.9	20	18
% Hispanic (ethnic origin)	10	4.2	2.1	4.0	6.9	18
Median Household Income (1k 2019$)	67	68	67	70	82	68
% Below Poverty Line	6.8	5.0	3.0	4.9	6.4	6.0
% Below Half the Poverty Line	5.1	3.6	1.5	2.9	4.3	6.6
Total Cancer Risk (per million)	23	18	20	20	20	20
Total Respiratory Risk (hazard quotient)	0.27	0.20	0.20	0.20	0.20	0.21

Table 8-8: Community Profiles and AirToxScreen Risks for Linde Inc. Whiting – East Chicago, IN

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	83	23	35	46	33
% Black or African American (race)	13	9.4	35	29	32	57
% Other (race)	15	7.3	43	36	22	11
% Hispanic (ethnic origin)	18	6.9	61	49	38	20
Median Household Income (1k 2019$)	71	62	34	39	45	47
% Below Poverty Line	7.3	7.0	17	14	12	11
% Below Half the Poverty Line	5.8	6.0	13	13	11	10

Total Cancer Risk (per million)	26	21	24	21	21	21
Total Respiratory Risk (hazard quotient)	0.31	0.25	0.30	0.30	0.30	0.30

Table 8-9: Community Profiles and AirToxScreen Risks for Air Products Geismar – Geismar, LA

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	70	63	70	56	68
% Black or African American (race)	7.6	25	30	26	39	27
% Other (race)	8.2	4.7	6.6	4.0	5.3	5.7
% Hispanic (ethnic origin)	10	3.6	1.2	3.3	4.7	5.0
Median Household Income (1k 2019$)	67	53	86	83	79	80
% Below Poverty Line	6.8	9.8	2.2	3.8	6.3	5.3
% Below Half the Poverty Line	5.1	7.8	6.5	5.3	8.3	5.4
Total Cancer Risk (per million)	23	33	67	68	64	54
Total Respiratory Risk (hazard quotient)	0.27	0.37	0.40	0.40	0.40	0.41

Table 8-10: Community Profiles and AirToxScreen Risks for Haltermann Carless Manvel – Manvel, TX

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	82	88	83	70	64
% Black or African American (race)	7.6	7.9	4.9	8.4	17	19
% Other (race)	8.2	9.8	6.7	9.0	12	18
% Hispanic (ethnic origin)	10	32	27	32	34	27
Median Household Income (1k 2019$)	67	70	71	80	82	99
% Below Poverty Line	6.8	7.1	4.6	4.5	5.1	3.5
% Below Half the Poverty Line	5.1	5.4	1.9	2.4	3.7	3.0
Total Cancer Risk (per million)	23	25	30	30	30	30
Total Respiratory Risk (hazard quotient)	0.27	0.27	0.30	0.32	0.34	0.34

Table 8-11: Community Profiles and AirToxScreen Risks for Air Products and Chemicals Inc. – Port Arthur, TX

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	74	33	32	51	69
% Black or African American (race)	13	12	61	63	37	22

% Other (race)	15	14	6.6	5.4	12	8.9
% Hispanic (ethnic origin)	18	39	5.4	18	35	25
Median Household Income (1k 2019$)	71	69	43	35	38	50
% Below Poverty Line	7.3	8.2	9.5	13	13	8.3
% Below Half the Poverty Line	5.8	6.2	14	14	11	7.4
Total Cancer Risk (per million)	26	28	44	48	54	73
Total Respiratory Risk (hazard quotient)	0.31	0.30	0.30	0.30	0.30	0.31

Table 8-12: Community Profiles and AirToxScreen Risks for Diversified Gas and Oil – Tad, WV

	Rural National Average	***Rural State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	84	95	99	97	96	90
% Black or African American (race)	7.6	2.4	0	0.29	0.96	6.2
% Other (race)	8.2	2.5	0.89	2.7	2.9	3.9
% Hispanic (ethnic origin)	10	1.4	0.45	0.91	0.9	0.89
Median Household Income (1k 2019$)	67	50	48	47	44	49
% Below Poverty Line	6.8	9.3	10	11	11	9
% Below Half the Poverty Line	5.1	6.6	5.5	7.4	5.9	9.1
Total Cancer Risk (per million)	23	26	30	30	30	30
Total Respiratory Risk (hazard quotient)	0.27	0.28	0.30	0.30	0.31	0.34

Table 8-13: Community Profiles and AirToxScreen Risks for Linde Inc. Decatur – Decatur, AL

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	68	44	60	67	74
% Black or African American (race)	13	27	52	32	23	17
% Other (race)	15	5.3	4.0	8.1	9.5	8.3
% Hispanic (ethnic origin)	18	4.3	13	14	14	9.1
Median Household Income (1k 2019$)	71	55	35	50	52	59
% Below Poverty Line	7.3	9.1	16	13	12	9.5
% Below Half the Poverty Line	5.8	7.2	9.0	6.8	6.1	5.5
Total Cancer Risk (per million)	26	34	54	43	42	36
Total Respiratory Risk (hazard quotient)	0.31	0.43	0.57	0.50	0.47	0.43

Table 8-14: Community Profiles and AirToxScreen Risks for CALAMCO – Stockton, CA

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	60	58	54	52	51
% Black or African American (race)	13	5.8	9.5	9.9	10	9.4
% Other (race)	15	35	33	36	38	40
% Hispanic (ethnic origin)	18	39	67	50	50	45
Median Household Income (1k 2019$)	71	83	49	55	55	62
% Below Poverty Line	7.3	7.3	12	11	11	9.9
% Below Half the Poverty Line	5.8	5.8	9.9	8.5	8	7
Total Cancer Risk (per million)	26	27	29	30	30	30
Total Respiratory Risk (hazard quotient)	0.31	0.34	0.39	0.35	0.34	0.33

Table 8-15: Community Profiles and AirToxScreen Risks for Diversified CPC International Inc. – Channahon, IL

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	72	95	92	86	79
% Black or African American (race)	13	14	0.88	2	7.4	12
% Other (race)	15	14	4.2	6.3	6.4	9.6
% Hispanic (ethnic origin)	18	17	10	13	16	19
Median Household Income (1k 2019$)	71	74	110	97	93	81
% Below Poverty Line	7.3	6.6	1.0	3.1	3.1	4.7
% Below Half the Poverty Line	5.8	5.6	2.6	1.5	2.6	3.7
Total Cancer Risk (per million)	26	24	20	20	20	20
Total Respiratory Risk (hazard quotient)	0.31	0.29	0.30	0.27	0.26	0.27

Table 8-16: Community Profiles and AirToxScreen Risks for Aeropress, Inc. – Sibley, LA

	Overall National Average	***Overall State Average***	***Within 1 mile of facility***	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	72	62	71	51	56	64
% Black or African American (race)	13	32	26	47	41	33
% Other (race)	15	5.8	2.7	1.3	2.5	2.5
% Hispanic (ethnic origin)	18	5.1	1.6	1.8	1.1	1.7
Median Household Income (1k 2019$)	71	54	27	27	33	38
% Below Poverty Line	7.3	10	11	18	20	18
% Below Half the Poverty Line	5.8	8.3	9.8	8.3	7.5	7.7

Total Cancer Risk (per million)	26	34	30	35	34	35
Total Respiratory Risk (hazard quotient)	0.31	0.39	0.40	0.42	0.41	0.41

8.6 Conclusion

This rule is expected to reduce GHG emissions, which would benefit populations that may be especially vulnerable to damages associated with climate change. We also expect that the restriction on use of certain HFCs will increase the production of HFC substitutes. 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. EPA finds evidence of environmental justice concerns near HFC production facilities from cumulative exposure to existing environmental hazards in these communities, and that further investigation is warranted. The proximity analysis of these communities demonstrates that:

- The characteristics of the communities near facilities are heterogeneous;
- Total baseline cancer risk and total respiratory risk from air toxics (not all of which stem from HFC substitute production) varies, but is generally higher, and in some cases much higher, within 1-3 miles of an HFC substitute production facility;
- In general, higher percentages of low income individuals and people of color live near HFC substitute 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 substitute production, but some feedstocks and byproducts are toxic; and
- Since multiple HFC substitutes are available, some of which have toxic profiles for the chemicals used as feedstocks in their production, continued analysis of HFC and HFC substitute production facilities and associated environmental justice concerns is appropriate.

Given the uncertainty about how the transition to lower-GWP substitutes and market trends independent of this rulemaking could affect production of predominant HFC substitutes at individual facilities, and how those changes in production could affect associated air pollutant emissions, particularly in communities that are disproportionately burdened by air pollution, EPA is seeking information to help better characterize these changes and their implications for nearby communities for analysis of the final rule.[50] The Agency will continue to evaluate the impacts of this program on communities with environmental justice concerns and consider further action, as appropriate, to protect health in communities affected by HFC substitute production.

[50] 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 9: Annexes

Annex A: Summary of Mitigation Technologies Modeled by End Use

Table A-1 Market Penetration in 2026, by Transition Technology, in Technology Transitions Base Case Compliance Scenario [a,b]

Sector	*Subsector*	*Transition Technology*	*2026 Market Penetration*
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to NIK	40%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to NIK	25%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFC-152a	11%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HC	23%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HC	20%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFO-1234ze(E)	15%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HFO-1234ze(E)	17%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) – HFC-245fa to HCs	50%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock – HFC-245fa Blend to HC	100%
Foam	Flexible PU Foam: Integral Skin Foam	Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs	100%
Foam	PU Rigid: Sandwich Panels: Continuous and Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs	100%
Foam	Commercial Refrigeration Foam	Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(E)	100%
Foam	PU Rigid: Sandwich Panels: Continuous and Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) – HFC-245fa/CO_2 to HCFO-1233zd(E)	100%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(E)	50%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(E)	70%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(E)	30%

Sector	***Subsector***	***Transition Technology***	***2026 Market Penetration***
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(E)	100%
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to HFO-1234ze(E)/HCFO-1233zd(E)	100%
RACHP	Cold Storage	CFC-12 Cold Storage - NH_3/CO_2	100%
RACHP	Cold Storage	HCFC-22 Cold Storage - NH_3/CO_2	100%
RACHP	Cold Storage	R-502 Cold Storage - NH_3/CO_2	100%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	24%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	24%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	24%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	63%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	63%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	63%
RACHP	Large Retail Food	CFC-12 Large Retail Food – R-407A to CO_2 Transcritical	33%
RACHP	Large Retail Food	R-502 Large Retail Food – R-407A to CO_2 Transcritical	33%
RACHP	Large Retail Food	CFC-12 Large Retail Food – R-404A/R-507A to CO_2 Transcritical	83%
RACHP	Large Retail Food	R-502 Large Retail Food – R-404A/R-507A to CO_2 Transcritical	83%
RACHP	Small Retail Food	R-12 Small Retail Food (Low Temperature) - HCs	8%
RACHP	Small Retail Food	R-12 Small Retail Food (RFPDE) - R-290	0%
RACHP	Small Commercial Unitary A/C	HCFC-22 Small Commercial Unitary A/C - R-32 and Microchannel Heat Exchanger (MCHE)	100%
RACHP	Large Commercial Unitary A/C	HCFC-22 Large Commercial Unitary A/C - R-32 and MCHE	100%
RACHP	Small Retail Food	R-12 Small Retail Food (Medium Temperature) - HCs	80%
RACHP	Refrigerated Appliances	CFC-12 Refrigerated Appliances - HFC-134a to R-600a	100%

Sector	*Subsector*	*Transition Technology*	*2026 Market Penetration*
RACHP	Medium Retail Food	HCFC-22 Large Condensing Units (Medium Retail Food) - CO_2	100%
RACHP	Medium Retail Food	HCFC-22 Small Condensing Units (Medium Retail Food) - CO_2	95%
RACHP	Dehumidifiers	HCFC-22 Dehumidifiers - HFC-32	100%
RACHP	Window Units	HCFC-22 Window Units - HFC-32	100%
RACHP	Ice Machines	CFC-12 Ice Makers - R-290	50%
RACHP	PTAC/PTHP	HCFC-22 PTAC/PTHP - HFC-32/R-452B	100%
RACHP	Water & Ground Source HP	HCFC-22 Water & Ground Source HP - HFC-32/R-452B	100%
RACHP	Residential Unitary A/C	HCFC-22 Residential Unitary A/C - R-454B and MCHE	100%
RACHP	Positive Displacement (PD) Chillers	Screw Chillers – R-410A/R-407C replaced w/ HFO-1234ze(E)	100%
RACHP	PD Chillers	Reciprocating Chillers – R-410A/R-407C replaced w/ HFO-1234ze(E)	100%
RACHP	Medium Retail Food	HCFC-22 Small Condensing Units (Medium Retail Food) (RFPDE) - R-448A/449A/449B	4%
RACHP	Ice Machines	CFC-12 Ice Makers - R-448A/R-449A	40%
RACHP	Small Retail Food	R-12 Small Retail Food (RFPDE) - R-448A/R-449A/R-449B	4%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (Ice Rinks) - R-454B	2%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (Ice Rinks) - R-454B	2%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (Ice Rinks) - R-454B	2%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (Data and IT Centers) - R-454B	3%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (Data and IT Centers) - R-454B	3%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (Data and IT Centers) - R-454B	3%
RACHP	Transport	Intermodal Containers - R-450A/R-513A	100%
RACHP	Transport	Merchant Fishing Transport - R-452A	100%
RACHP	PD Chillers	Scroll Chillers – R-410A/R-407C replaced w/ R-452B	100%
RACHP	Transport	Reefer Ships - R-452A	100%

Sector	Subsector	Transition Technology	2026 Market Penetration
RACHP	Transport	Road Transport - R-452A	100%
RACHP	Centrifugal Chillers	CFC-114 Chillers - HFC-134a replaced w/ R-450A/R-513A	100%
RACHP	Centrifugal Chillers	CFC-11 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	100%
RACHP	Centrifugal Chillers	CFC-12 Centrifugal Chillers – HFC-134a replaced w/ R-450A/R-513A	100%
RACHP	Centrifugal Chillers	R-500 Chillers – HFC-134a replaced w/ R-450A/R-513A	100%
RACHP	Centrifugal Chillers	CFC-12 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(E)	100%
RACHP	Centrifugal Chillers	R-500 Chillers – HFC-245fa replaced w/ HCFO-1233zd(E)	100%
RACHP	Centrifugal Chillers	CFC-11 Centrifugal Chillers – HFC-245fa replaced w/ HCFO-1233zd(E)	100%
RACHP	Vending Machines	CFC-12 Vending Machines - R-290	100%
Solvents	Electronics Cleaning	Aerosol Solvent Electronics Cleaning - Not-in-kind Aqueous	3%
Solvents	Precision Cleaning	Aerosol Solvent Precision Cleaning - Not-in-kind Aqueous	3%
Solvents	Electronics Cleaning	Aerosol Solvent Electronics Cleaning - Not-in-kind Semi-aqueous	3%
Solvents	Precision Cleaning	Aerosol Solvent Precision Cleaning - Not-in-kind Semi-aqueous	3%

a. Market penetration for aerosols is given as the percent in the original chemical (i.e., HFC-134a or HFC-152a).

b. Market penetrations for HFC-134a aerosols do not reach 100% to account for a portion that is used in defense sprays and not subject to this rule.

Table A-2 Percent reduction off of BAU

Sector	Subsector	Transition Technology	Reduction Efficiency	Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type					
				2025	2030	2035	2040	2045	2050
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to NIK	100%	15%	15%	15%	15%	15%	15%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to NIK	100%	16%	16%	16%	16%	16%	16%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFC-152a	91%	6%	7%	7%	7%	7%	7%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HC	100%	13%	16%	16%	16%	16%	16%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HC	95%	7%	7%	7%	7%	7%	7%

Sector	*Subsector*	*Transition Technology*	*Reduction Efficiency*	*Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type*					
				2025	*2030*	*2035*	*2040*	*2045*	*2050*
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-134a to HFO-1234ze(E)	100%	9%	16%	16%	16%	16%	16%
Aerosols	Non-MDI Aerosols	non-MDI Aerosols HFC-152a to HFO-1234ze(E)	95%	6%	7%	7%	7%	7%	7%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCs	99%	0%	0%	0%	0%	0%	0%
Foam	PU and PIR Rigid: Boardstock	PU and PIR Rigid: Boardstock - HFC-245fa Blend to HC	99%	100%	100%	100%	100%	100%	100%
Foam	Flexible PU Foam: Integral Skin Foam	Integral Skin Polyurethane (Flexible PU Foam: Integral Skin Foam) - HFC-134a to HCs	100%	100%	100%	100%	100%	100%	100%
Foam	PU Rigid: Sandwich Panels: Continuous and Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-134a to HCs	100%	59%	59%	59%	59%	59%	59%
Foam	Commercial Refrigeration Foam	Rigid PU: Commercial Refrigeration (Commercial Refrigeration Foam) - HFC-245fa to HCFO-1233zd(E)	99%	99%	99%	99%	99%	99%	99%
Foam	PU Rigid: Sandwich Panels: Continuous and Discontinuous	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) - HFC-245fa/CO_2 to HCFO-1233zd(E)	99%	41%	41%	41%	41%	41%	41%
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	Rigid PU: Appliance (PU Rigid: Domestic Refrigerator and Freezer Insulation) - HFC-245fa to HCFO-1233zd(E)	99%	0%	0%	0%	0%	0%	0%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (High-Pressure) - HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(E)	99%	69%	69%	69%	69%	69%	69%
Foam	PU Rigid: Spray Foam	PU Rigid: Spray Foam (Low-Pressure) - HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(E)	99%	30%	30%	30%	30%	30%	30%
Foam	PU Rigid: One Component Foam	PU Rigid: One Component Foam - HFC-134a to HFO-1234ze(E)	100%	94%	94%	94%	94%	94%	94%

Sector	*Subsector*	*Transition Technology*	*Reduction Efficiency*	*Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type*					
				2025	***2030***	***2035***	***2040***	***2045***	***2050***
Foam	XPS: Boardstock Foam	Polystyrene: Extruded Boardstock and Billet (XPS: Boardstock Foam) - HFC-134a/CO_2 to HFO-1234ze(E)/HCFO-1233zd(E)	100%	99%	99%	99%	99%	99%	99%
RACHP	Cold Storage	CFC-12 Cold Storage - NH_3/CO_2	100%	48%	79%	99%	100%	100%	100%
RACHP	Cold Storage	HCFC-22 Cold Storage - NH_3/CO_2	100%	46%	63%	86%	100%	100%	100%
RACHP	Cold Storage	R-502 Cold Storage - NH_3/CO_2	100%	42%	67%	87%	100%	100%	100%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	100%	15%	27%	32%	32%	32%	32%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	100%	18%	31%	31%	30%	30%	31%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (<-22F or -30C) - NH_3/CO_2	100%	12%	20%	27%	30%	30%	30%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	100%	40%	56%	67%	67%	67%	67%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	100%	47%	65%	65%	65%	64%	65%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (>-22F or -30C) - NH_3/CO_2	100%	32%	42%	58%	64%	64%	64%
RACHP	Large Retail Food	CFC-12 Large Retail Food – R-407A to CO_2 Transcritical	100%	5%	38%	54%	60%	61%	61%
RACHP	Large Retail Food	R-502 Large Retail Food – R-407A to CO_2 Transcritical	100%	5%	38%	54%	60%	61%	61%
RACHP	Large Retail Food	CFC-12 Large Retail Food – R-404A/R-507A to CO_2 Transcritical	100%	12%	28%	34%	40%	39%	39%
RACHP	Large Retail Food	R-502 Large Retail Food – R-404A/R-507A to CO_2 Transcritical	100%	12%	28%	34%	40%	39%	39%

Sector	Subsector	Transition Technology	Reduction Efficiency	Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type					
				2025	*2030*	*2035*	*2040*	*2045*	*2050*
RACHP	Small Retail Food	R-12 Small Retail Food (Low Temperature) - HCs	100%	20%	20%	20%	29%	29%	29%
RACHP	Small Retail Food	R-12 Small Retail Food (RFPDE) - R-290	100%	0%	11%	12%	6%	6%	6%
RACHP	Small Commercial Unitary A/C	HCFC-22 Small Commercial Unitary A/C - HFC-32 and MCHE	68%	49%	71%	92%	80%	80%	80%
RACHP	Large Commercial Unitary A/C	HCFC-22 Large Commercial Unitary A/C - HFC-32 and MCHE	68%	51%	76%	97%	80%	80%	80%
RACHP	Small Retail Food	R-12 Small Retail Food (Medium Temperature) - HCs	100%	67%	67%	67%	58%	58%	58%
RACHP	Refrigerated Appliances	CFC-12 Refrigerated Appliances - HFC-134a to R-600a	100%	100%	100%	100%	100%	100%	100%
RACHP	Medium Retail Food	HCFC-22 Large Condensing Units (Medium Retail Food) - CO_2	100%	24%	73%	94%	100%	100%	100%
RACHP	Medium Retail Food	HCFC-22 Small Condensing Units (Medium Retail Food) - CO_2	100%	23%	87%	97%	97%	97%	95%
RACHP	Dehumidifiers	HCFC-22 Dehumidifiers - HFC-32	68%	98%	100%	90%	55%	55%	55%
RACHP	Window Units	HCFC-22 Window Units - HFC-32	68%	96%	100%	100%	68%	68%	68%
RACHP	Ice Machines	CFC-12 Ice Makers - R-290	100%	50%	75%	50%	50%	50%	50%
RACHP	PTAC/PTHP	HCFC-22 PTAC/PTHP - HFC-32/R-452B	67%	72%	85%	99%	67%	67%	67%
RACHP	Water & Ground Source HP	HCFC-22 Water & Ground Source HP - HFC-32/R-452B	67%	42%	61%	74%	84%	63%	63%
RACHP	Residential Unitary A/C	HCFC-22 Residential Unitary A/C - R-454B and MCHE	78%	51%	75%	98%	86%	86%	86%
RACHP	PD Chillers	Screw Chillers – R-410A/R-407C replaced w/ HFO-1234ze(E)	100%	92%	100%	100%	100%	100%	100%
RACHP	PD Chillers	Reciprocating Chillers – R-410A/R-407C replaced w/ HFO-1234ze(E)	100%	87%	100%	100%	100%	100%	100%
RACHP	Medium Retail Food	HCFC-22 Small Condensing Units (Medium Retail Food) (RFPDE) - R-448A/R-449A/R-449B	65%	1%	2%	3%	3%	3%	3%
RACHP	Ice Machines	CFC-12 Ice Makers - R-448A/R-449A	58%	23%	43%	29%	29%	29%	29%

Sector	*Subsector*	*Transition Technology*	*Reduction Efficiency*	*Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type*					
				2025	*2030*	*2035*	*2040*	*2045*	*2050*
RACHP	Small Retail Food	R-12 Small Retail Food (RFPDE) - R-448A/R-449A/R-449B	58%	1%	2%	2%	1%	1%	1%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (Ice Rinks) - R-454B	88%	0%	0%	0%	0%	1%	0%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (Ice Rinks) - R-454B	88%	1%	1%	1%	2%	2%	1%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (Ice Rinks) - R-454B	88%	1%	1%	2%	2%	2%	2%
RACHP	Industrial Process Refrigeration	CFC-11 Industrial Process Refrigeration (Data and IT Centers) - R-454B	88%	0%	1%	1%	1%	1%	1%
RACHP	Industrial Process Refrigeration	CFC-12 Industrial Process Refrigeration (Data and IT Centers) - R-454B	88%	1%	2%	3%	3%	4%	3%
RACHP	Industrial Process Refrigeration	HCFC-22 Industrial Process Refrigeration (Data and IT Centers) - R-454B	88%	1%	2%	3%	3%	4%	4%
RACHP	Transport	Intermodal Containers - R-450A/R-513A	77%	2%	4%	6%	5%	5%	5%
RACHP	Transport	Merchant Fishing Transport - R-452A	46%	7%	14%	20%	26%	32%	34%
RACHP	PD Chillers	Scroll Chillers – R-410A/R-407C replaced w/ R-452B	64%	62%	100%	100%	100%	63%	63%
RACHP	Transport	Reefer Ships - R-452A	31%	8%	13%	19%	25%	30%	30%
RACHP	Transport	Road Transport - R-452A	20%	13%	30%	45%	42%	42%	42%
RACHP	Centrifugal Chillers	CFC-114 Chillers - HFC-134a replaced w/ R- 450A/R-513A	57%	0%	100%	100%	100%	57%	57%
RACHP	Centrifugal Chillers	CFC-11 Centrifugal Chillers - HFC-134a replaced w/ R-450A/R-513A	57%	48%	55%	64%	67%	93%	45%
RACHP	Centrifugal Chillers	CFC-12 Centrifugal Chillers - HFC-134 replaced w/ R-450A/R-513A	57%	54%	61%	70%	77%	85%	74%
RACHP	Centrifugal Chillers	R-500 Chillers – HFC-134a replaced w/ R-450A/R-513A	57%	54%	61%	71%	77%	85%	74%
RACHP	Centrifugal Chillers	CFC-12 Centrifugal Chillers - HFC-245fa replaced w/ HCFO-1233zd(E)	99%	19%	20%	23%	24%	26%	15%

Sector	Subsector	Transition Technology	Reduction Efficiency	Technical Effectiveness – Percent Reduction off of BAU Relative to Consumption from Model Facility Type					
				2025	2030	2035	2040	2045	2050
RACHP	Centrifugal Chillers	R-500 Chillers - HFC-245fa replaced w/ HCFO-1233zd(E)	99%	19%	20%	23%	24%	26%	15%
RACHP	Centrifugal Chillers	CFC-11 Centrifugal Chillers - HFC-245fa replaced w/ HCFO-1233zd(E)	99%	31%	34%	38%	38%	45%	20%
RACHP	Vending Machines	CFC-12 Vending Machines - R-290	100%	100%	100%	99%	99%	99%	99%
Solvents	Electronics Cleaning	Aerosol Solvent Electronics Cleaning - Not-in-kind Aqueous	100%	3%	3%	3%	3%	3%	3%
Solvents	Precision Cleaning	Aerosol Solvent Precision Cleaning - Not-in-kind Aqueous	100%	3%	3%	3%	3%	3%	3%
Solvents	Electronics Cleaning	Aerosol Solvent Electronics Cleaning - Not-in-kind Semi-aqueous	100%	3%	3%	3%	3%	3%	3%
Solvents	Precision Cleaning	Aerosol Solvent Precision Cleaning - Not-in-kind Semi-aqueous	100%	3%	3%	3%	3%	3%	3%

Table A-3 – Transitions Modeled in Allocation Rule Reference Case and Technology Transitions Compliance Case

Sector	Subsector	Transitions in Allocation Rule Reference Case	Technology Transitions Rule Base Case
Aerosols	Non-Metered Dose Inhaler Aerosols	HFC-152a to NIK	HFC-152a to NIK
		HFC-134a to NIK	HFC-134a to NIK
		HFC-134a to HFC-152a	HFC-134a to HFC-152a
		HFC-134a to HC	HFC-134a to HC
		HFC-152a to HC	HFC-152a to HC
		HFC-134a to HFO-1234ze(E)	HFC-134a to HFO-1234ze(E)
		HFC-152a to HFO-1234ze(E)	HFC-152a to HFO-1234ze(E)
Fire	Flooding Agents	Inert Gas	Not modeled in base case
		Water Mist	
		Fluoroketone (FK) 5-1-12	

Sector	*Subsector*	*Transitions in Allocation Rule Reference Case*	*Technology Transitions Rule Base Case*
Foam	Rigid PU: Commercial Refrigeration Foam	HFC-245fa to HCFO-1233zd(E)	HFC-245fa to HCFO-1233zd(E)
Foam	Flexible Polyurethane (PU) Foam: Integral Skin Foam	HFC-134a to HCs	HFC-134a to HCs
Foam	PU and Polyisocyanurate (PIR) Rigid: Boardstock	HFC-245fa Blend to HC	HFC-245fa Blend to HC
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	HFC-245fa to HCs	HFC-245fa to HCs
		HFC-245fa to HCFO-1233zd(E)	HFC-245fa to HCFO-1233zd(E)
Foam	PU Rigid: One Component Foam	HFC-134a to HFO-1234ze(E)	HFC-134a to HFO-1234ze(E)
Foam	PU Rigid: Sandwich Panels: Continuous and Discontinuous	HFC-134a to HCs	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) – HFC-134a to HCs
		HFC-245fa/CO_2 to HCFO-1233zd(E)	Rigid PU: Sandwich Panels (PU Rigid: Sandwich Panels: Continuous and Discontinuous) – HFC-245fa/CO_2 to HCFO-1233zd(E)
Foam	PU Rigid: Spray Foam	High-Pressure – HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(E)	HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(E)
		Low-Pressure – HFC-245fa and HFC-245fa/CO_2 blend to HFO-1234ze(E)	HFC-245fa and HFC-245fa/CO_2 blend to HFO-1234ze(E)
Foam	Extruded Polystyrene (XPS): Boardstock Foam	HFC-134a/CO_2 to HFO-1234ze(E)/HCFO-1233zd(E)	HFC-134a/CO_2 to HFO-1234ze(E)/1233zd(E)
Refrigeration, A/C, & Heat Pumps	Centrifugal Chillers	CFC-114 Chillers - HFC-134a to R-450A/R-513A	CFC-114 Chillers - HFC-134a to R-450A/R-513A
		CFC-11 Centrifugal Chillers - HFC-134a to R-450A/R-513A	CFC-11 Centrifugal Chillers - HFC-134a to R-450A/R-513A
		CFC-12 Centrifugal Chillers - HFC-134a to R-450A/R-513A	CFC-12 Centrifugal Chillers - HFC-134a to R-450A/R-513A
		R-500 Chillers - HFC-134a to R-450A/R-513A	R-500 Chillers - HFC-134a to R-450A/R-513A
		CFC-12 Centrifugal Chillers – HFC-245fa to HCFO-1233zd(E)	CFC-12 Centrifugal Chillers - HFC-245fa to HCFO-1233zd(E)
		R-500 Chillers - HFC-245fa to HCFO-1233zd(E)	R-500 Chillers - HFC-245fa to HCFO-1233zd(E)
		CFC-11 Centrifugal Chillers - HFC-245fa to HCFO-1233zd(E)	CFC-11 Centrifugal Chillers - HFC-245fa to HCFO-1233zd(E)
Refrigeration, A/C, & Heat Pumps	Commercial Unitary	Commercial Unitary A/C - R-410A to HFC-32 and MCHE	HCFC-22 Small Commercial Unitary A/C - R-410A to HFC-32 and MCHE
		Commercial Unitary A/C – R-410A to R-410A and MCHE	

Sector	***Subsector***	***Transitions in Allocation Rule Reference Case***	***Technology Transitions Rule Base Case***
		Commercial Unitary A/C - R-410A to HFC-32	HCFC-22 Large Commercial Unitary A/C - R-410A to HFC-32 and MCHE
Refrigeration, A/C, & Heat Pumps	Disposal	Recovery at Disposal for ALL Equipment	Not modeled in base case
Refrigeration, A/C, & Heat Pumps	Heat Pumps (HP)	HP - R-410A to HFC-32/R-452B	HCFC-22 PTAC/PTHP - R-410A to HFC-32/R-452B
			HCFC-22 Water & Ground Source HP - R-410A to HFC-32/R-452B
Refrigeration, A/C, & Heat Pumps	Ice Machines	Ice Makers – R-404A/HFC-134a to R-290	CFC-12 Ice Makers - R-404A/HFC-134a to R-290
			CFC-12 Ice Makers - R-404A to R-448A/R-449A
Refrigeration, A/C, & Heat Pumps	Industrial Process Refrigeration (IPR), Cold Storage (CS)	IPR and Cold Storage – HFCs to NH_3/CO_2	IPR and Cold Storage – HFCs to NH_3/CO_2
Refrigeration, A/C, & Heat Pumps	Large Retail Food	Large Retail Food – R-404A/R-507A to Direct Expansion (DX) R-407A/R-407F	CFC-12 Large Retail Food – R-407A to CO_2 Transcritical
		Large Retail Food – R-404A/R-507A to CO_2 Transcritical	R-502 Large Retail Food – R-407A to CO_2 Transcritical
		Large Retail Food – R-404A/R-507A to R-407A/R-407F Secondary Loop Systems (SLS)	CFC-12 Large Retail Food – R-404A/R-507A to CO_2 Transcritical
			R-502 Large Retail Food – R-404A/R-507A to CO_2 Transcritical
Refrigeration, A/C, & Heat Pumps	Leak Repair	Leak Repair for Large Equipment	Not modeled in base case
Refrigeration, A/C, & Heat Pumps	Medium Retail Food	Medium Retail Food – R-404A/R-507A/HFC-134a to CO_2	HCFC-22 Large Condensing Units (Medium Retail Food) – R-404A/R-507A to CO_2
		Medium Retail Food – R-404A/R-507A/HFC-134a to DX R-407A/R-407F	HCFC-22 Small Condensing Units (Medium Retail Food) – R-404A/HFC-134a to CO_2
			HCFC-22 Small Condensing Units (Refrigerated Food Processing and Dispensing) – R-404A/HFC-134a to R-448A/R-449A/R-449B
Refrigeration, A/C, & Heat Pumps	Positive Displacement Chillers	Screw Chillers – R-410A/R-407C to HFO-1234ze(E)	Screw Chillers - R-410A/R-407C to HFO-1234ze(E)
		Reciprocating Chillers - R-410A/R-407C to HFO-1234ze(E)	Reciprocating Chillers - R-410A/R-407C to HFO-1234ze(E)
		Scroll Chillers – R-410A/R-407C to R-452B	Scroll Chillers – R-410A/R-407C to R-452B
Refrigeration, A/C, & Heat Pumps	Refrigerated Appliances	CFC-12 Refrigerated Appliances – HFC-134a to R-600a	CFC-12 Refrigerated Appliances – HFC-134a to R-600a
Refrigeration, A/C, & Heat Pumps	Residential Unitary	Residential Unitary A/C - R-410A to R-454B and MCHE	HCFC-22 Residential Unitary A/C - R-410A to R-454B and MCHE
Refrigeration, A/C, & Heat Pumps	Service	Recovery at Service for Small Equipment	Not modeled in base case
	Small Retail Food	R-12 Small Retail Food (Low Temperature) – R-404A to HCs	R-12 Small Retail Food (Low Temperature) – R-404A to HCs

Sector	***Subsector***	***Transitions in Allocation Rule Reference Case***	***Technology Transitions Rule Base Case***
Refrigeration, A/C, & Heat Pumps		R-12 Small Retail Food (Low Temperature) - R-404A to R-448A/R-449A	R-12 Small Retail Food (Refrigerated Food Processing and Dispensing) – R-404A to R-448A/R-449A/R-449B
		R-12 Small Retail Food (Low Temperature) - R-404A to R-450A/R-513A	Not modeled in base case
		R-12 Small Retail Food (Medium Temperature) – HFC-134a to R-448A/R-449A	R-12 Small Retail Food (Medium Temperature) – HFC-134a to HCs
Refrigeration, A/C, & Heat Pumps	Transport	Transport – R-404A to R-452A	Intermodal Containers – R-404A/HFC-134a to R-450A/R-513A
			Merchant Fishing Transport – R-404A/R-507A to R-452A
			Reefer Ships – R-404A/R-507A to R-452A
			Road Transport - R-404A to R-452A
Refrigeration, A/C, & Heat Pumps	Vending Machines	CFC-12 Vending Machines – HFC-134a to R-450A/R-513A	CFC-12 Vending Machines – HFC-134a to R-290
		CFC-12 Vending Machines – HFC-134a to R-290	
Refrigeration, A/C, & Heat Pumps	Window AC, Dehumidifiers	Window AC, Dehumidifiers – R-410A to HFC-32	HCFC-22 Dehumidifiers - R-410A to HFC-32
			HCFC-22 Window Units - R-410A to HFC-32
Solvents	Electronics Cleaning	Precision Cleaning applications - retrofitted HFC to Hydrofluoroether (HFE)	Aerosol Solvent Electronics Cleaning - Not-in-kind Aqueous
		Electronic Cleaning applications - retrofitted HFC to HFE	Aerosol Solvent Electronics Cleaning - Not-in-kind Semi-aqueous
		Electronic Cleaning applications - retrofitted Not-in-kind Aqueous	Aerosol Solvent Precision Cleaning - Not-in-kind Aqueous
		Electronic Cleaning applications - retrofitted Not-in-kind Semi-aqueous	Aerosol Solvent Precision Cleaning - Not-in-kind Semi-aqueous

Table A-4 Incremental Costs and Abatement by Subsector for Technology Transitions base case relative to Allocation Rule Reference Case

Subsector	***Incremental Abatement (MMTEVe)***		***Incremental Costs ($ millions)***	
	2025	***2030***	***2025***	***2030***
Chillers	1.58	9.18	$142.59	$398.31
Commercial Refrigeration Foam	0.00	0.00	$0.00	$0.00
Commercial Unitary	1.85	0.41	-$11.33	-$6.25
Disposal	-20.76	-22.08	-$298.30	-$317.15
Electronics Cleaning	-0.46	-0.65	$3.17	$3.50
Flexible PU Foam: Integral Skin Foam	0.00	0.00	$0.00	$0.00

Subsector	*Incremental Abatement (MMTEVe)*		*Incremental Costs ($ millions)*	
	2025	*2030*	*2025*	*2030*
Flooding Agents	-1.30	-1.96	-$0.42	$2.37
Heat Pumps	0.72	0.24	$3.64	$1.19
Ice Machines	0.73	0.78	$2.53	$4.65
IPR and Cold Storage	-5.07	-1.43	$260.28	$136.27
Large Retail Food	4.53	20.36	-$76.18	-$361.89
Leak Repair	-4.49	-4.08	$6.70	$6.09
Medium Retail Food	-2.96	1.02	$0.09	-$17.31
Non-MDI Aerosols	0.85	1.69	$50.47	$71.09
Positive Displacement Chillers	0.00	7.54	$0.00	$117.26
Precision Cleaning	-0.48	-0.64	$4.15	$4.59
PU and PIR Rigid: Boardstock	0.00	0.00	$0.00	$0.00
PU Rigid: Domestic Refrigerator and Freezer Insulation	0.00	0.00	$0.00	$0.00
PU Rigid: One Component Foam	0.00	0.00	$0.00	$0.00
PU Rigid: Sandwich Panels: Continuous and Discontinuous	0.00	0.00	$0.00	$0.00
PU Rigid: Spray Foam	0.00	0.00	$0.00	$0.00
Refrigerated Appliances	0.00	0.00	$0.00	$0.00
Residential Unitary	13.61	2.40	$76.66	$13.50
Service	-7.35	0.00	-$171.18	$0.00
Small Retail Food	0.03	0.19	-$1.99	-$1.84
Transport	1.30	3.27	$23.45	$59.35
Vending Machines	0.00	0.00	$0.00	$0.00
Window Units and Dehumidifiers	5.88	4.41	-$5.30	-$3.97
XPS: Boardstock Foam	6.99	2.43	$57.68	$20.01

Table A-5 Summary of Costs and Revenue (2015 USD) of Transition Technologies

Sector	***Subsector***	***Abatement Option***	***Capital Cost***	***Annual Revenue***	***Annual O&M Costs***	***Abatement Amount ($mtCO_2e$)***	***Breakeven Cost ($\$/mtCO_2e$)***
Aerosols	Non-MDI Aerosols	HFC-134a to HC	$325,000	$2,551,500	$0	807,124.5	($3.10)
Aerosols	Non-MDI Aerosols	HFC-134a to HFC-152a	$500,000	$2,551,500	$0	740,502.0	($3.34)
Aerosols	Non-MDI Aerosols	HFC-134a to HFO-1234ze(*E*)	$500,000	$0	$4,252,500	807,408.0	$5.37
Aerosols	Non-MDI Aerosols	HFC-134a to NIK	$250,000	$4,536,000	$500,000	810,810.0	($4.93)
Aerosols	Non-MDI Aerosols	HFC-152a to HC	$325,000	$0	$0	66,622.5	$0.79
Aerosols	Non-MDI Aerosols	HFC-152a to HFO-1234ze(*E*)	$500,000	$0	$6,804,000	66,906.0	$102.90
Aerosols	Non-MDI Aerosols	HFC-152a to NIK	$250,000	$1,984,500	$500,000	70,308.0	($20.54)
Foam	Rigid PU: Commercial Refrigeration Foam	HFC-245fa to HCFO-1233zd(*E*)	$0	$0	$280,000	71,610.0	$3.91
Foam	Flexible PU Foam: Integral Skin Foam	HFC-134a to HCs	$405,000	$135,000	$0	42,705.0	($2.13)
Foam	PU and PIR Rigid: Boardstock	HFC-245fa blend to HCs	$695,500	$520,000	$0	66,527.5	($6.68)
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	HFC-245fa to HCFO-1233zd(*E*)	$0	$0	$2,147,162	549,136.6	$3.91
Foam	PU Rigid: Domestic Refrigerator and Freezer Insulation	HFC-245fa to HCs	$5,610,000	$4,351,836	$0	549,405.0	($6.81)
Foam	PU Rigid: One Component Foam	HFC-134a to HFO-1234ze(*E*)	$399,000	$0	$1,320,480	185,780.7	$7.34
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	HFC-134a to HCs	$201,500	$2,038,500	$2,490,000	644,845.5	$0.73
Foam	PU Rigid: Sandwich Panels: Continuous & Discontinuous	HFC-245fa/CO_2 to HCFO-1233zd(*E*)	$0	$0	$1,812,000	463,419.0	$3.91
Foam	PU Rigid: Spray Foam (High-pressure)	HFC-245fa and HFC-245fa/CO_2 blend to HCFO-1233zd(*E*)	$250,000	$0	$230,124	58,854.2	$4.37
Foam	PU Rigid: Spray Foam (Low-pressure)	HFC-245fa and HFC-245fa/CO_2 to HFO-1234ze(*E*)	$550,000	$0	$230,124	58,911.7	$4.92

Sector	Subsector	Abatement Option	Capital Cost	Annual Revenue	Annual O&M Costs	Abatement Amount ($mtCO_2e$)	Breakeven Cost ($\$/mtCO_2e$)
Foam	XPS: Boardstock Foam	HFC-134a/CO_2 to HFO-1234ze(*E*)/HCFO-1233zd(*E*)	$19,300,000	$0	$5,529,000	1,003, 852.2	$7.59
Refrigeration, A/C, & Heat Pumps	Chillers	CFC-11 Centrifugal Chillers – HFC-134a to R-450A/R-513A	$12,695	$0	$762	74.2	$28.84
Refrigeration, A/C, & Heat Pumps	Chillers	CFC-11 Centrifugal Chillers – HFC-245fa to HCFO-1233zd(*E*)	$53,800	$0	$168	71.8	$83.62
Refrigeration, A/C, & Heat Pumps	Chillers	CFC-114 Chillers – HFC-134a to R-450A/R-513A	$16,793	$0	$1,008	111.3	$26.53
Refrigeration, A/C, & Heat Pumps	Chillers	CFC-12 Centrifugal Chillers – HFC-134a to R-450A/R-513A	$13,057	$0	$783	73.2	$29.70
Refrigeration, A/C, & Heat Pumps	Chillers	CFC-12 Centrifugal Chillers – HFC-245fa to HCFO-1233zd(*E*)	$53,880	$0	$173	71.7	$82.51
Refrigeration, A/C, & Heat Pumps	Chillers	R-500 Chillers – HFC-134a to R-450A/R-513A	$13,057	$0	$783	73.2	$29.70
Refrigeration, A/C, & Heat Pumps	Chillers	R-500 Chillers – HFC-245fa to HCFO-1233zd(*E*)	$53,880	$0	$173	71.7	$82.51
Refrigeration, A/C, & Heat Pumps	Commercial Unitary AC	Small & Large Commercial Unitary A/C - R-410A to HFC-32	($46)	$4	$0	2.1	($4.72)
Refrigeration, A/C, & Heat Pumps	Heat Pumps	Water & Ground-Source Heat Pumps, PTAC/PTHPs – R-410A to HFC-32/R-452B	$4	$0	$1	0.3	$4.64
Refrigeration, A/C, & Heat Pumps	Ice Machines (self-contained <,=1,000 lb/day harvest rate (batch type) and <=1,200 lb/day harvest rate (continuous type))	Ice Makers – R-404A/HFC-134a to R-290	$107,125	$9,587	$0	14,213.1	$0.73
Refrigeration, A/C, & Heat Pumps	Ice Machines (remote; self-contained >1,000 lb/day harvest rate (batch type) and >1,200 lb/day harvest rate (continuous type))	Ice Makers – R-404A to R-448A/R-449A	$323,251	$0	$14,223	12,656.8	$5.88
Refrigeration, A/C, & Heat Pumps	Industrial Process Refrigeration >=-58 ºF (50 ºC)	IPR – HFCs to NH_3/CO_2	$193,000	$50,180	$0	711.6	($41.09)
Refrigeration, A/C, & Heat Pumps	Cold Storage	Cold Storage – HFCs to NH_3/CO_2	$193,000	$50,180	$0	711.6	($41.09)
Refrigeration, A/C, & Heat Pumps	Large Retail Food	Large Retail Food – R-404A/R-507A to CO_2 Transcritical	$19,610	$13,445	$0	1,096.4	($10.11)
Refrigeration, A/C, & Heat Pumps	Large Retail Food	Large Retail Food – R-407A to CO_2 Transcritical	$19,610	$13,445	$0	589.0	($18.82)

Sector	*Subsector*	*Abatement Option*	*Capital Cost*	*Annual Revenue*	*Annual O&M Costs*	*Abatement Amount (mtCO₂e)*	*Breakeven Cost ($/mtCO₂e)*
Refrigeration, A/C, & Heat Pumps	Medium Retail Food	Medium Retail Food – R-404A/R-507A to CO_2	($108)	$13	$0	8.1	($3.16)
Refrigeration, A/C, & Heat Pumps	Medium Retail Food (RFPDE)	Medium Retail Food (Refrigerated Food Processing and Dispensing Equipment) – R-404A to R-448A/R-449A/R-449B	$149	$0	$18	6.06	$5.80
Refrigeration, A/C, & Heat Pumps	Positive Displacement Chillers: Reciprocating	Chillers –R-410A/R-407C to HFO-1234ze(*E*)	$2,048	$0	$123	66.8	$5.39
Refrigeration, A/C, & Heat Pumps	Positive Displacement Chillers: Screw	Chillers – R-410A/R-407C to HFO-1234ze(*E*)	$1,950	$0	$117	63.6	$5.39
Refrigeration, A/C, & Heat Pumps	Positive Displacement Chillers: Scroll	Chillers – R-410A/R-407C to R-452B	$3,334	$0	$200	40.9	$14.33
Refrigeration, A/C, & Heat Pumps	Refrigerated Appliances	CFC-12 Refrigerated Appliances –HFC-134a to R-600a	($201,075)	$3,156	$0	8,798.0	($3.43)
Refrigeration, A/C, & Heat Pumps	Residential Unitary AC	Residential Unitary A/C – R-410A to R-454B	$28	$0	$2	1.2	$5.18
Refrigeration, A/C, & Heat Pumps	Small Retail Food	R-12 Small Retail Food (Low Temperature) – HCs	($4)	$0.3	$0	0.1	($6.54)
Refrigeration, A/C, & Heat Pumps	Small Retail Food	R-12 Small Retail Food (Medium Temperature) – R-404A to HCs	($2)	$0.2	$0	0.1	($4.22)
Refrigeration, A/C, & Heat Pumps	Small Retail Food (RFPDE)	R-12 Small Retail Food (Refrigerated Food Processing and Dispensing Equipment <500 g charge size) – HFC-134a/R-404A to R-290	($4)	$0.3	$0	0.1	($6.54)
Refrigeration, A/C, & Heat Pumps	Small Retail Food (RFPDE)	R-12 Small Retail Food (Refrigerated Food Processing and Dispensing Equipment) – HFC-134a/R-404A to R-448A/R-449A/R-449B	$6	$0	$1	0.2	$6.34
Refrigeration, A/C, & Heat Pumps	Refrigerated Transport—Road	R-404A to R-452A	$86	$0	$28	2.0	$20.44
Refrigeration, A/C, & Heat Pumps	Refrigerated Transport—Intermodal Containers	R-404A/HFC-134a to R-450A/R-513A	$88	$0	$29	4.5	$9.29
Refrigeration, A/C, & Heat Pumps	Refrigerated Transport—Marine	Merchant Fishing - R-404A/R-507A to R-452A	$6,426	$0	$643	130.7	$10.25
Refrigeration, A/C, & Heat Pumps	Refrigerated Transport—Marine	Reefer Ships - R-404A/R-507A to R-452A	$42,775	$0	$4,278	543.3	$16.41
Refrigeration, A/C, & Heat Pumps	Vending Machines	Vending Machines – HFC-134a to R-290	$305,950	$191	$0	554.0	$88.76
Refrigeration, A/C, & Heat Pumps	Residential AC	Window AC - R-410A to HFC-32	($0.5)	$0.003	$0	0.1	($0.83)
Refrigeration, A/C, & Heat Pumps	Residential Dehumidifiers	Residential Dehumidifiers - R-410A to HFC-32	($0.5)	$0.003	$0	0.1	($0.83)

Sector	***Subsector***	***Abatement Option***	***Capital Cost***	***Annual Revenue***	***Annual O&M Costs***	***Abatement Amount ($mtCO_2e$)***	***Breakeven Cost ($\$/mtCO_2e$)***
Aerosol Solvents	Electronics Cleaning	Electronic Cleaning applications - Not-in-kind Aqueous	$50,000	$1,000	$700	186.0	$33.33
Aerosol Solvents	Electronics Cleaning	Electronic Cleaning applications - Not-in-kind Semi-aqueous	$55,000	$0	$5,900	186.0	$70.16
Aerosol Solvents	Precision Cleaning	Electronic Cleaning applications - Not-in-kind Aqueous	$50,000	$1,000	$700	186.0	$33.33
Aerosol Solvents	Precision Cleaning	Electronic Cleaning applications – Not-in-kind Semi-aqueous	$55,000	$0	$5,900	186.0	$70.16

Annex B: Annual Emission Reductions by Gas

Tables B-1 through B-10 provide the emission reductions by year for the ten HFCs that are addressed by either the Technology Transitions Rule or in the Allocation Rule Reference Case.

Table B-1 – HFC-32 Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-32 Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-32 Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	0.27	7.10	-6.82
2026	0.40	6.76	-6.36
2027	0.60	7.43	-6.84
2028	0.79	7.29	-6.50
2029	0.98	4.78	-3.81
2030	1.17	5.01	-3.84
2031	1.35	5.21	-3.85
2032	1.50	5.31	-3.81
2033	1.65	5.38	-3.73
2034	1.80	5.38	-3.58
2035	1.95	5.43	-3.48
2036	2.03	27.40	-25.37
2037	1.50	12.49	-10.98
2038	1.83	11.18	-9.35
2039	2.11	11.61	-9.50
2040	2.31	13.90	-11.59
2041	2.42	22.03	-19.61
2042	2.54	18.71	-16.17
2043	2.67	15.58	-12.90
2044	2.79	12.61	-9.82
2045	2.83	9.82	-6.99
2046	2.86	9.91	-7.05
2047	2.89	10.01	-7.12
2048	2.92	10.10	-7.18
2049	2.94	10.19	-7.24
2050	2.97	10.27	-7.30

Table B-2 – HFC-125 Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-125 Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-125 Emission Reductions (MMTEVe)***	***Difference***
2025	12.99	48.20	-35.21
2026	19.30	50.28	-30.99
2027	26.30	57.10	-30.80
2028	33.32	59.76	-26.44
2029	40.33	47.40	-7.07
2030	47.38	53.75	-6.37
2031	54.54	60.02	-5.48
2032	61.95	66.31	-4.36
2033	69.42	72.48	-3.06
2034	76.80	78.39	-1.59
2035	84.43	84.52	-0.10
2036	91.96	79.62	12.34
2037	103.12	99.64	3.49
2038	114.86	105.84	9.01
2039	125.10	110.40	14.71
2040	134.93	113.25	21.68
2041	137.67	110.04	27.63
2042	140.53	117.59	22.94
2043	143.32	124.13	19.18
2044	145.99	129.85	16.14
2045	148.45	134.85	13.60
2046	150.32	136.35	13.97
2047	152.02	137.80	14.22
2048	153.65	139.17	14.48
2049	155.21	140.48	14.73
2050	156.72	141.72	15.00

Table B-3 – HFC-134a Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-134a Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-134a Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	10.93	13.72	-2.79
2026	11.43	13.33	-1.90
2027	12.51	15.63	-3.12
2028	13.65	17.35	-3.70
2029	14.83	15.83	-0.99
2030	16.13	17.35	-1.22

2031	17.12	17.81	-0.69
2032	18.28	17.15	1.13
2033	19.44	16.52	2.92
2034	20.98	16.04	4.94
2035	21.91	15.40	6.51
2036	23.24	16.45	6.78
2037	24.41	14.75	9.66
2038	25.42	15.18	10.23
2039	26.43	15.61	10.82
2040	27.45	16.04	11.41
2041	28.48	16.47	12.01
2042	29.60	16.93	12.67
2043	30.79	17.37	13.42
2044	31.92	17.81	14.11
2045	32.93	18.25	14.68
2046	33.53	18.65	14.87
2047	34.11	19.05	15.06
2048	34.66	19.42	15.24
2049	35.21	19.77	15.44
2050	35.73	20.09	15.64

Table B-4 – HFC-143a Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-143a Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-143a Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	4.74	13.16	-8.42
2026	6.59	13.97	-7.38
2027	8.58	13.93	-5.35
2028	10.63	16.30	-5.67
2029	12.72	16.94	-4.21
2030	14.86	17.99	-3.13
2031	17.12	19.09	-1.97
2032	19.40	20.25	-0.85
2033	21.69	21.47	0.22
2034	23.76	24.02	-0.26
2035	26.13	25.41	0.72
2036	28.20	26.62	1.58
2037	30.27	27.73	2.54
2038	32.00	28.73	3.26
2039	33.74	29.70	4.04
2040	35.48	30.64	4.85
2041	37.23	31.53	5.70

2042	38.93	32.39	6.54
2043	40.55	33.22	7.33
2044	42.10	34.05	8.05
2045	43.59	34.85	8.74
2046	44.91	35.58	9.34
2047	46.00	36.23	9.77
2048	47.02	36.81	10.20
2049	47.95	37.32	10.63
2050	48.69	37.74	10.96

Table B-5 –HFC-152a Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-152a Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-152a Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	0.29	0.83	-0.54
2026	0.30	0.87	-0.58
2027	0.31	0.89	-0.58
2028	0.32	0.91	-0.59
2029	0.33	0.93	-0.60
2030	0.34	0.95	-0.60
2031	0.35	0.95	-0.61
2032	0.35	0.96	-0.61
2033	0.35	0.97	-0.62
2034	0.36	0.98	-0.62
2035	0.36	0.98	-0.63
2036	0.36	0.99	-0.63
2037	0.36	1.00	-0.64
2038	0.37	1.01	-0.64
2039	0.37	1.02	-0.65
2040	0.37	1.02	-0.65
2041	0.38	1.03	-0.66
2042	0.38	1.04	-0.66
2043	0.38	1.05	-0.67
2044	0.38	1.06	-0.67
2045	0.39	1.07	-0.68
2046	0.42	1.07	-0.66
2047	0.44	1.08	-0.64
2048	0.46	1.09	-0.63
2049	0.49	1.10	-0.61
2050	0.51	1.11	-0.60

Table B-6 – HFC-227ea Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	Technology Transitions Base Case HFC-227ea Emission Reductions (MMTEVe)	Allocation Rule Reference Case HFC-227ea Emission Reductions (MMTEVe)	Difference (MMTEVe)
2025	0.00	0.07	-0.07
2026	0.00	0.08	-0.08
2027	0.00	0.10	-0.10
2028	0.00	0.11	-0.11
2029	0.00	0.13	-0.13
2030	0.00	0.15	-0.15
2031	0.00	0.17	-0.17
2032	0.00	0.19	-0.19
2033	0.00	0.21	-0.21
2034	0.00	0.23	-0.23
2035	0.00	0.26	-0.26
2036	0.00	0.28	-0.28
2037	0.00	0.30	-0.30
2038	0.00	0.32	-0.32
2039	0.00	0.34	-0.34
2040	0.00	0.36	-0.36
2041	0.00	0.37	-0.37
2042	0.00	0.39	-0.39
2043	0.00	0.41	-0.41
2044	0.00	0.42	-0.42
2045	0.00	0.43	-0.43
2046	0.00	0.45	-0.45
2047	0.00	0.46	-0.46
2048	0.00	0.47	-0.47
2049	0.00	0.48	-0.48
2050	0.00	0.49	-0.49

Table B-7 – HFC-236fa Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case (2020 dollars per metric ton of HFC-236fa)

Year	Technology Transitions Base Case HFC-236fa Emission Reductions (MMTEVe)	Allocation Rule Reference Case HFC-236fa Emission Reductions (MMTEVe)	Difference (MMTEVe)
2025	0.00	0.05	-0.05
2026	0.00	0.03	-0.03
2027	0.00	0.02	-0.02
2028	0.00	0.01	-0.01
2029	0.00	0.00	0.00
2030	0.00	0.00	0.00

2031	0.00	0.00	0.00
2032	0.00	0.00	0.00
2033	0.00	0.00	0.00
2034	0.00	0.00	0.00
2035	0.00	0.00	0.00
2036	0.00	0.00	0.00
2037	0.00	0.00	0.00
2038	0.00	0.00	0.00
2039	0.00	0.00	0.00
2040	0.00	0.00	0.00
2041	0.00	0.00	0.00
2042	0.00	0.00	0.00
2043	0.00	0.00	0.00
2044	0.00	0.00	0.00
2045	0.00	0.00	0.00
2046	0.00	0.00	0.00
2047	0.00	0.00	0.00
2048	0.00	0.00	0.00
2049	0.00	0.00	0.00
2050	0.00	0.00	0.00

Table B-8 – HFC-245fa Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-245fa Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-245fa Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	4.10	4.66	-0.56
2026	4.98	5.21	-0.23
2027	5.61	5.79	-0.18
2028	6.25	6.41	-0.16
2029	6.86	7.02	-0.15
2030	7.58	7.73	-0.15
2031	8.08	8.23	-0.15
2032	8.78	8.93	-0.15
2033	10.08	10.23	-0.15
2034	11.42	11.58	-0.16
2035	12.20	12.36	-0.16
2036	13.02	13.34	-0.32
2037	13.89	14.22	-0.33
2038	14.34	14.68	-0.34
2039	14.79	15.15	-0.36
2040	15.23	15.61	-0.38
2041	15.68	16.07	-0.39

2042	16.13	16.53	-0.41
2043	16.50	17.01	-0.52
2044	17.08	17.70	-0.62
2045	17.68	18.41	-0.73
2046	18.29	18.99	-0.71
2047	18.92	19.59	-0.67
2048	19.55	20.18	-0.63
2049	19.84	20.78	-0.94
2050	20.45	21.37	-0.93

Table B-9 – HFC-43-10mee Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	***Technology Transitions Base Case HFC-43-10mee Emission Reductions (MMTEVe)***	***Allocation Rule Reference Case HFC-43-10mee Emission Reductions (MMTEVe)***	***Difference (MMTEVe)***
2025	1.30	0.92	0.37
2026	1.35	0.98	0.37
2027	1.41	1.04	0.36
2028	1.46	1.10	0.36
2029	1.52	1.17	0.35
2030	1.59	1.24	0.35
2031	1.63	1.29	0.34
2032	1.68	1.35	0.33
2033	1.72	1.40	0.32
2034	1.77	1.46	0.31
2035	1.86	1.51	0.34
2036	1.87	2.31	-0.44
2037	1.88	2.33	-0.45
2038	1.90	2.35	-0.45
2039	1.91	2.37	-0.46
2040	1.93	2.39	-0.46
2041	1.94	2.41	-0.47
2042	1.96	2.43	-0.47
2043	1.97	2.45	-0.47
2044	1.99	2.47	-0.48
2045	2.00	2.49	-0.48
2046	2.02	2.51	-0.49
2047	2.03	2.53	-0.49
2048	2.05	2.55	-0.50
2049	2.06	2.57	-0.50
2050	2.08	2.59	-0.51

Table B-10 – HFC-23 Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	Technology Transitions Base Case HFC-23 Emission Reductions (MMTEVe)	Allocation Rule Reference Case HFC-23 Emission Reductions (MMTEVe)	Difference (MMTEVe)
2025	3.71	3.71	0.00
2026	3.82	3.82	0.00
2027	3.70	3.70	0.00
2028	3.77	3.77	0.00
2029	3.80	3.80	0.00
2030	3.78	3.78	0.00
2031	3.78	3.78	0.00
2032	3.77	3.77	0.00
2033	3.76	3.76	0.00
2034	3.77	3.77	0.00
2035	3.77	3.77	0.00
2036	3.77	3.77	0.00
2037	3.77	3.77	0.00
2038	3.78	3.78	0.00
2039	3.77	3.77	0.00
2040	3.77	3.77	0.00
2041	3.77	3.77	0.00
2042	3.77	3.77	0.00
2043	3.77	3.77	0.00
2044	3.77	3.77	0.00
2045	3.77	3.77	0.00
2046	3.77	3.77	0.00
2047	3.77	3.77	0.00
2048	3.77	3.77	0.00
2049	3.77	3.77	0.00
2050	3.77	3.77	0.00

Table B-11 sums the above ten HFC-specific tables for total emission reductions.

Table B-11 – Total HFC Emission Reductions by Year from the Technology Transitions Rule and the Allocation Rule Reference Case

Year	Technology Transitions Base Case Total HFC Emission Reductions (MMTEVe)	Allocation Rule Reference Case Total HFC Emission Reductions (MMTEVe)	Difference (MMTEVe)
2025	38.32	92.41	-54.09
2026	48.17	95.35	-47.18
2027	59.02	105.64	-46.62
2028	70.19	113.01	-42.82
2029	81.38	97.99	-16.61

2030	92.83	107.95	-15.12
2031	103.97	116.55	-12.58
2032	115.71	124.22	-8.51
2033	128.12	132.43	-4.31
2034	140.65	141.84	-1.18
2035	152.60	149.65	2.95
2036	164.45	170.78	-6.33
2037	179.21	176.22	2.99
2038	194.48	183.07	11.41
2039	208.23	189.97	18.26
2040	221.48	196.97	24.51
2041	227.57	203.73	23.84
2042	233.84	209.78	24.06
2043	239.96	214.99	24.97
2044	246.03	219.74	26.29
2045	251.63	223.93	27.71
2046	256.12	227.29	28.82
2047	260.18	230.51	29.67
2048	264.08	233.57	30.51
2049	267.48	236.45	31.03
2050	270.92	239.14	31.78

Annex C: Industries Potentially Affected by Subsection (i) of the AIM Act

Companies that may be potentially affected by this rule include those that use HFCs to manufacture products, such as refrigeration and air conditioning systems, foams, and aerosols. Industries that may be potentially affected tangentially by this rule are those that produce, import, export, destroy, use as a feedstock, reclaim, or otherwise distribute HFCs. Potentially affected categories, North American Industry Classification System (NAICS) codes, and examples of potentially regulated entities are included in Table C-1.

Table C-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
325992	Photographic Film, Paper, Plate and Chemical Manufacturing
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing
326150	Urethane and Other Foam Product
331420	Copper Rolling, Drawing, Extruding, and Alloying
332312	Fabricated Structural Metal Manufacturing
332313	Plate Work Manufacturing
333132	Oil and Gas Field Machinery and Equipment Manufacturing
333314	Optical Instrument and Lens Manufacturing
333316	Photographic and Photocopying Equipment Manufacturing
333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing
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
334419	Other Electronic Component Manufacturing

NAICS Code	NAICS Industry Description
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
334516	Analytical Laboratory Instrument Manufacturing
334613	Blank Magnetic and Optical Recording Media Manufacturing
336510	Railroad Rolling Stock Manufacturing
336611	Ship Building and Repairing
336612	Boat Building
339999	All Other Miscellaneous Manufacturing
423120	Motor Vehicle Supplies and New Parts Merchant Wholesalers
423450	Medical, Dental, and Hospital Equipment and Supplies Merchant Wholesalers
423460	Ophthalmic Goods Merchant Wholesalers
423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers
423740	Refrigeration Equipment and Supplies Merchant Wholesalers
423830	Industrial Machinery and Equipment Merchant Wholesalers
423860	Transportation Equipment and Supplies (except Motor Vehicle) Merchant Wholesalers
423990	Other Miscellaneous Durable Goods Merchant Wholesalers
424210	Drugs and Druggists’ Sundries Merchant Wholesalers
424410	General Line Grocery Merchant Wholesalers
424610	Plastics Materials and Basic Forms and Shapes Merchant Wholesalers
424690	Other Chemical and Allied Products Merchant Wholesalers
424910	Farm Supplies Merchant Wholesalers
441310	Automotive Parts and Accessories Stores
443141	Household Appliance Stores
443142	Electronics Stores
444130	Hardware Stores
446191	Food (Health) Supplement Stores
452311	Warehouse Clubs and Supercenters
453998	All Other Miscellaneous Store Retailers (except Tobacco Stores)
454110	Electronic Shopping and Mail-Order Houses
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

NAICS Code	***NAICS Industry Description***
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

Annex D: Imports of Products Containing HFCs

D.1 Introduction and Background

This Annex analyzes the historical and projected import of products containing HFCs listed as regulated substances under the AIM Act.

As noted earlier, EPA prepared a Regulatory Impact Analysis (RIA) for the Allocation Framework Rule (86 FR 55116, October 5, 2021) establishing the framework for allocating HFC production and consumption allowances for the years 2022 and 2023.[51] In the Allocation Framework RIA accompanying those rules, EPA estimated the potential consumption reductions from 2022 through 2036 and emission reductions from 2022 to 2050 achieved by codifying the AIM Act HFC phasedown consumption limits. Because EPA's analytic approach using the Vintaging Model and MAC curves does not distinguish between products manufactured in the United States and those that are imported from other countries, the Allocation Framework RIA did not specifically examine the impacts of importing products containing HFCs ("products") in terms of the amount of HFCs supplied to the U.S. market or potentially abated therefrom vis-à-vis the reductions achieved under the phasedown. Under the Allocation Framework Rule such imports do not require the expenditure of allowances; therefore, the adoption of lower-GWP substances in imported products would not be the direct result of compliance with the Allocation Framework Rule.

The same analytic limitations regarding differentiating between domestic and imported products applies to the analysis of the Technology Transitions Rule. This Annex uses other techniques and information sources to analyze the market for imported products containing HFCs. It is important to provide analysis of the consumption and emissions impacts of the Technology Transitions Rule's provisions affecting imported products. Domestic manufacturers must operate under the constraints of the Technology Transitions Rule as well as the overall AIM Act production and consumption caps. On the other hand, imported products will only be subject to the constraints of the Technology Transitions Rule. To the extent that the Allocation Rules' analyses include reductions due to imported products containing HFCs, those analyses may underestimate the domestic adoption of abatement options required to meet the AIM Act consumption cap. This, in turn, may result in an overestimate of the subsequent availability of options

[51] As noted previously, the original RIA was updated based on the 2024 Allocation Rule (88 FR 46836; July 20, 2023). We use "Allocation Framework RIA" to refer to the analysis of the Allocation Framework Rule as promulgated on October 5, 2021 and updated based on the 2024 Allocation Rule RIA Addendum. This Annex provides supplementary analysis to address additional aspects of that updated RIA.

for the abatement in domestically produced equipment to comply with the lower-GWP requirements of this rule.

D.1.1 Imported Products Containing HFCs

Several types of products containing HFCs are imported to the United States. Under EPA's Greenhouse Gas Reporting Program (GHGRP), codified at 40 CFR Part 98, the net supply of HFCs in a subset of imported products, i.e., appliances and closed-cell foam, has risen from 7.4 $MMTCO_2e$ in 2011 to 35.2 $MMTCO_2e$ in 2020. These totals are the amount of all reported imports minus all reported exports and thus the total amount of imports is greater than these totals.

The data reported under the GHGRP represents less than the total amount of HFCs contained in products imported into the United States due to two limitations. First, the scope of the GHGRP excludes certain product types that contain HFCs. For instance, aerosol cans and fire extinguishers are not reported. Second, reporting is not required for those who import and export less than 25,000 $MTCO_2e$ annually. Even so, the reported 2020 net import of saturated HFCs in products and foams equates to 11.4% of the net supply of HFCs in bulk.[52]

To conduct the analysis in this Annex, we examined the categories of products typically containing HFCs when imported to the United States. Product categories included in this Annex include closed-cell foams and aerosol cans that contain HFCs. The term "closed-cell" is used to describe many types of foam products and indicates that unlike for "open-cell" foams the intent is for the blowing agent, in this case an HFC, to be contained within the cells of the foam. An aerosol can is another example. In this case, the useful product is not the metal can itself, but the material within the can that is to be distributed (aerosolized) from the can. An HFC may be used as the propellant to create the aerosolized product (e.g., hairspray or body deodorant), may be both the propellant and the useful product itself (e.g., as a duster), or may be the solvent carrier (e.g., HFC-134a as the propellant carrying HFC-43-10mee as a solvent for removal of grease, flux, and other soils from electrical equipment or electronics).

In other types of products, the HFC is required for the equipment to work, and is often pre-charged when the product is manufactured. For example, a self-contained room air conditioner (e.g., a "window AC") is pre-charged with the refrigerant and the cooling circuit is closed at the factory. This avoids the need for a homeowner or technician to provide the refrigerant and seal the system before it can be plugged in and used. Several other types of products come fully charged with the appropriate amount of a refrigerant, including household dehumidifiers, portable air conditioners, packaged terminal air conditioners and heat pumps, beverage and food coolers, and vending machines. Walk-in cold storage "rooms" and chillers

[52] *https://www.epa.gov/ghgreporting/suppliers-industrial-ghgs-and-products-containing-ghgs*, viewed on March 10, 2023.

could also be pre-charged, although in some instances—typically when the product is too large to fit in a standard sized shipping truck—the individual components for these types of products would be manufactured separately and the system would be installed and charged with a refrigerant on-site.

Another type of pre-charged product includes those that typically contain a "holding charge." A common example is the "condensing unit" for a residential air conditioner. The condensing unit typically is placed outside and contains the compressor, the condenser, and often other parts of the air conditioner. Refrigerant lines are connected to the indoor unit, which contains the evaporator. Condensing units, especially those of smaller capacity and intended primarily for residential applications, generally contain a holding charge of the refrigerant. The amount is meant to be close to the full charge required in applications with a defined length of refrigerant lines. As each application of such units vary, notably in the length of refrigerant lines required to reach the indoor unit, the system is typically "balanced" by the installer to provide the correct amount of refrigerant needed for the application.

D.1.2 Allocation Framework Rule Coverage of Imports

The Allocation Framework Rule provided the methodology for allocating allowances for the production and import of bulk substances. Apart from allocations for the discreet and statutorily required applications listed in (e)(4)(B)(iv) of the AIM Act, the Allocation Framework Rule did not provide for the allocation of allowances based on a company's manufacture or import of products that use HFCs. Furthermore, in defining the terms "consumption" and establishing the baseline based on the formula provided in the AIM Act, EPA did not include the quantity of HFCs contained in imported products.

There were several reasons for this approach as discussed in the Allocation Framework Rule (see 86 FR 55130-55132; 86 FR 55137-55140). The Agency surmised that subsection (i) of the AIM Act provided clearer authority to address imported products while achieving the goals of the AIM Act and noted that at that time already more than a dozen petitions under subsection (i) had been received to address both imported and domestically manufactured products.

D.1.3 Allocation Framework RIA Coverage of Imports

The Allocation Framework RIA estimated the potential consumption and associated emission reductions possible while complying with the HFC phasedown requirements in the AIM Act. The Allocation Framework RIA describes EPA's process for such estimates. EPA used a Marginal Abatement Cost (MAC) analysis based on previous work to develop a cost scenario that would reduce consumption to the amount required under the AIM Act. The MAC analysis required the use of abatement options that provided the cost and consumption reductions possible in the U.S. market. EPA relied on its Vintaging Model to calculate a "business as usual" (BAU) projection of HFC consumption and to determine the reduction in consumption, and the associated reduction in emissions, achieved under the individual abatement options.

The Allocation Framework RIA is agnostic as to whether products under each abatement option are imported or manufactured domestically. In other words, if an abatement option assumed that a certain HFC was replaced by a lower-GWP substance, such change was assumed for all products equally. Several abatement options included in the analysis needed to reduce domestic consumption of HFCs to reach the AIM Act consumption caps involve an equipment market that is at least in part imported to the United States. In the Allocation Framework RIA, if a specific HFC subsector was assumed to fully convert to a lower-GWP substance, the analysis included HFC consumption reduction for all products – both those products produced domestically and those imported. If only a portion of a subsector was assumed to convert, the percentage assumed as not transitioning was based on information and conclusions on the particular subsector and the viability of the alternative substance; that portion not converting was not meant to represent the percentage of the subsector that is imported.

D.2 Imports of Products Containing HFCs

Because of the limitations in the Allocation Framework RIA, EPA undertook a scoping analysis to estimate the amount of HFCs historically contained in imported products and to project such HFC supply in the future. This scoping analysis was conducted using supplementary data from the U.S. Census, previous EPA rulemakings, EPA's Vintaging Model, and other sources. A table summarizing the types of products analyzed and the related assumptions, explained below, is provided in Section D.3 of this Annex. In addition, EPA estimated the potential reductions in such supply and in the associated emissions based on the Technology Transitions Rule.

D.2.1 Historical Information on Imported Products

Import data were available from the United States International Trade Commission, with divisions by the U.S. Census Bureau's 6-digit North American Industry Classification System (NAICS), the 10-digit Harmonized Tariff Schedule (HTS), and 5-digit Standard International Trade Classification (SITC).[53] EPA first used expert judgement to gather the product types that were likely to be imported containing HFCs, which included one aerosols subsector, one polyurethane foams subsector, and nine subsectors in the Refrigeration, Air Conditioning, and Heat Pump sector. Based on feedback from the National Aerosol Association (NAA) and the Household and Commercial Production Association (HCPA), EPA gathered aerosol import data from 27 import categories represented by 35 separate HTS codes. For the other types of products, EPA used the SITC codes, as these offered greater differentiation than other methods such as

[53] *https://dataweb.usitc.gov/.* See Table D-1 below for a list of the classification codes used.

HTS codes. In this way, EPA gathered the imports of products (by number of units) for the years 2016-2021.

D.2.2 Current HFCs Contained in Imported Products

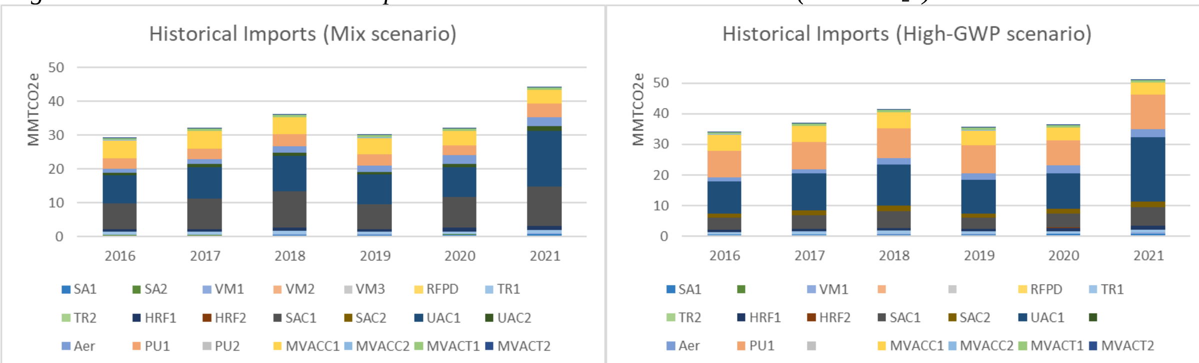
EPA then determined which HFC is likely contained in these products and the amount or charge size to calculate the quantity, in metric tons and CO_2e, contained in such products. Product lifetimes were also gathered so that emissions could be calculated while accounting for the time lag between product manufacture and emissions. In terms of the HFC contained in the imported products, EPA evaluated two scenarios:

A. Mix. We assumed that the products being imported included some products using traditional, higher-GWP HFCs and others using lower-GWP alternative substances. Using previous work under EPA's Significant New Alternatives Policy (SNAP) program, Small Business Regulatory Enforcement Fairness Act (SBREFA) analysis, the Vintaging Model, and other sources, we estimated the market share amongst the imports between the baseline higher-GWP HFC(s) and the likely alternative substance(s). This is considered conservative (lower reductions on a CO_2e basis), as we would expect the imported products to be reliant more on the older, higher-GWP options whereas the overall market may be a mix with some newer lower-GWP options.
B. High-GWP. As a bounding exercise, we assumed the imported products contained the higher-GWP HFC(s) that have historically been used in the individual subsectors. However, where it was reasonably concluded that the transition in imported products was already occurring, we did not make such an adjustment to that subsector. For instance, information from the GHGRP shows us that some light-duty passenger cars are imported with HFO-1234yf, and others with HFC-134a, so the imports were divided between these two options as before.

The following graphs display the total imports for each year 2016 through 2021 by subsector in CO_2e terms.[54]

[54] Blank items in the legend of the right (high-GWP) graph represent subsectors wherein lower-GWP alternative substances were removed from the historical imports, and which were instead assumed to have contained only higher-GWP HFCs.

Figure D-1: Historical HFCs in Imported Products under Two Scenarios (MMTCO$_2$e)



These estimates of historical quantities of HFCs in imported products seem reasonable when compared to the available data from GHGRP. The values here range from 29 MMTCO$_2$e to 44 MMTCO$_2$e (Mix scenario) or 34 MMTCO$_2$e to 51 MMTCO$_2$e (High-GWP scenario) for the years 2016-2020.[55] Values from the GHGRP, which are net supply, not imports only, and are limited in scope and coverage as explained above, range from 28 MMTCO$_2$e to 35 MMTCO$_2$e over the same time period.

D.2.3 Projecting Future Imports of Products

Although the market fluctuates from year to year, there is a general growth in imports in CO$_2$e terms, with an annual linear increase of 1.9 to 2.2 MMTCO$_2$e. The GHGRP data, which dates back to 2011, shows an even steeper linear growth of 2.7 MMTCO$_2$e per annum, although the increase is only 1.14 MMTCO$_2$e per year for the 2016-2020 timeframe. Given this increasing trend, it is important to estimate what the import of products containing HFCs could be in the future if no restrictions were placed on them. For this factor we used two scenarios to bound the analysis:

1. BAU-linked. We assumed the imports grow or decline at the same rates as the business-as-usual (BAU) consumption curve presented in the Allocation Framework RIA. This assumption would imply the portion of the overall market supplied by imports remains the same.
2. Linear trend. We used a linear regression of the historical import data. Each subsector was trended separately. These projections were higher than the BAU-linked estimates for most years.

These projections can be considered as "business as usual" projections; that is, they show how imported products would grow without the Technology Transitions Rule in place. As discussed in Sections D.1.2 and D.1.3 of this Annex, the Allocation Framework Rule, and the related 2024 Allocation Rule, do not

[55] GHGRP data for 2021 indicated a total supply of 13 MMTCO$_2$e. Upon review, EPA finds that this total was calculated before some importers reported data and, more importantly, that the market for imports was severely impacted by supply chain issues related to the pandemic. Therefore, data for 2021 are not included in this comparison.

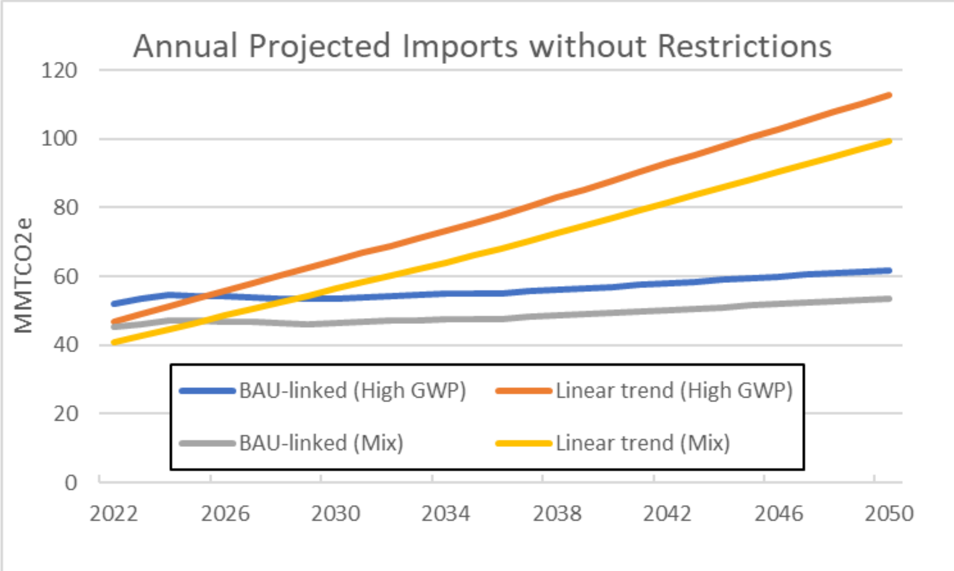
constrain the import of products containing HFCs. Thus, these “business as usual” projections apply irrespective of those rules.

There is much uncertainty in such estimates and this fact is the reason why we offer two scenarios that we feel would bound the most likely outcomes. However, in the absence of the Technology Transitions Rule, it might be expected that as the production and consumption of HFCs are phased down under the Allocation Rules, the available HFC might be directed towards those applications that could not be imported (e.g., field-erected refrigeration systems). This could mean that imported products containing HFCs may grow even faster than the projection scenarios analyzed, and domestic manufacture of such products would decline. This might also cause economic harm to domestic manufacturers or lead those manufacturers to open manufacturing lines outside of the United States. Many U.S.-headquartered businesses already have overseas facilities, and so for them it might be simply a redistribution of where products containing HFCs are made, if not already 100% outside the United States.

As discussed below in Section D.5.2 of this Annex, the redistribution of manufacturing, even in absence of this Technology Transitions Rule, would be constrained by several factors. We note that currently, major U.S. trading partners are parties to the Kigali Amendment to the Montreal Protocol, so the availability of HFCs would also be constrained in those countries. Further, the U.S. is a large market for HFC-containing products, which would lead manufacturers to offer only products that comply with our regulations. Also, other countries are adopting similar restrictions, and many States have promulgated such regulations or would do so in the absence of the Technology Transitions Rule, again leading manufacturers to offer a limited selection of products, specifically ones that comply with the restrictions in this rule.

For these reasons, we feel the projections are reasonable bounds on the “business as usual” imports of products containing HFCs. The following graph shows the annual projected imports in CO_2e terms without restrictions using the two projection methods discussed above, with each shown under the two scenarios regarding the types of chemicals contained in the imported products.

Figure D-2: Projected HFC Imports in Products in the Absence of the Technology Transitions Rule (MMTCO$_2$e)



.

D.2.4 Future Alternative Substances Contained in Imported Products

The Technology Transitions Rule establishes GWP limits on several types of products, including most all those assumed to be imported with HFCs contained in them, and applies such limits equally to imported products and domestically manufactured products.[56] These restrictions require imported products that do not already comply with the restrictions to transition to alternative substances. Such restrictions could affect multinational companies' decisions regarding where to manufacture products and hence change the dynamics of the import market. Such decisions are difficult to predict, so here we assume the trends as discussed above continue while the Technology Transitions Rule takes effect.

Importers of products, like the domestic manufacturers, have a variety of alternative substances to choose from while complying with the Technology Transitions Rule restrictions. Multiple choices for each product subsector exist as discussed in the preamble to the Technology Transitions Rule and the Technical Support Documents referenced therein. We made two assumptions regarding what substance products would transition to under this rule:

I. GWP limits. We assumed products with imported HFCs above the GWP limit would change to a substance or blend with a GWP exactly at the GWP limit. Few alternative substances currently exist at the exact GWP limits, so this approach would require such hypothetical blends to be developed. To attribute emissions by chemical (so that individual social costs of HFCs could be

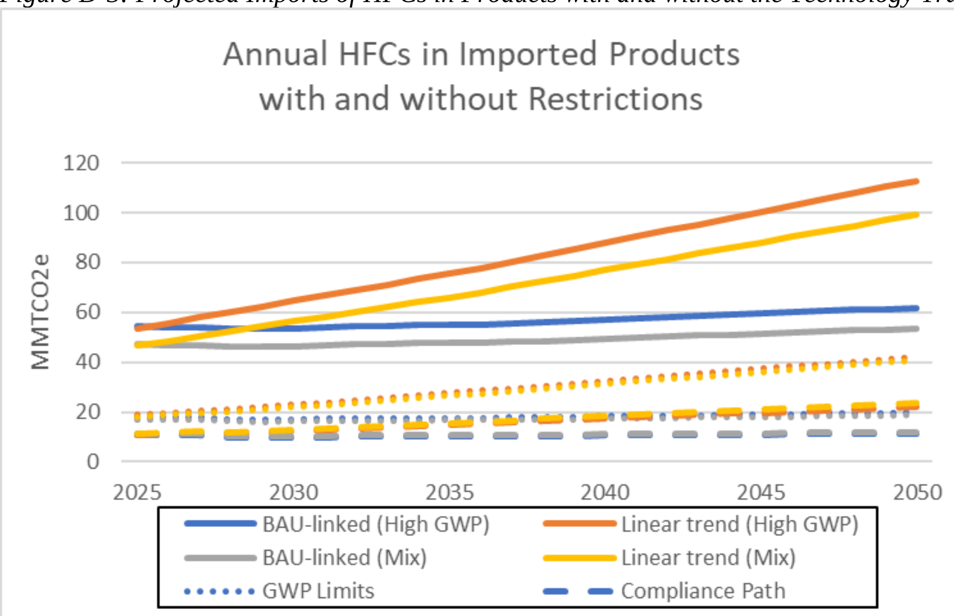
[56] The exceptions are road transport refrigeration, and certain types of automatic commercial ice machines and refrigerated food processing and dispensing equipment, wherein EPA is restricting specific HFCs and blends containing HFCs. As explained above, for this analysis we apply a GWP limit of either 1,425 or 2,200, depending on which HFCs are restricted, to model these subsectors.

applied), we assumed the current high-GWP HFC would be "blended down" with another non-HFC chemical (e.g., an HFO or a hydrocarbon) to reach the exact GWP limit. This would result in the highest level (in CO_2e terms) of imports allowed under the restrictions and hence lower reductions in both the amount imported and the resulting emissions than the following approach.

II. Compliance Path. Because the alternative substances contained in imported products would not necessarily have GWPs at the exact limit, and instead would likely be other existing or developing alternative substances that are below that limit, we developed a compliance path of most likely alternative substances based on the abatement options analyzed previously in the Allocation Framework RIA and our knowledge of the subsectors.

With the various projections estimated above and the two possible approaches in the alternative substances chosen, we can estimate the resulting supply of HFCs in imported products with restrictions. The projected import of HFCs with and without restrictions is shown in the following graph.

Figure D-3: Projected Imports of HFCs in Products with and without the Technology Transitions Rule (MMTCO$_2$e)

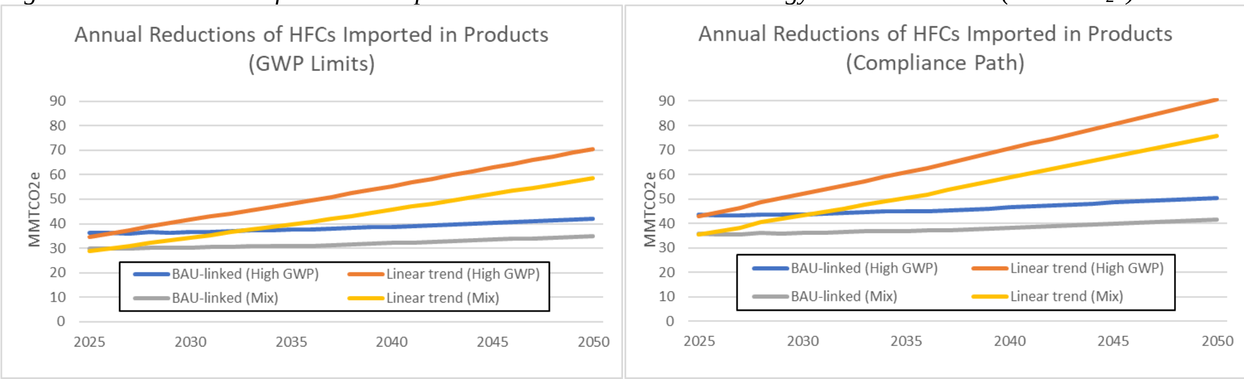


Four estimates each under the GWP Limits and Compliance Path scenarios are shown. Each of the lines is color-coded to match the estimated annual HFCs in imported products without restrictions (solid lines). For brevity, only one entry each is shown in the legend to indicate the format of the four GWP Limits estimates with restrictions (dotted lines) and the four Compliance Path estimates with restrictions (dashed lines).

The difference between the with and without restriction scenarios indicates how much supply of HFCs is avoided by restricting imports. We do not consider these additional benefits beyond the MAC approach used to analyze this rule and the Allocation Rules, because as discussed above the model used for the MAC approach assumes compliance for the entire U.S. market and remains agnostic as to whether the affected subsector includes products that are imported with HFCs or not.

The following graphs display the annual reductions in HFCs imported in products over time. Reductions start in 2025, the first compliance date in the Technology Transitions Rule.

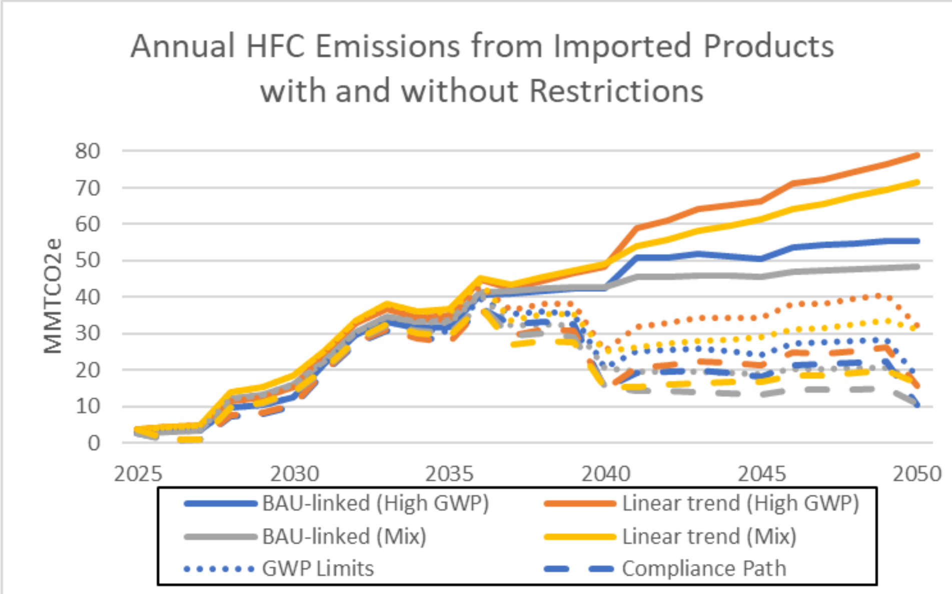
Figure D-4: Reductions of HFCs in Imported Products with the Technology Transitions Rule (MMTCO$_2$e)



D.2.5 Emissions

Once imported to the United States, emissions from products containing HFCs will occur. To estimate the emissions from the imported products, EPA applied a simplified emission profile to each subsector, assuming that the full charge imported would be emitted at the product's end-of-life. For aerosols, this is the same emission profile used in Vintaging Model and conforms with guidelines from the Intergovernmental Panel on Climate Change. The estimate is conservative (i.e., modeled emissions occur later than actual) for foam products, which would typically have diffusive emissions from the foam during product use, and full emissions either at disposal (e.g., from crushing the foams) or possibly thereafter (e.g., remaining HFCs emitted after the foam has been put in a landfill). For many of the air conditioning and refrigeration appliances, the emission profile is similar to real-life use. For example, window air-conditioners, domestic refrigerators, and other types of self-contained products generally maintain their refrigerant charge throughout the lifetime, with no service or "topping-off" of the refrigerant required. Regulations under Section 608 of the CAA require recovering the refrigerant before the equipment is disposed; however, we have not modeled the fate of any refrigerant so recovered, and hence these emissions may lead to less conservative (i.e., modeled emissions occurring earlier than actual) results. Finally, some imported air conditioning and refrigeration products (e.g., condensing units used in residential AC) are typically serviced throughout their useful life. Here the modeled emissions are again conservative, as this analysis did not account for any additional refrigerant needed for service. Using this emission profile, annual emissions from imported products with and without the restrictions in the Technology Transitions Rule are generated, as shown in the graph below.

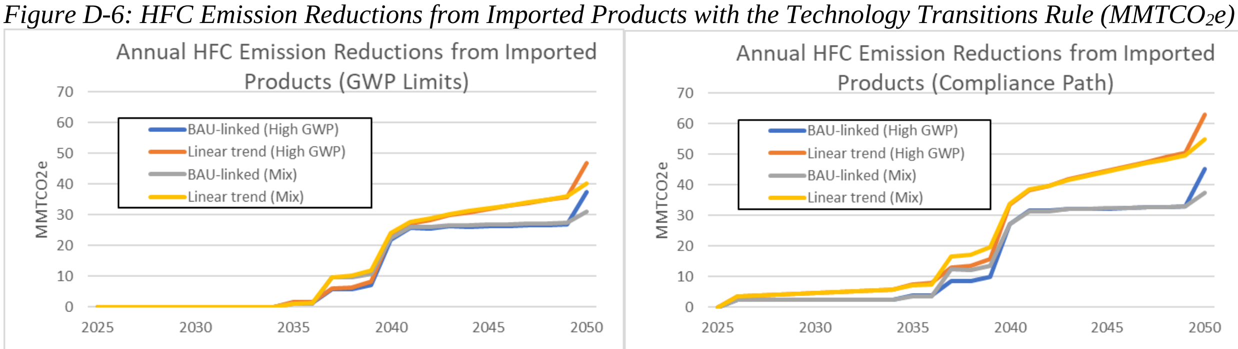
Figure D-5: HFC Emissions from Imported Products with and without Technology Transitions Rule ($MMTCO_2e$)



Four estimates each under the GWP Limits and Compliance Path scenarios are shown. Each of the lines is color-coded to match the estimated annual HFC emissions from imported products without restrictions (solid lines). For brevity, only one entry each is shown in the legend to indicate the format of the four GWP Limits estimates with restrictions (dotted lines) and the four Compliance Path estimates with restrictions (dashed lines).

Annual emission reductions due to the restrictions on imported products are shown in the graphs below. In general, the linear trend scenarios achieve higher reductions than the BAU-linked scenarios because the amount imported in products is higher under that growth scenario. All scenarios see certain years where emission reductions increase significantly. This is due to the emission profile assumption that emissions occur at the product end-of-life, and that different product types have different lifetimes. For example, a final increase in 2050 is seen arising from the polyurethane foam products, which have a 25-year lifetime and a compliance date beginning in 2025.

Figure D-6: HFC Emission Reductions from Imported Products with the Technology Transitions Rule ($MMTCO_2e$)



D.2.6 Climate Benefits

The emission projections discussed above were compiled for each HFC regulated, both with and without the restrictions. The differences in these results were then used to monetize the incremental climate benefits of emission reductions from imported products. To do this, the change in emissions for each HFC in each year is multiplied by the corresponding SC-HFC for that HFC in that year.

The monetization of climate benefits in this analysis uses the same HFC-specific SC-HFC estimates as the estimation of the benefits of the full HFC phasedown in the Allocation Framework RIA. The complete listing of these values can be found in Appendix D of the Costs and Benefits Addendum for the 2024 Allocation Rule. Section 4.2 of that document discusses other aspects of the SC-HFC estimates, including discounting. The SC-HFC values are listed in 2020 dollars per metric ton of HFC emitted by year. 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. A more complete discussion of the development of these SC-HFC estimates can be found in Section 4.1 of the Allocation Framework RIA.

D.2.7 Costs

There are expected to be costs or savings to transition imported products from HFCs to lower-GWP alternatives. The costs to convert factory lines would occur outside the United States, as would any costs or savings from making the product with the alternative in lieu of the HFC, and the costs or savings associated with the equipment itself. For instance, in this rule, EPA notes that if an alternative is more efficient than the HFC, less materials (e.g., copper, aluminum) may be needed to provide the necessary heat transfer surfaces in an air conditioner. This would lower the material cost to produce that air conditioner, a savings that would go to the overseas producer.

It is unknown whether or how a manufacturer might recoup any such costs or pass through any such savings. For instance, if a manufacturer already planned and financed a transition for other reasons (such as increasing energy efficiency of their products to compete within all markets), the additional costs of adopting an alternative refrigerant might be minimal compared to the overall increased costs. Likewise, a manufacturer might have already planned to adopt an alternative chemical so that their products could be sold in markets with similar restrictions, such as the European Union. Manufacturers that are in countries that are parties to the Kigali Amendment to the Montreal Protocol might likewise be compelled to adopt lower-GWP alternatives or at least see the financial advantage to do so. Also, several manufacturers have internal policies and goals related to climate change and sustainability, and so might transition for those reasons.

Costs or savings from using a less or more efficient product would occur in the United States, as customers would be paying for the electricity to operate such products. However, manufacturers, knowing the potential energy efficiency aspects of a new product, might price more efficient equipment at a premium or might lower prices for less efficient equipment. Again, what decisions would be made by foreign manufacturers, or even domestic manufacturers, are difficult to predict with any degree of certainty.

As discussed above, the GWP Limits scenarios assumed an alternative existed at the exact GWP limit set. While one could determine the reductions associated with such an alternative, assessing the costs would be difficult. A specific GWP limit could be satisfied in a theoretically infinite set of possible options, but it is reasonable that costs of each such options would be different. For instance, blends that would have a GWP of exactly the limit are blends of one HFC and an inert gas or other substance with a GWP of zero. For example, 22.2% (by weight) HFC-32 or 4.3% HFC-125 or 10.5% HFC-134a could be blended with an inert gas and yield a GWP of exactly 150. Likewise, a 4.7%/95.3% blend of HFC-32 and HFC-152a would have a GWP of 150, as would a 2.0%/98.0% blend of HFC-134a and HFC-152a. The absolute price of these different blends would be very different, as would the social costs.

For the Compliance Path scenarios, EPA assumed a particular substitute for each subsector. In part the substitute was determined by looking at the MAC abatement options as discussed in Chapter 4. For those subsectors, we determine an abatement cost in terms of dollars per metric ton of CO_2e abated. To get an estimate of the costs—which again are not necessarily the costs to the United States economy—we can simply multiply this factor by the total reductions of HFCs in imported products (see Section D.2.4 of this Annex). Annual costs for the four Compliance Path scenarios are shown below in Section D.4 of this Annex, and range from approximately $200 million to $800 million, depending on the scenario and year. Cumulative costs through 2050 range from $6.3 billion to $15.3 billion. These costs are rather large compared to the overall cost of the Technology Transitions Rule for a few reasons. First, the analysis in this RIA addendum looks at the incremental costs of the rule as compared to the Allocation Framework Rule and the 2024 Allocation Rule. Thus, this analysis is only covering a portion of the market change whereas the costs in this Annex are estimated for the entire market change. Second, the Technology Transitions Rule cost analysis includes a larger mix of transitions, and significant savings were found in some subsectors which do not contain imported pre-charged products, reducing the overall costs. Third, as explained in Section D.5.1 of this Annex, under some assumptions the import of HFCs in products could, in absence of this rule, exceed the consumption limits established by the HFC phasedown. In that sense, this Annex is estimating a larger import of such products that are otherwise implicit in the scenarios used in evaluating the overall costs of the Allocation Rules and the incremental costs of the Technology Transitions Rule.

We note that this methodology to estimate costs cannot be applied to the motor vehicle air conditioning (MVAC) option. For the medium-duty (MD) vehicles and the heavy-duty (HD) pick-up trucks, abatement options were not applied because the Vintaging Model used for the MAC analysis, in this RIA addendum as well as the Allocation Framework RIA and the 2024 Allocation Rule RIA Addendum, did not model such equipment. For the light-duty (LD) passenger vehicles and trucks subsector, the Vintaging Model already assumed a complete transition to HFO-1234yf in the baseline before the 2025 compliance date; therefore, no abatement option was assumed in the MAC analyses. Therefore, the costs calculated do not include those associated with these subsectors.

D.3 Data and Assumptions

The following table provides a summary of the subsectors of products assumed to be imported with HFCs, Customs codes, assumed HFC type and quantity contained, and assumed product lifetime.

Table D-1: Assumptions Applied to Imported Products Containing HFCs

Subsector	***SITC***	***HFC/Substitutes(s)***[1]	***Charge Size (kg)***	***Lifetime (years)***
Stand-alone/Self-contained Refrigeration Systems	74143	HFC-134a, *R-450A*, *R-513A*, HC-290	0.29	10
Vending Machines	74595	HFC-134a, R-404A, *R-450A*, *R-513A*, HC-290	0.29	10
Retail Food Refrigeration – Refrigerated Food Processing and Dispensing Equipment	74597	HFC-134a, R-404A, *R-450A*, *R-513A*, *HC-290*	0.29	10
Transport Refrigeration	78629	R-404A, R-452A, R-507A	6.4	12
Household Refrigerators and Freezers	77521, 77522	HFC-134a, HC-600a	0.16	14
Window/Room/Portable AC & Dehumidifiers	74151	HFC-32, R-410A	0.5	12
Residential and Non-residential A/C, Excluding Small AC Appliances	74155	*HFC-32*, R-410A, *R-454B*	1.0	15
Aerosol Products	HTS Codes[2]	HFC-134a, HFC-152a, NIK, HCs, HFO-1234ze(E), DME, Compressed Gas	0.13	1
Polyurethane Products	57545	HFC-134a, HFC-245fa, *HCFO-1233zd(E)*, *HFO-1234ze(E)*, *HC*, *CO_2*, *H_20*	0.16	25
LD Passenger Vehicles and Trucks	78120	HFC-134a, HFC-152a, HFO-1234yf, CO_2	0.6	16
MD Passenger Vehicles and HD Pick-up Trucks	78219	HFC-134a, HFC-152a, HFO-1234yf, CO_2	0.8	15

[1] Substitutes in *italics* are those that are assumed to not be used in the High-GWP scenarios. Alternatives underlined are the assumed substitute in the Compliance Path scenarios.
[2] Based on NAA and HCPA feedback, in lieu of SITC codes, aerosol products were analyzed based on the following HTS codes (up to three ending zeros removed for brevity): 3307.30.5, 3307.49.0, 3303.00.3, 3402.90.503, 3307.20.0, 3808.59.4, 3808.94.1, 3305.10.0, 2903.39.2045, 2903.39.202, 3824.99.55, 3403.19.1, 3824.79.9079, 3403.99.0, 3824.99.9297, 3402.13.5, 3402.20.51, 3305.90.0, 3305.30.0, 3305.20.0, 3808.91.2501, 3808.59.1, 3808.91.5001, 2710.19.308, 2710.19.4, 2710.19.459, 2710.19.9, 3208.90.0, 3910.00.0, 3814.00.1, 3814.00.509, 9503.00.0073, 9304.00.6, 3340.99.5, and 3506.99.0.

The following table presents the number of products historically imported.

Table D-2: Historical Imports of Products Containing HFCs

Subsector	***Historical Imports (number of units)***					
	2016	***2017***	***2018***	***2019***	***2020***	***2021***
Stand-alone/Self-contained Refrigeration Systems	1,262,726	1,282,473	1,570,103	1,501,740	1,949,071	2,369,816
Vending Machines	118,937	177,623	377,538	225,755	176,358	366,746
Retail Food Refrigeration – Refrigerated Food Processing and Dispensing Equipment	0	0	0	0	3,380	4,602
Transport Refrigeration	34,288	34,595	37,490	32,692	26,268	33,231
Household Refrigerators and Freezers	14,140,520	14,536,051	16,210,635	14,563,713	22,088,725	22,661,507
Window/Room/ Portable AC & Dehumidifiers	7,601,183	8,901,440	10,572,457	7,216,190	8,877,754	11,572,778
Residential and Non-residential A/C, Excluding Small AC Appliances	5,038,993	5,712,015	6,425,533	5,300,644	5,487,311	10,060,600
Aerosol Products[1]	265,119,336	302,612,257	412,503,772	435,655,906	584,041,797	553,443,114
Polyurethane Products[1]	44,517,187	45,301,179	51,055,137	46,933,601	41,996,017	57,765,298
LD Passenger Vehicles and Trucks	10,276,390	10,264,987	9,834,511	9,571,266	8,111,633	7,847,343
MD Passenger Vehicles and HD Pick-up Trucks	979,498	992,042	1,029,316	1,089,792	861,911	974,658

[1] Aerosol Products and Polyurethane Products are shown in kilograms.

D.4 Results

The following table shows the estimated import of HFCs in products in absence of the restrictions in the Technology Transitions Rule. Four BAU scenarios are provided as described above in Section D.2.3 of this Annex, depending on both the future growth of HFCs from the historical trends (termed “BAU-linked” and “Linear trend”) and assumptions regarding the mix of chemicals in those imported products (termed “Mix” and “High-GWP”).

Table D-3: Annual Quantity of HFCs in Imported Products in the Absence of the Technology Transitions Rule

	Historical and Future Annual Imports without Restrictions (MMTCO₂e)			
	Mix		***High-GWP***	
Year	***BAU-linked***	***Linear trend***	***BAU-linked***	***Linear trend***
2016	29	29	34	34
2017	32	32	37	37
2018	36	36	41	41
2019	30	30	35	35
2020	32	32	36	36
2021	44	44	51	51
2022	45	41	52	47
2023	46	43	53	49
2024	47	45	55	51
2025	47	47	54	53
2026	47	49	54	56
2027	47	50	54	58
2028	46	52	54	60
2029	46	54	53	62
2030	46	56	54	65
2031	47	58	54	67
2032	47	60	54	69
2033	47	62	55	71
2034	48	64	55	73
2035	48	66	55	76
2036	48	68	55	78
2037	48	70	56	80
2038	49	73	56	83
2039	49	75	57	85
2040	49	77	57	88
2041	50	79	58	90
2042	50	81	58	93
2043	51	84	59	95
2044	51	86	59	98
2045	52	88	60	100
2046	52	90	60	103
2047	52	93	60	105
2048	53	95	61	108
2049	53	97	61	110
2050	54	99	62	113
Total[1]	**1,618**	**2,206**	**1,869**	**2,521**

[1] Totals may not sum due to independent rounding.

Two possible scenarios to comply with the restrictions in the Technology Transitions Rule were explored (termed "GWP Limits" and "Compliance Path") for each of the four scenarios above, as explained in Section D.2.4 of this Annex. The following table displays the reductions in the supply of HFCs under these scenarios.

Table D-4: Annual Reductions of the Quantity of HFCs in Imported Products under the Technology Transitions Rule

	Annual Reductions of HFCs in Imported Products (MMTCO$_2$e)							
	GWP Limits				***Compliance Path***			
	Mix		***High-GWP***		***Mix***		***High-GWP***	
Year	***BAU-linked***	***Linear trend***	***BAU-linked***	***Linear trend***	***BAU-linked***	***Linear trend***	***BAU-linked***	***Linear trend***
2025	30	29	36	35	36	35	44	43
2026	30	30	36	36	36	37	43	45
2027	30	31	36	37	35	38	43	46
2028	30	32	36	39	36	40	44	49
2029	30	33	36	40	36	42	44	50
2030	30	34	37	42	36	43	44	52
2031	30	35	37	43	36	45	44	54
2032	31	36	37	44	37	46	44	56
2033	31	37	37	45	37	48	45	57
2034	31	39	37	47	37	49	45	59
2035	31	40	37	48	37	50	45	61
2036	31	41	38	49	37	52	45	63
2037	31	42	38	51	37	54	45	65
2038	32	43	38	52	38	55	46	67
2039	32	44	38	54	38	57	46	69
2040	32	46	39	55	38	59	47	71
2041	32	47	39	57	39	60	47	73
2042	33	48	39	58	39	62	47	75
2043	33	50	40	60	39	64	48	77
2044	33	51	40	61	40	66	48	79
2045	33	52	41	63	40	67	49	81
2046	34	53	41	64	40	69	49	83
2047	34	55	41	66	41	71	49	85
2048	34	56	41	68	41	72	50	87
2049	35	57	42	69	41	74	50	89
2050	35	58	42	71	42	76	50	91
Total[1]	**828**	**1,120**	**1,001**	**1,356**	**988**	**1,432**	**1,200**	**1,720**

[1] Totals may not sum due to independent rounding.

As discussed above in Section D.2.5 of this Annex, a simplified emission profile was applied to the products imported with HFCs. The next two tables display the estimated emissions under the case without and with the Technology Transitions Rule, respectively. The third table below shows the emission reductions achieved under the eight scenarios.

Table D-5: Annual HFC Emissions from Imported Products in the Absence of the Technology Transitions Rule

	Annual Emissions from Products Imported with HFCs without Restrictions ($MMTCO_2e$)			
	Mix		High-GWP	
Year	BAU-linked	Linear trend	BAU-linked	Linear trend
2025	3	4	3	4
2026	3	4	3	5
2027	3	5	3	5
2028	12	14	10	12
2029	13	15	11	13
2030	16	18	13	15
2031	22	25	22	25
2032	31	34	30	33
2033	35	38	33	37
2034	33	36	31	34
2035	34	37	32	35
2036	42	45	41	45
2037	42	44	41	43
2038	42	45	42	45
2039	43	47	42	46
2040	43	49	42	48
2041	46	54	51	59
2042	46	56	51	61
2043	46	58	52	64
2044	46	60	51	65
2045	46	61	50	66
2046	47	64	54	71
2047	47	66	54	72
2048	48	68	55	74
2049	48	70	55	77
2050	48	72	55	79
Total[1]	**884**	**1,089**	**928**	**1,132**

[1] Totals may not sum due to independent rounding.

Table D-6: Annual HFC Emissions from Imported Products under the Technology Transitions Rule

	Annual Emissions from Products Imported with HFCs ($MMTCO_2e$)							
	GWP Limits				Compliance Path			
	Mix		High-GWP		Mix		High-GWP	
Year	BAU-linked	Linear trend	BAU-linked	Linear trend	BAU-linked	Linear trend	BAU-linked	Linear trend
2025	3	4	3	4	3	4	3	4
2026	3	4	3	5	1	1	1	1
2027	3	5	3	5	1	1	1	1
2028	12	14	10	12	10	10	7	8
2029	13	15	11	13	11	11	8	8
2030	16	18	13	15	14	14	10	11
2031	22	25	22	25	20	20	19	20
2032	31	34	30	33	28	28	27	28
2033	35	38	33	37	32	33	31	31
2034	33	36	31	34	31	30	29	29
2035	33	36	31	34	30	30	28	28
2036	41	44	40	43	38	38	37	37
2037	32	34	35	36	29	27	33	30
2038	33	35	36	38	30	28	33	31
2039	32	35	35	38	29	28	32	31
2040	20	25	20	25	16	15	15	15
2041	20	26	25	32	14	16	19	21
2042	20	27	25	33	14	16	19	21
2043	19	28	26	34	14	16	20	22
2044	19	29	25	34	14	17	19	22
2045	19	29	24	34	13	17	18	21
2046	20	31	27	38	14	18	21	25
2047	20	32	28	38	15	19	22	25
2048	20	33	28	40	15	19	22	25
2049	21	34	29	41	15	20	22	26
2050	17	31	18	32	11	17	10	16
Total[1]	**558**	**702**	**611**	**753**	**461**	**491**	**508**	**534**

[1] Totals may not sum due to independent rounding.

Table D-7: Annual HFC Emission Reductions from Imported Products under the Technology Transitions Rule

	Annual Emission Reductions from Products Imported with HFCs ($MMTCO_2e$)							
	GWP Limits				Compliance Path			
	Mix		High-GWP		Mix		High-GWP	
Year	BAU-linked	Linear trend	BAU-linked	Linear trend	BAU-linked	Linear trend	BAU-linked	Linear trend
2025	0	0	0	0	0	0	0	0

2026	0	0	0	0	2.5	3.6	2.5	3.6
2027	0	0	0	0	2.4	3.8	2.4	3.8
2028	0	0	0	0	2.4	4.1	2.4	4.1
2029	0	0	0	0	2.4	4.4	2.4	4.4
2030	0	0	0	0	2.4	4.7	2.4	4.7
2031	0	0	0	0	2.4	4.9	2.4	4.9
2032	0	0	0	0	2.4	5.2	2.4	5.2
2033	0	0	0	0	2.5	5.5	2.5	5.5
2034	0	0	0	0	2.5	5.8	2.5	5.8
2035	0.92	1.1	1.2	1.4	3.5	7.3	3.8	7.6
2036	0.91	1.2	1.2	1.5	3.5	7.6	3.8	8.0
2037	10	10	5.9	6.2	12	17	8.6	13
2038	10	10	5.8	6.4	12	17	8.6	14
2039	11	12	7.0	8.1	14	20	9.9	16
2040	22	24	22	23	27	34	27	34
2041	26	28	26	27	32	39	32	38
2042	26	29	26	28	31	40	32	40
2043	27	30	26	30	32	42	32	42
2044	27	31	26	31	32	43	32	43
2045	27	32	26	32	32	44	32	45
2046	27	33	26	33	33	46	33	46
2047	27	34	27	34	33	47	33	48
2048	27	35	27	35	33	48	33	49
2049	27	36	27	36	33	50	33	50
2050	31	40	37	47	37	55	45	63
Total[1]	**326**	**386**	**317**	**379**	**423**	**598**	**420**	**598**

[1] Totals may not sum due to independent rounding.

As discussed in Section D.2.7 of this Annex, costs can be estimated under the Compliance Path abatement options. We stressed in the discussion above that these costs are not necessarily those that would be experienced by the U.S. economy. Furthermore, as this is a scoping analysis and the Allocation Framework RIA, the 2024 Allocation Rule RIA Addendum, and the Technology Transitions Rule RIA Addendum are considered whole market analyses, accounting for the transition in both domestically produced and imported products, these costs are not considered additive to the costs of those rules.

Table D-8: Annual Costs from Reductions in HFCs Imported in Products under the Compliance Path Scenarios

	Annual Costs from Reductions of HFC in Imported Products Compliance Path Scenarios ($2020 millions)			
	Mix		***High-GWP***	
Year	***BAU-linked***	***Linear trend***	***BAU-linked***	***Linear trend***
2025	234	242	340	347

2026	233	257	338	366
2027	231	271	336	386
2028	230	285	335	405
2029	229	299	333	425
2030	231	314	335	444
2031	232	328	337	463
2032	233	342	339	483
2033	235	357	341	502
2034	236	371	344	522
2035	237	385	344	541
2036	237	400	344	560
2037	239	414	347	580
2038	241	428	350	599
2039	243	443	353	619
2040	245	457	356	638
2041	247	471	359	657
2042	249	486	362	677
2043	251	500	365	696
2044	253	514	368	716
2045	256	529	372	735
2046	258	543	375	755
2047	260	557	377	774
2048	262	572	380	793
2049	264	586	383	813
2050	266	600	386	832

Emissions by gas were analyzed to estimate social benefits from the above emission reductions. The sum of the monetized benefits from all of the regulated HFCs from each year and scenario are shown in Table E-9. When the benefits are discounted to 2022 using a discount rate of 3 percent, the present value of the benefits of this provision from 2025–2050 are estimated to range from $18 to $28.5 billion in 2020 dollars. This is equivalent to an annual benefit ranging from $1.1 to $1.7 billion per year over that time frame. As with the costs discussed above, these climate benefits are not considered additional to the Allocation Rules or the Technology Transitions Rule.

Table D-9: Social Cost of HFC Emission Reductions for the 2025-2050 Timeframe from Imported Products under the Technology Transitions Rule (3% discount rate) (billions of 2020$, discounted to 2022)[a,b,c]

Year	Climate Benefits (3% DR)[c] by Scenario (Billion 2020$)							
	BAU-linked (High GWP) GWP Limits	BAU-linked (High GWP) Compliance Path	BAU-linked (Mix) GWP Limits	BAU-linked (Mix) Compliance Path	Linear Trend (High GWP) GWP Limits	Linear Trend (High GWP) Compliance Path	Linear Trend (Mix) GWP Limits	Linear Trend (Mix) Compliance Path
2025	0	0	0	0	0	0	0	0
2026	0	0.1	0	0.1	0	0.1	0	0.1
2027	0	0.1	0	0.1	0	0.1	0	0.1
2028	0	0.1	0	0.2	0	0.2	0	0.2
2029	0	0.1	0	0.2	0	0.2	0	0.2
2030	0	0.1	0	0.2	0	0.2	0	0.2
2031	0	0.1	0	0.2	0	0.2	0	0.2
2032	0	0.1	0	0.2	0	0.2	0	0.2
2033	0	0.1	0	0.2	0	0.2	0	0.2
2034	0	0.1	0	0.3	0	0.3	0	0.3
2035	0.1	0.2	0.1	0.4	0.1	0.4	0.1	0.4
2036	0.1	0.2	0.1	0.4	0.1	0.5	0.1	0.4
2037	0.6	0.7	0.9	1.2	0.6	0.9	0.9	1.2
2038	0.6	0.7	0.9	1.3	0.6	1	1	1.3
2039	0.7	0.9	1.1	1.6	0.8	1.2	1.2	1.6
2040	2.2	2.6	2.3	3	2.4	3	2.4	3
2041	2.7	3.1	2.7	3.6	2.9	3.6	2.9	3.6
2042	2.8	3.2	2.8	3.8	3	3.8	3.1	3.8
2043	2.9	3.3	2.9	4.1	3.3	4.1	3.3	4.1
2044	2.9	3.4	3	4.3	3.4	4.3	3.5	4.3
2045	3	3.5	3.1	4.5	3.6	4.5	3.7	4.5
2046	3.1	3.6	3.2	4.7	3.8	4.8	3.8	4.7
2047	3.2	3.7	3.2	4.9	4	5	4	4.9
2048	3.3	3.8	3.3	5.2	4.2	5.3	4.2	5.2
2049	3.4	3.9	3.4	5.4	4.4	5.5	4.4	5.4
2050	4.9	5.6	4	6.2	6	7.3	5.1	6.2
PV	18.0	21.6	18.5	28.4	21.3	28.5	21.7	28.4
EAV	1.1	1.3	1.1	1.7	1.3	1.7	1.3	1.7

[a] The annualized present value of costs and benefits are calculated as if they occur over a 26-year period from 2025 to 2050.

[b] Climate benefits are based on changes in HFC emissions and are calculated using four different estimates of the SC-HFCs (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For purposes of this table, we show the effects 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 effects calculated using discount rates below 3 percent, including 2 percent and lower, is also warranted when discounting intergenerational impacts.

[c] These estimates are year-specific estimates.

D.5 Discussion

D.5.1 Summary

In addition to providing a level playing field for domestic manufacturers, restrictions on imported products consistent with the Technology Transitions Rule will reduce the supply of HFCs in products, reduce emissions occurring in the United States, reduce the need for HFCs to service imported equipment experiencing those emissions, and help achieve the climate benefits calculated in the Allocation Framework Rule and the Technology Transitions Rule.

The supply of HFCs in imported products is growing and without applying restrictions this growth will likely continue even while the United States is phasing down bulk consumption. The amount contained in imported products, compared to the bulk supply, would likely become more significant as the phasedown of bulk HFC consumption continues. The projections shown above indicate the supply of HFCs in imported products are approximately 43 to 53 MMTCO_2e currently, or equal to about 16% to 20% compared to the allowable consumption in 2023. In 2029, the amount in imports could be 51% to 69% compared to allowable bulk consumption of approximately 90 MMTEVe. Under two scenarios the growth in imported products would exceed the 2034 allowable bulk consumption, and by 2036 all four projections would exceed bulk consumption.

Restricting the HFCs contained in imported products, while not expected to eliminate that supply of HFCs, will curtail it. For several products, lower-GWP HFCs can replace the higher-GWP HFCs currently used. For others, non-fluorinated alternative substances may be used. We analyzed two possible ways in which importers could comply with the restrictions. Because emissions lag consumption, the full scope of emission reductions would not be seen immediately. Emission reductions from aerosols (1-year lifetime) would start in 2026 while most other products would show emission reductions in the mid-2030's to early 2040's (10- to 16-year lifetimes). Emission reductions from polyurethane foam products (25-year lifetime) would not be seen until 2050. In 2050, the annual emissions of HFCs reduced from imported products range from 31 to 63 MMTCO_2e, and total emission reductions from 2025, when the Technology Transitions Rule restrictions take effect, range from 317 to 598 MMTCO_2e.

As shown above, the emission reductions provide significant climate benefits, which can be calculated using the social cost of HFCs methodology from the Allocation Framework Rule. When the benefits are discounted to 2022 using a discount rate of 3 percent, the present value of the benefits of this provision from 2025–2050 are estimated to range from $18 to $28.5 billion in 2020 dollars. This is equivalent to an annual benefit ranging from $1.1 to $1.7 billion per year over that time frame

D.5.2 Leakage and Market Spillover

The concept of leakage is an uncertainty that is important to consider. See for instance the discussion in Section 4.3 of Appendix B of the Allocation Framework RIA. Under the Technology Transitions Rule, restrictions are placed on products imported with HFCs. The scoping analysis in this Annex quantifies the possible trends in future imports of such products both with and without the rule in effect. The reductions in the supply of HFCs contained in imported products as well as the emissions from those products is estimated under several scenarios.

Leakage could occur if by these restrictions the HFCs that would have been used in such products are instead used in other sectors, including the same products destined for markets other than the United States or other countries with similar restrictions. For instance, if a factory in another country currently manufactures air conditioners using R-410A and based on this rule such products are restricted, that manufacturer could still sell those R-410A air conditioners to other customers outside the United States. Likewise, the manufacturer could choose to run the manufacturing line for a certain amount of time using a refrigerant that is allowed under the rule, and sell those products into the U.S. market, while running the line the remaining time using R-410A and selling those products elsewhere.

We do not have the information to know how foreign manufacturers will respond to the restrictions in this rule. Most, we expect, will still want to profit by selling products to the United States, and will modify their products to be acceptable under this rule. Whether such production would consume the total capacity of a given production line is unknown. However, it does not seem likely that the amount of product sold to other markets would increase solely due to this rule. If there were such a demand for those products, presumably the manufacturer would have already responded by increasing manufacturing capacity, for instance by adding night shifts or building another line. Future changes in demand are hard to predict, but the socio-economic factors that would increase (or decrease) the demand for HFC-containing products is not likely to be directly affected by this rule.

We did not analyze in detail the countries from which imported products come; however, it is clear that there are a few major trading countries or regions to consider, including, Canada, China, the European Union, Japan, Mexico, and South Korea. All of these countries are parties to the Kigali Amendment to the Montreal Protocol, meaning they must reduce their own consumption of HFCs, including the HFCs they place in products exported to the United States or elsewhere. Hence, by requiring those products shipped to the United States to use lower-GWP substances, this rule could provide extra room under their national HFC consumption limits. It may be the case that this extra room could make HFCs less expensive and available to more customers in those countries. To the extent that such reactions cause an increase in the use and emissions of HFCs in those countries, there would be effects to the United States, as emissions of greenhouses anywhere affects the entire world. That said, given the Kigali Amendment reduces the allowed HFC consumption, and does so in a fairly quick timeframe, we would expect such a phenomenon to be short-lived, if it arises at all. For instance, Canada, the EU, and Japan must reduce HFC consumption to 15% of their respective baselines by 2036, and China and Mexico must reduce HFC consumption to 20% of their baselines by 2045.[57] Furthermore, some countries restrict exports. For instance, Canada restricts the use of higher-GWP HFCs in some product types addressed by this rule, and these bans apply to both domestically produced equipment and products exported to any other country. In the EU and Canada, GWP limits are placed on certain products and manufacturers have to expend allowances to make HFC-containing products, irrespective of the market for which they are destined.

The rule could also have market spillover effects. While the restrictions affect products containing HFCs imported to the United States, the large size of the U.S. market is likely to create a spillover effect on other markets. For instance, using the R-410A air conditioner example above, a manufacturer may decide to change its entire manufacturing line to a lower-GWP substitute compliant with the U.S. rule. The portion of that manufacturer's products sold outside the United States would lead to lower GHG emissions in other countries, which would be a societal benefit to all countries.

[57] Internal EU regulations also establish a phasedown of HFC consumption; however, they will not ensure compliance with the Kigali Amendment notably beyond 2030 (see *https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF*).

Annex E: Supplemental Approach for Environmental Justice Analysis

E.1 Background

As described in Chapter 8 "Environmental Justice Analysis" of this RIA addendum, EPA seeks to better quantify the impacts of this rule on vulnerable and burdened communities. In seeking to reduce disproportionate negative environmental consequences on overburdened communities, and in our efforts to "conduct the highest quality analysis feasible,"[58] EPA is considering the use of additional analytical tools to understand burdens facing communities.

Section 8.4 "Aggregate Average Characteristics of Communities Near Potentially Affected Production Facilities" provides an analysis of the environmental justice aspects of this rule by discussing the characteristics of Census block groups near the nine identified facilities, as described by the American Community Survey (ACS).

In this supplemental analysis, EPA is providing a demonstration of analysis using a statistical technique called "microsimulation" to assess these communities in more detail. EPA requested comment on the use of microsimulation analyses generally for future application to environmental justice analyses.

Microsimulation techniques have been used for various analyses for decades. By combining data from different surveys with geospatial information, microsimulation provides analytical utility beyond that possible with the respective individual datasets, surveys, and maps. Increases in computing power and the advances in software development have made microsimulation approaches faster and more flexible.[59] Data science has advanced to allow for the identification of populations with multiple characteristics – for the case of environmental justice analysis, for example, it is possible to identify communities facing multiple burdens and multiple vulnerabilities.

The technique employed for this demonstration analysis was used originally by the National Institutes of Health for the National Infectious Disease Study.[60] The method involves using statistics to combine two databases[61] to create a population of anonymous "synthetic households." Using the 2010 decennial

[58] EPA. Technical Guidance for Assessing Environmental Justice in Regulatory Analysis. 2016. Available at: *https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.*
[59] Lovelace, R., Dumont, M., 2016. Spatial microsimulation with R. CRC Press.
[60] Wheaton WD, Cajka JC, Chasteen BM, Wagener D, Cooley PC, Ganapathi L, et al. *Synthesized population databases: a US geospatial database for agent-based models.* Research Triangle Park, NC: RTI Press; 2009.
[61] Wheaton, W.D. (May 2014) 2010 U.S. Synthetic Population Ver. 1. *RTI* International.

census, the 2007–2011 ACS, and a very fine-scale model of the geographic density of U.S. population,[62] analysts can generate a "synthetic population" of approximately 116 million households. The synthetic households are assigned demographic characteristics according to the population characteristics of their respective Census block group. This microsimulation has additional analytical capability because each of the simulated households are mapped to a 90x90 meter grid of actual physical locations of residences in 2010. In other words, maps using this dataset can show dots on a map representing every known residence in 2010 with an accuracy of 45 meters. (Maps presented in Figures E-1 through E-14 show distributions of household locations near the facilities of interest – the points are accurate for residences in 2010 within the dimensions of the printed dots). The techniques employed are reproducible using current data, which while beyond the scope of current efforts, would offer much more detailed proximity analysis of communities near specific facilities.

The dataset used for this supplementary analysis is publicly available.[63] Because it is not up to date, EPA does not represent information in this appendix to be descriptive of current demographic features of communities near the facilities potentially affected by the rule, but rather as a potential tool to identify locations that may merit additional consideration due to population patterns in the recent past. EPA is investigating the utility of microsimulation for environmental justice analysis of atmospheric pollution by combining various geospatial information with the demographic specificity and large sample size of the ACS.

In addition to the synthetic dataset mentioned above, EPA is exploring novel methods to combine the spatial and socio-demographic information of the ACS with estimates of household characteristics from smaller surveys. Whereas the previous method provides a precise location estimate, the novel method provides greater detail on household characteristics. Example surveys include the Consumer Expenditure Survey, the EIA Residential Energy Consumption Survey, the American Housing Survey, and the National Household Transportation Survey. While these surveys provide useful analytical insight that can inform environmental justice analysis, they are smaller surveys compiled of responses from fewer individuals and they are not as spatially disaggregated as the ACS. Using microsimulation approaches to combine the ACS with other surveys can allow analysis of synthetic populations at finer geographic scale that statistically represent the detail of the smaller, specialized surveys.

[62] ICLUSE Tools and Datasets (V1.3 and 1.3.1) U.S. EPA. ICLUS Tools and Datasets (Version 1.3 & 1.3.1). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/143F, 2010. Current and previous version available at *https://www.epa.gov/gcx/about-iclus.*

[63] The dataset is available on request from *https://www.rti.org/synthpop-synthetic-population-data-analysis*. The Synthpop viewer is accessible at *https://synthpopviewer.rti.org/*.

Many different surveys and datasets can be incorporated within microsimulation. Existing microsimulation models featuring different datasets provide insight into healthcare availability and inform tax policy.[64] Potential uses of microsimulation by EPA includes identification of communities facing burdens ranging from proximity to manufacturing facilities, environmental hazards such as air quality, and other vulnerabilities including poverty, natural hazard risk, food insecurity, energy insecurity, and inadequate access to medical care. By combining data from surveys, it is likely to be possible in the future, for example, to characterize the demographics of communities not just by their residents, but also considering locations where individuals are likely to work and go to school. It may be that residents of a community do not live close to specific hazardous facilities, but many work in areas with such facilities. Additionally, by combining data from surveys on employment and jobs, future microsimulation analysis may be able to identify communities at risk of adverse economic impacts both of environmental hazards and, potentially, the unintended impacts of different kinds of policies.

In the past, the approach to analyzing environmental justice for many atmospheric emissions rules has typically been conducted at higher levels of geographic aggregation. With advances in data availability, data science, and computational power, more local detail may be available for actions with regional or national environmental implications. While the utility of microsimulations may be limited by the statistical representation represented by the sample size of the datasets used, the ability to combine different surveys to address novel questions may help identify communities facing multiple, cumulative burdens. This capability may be extremely important in analyses of proximity exposure to certain risks, such as toxics or HAPs in which the atmospheric concentration of a pollutant is important. Of course, these methodologies can apply to other wide-scale risks with locally vulnerable populations (e.g., clean water, wildfire, and flooding[65]).

The method used in this supplementary analysis has been used by EPA in the context of analysis by the Office of Solid Waste and Emergency Response. In 2011, EPA was able to identify households potentially affected by leaking underground storage tanks.[66] The method identified, with a high degree of statistical likelihood, the number of households using well water potentially affected within the probably plume of contaminants from known underground storage tanks. In addition to estimating the number of affected households, the technique estimated the number of households with certain characteristics

---

[64] Including: *Cronin***,** Julie-Anne. *1999*. U.S. Treasury *Distributional Analysis Methodology*. OTA Paper 85. Washington, DC: U.S. Department of the Treasury.
[65] Brouwers, L. 2005. "Microsimulation Models for Disaster Policy Making." Stockholm University.
[66] "Risk Analysis to Support Potential Revisions to Underground Storage Tank (UST) Regulations" prepared by RTI International, December 22, 2010.

relevant to environmental justice, including the number of affected vulnerable households, and the number of households with young children.

It is important to note, however, that while the microsimulation methods described in this analysis provide more refined measures of the number of households near a facility, evaluating the characteristics of these households relies on a strong assumption that key demographics are uniformly distributed across the households in a census block group and, therefore, uniformly distributed within the resulting simulated population. Evaluating exposure and risk using the simulated population across dimensions such as race, ethnicity, and income would, by necessity, assume that these groups are no more or less likely to live in households on the fence line side of a block group than they are to live on the opposite side of that same block group.

E.2 Comparing Microsimulation and the ACS/AirToxScreen Analyses

The Allocation Framework RIA and Chapter 8 of this RIA addendum use the ACS to estimate the percentage of communities that identify as members of specific races/ethnicities and to provide information on income. However, these analyses are based on the "average" characteristics of Census block groups within a specific distance from identified facilities. The analyses include Total Cancer Risk data and Total Respiratory Risk data as reported in the AirToxScreen data as well, and these are also based on the "average" risk characteristics across these Census tracts.

Because the demographic characteristics and the risk quantifications are averaged across the geographic area of the Census blocks groups, the ACS and AirToxScreen data cannot identify the distribution of household locations within the boundaries of the block groups. The Census Bureau data divides communities into separate geographic areas called blocks, and the ACS reports data for "block groups" each with populations of a few thousand individuals.[67] While urban Census block groups may be relatively small geographically, more rural blocks may represent many square miles. Consider, for example, a case in which a specific facility is located near one boundary of its Census block, but the actual residences of households within the block are clustered in a town that is miles from the facility. In a case like this, the ACS/AirToxScreen analysis may overstate the actual risks to nearby residents. Conversely, a community may be "at the fence line" of a facility, and these specific households may face higher risks than the averages that are estimated across the Census block group.

The publicly available dataset used for this analysis allows for the creation of detailed maps, showing the (2010) location of households within as mapped to a 90x90 meter grid, and it can assign each household

[67] See *https://www2.census.gov/geo/pdfs/reference/GARM/Ch11GARM.pdf.*

with statistically likely racial, income, age, and education characteristics based on the probabilities of these characteristics as reported for their respective Census block in the ACS.

This analysis shows that there are circumstances in which the use of this specific microsimulation tool can show differences in the number of households estimated to be close to a specific facility. In cases for which the 2010 individual households are distributed very differently from the average population density for their respective Census block groups (for example, a town in a relatively rural block group), the tool can show that the ACS/AirToxScreen average calculations are likely to either overstate or understate proximity of populations to the facility. These cases appear to involve geographically large Census block groups. The differences appear most dramatic in the one-mile radius analyses – differences between the Census block group averages and the household location analyses are reduced as the distance from the facility increases.

E.3 Comparison of Demographic Analysis for Each Identified Facility

Following the approach taken in Chapter 8, this analysis assesses the communities within 1, 3, 5, and 10 mile radii of each of the nine affected facilities. For each community, the technique identifies modeled "actual" locations of households. Household locations are modeled using the ICLUS database based on the location of actual residences identified by the 2010 Census, anonymized, and assigned to a grid of 90x90 meter squares, based on actual residences in the 2010 Census. We report the number of households identified in this manner within 1, 3, 5, and 10 miles of each facility, and offer tables comparing the results of the microsimulation analysis with the estimates calculated using the ACS data.

This supplemental analysis then, will have different results in cases where a concentration of households – in a town for example – may be within the proximity buffers. For each facility, we present a map showing the communities surrounding the site. The maps show concentric circles centered on the facility location representing the 1-, 3-, 5-, and 10-mile distances used for analysis. The modeled household locations using the 2010 synthetic population are presented as dark grey dots. The dots do not represent current household locations: they merely show locations of residences in 2010 as determined by Census, ACS, and population density modeling. While some residential structures may have changed use since 2010, many locations that were household residences in 2010 are likely to be locations of current households. These recent residential patterns may help identify communities where more detailed assessments may be helpful to address environmental justice issues in these communities.

In the data table accompanying each map, each column represents the analysis for the communities within the specified distance of the facility. The number in **bold** is our calculation using the current ACS as presented in Chapter 8. The simulated population numbers based on the modeled households for 2010 are presented for comparison in *(italics)*. While potentially helpful for presenting patterns of recent residential locations as a way of identifying communities of concern, the specific numbers are out of date. The percentages of population by race or by relative income, for example, can change rapidly in some communities. In many cases, estimates of the percentage of people living below the federal poverty line, and separately, the percentage living below 50 percent of the poverty line, are different from the assessments of the current ACS.

One example of how the analysis of modeled 2010 household locations differs from that using the current ACS is the community near the Chemours Corpus Christi Facility, located near Gregory, Texas. To understand differences between the microsimulation tool based on modeled 2010 household locations and the ACS analysis for this facility, we present two maps. In Figure E-1(a), the modeled 2010 simulated household locations are represented. The facility is at the center of the “bull’s eye” of the 1-, 3-, 5-, and 10-mile distance. The dots are the modeled locations of households in 2010 within the 90x90 meter squares of the population density model. Within the one-mile circle, there are a very small number of dots representing residences in 2010. The microsimulation result shows that there were just three households within the one-mile radius circle.

Figure E-1(b) is a map of the same location showing the boundaries of the relevant ACS Census block groups. (This map is from ArcGIS Hub.[68]) The colored polygons in the map are individual Census block groups mapped from the ACS. The facility is located in the large, medium shaded, block group bounded on the south by Corpus Christi Bay, extending west off the map, with northern boundary the diagonal line running from Taft southeast to Gregory and then to the northeastern corner near Ingleside. (This is block group as 484090107002, showing a 2019 population of 3,220, and a population density of 38.4 people per square mile. In 2010, the population was 2,666, with a population density of 31.8 people per square mile). Comparing the maps, one notes that the dots representing the locations of residences in 2010 were clustered to the west side of this region, in Portland, and to the east, near Ingleside. The facility is near the center of the rectangle. In 2010 the area was a large industrial area with few residences. Analysis at the level of the block group, as done in Chapter 8 and in many other demographic studies using survey data, geometrically calculates the area at a given distance from the given coordinates (in this case, the Chemours facility) and assumes that the population of the block group is distributed evenly. In this case, the one-mile circle represents a fraction of the area of the block group, and with a population density of 38.4 people per square mile, that calculation yields an estimate of 120 people living within one mile of the site. Since the AirToxScreen database associates risk disaggregated to the Census tract level, the risk is

[68] ArcGIS Hub data referenced for GEOID 484090107002 *https://hub.arcgis.com/datasets/TEA-Texas::census-block-group-map/explore?location=27.906983%2C-97.233085%2C11.43*.

assumed to be constant across the area of the polygon. Note in Table E-1, the discrepancy between the **bold** numbers estimated using the previous ACS methodology, and the *(italicized)* numbers from the 2010 microsimulation.

In this case, household location model suggests that the ACS Census block group average approach overestimates the number of individuals living within the one-mile distance. EPA is not modeling the transport nor does the Agency have sufficient information on emissions to measure the health impacts at specific distances, but the modeling shows that as of 2010 fewer households were likely within a one-mile radius of the facility than are estimated using the averaging method.

Chemours Corpus Christi – Gregory, TX

FigureE-1(a) Chemours Corpus Christi: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

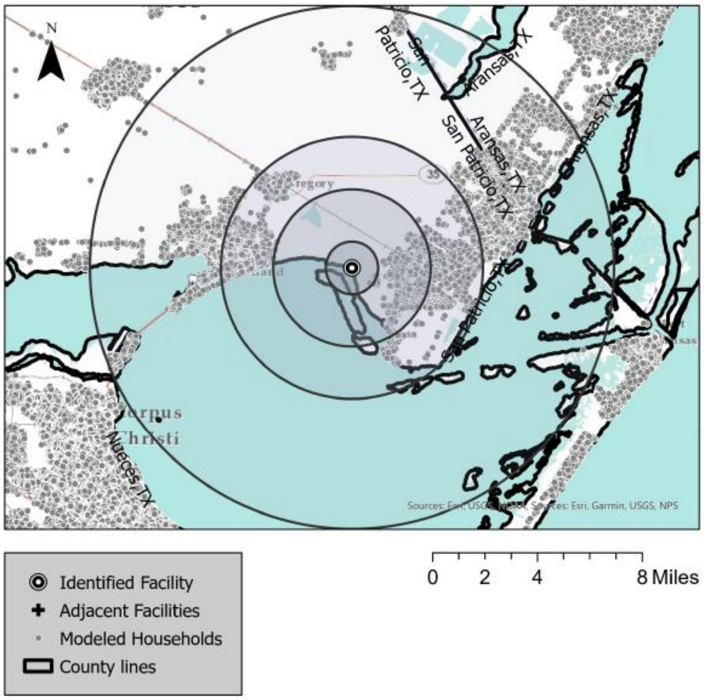


Figure E-1(b). San Patricio and Aransas Counties, TX, showing Gregory, Portland, and Ingleside

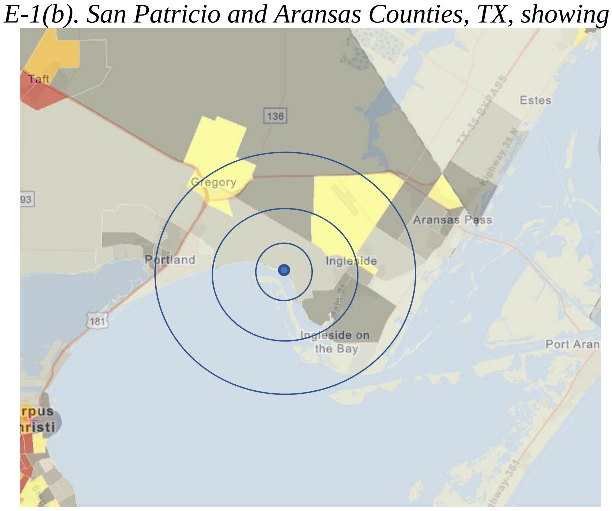


Table E-1. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Chemours Corpus Christi

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**95** *(100)*	**91** *(91.9)*	**92** *(91.0)*	**91** *(91.0)*
% Black or African American (race)	**1.6** *(0)*	**2.3** *(2.5)*	**2.2** *(1.9)*	**2.1** (*2.2*)
% Other (race)	**3.6** *(0)*	**6.3** *(5.6)*	**6.2** *(7.1)*	**7.1** *(6.8)*
% Below Poverty Line	**1.4** *(0)*	**4.1** *(7.3)*	**3.4** *(7.4)*	**6.0** *(9.4)*
% Below Half the Poverty Line	**1** *(0)*	**2.8** *(3.3)*	**3.7** *(4.1)*	**4.9** *(4.1)*

Chemours El Dorado – El Dorado AR

Figure E-2. Chemours El Dorado: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

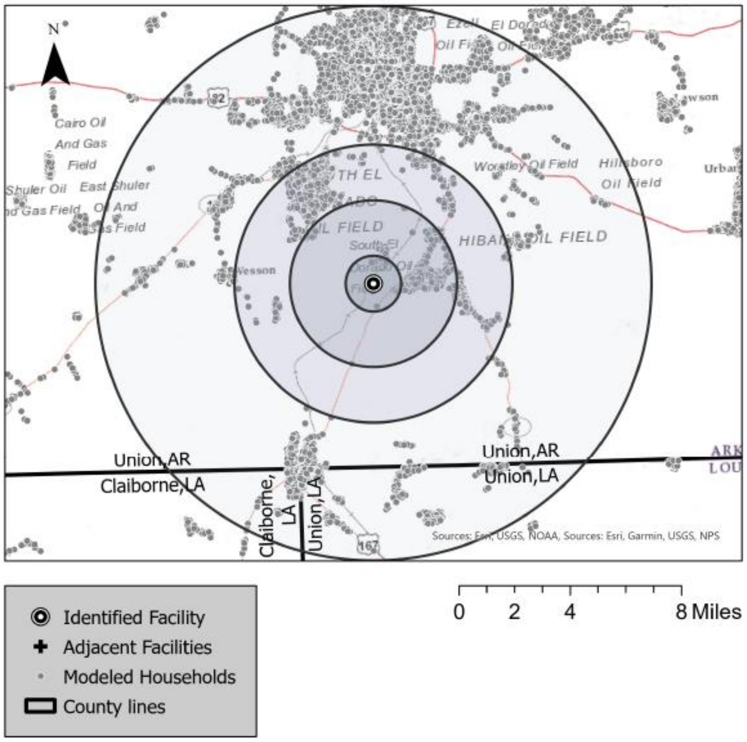


Table E-2. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Chemours El Dorado

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**94** *(92.7)*	**94** *(96.8)*	**82** *(93.9)*	**62** *(62.1)*
% Black or African American (race)	**1.4** *(4.9)*	**1.4** *(2.9)*	**15** *(4.5)*	**35** *(36.4)*
% Other (race)	**4.7** *(2.4)*	**4.7** *(0.3)*	**2.9** *(1.6)*	**3.4** *(1.5)*
% Below Poverty Line	**8.0** *(9.8)*	**8.0** *(6.4)*	**11** *(5.6)*	**13** *(15.0)*
% Below Half the Poverty Line	**5.2** *(0)*	**5.2** *(1.9)*	**4.2** *(2.3)*	**7.7** *(8.0)*

Honeywell Geismar Complex – Geismar, LA

The Honeywell Geismar Complex, in Ascension Parish, LA, near the border with Iberville Parish, is one of three facilities EPA analyzed in connection with the AIM Act, the other two being the Mexichem Flour Plant to the west in San Gabriel, Iberville, and the Air Products facility to the west in Geismar. The overlapping concentric rings of the analyses are shown in Figure E-3. The 2010 synthetic household analysis shows no residences within one mile of the Honeywell Complex, as indicated in the comparison between the ACS calculations and the 2010 household model in the first column of Table E-3.

Figure E-3. Honeywell Geismar Complex: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

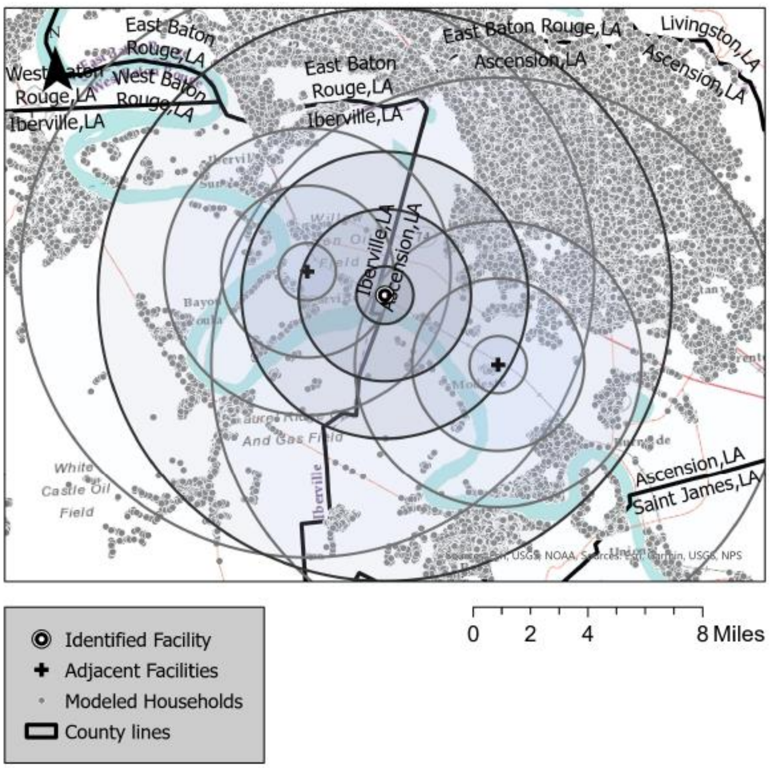


Table E-3. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Honeywell Geismar

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**57** *(n/a)*	**63** *(52.8)*	**62** *(62.8)*	**66** *(69.8)*
% Black or African American (race)	**38** *(n/a)*	**34** *(33.4)*	**36** *(33.4)*	**27** *(26.6)*
% Other (race)	***5.4*** *(n/a)*	**2.5** *(3.9)*	**3.0** *(3.9)*	**7.1** *(3.6)*
% Below Poverty Line	**2.3** *(n/a)*	**2.5** *(10.6)*	**2.8** *(8.1)*	**5.7** *(6.2)*
% Below Half the Poverty Line	**7.2** *(n/a)*	**5.0** *(4.7)*	**5.5** *(4.9)*	**4.9** *(3.8)*

Aeropress Corporation San Dimas – San Dimas, CA

Figure E-4. Aeropress San Dimas: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

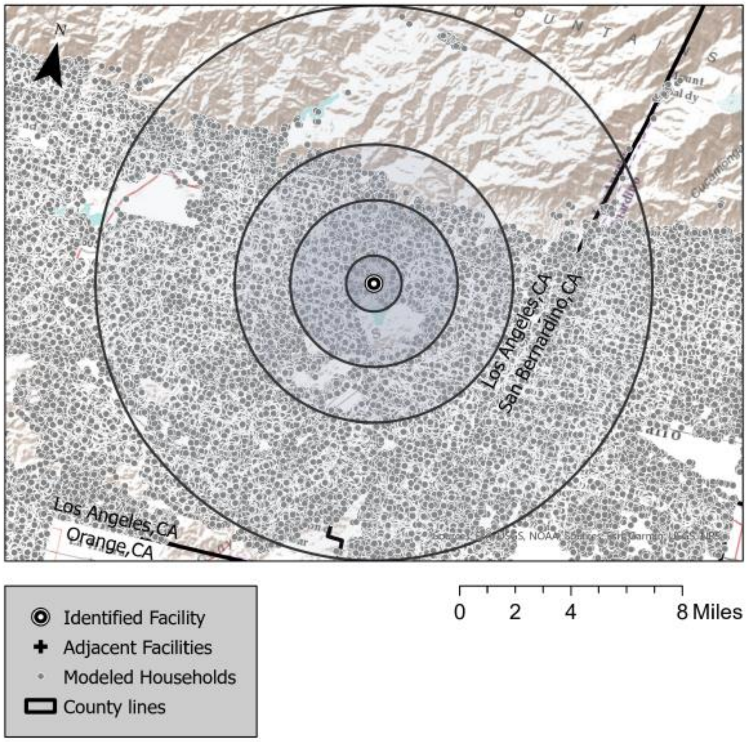


Table E-4. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Aeropress San Dimas

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**73** *(71.3)*	**65** *(73.8)*	**58** *(67.1)*	**49** *(56.4)*
% Black or African American (race)	**2.1** *(4.1)*	**3.0** *(4.1)*	**3.9** *(5.5)*	**3.6** *(4.9)*
% Other (race)	**25** *(24.2)*	**32** *(22.1)*	**39** *(27.4)*	**47** *(38.7)*
% Below Poverty Line	**3.5** *(7.1)*	**4.8** *(8.0)*	**6.0** *(10.0)*	**6.5** *(11.0)*
% Below Half the Poverty Line	**5.6** *(3.7)*	**4.1** *(3.1)*	**5.0** *(3.4)*	**4.6** *(3.7)*

CF Industries Holdings Inc. Port Neal Nitrogen Complex – Sergeant Bluff, IA

The Sergeant Bluff facility is on the Nebraska border with western Iowa. There were no households modeled in the 2010 population density data within a one-mile radius of the facility, and no synthetic households represented on the map in Figure E-5. The ACS analysis of the area, as indicated of the first column of Table E-5, shows the figures in **bold** for the "average" of the block groups, compared to the microsimulation result for the 2010 synthetic households shown as *(n/a)* because the calculation is not applicable.

Figure E-5. CF Industries Holdings Port Neal: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

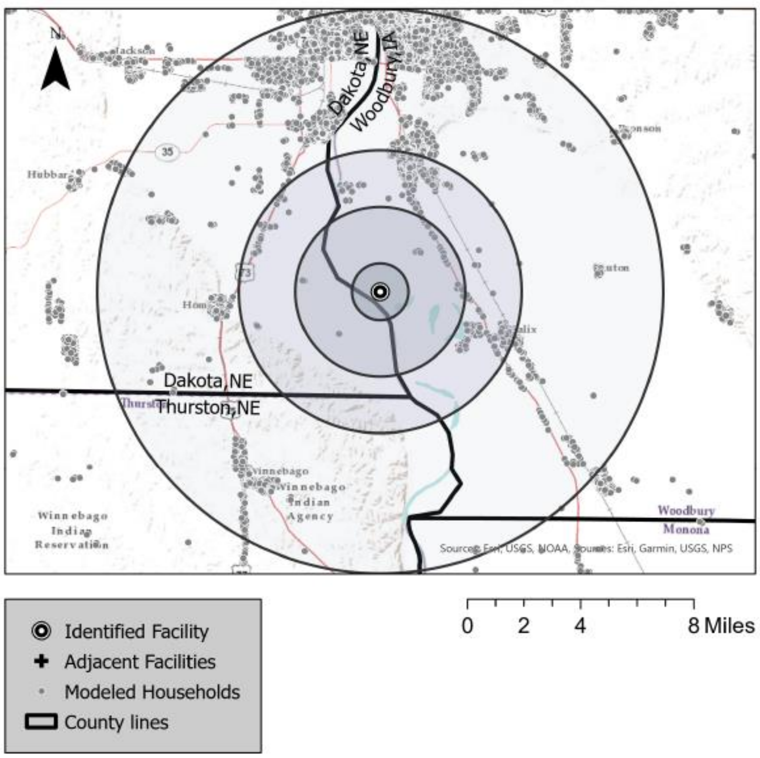


Table E-5. Comparison **ACS Census Block** and (*2010 Synthetic Households)*: CF Industries Nitrogen Complex

	Within 1 mile of facility	*Within 3 miles of facility*	*Within 5 miles of facility*	*Within 10 miles of facility*
% White (race)	**94** *(n/a)*	**90** *(100)*	**79** *(99.4)*	**79** *(87.7)*
% Black or African American (race)	**0.13** *(n/a)*	**0.07** *(0)*	**0.25** *(0)*	**3.0** *(2.4)*
% Other (race)	**5.7** *(n/a)*	**9.9** *(0)*	**20** *(0.50)*	**18** *(9.8)*
% Below Poverty Line	**3.0** *(n/a)*	**4.9** *(4.2)*	**6.4** *(3.0)*	**6.0** *(11.2)*
% Below Half the Poverty Line	**1.5** *(n/a)*	**2.9** *(0)*	**4.3** *(0.50)*	**6.6** *(3.5)*

Linde, Inc. Whiting – East Chicago, IN

Figure E-6. Linde Inc. Whiting: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

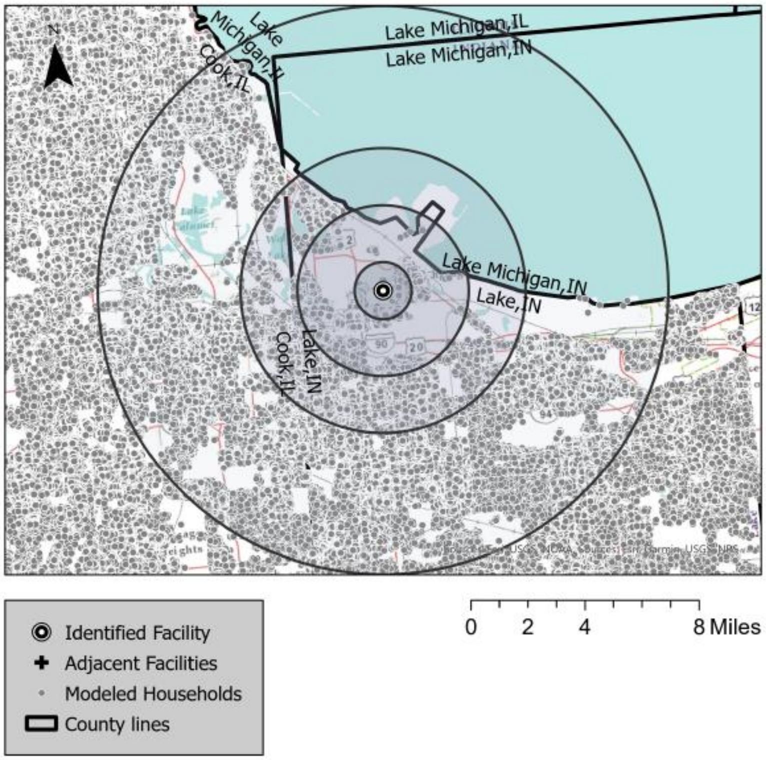


Table E-6. Comparison **ACS Census Block** and (*2010 Synthetic Households)*: Linde Inc. Whiting

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**23** *(20.1)*	**35** *(38.5)*	**46** *(50.0)*	**33** *(41.3)*
% Black or African American (race)	**35** *(48.1)*	**29** *(33.9)*	**32** *(31.1)*	**57** *(49.3)*
% Other (race)	**43** *(31.1)*	**36** *(27.5)*	**22** *(18.8)*	**11** *(9.4)*
% Below Poverty Line	**17** *(28.7)*	**14** *(30.5)*	**12** *(22.5)*	**11** *(20.2)*
% Below Half the Poverty Line	**13** *(13.0)*	**13** *(14.2)*	**11** *(10.0)*	**10** *(9.2)*

Air Products and Chemicals, Inc. Geismar – Geismar, LA

The Air Products and Chemicals SMR Facility in Ascension Parish is another of three facilities EPA has analyzed in these communities in connection with the AIM Act. The Honeywell Geismar Complex, also in Geismar, and the Mexichem Flour facility to the west in San Gabriel are the other two. The overlapping concentric rings of the analyses are shown in Figure E-7. The 2010 synthetic household analysis shows a community within the 1-mile radius the facility. A small number of households appear to be within the 3-mile radius of the Air Products and Chemicals Facility and within 5 miles of the Honeywell Complex.

Figure E-7. Air Products and Chemicals: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

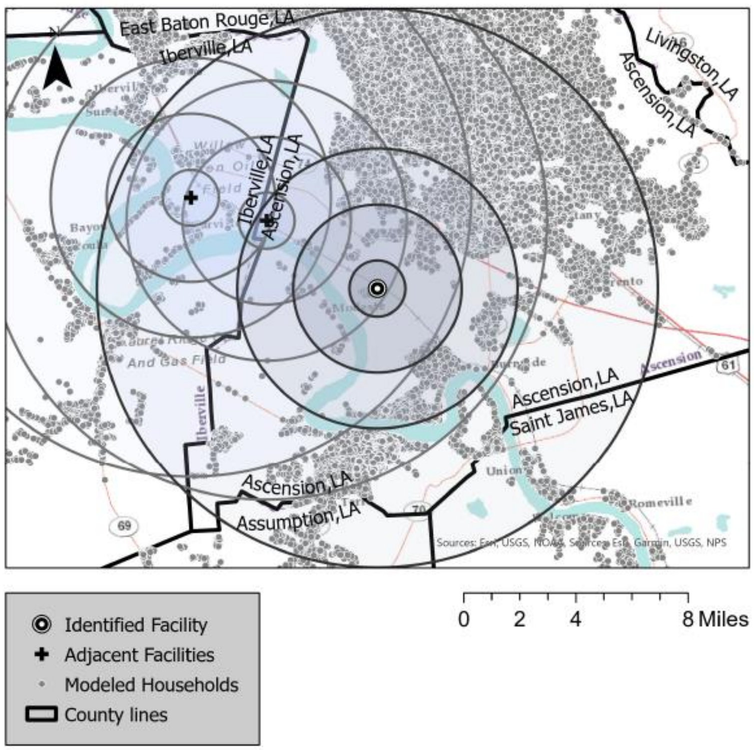


Table E-7. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Air Products Geismar

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**63** *(72.0.)*	**70** *(60.8)*	**56** *(57.5)*	**68** *(71.4)*
% Black or African American (race)	**30** *(28.0)*	**26** *(36.5)*	**39** *(39.0)*	**27** *(25.8)*
% Other (race)	**6.6** *(0)*	**4.0** *(2.7)*	**5.3** *(3.5)*	**5.7** *(2.7)*
% Below Poverty Line	**2.2** *(8.0)*	**3.8** *(12.2)*	**6.3** *(12.4)*	**5.3** *(11.5)*
% Below Half the Poverty Line	**6.5** *(0)*	**5.3** *(3.5)*	**8.3** *(4.9)*	**5.4** *(4.3)*

Haltermann Carless Inc. – Manvel, TX

Figure E-8. HC Manvel: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

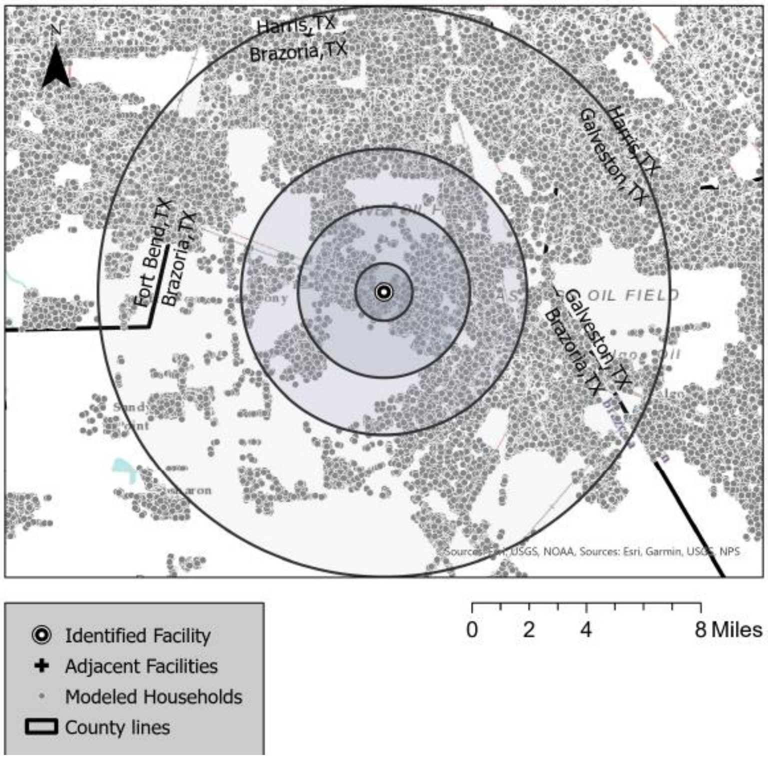


Table E-8. Comparison **ACS Census Block** and (*2010 Synthetic Households*): HC Manvel

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**88** *(91.1)*	**83** *(91.7)*	**70** *(86.4)*	**64** *(72.9)*
% Black or African American (race)	**4.9** *(028)*	**8.4** *(1.2)*	**17** *(3.1)*	**19** *(13.5)*
% Other (race)	**6.7** *(8.5)*	**9.0** *(7.1)*	**12** *(10.5)*	**18** *(13.6)*
% Below Poverty Line	**4.6** *(6.6)*	**4.5** *(8.8)*	**5.1** *(13.9)*	**3.5** *(8.0)*
% Below Half the Poverty Line	**1.9** *(2.7)*	**2.4** *(3.0)*	**3.7** *(5.5)*	**3.0** *(3.1)*

Air Products and Chemicals Inc Port Arthur Facility – Port Arthur, TX

Air Products and Chemicals' Port Arthur facility is very near the eastern Texas border with Louisiana. The Census block groups closest to the plant are very diverse. To the south and west, extends group 48245011600. It is very large (nearly 400 square miles) extending off the map in Figure E-9. It is predominantly open space including wildlife management areas, state parks, oil fields, and the Texas Point National Wildlife Refuge. The population density is 2.6 per square mile, mainly in communities near Winnie and Stowell that are some 20 miles west of the facility. Approximately 95 percent of the population of this block group identifies as White. In the Port Arthur communities immediately east of the center the map, there are Census Block Groups 482450051002, 482450059002, and 482450059001. These are much smaller, denser, and between 90 and 99 percent Black or African American.

Figure E-9. Air Products and Chemicals Port Arthur: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

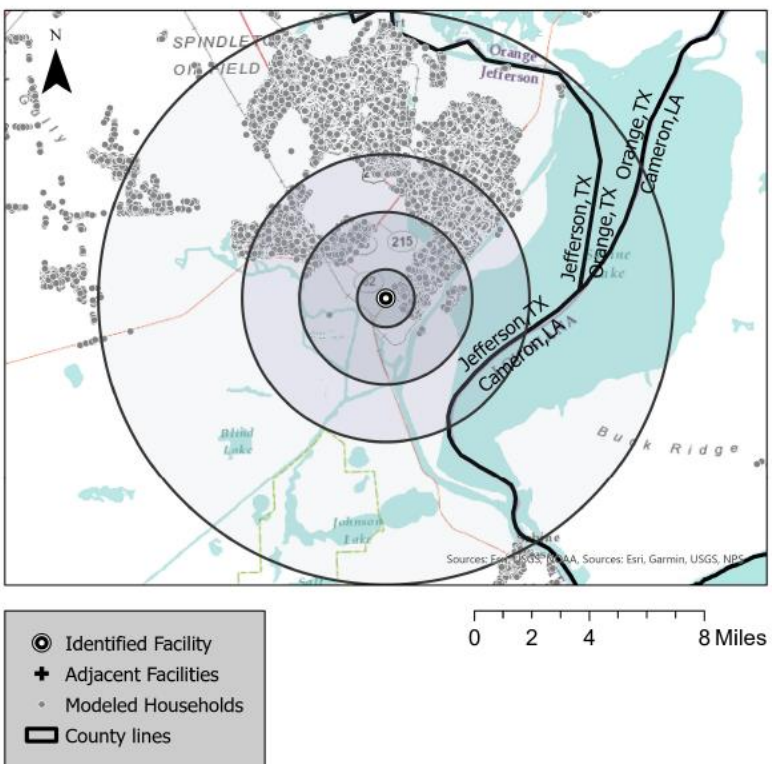


Table E-9. Comparison **ACS Census Block** and (*2010 Synthetic Households*): APC Port Arthur

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**33** *(1.4)*	**32** *(9.7)*	**51** *(39.4)*	**69** *(66.8)*
% Black or African American (race)	**61** *(98.5)*	**63** *(88.9)*	**37** *(46.1)*	**22** *(22.5)*
% Other (race)	**6.6** *(0)*	**5.4** *(1.4)*	**12** *(14.4)*	**8.9** *(10.7)*
% Below Poverty Line	**9.5** *(51.7)*	**13** *(30.7)*	**13** *(25.2)*	**8.3** *(17.0)*
% Below Half the Poverty Line	**14** *(25.6)*	**14** *(12.8)*	**11** *(10.5)*	**7.4** *(6.8)*

Diversified Gas and Oil Corp. KSP CO_2 Plant – Tad, WV

Figure E-10. Diversified KSP Plant: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

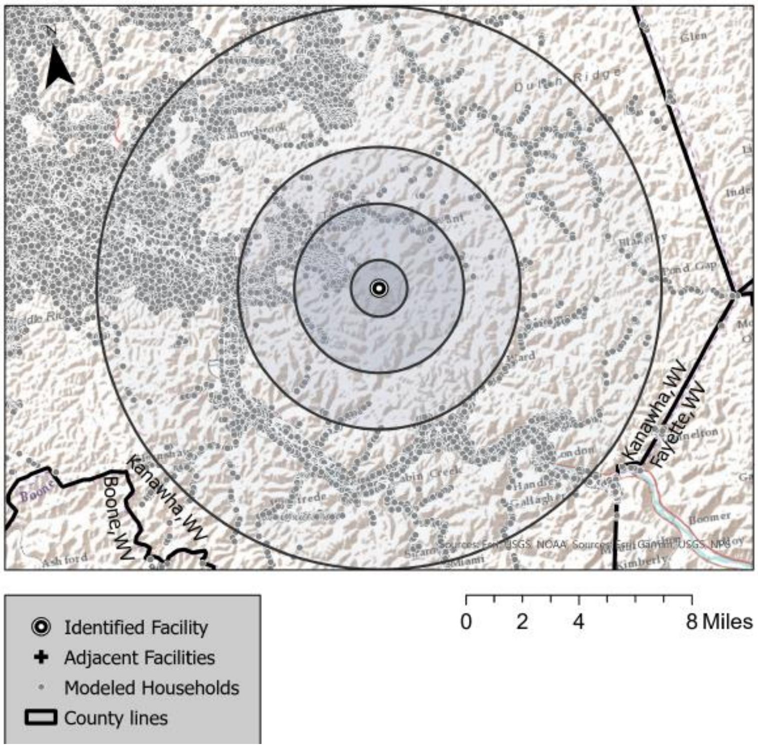


Table E-10. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Diversified KSP Plant

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**99** *(n/a)*	**97** *(91.8)*	**96** *(94.0)*	**90** *(88.2)*
% Black or African American (race)	**0** *(n/a)*	**0.29** *(0)*	**0.96** *(0)*	**6.2** *(4.6)*
% Other (race)	**0.89** *(n/a)*	**2.7** *(8.2)*	**2.9** *(5.9)*	**3.9** *(7.2)*
% Below Poverty Line	**10** *(n/a)*	**11** *(13.1)*	**11** *(12.3)*	**9.0** *(14.7)*
% Below Half the Poverty Line	**5.5** *(n/a)*	**7.4** *(3.7)*	**5.9** *(3.5)*	**9.1** *(5.1)*

Linde, Inc. Decatur – Decatur, AL

The Linde Decatur facility is near another facility EPA has analyzed in connection with the AIM Act. The other is the Daikin America facility to the west of the Linde site. The overlapping concentric rings of the analyses are shown in Figure E-11. The synthetic household analysis identified 68 households within 1 mile of the Linde facility in 2010, clustered to the south as indicated on the map. The 1-mile radii of the two facilities overlap, and there are many households within 3 miles of both facilities.

Figure E-11. Linde Decatur: Modeled Household Locations (in 2010) within 1, 3, 5, 10 Miles

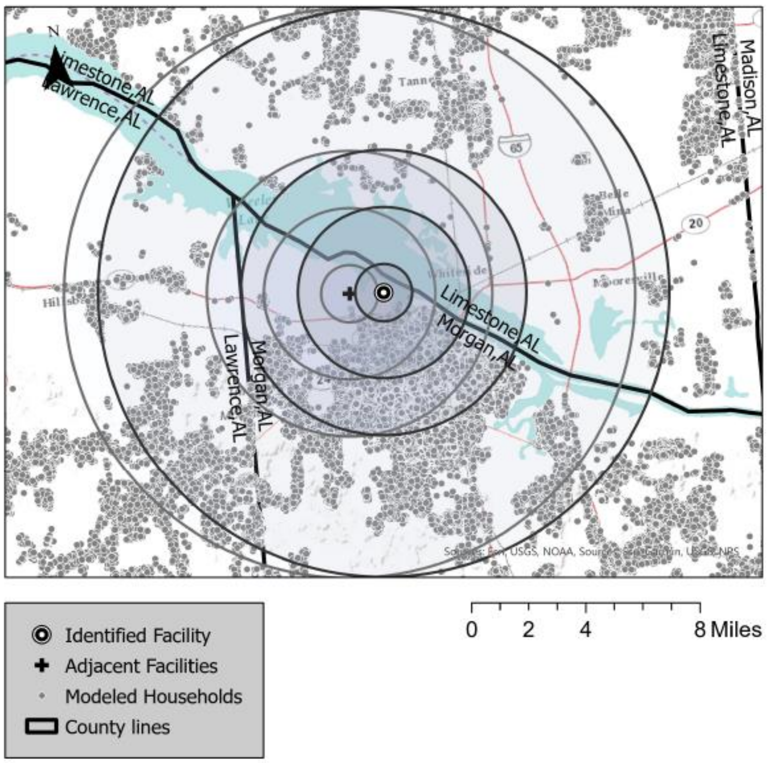


Table E-11. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Linde Decatur

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**44** *(30.9)*	**60** *(46.6)*	**67** *(68.9)*	**74** *(74.8)*
% Black or African American (race)	**52** *(64.7)*	**32** *(45.9)*	**23** *(24.6)*	**17** *(19.7)*
% Other (race)	**4.0** *(4.4)*	**8.1** *(7.4)*	**9.5** *(6.5)*	**8.3** *(5.4)*
% Below Poverty Line	**16** *(32.4)*	**13** *(23.4)*	**12** *(16.4)*	**9.5** *(15.2)*
% Below Half the Poverty Line	**9.0** *(16.2)*	**6.8** *(7.5)*	**6.1** *(5.3)*	**5.5** *(4.9)*

CALAMCO – Stockton, CA

Figure E-12. CALAMCO: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

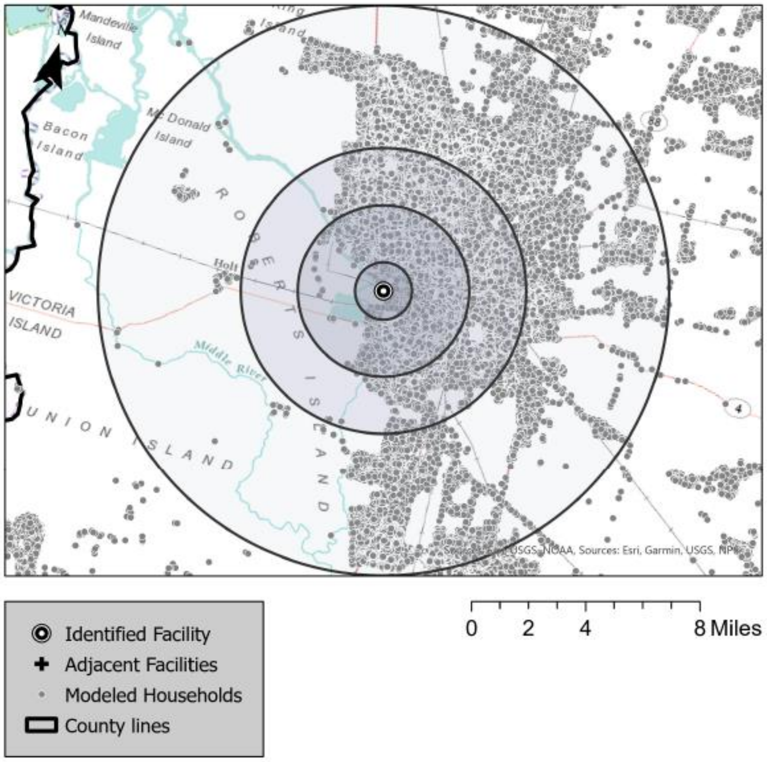


Table E-12. Comparison **ACS Census Block** and (*2010 Synthetic Households)*: CALAMCO

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**58** *(67.0)*	**54** *(57.2)*	**52** *(56.6)*	**51** *(53.4)*
% Black or African American (race)	**9.5** *(11.3)*	**9.9** *(12.8)*	**10** *(13.0)*	**9.4** *(11.3)*
% Other (race)	**33** *(21.7)*	**36** *(30.0)*	**38** *(30.5)*	**40** *(32.3)*
% Below Poverty Line	**12** *(27.1)*	**11** *(19.9)*	**11** *(20.6)*	**9.9** *(17.2)*
% Below Half the Poverty Line	**9.9** *(6.3)*	**8.5** *(6.9)*	**8.0** *(6.8)*	**7.0** *(5.5)*

Diversified CPC International – Channahon, IL

Figure E-13. Diversified CPC: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

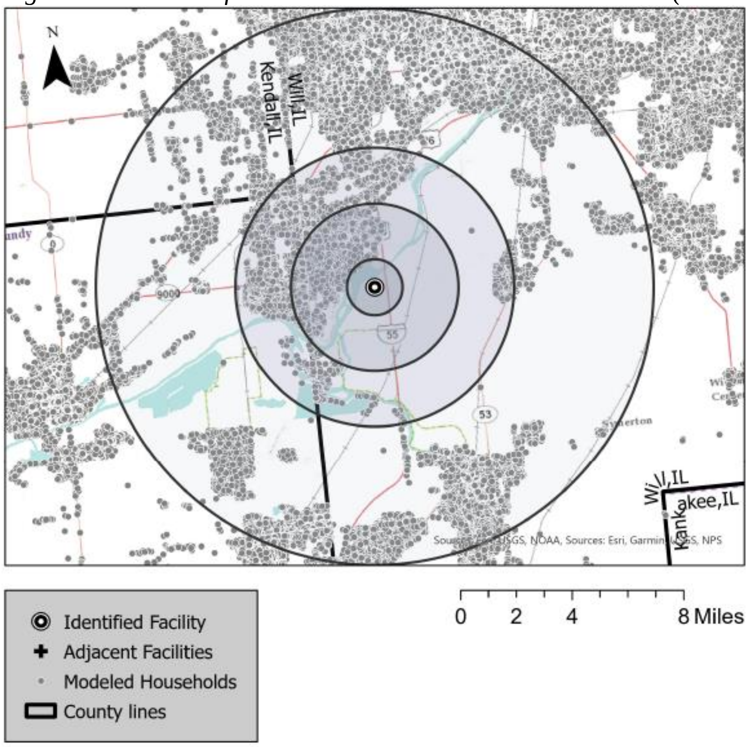


Table E-13. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Diversified CPC

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**95** *(100)*	**92** *(95.5)*	**86** *(95.3)*	**79** *(83.7)*
% Black or African American (race)	**0.88** *(0)*	**2.0** *(2.2)*	**7.4** *(2.5)*	**12** *(10.3)*
% Other (race)	**4.2** *(0)*	**6.3** *(2.3)*	**6.4** *(2.1)*	**9.6** *(5.9)*
% Below Poverty Line	**1.0** *(12.5)*	**3.1** *(2.2)*	**3.1** *(4.3)*	**4.7** *(8.1)*
% Below Half the Poverty Line	**2.6** *(0)*	**1.5** *(0.7)*	**2.6** *(1.5)*	**3.7** *(2.9)*

Aeropress Corporation Sibley – Sibley, LA

Figure E-14. Aeropress Sibley: Modeled Household Locations (in 2010) within 1, 3, 5, and 10 Miles

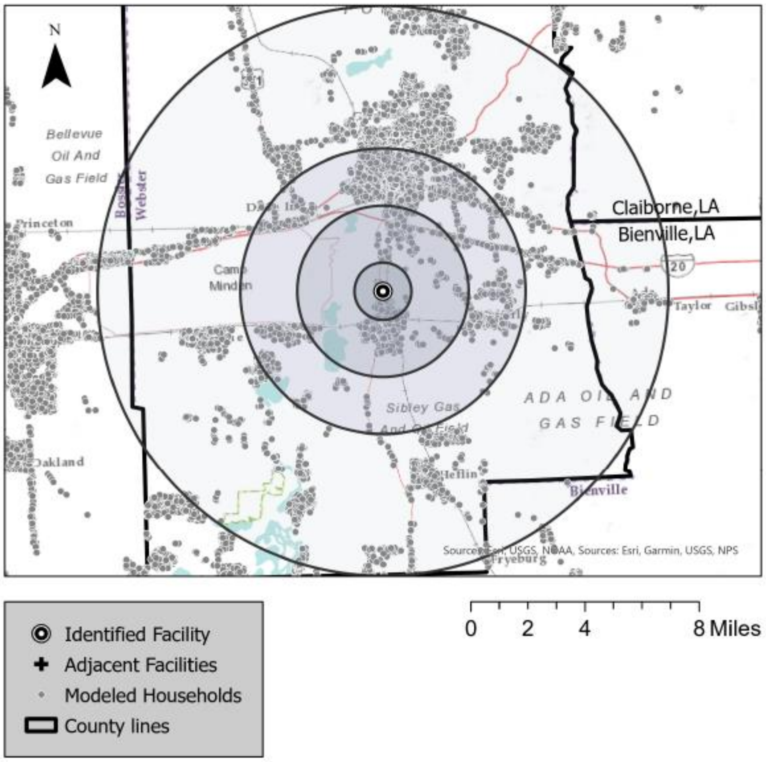


Table E-14. Comparison **ACS Census Block** and (*2010 Synthetic Households*): Aeropress Sibley

	Within 1 mile of facility	***Within 3 miles of facility***	***Within 5 miles of facility***	***Within 10 miles of facility***
% White (race)	**71** *(46.7)*	**51** *(58.0)*	**56** *(43.5)*	**64** *(62.4)*
% Black or African American (race)	**26** *(48.7)*	**47** *(39.1)*	**41** *(55.1)*	**33** *(36.2)*
% Other (race)	**2.7** *(4.5)*	**1.3** *(2.9)*	**2.5** *(1.4)*	**2.5** *(1.3)*
% Below Poverty Line	**11** *(14.7)*	**18** *(23.3)*	**20** *(30.2)*	**18** *(21.9)*
% Below Half the Poverty Line	**9.8** *(2.5)*	**8.3** *(6.9)*	**7.5** *(9.7)*	**7.7** *(7.2)*

E.4 Conclusion

Using microsimulation techniques can provide additional analytical information by using advanced data science and statistics to combine data from different surveys and geospatial datasets. The dataset used here, with a synthetic population featuring modeled locations of residences in 2010 combined with information from the 2010 Decennial Census and the ACS can show statistically representative demographic information for household locations in 2010. We are not presenting the demographic results as these are considered to be more out-of-date than the location of residences. The current version of the database used here is not publicly available. The publicly available data results presented here may, by showing patterns of residence in the recent past, show communities that merit more environmental justice analysis. In the time available, EPA is not pursuing additional analysis of communities for this rule. Other synthetic datasets are available and being developed. These have additional analytic capabilities and may be useful in identifying overburdened communities.

Works Cited

Anthoff, David, and Richard S. J. Tol. "The uncertainty about the social cost of carbon: a decomposition analysis using FUND." *Climatic Change*, vol. 117, 2013a, pp. 515–530, doi: 10.1007/s10584-013-0706-7.

Anthoff, David, and Richard S. J. Tol. "Erratum to: The uncertainty about the social cost of carbon: A decomposition analysis using FUND." *Climatic Change*, vol. 121, 2013b, p. 413, doi: 10.1007/s10584-013-0959-1.

ArcGIS, GEOID 484090107002. https://hub.arcgis.com/datasets/TEA-Texas::census-block-group-map/explore?location=27.906983%2C-97.233085%2C11.43.

Banzhaf, Spencer, Lala Ma, and Christopher Timmins. "Environmental Justice: The Economics of Race, Place, and Pollution." *Journal of Economic Perspectives*, vol. 33, no.1, 2019, pp.185-208, doi: 10.1257/jep.33.1.185.

Brouwers, Lisa. *Microsimulation Models for Disaster Policy Making*. Stockholm University, Report Series, no. 05-012, May 2005.

Cronin**,** Julie-Anne. *U.S. Treasury Distributional Analysis Methodology*, OTA Paper 85, U.S. Department of the Treasury, Sept. 1999, https://home.treasury.gov/system/files/131/WP-85.pdf.

European Commission. *Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014.* Directorate-General for Climate Action, 2022. https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF.

Executive Order. No. 12898, 1994. https://www.federalregister.gov/d/94-3685.

Executive Order. No. 13783, 2017. https://www.federalregister.gov/d/2017-06576.

Executive Order. No. 13990, 2021. https://www.federalregister.gov/d/2021-01765/p-1.

Executive Order. No. 14008, 2021. https://www.federalregister.gov/d/2021-02177/p-1.

Federal Register 86. "Notice of Availability and Request for Comment on "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates Under Executive Order 13990." May 2021, pp. 24669-24670. https://www.federalregister.gov/d/2021-09679.

Federal Register 86. "Notice of Determination to Grant or Partially Grant Certain Petitions Submitted Under Subsection (i) of the American Innovation and Manufacturing Act of 2020." October 2021, pp. 57141–57142. https://www.federalregister.gov/d/2021-22318.

Federal Register 86. "Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program Under the American Innovation and Manufacturing Act." Oct. 2021, pp. 55116–55222. https://www.federalregister.gov/d/2021-21030.

Federal Register 88. "Phasedown of Hydrofluorocarbons: Allowance Allocation Methodology for 2024 and Later Years." Jul. 2023, pp. 46836–46898. https://www.federalregister.gov/d/2023-14312.

Forster, P., et al. "Changes in Atmospheric Constituents and in Radiative Forcing." In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)].* Cambridge University Press, 2007, https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf.

Georgies, Nicholas, and Douglas Raymond. *Harmonized Tariff Schedule Codes for Aerosol Products Containing Hydrofluorocarbons*, Correspondence with Cindy Newberg. Household & Commercial Products Association, National Aerosol Association, 1 February 2022.

Hernandez-Cortes, Danae, and Kyle Meng. "Do Environnemental Markets Cause Environnemental Injustice? Evidence from California's Carbon Market." *NBER Working Paper*, 2020, doi:10.3386/w27205.

Hope, Chris. "Critical issues for the calculation of the social cost of CO2: why the estimates from PAGE09 are higher than those from PAGE2002." *Climatic Change*, vol. 117, no. 3, 2013, pp. 531–543, doi:10.1007/s10584-012-0633-z.

Hu, Lei, et al. "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*, vol. 113, no. 11, 2016, pp. 2880–2885, doi:10.1073/pnas.1522284113.

Interagency Working Group on Social Cost of Carbon. *Addendum to Technical Support Document on Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866: Application of the Methodology to Estimate the Social Cost of Methane and the Social Cost of Nitrous Oxide.* United States Government, Aug. 2016b. https://www.epa.gov/sites/production/files/2016-12/documents/addendum_to_sc-ghg_tsd_august_2016.pdf.

Interagency Working Group on Social Cost of Carbon. *Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866.* United States Government, Jul. 2015, https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf.

Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. United States Government, Feb. 2010, https://www.epa.gov/sites/production/files/2016-12/documents/scc_tsd_2010.pdf.

Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.* United States Government, May 2013. https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

Interagency Working Group on Social Cost of Carbon. *Technical Support Document: Technical Update of the Social Cost of*

Carbon for Regulatory Impact Analysis Under Executive Order 12866. United States

Government, Aug. 2016a. https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

Interagency Working Group on Social Cost of Greenhouse Gases (IWG). *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. United States Government, Feb. 2021. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. IPCC, Geneva, 2014, https://www.ipcc.ch/report/ar5/syr/.

IPCC. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and Reisinger, A. (eds.)]*. IPCC, Geneva, 2007, https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf.

IPCC. *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M, Belkacemi, J. Malley, (eds.)]*. IPCC, Geneva, 2019a, https://www.ipcc.ch/srccl/.

IPCC. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]*. IPCC, Geneva, 2018, https://www.ipcc.ch/sr15/.

IPCC. *Technical Summary In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]*. IPCC, Geneva, 2019b, https://www.ipcc.ch/srocc/.

Lovelace, Robin and Morgane Dumont. *Spatial microsimulation with R*. CRC Press, 2016.

Mansur, Erin, and Glenn Sheriff. “On the Measurement of Environmental Inequality: Ranking Emissions Distributions Generated by Different Policy Instruments.” *Journal of the Association of Environmental and Resource Economists*, 2021, doi:10.1086/713113.

Marten, Alex L., and Stephen C. Newbold. “Estimating the Social Cost of Non-CO2 GHG Emissions: Methane and Nitrous Oxide.” *Energy Policy*, vol. 51, 2012, pp. 957–972, doi:10.1016/j.enpol.2012.09.073.

Marten, Alex L., et al. "Incremental CH4 and N2O Mitigation Benefits Consistent with the U.S. Government's SC-CO2 Estimates." *Climate Policy*, vol. 15, no. 2, 2015, pp. 272-298, doi: 10.1080/14693062.2014.912981.

National Academies of Sciences, Engineering, and Medicine. *Climate Change and Ecosystems*. The National Academies Press, 2019, doi: 10.17226/25504.

National Academies of Sciences, Engineering, and Medicine. *Framing the Challenge of Urban Flooding in the United States*. The National Academies Press, 2019, doi:10.17226/25381.

National Academies of Sciences, Engineering, and Medicine. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*. The National Academies Press, 2017, doi: 10.17226/24651.

Nordhaus, William D. "Economic aspects of global warming in a post-Copenhagen environment." *Proceedings of the National Academy of Sciences*, vol. 107, no. 26, 2010, pp. 11721-11726, doi: 10.1073/pnas.1005985107.

OMB Circular A-4. Washington, D.C.: Executive Office of the President, Office of Management and Budget, 2003. https://www.federalregister.gov/d/03-25606/p-3.

Ramaswamy, V., et al. "Stratospheric Temperature Trends: Observations and Model Simulations." *Reviews of Geophysics*, vol. 39, no. 1, 2001, pp. 71–122, doi: 10.1029/1999rg000065.

Ramaswamy, V., et al. *TAR Climate Change 2001: The Scientific Basis, Chapter 6 Radiative Forcing of Climate Change*. IPCC, Geneva, 2001, https://www.ipcc.ch/report/ar3/wg1/.

RTI International. *RTI SynthPop*. https://www.rti.org/synthpop-synthetic-population-data-analysis.

, https://hub.arcgis.com/datasets/TEA-Texas::census-block-group-map/explore?location=27.906846%2C-97.233085%2C11.00., https://hub.arcgis.com/datasets/TEA-Texas::census-block-group-map/explore?location=27.906846%2C-97.233085%2C11.00.

United States Census Bureau. *American Community Survey and Puerto Rico Community Survey 2019 Subject Definitions.* 2021, *https://www2.census.gov/programs-surveys/acs/tech_docs/subject_definitions/2019_ACSSubjectDefinitions.pdf*.

United States Census Bureau. *Chapter 11 Census Blocks and Block Groups, Geographic areas reference manual.* Washington D.C.: U.S. Department of Commerce, 1994, https://www2.census.gov/geo/pdfs/reference/GARM/Ch11GARM.pdf.

United States International Trade Commission. "DataWeb." *Usitc.gov*, https://dataweb.usitc.gov/.

U.S. EPA. "Addendum to the Regulatory Impact Analysis for the Phasedown of Hydrofluorocarbons, Notice of Final Rule - Phasedown of Hydrofluorocarbons: Allowance Allocation Methodology for 2024 and Later Years." *Regulations.gov*, 20 Jul. 2023, https://www.regulations.gov/document/EPA-HQ-OAR-2022-0430-0111.

U.S. EPA. "AHAM HFC Petition for RACs PACs and Dehums (00102452) April 13 2021." *Regulations.gov*, 28 Apr. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0005.

U.S. EPA. "AHRI-4 Step 2 Petition Refrigeration Chillers Applications Final Signatures." *Regulations.gov*, 20 Oct. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0052.

U.S. EPA. "AHRI AIM Act Petition Commercial Refrigeration April 13 2021." *Regulations.gov*, 28 Apr. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0012.

U.S. EPA. "AHRI AIM Act Petition - Stationary AC April 13 2021." *Regulations.gov*, 28 Apr. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0011.

U.S. EPA. "AHRI AIM Act Petition - Step 2 Petition Refrigeration Applications August 19 2021." *Regulations.gov*, 1 Sept. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0047.

U.S. EPA. "AHRI Amended Step 2 Petition Refrigeration Applications." *Regulations.gov*, 11 Apr. 2022, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0054.

U.S. EPA. "CPI Petition Technology Transition May 26 2021." *Regulations.gov*, 11 Jun. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0032.

U.S. EPA. "DuPont Petition To EPA Re AIM And 2K-LP SPF End Use May 10 2021." *Regulations.gov*, 27 May 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0020.

U.S. EPA. "DuPont Petition To EPA Re AIM And XPS End Use May 10 2021." *Regulations.gov*, 27 May 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0021.

U.S. EPA. "EIA AIM Act Petition for Technology Transitions April 13 2021." *Regulations.gov*, 28 Apr. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0006.

U.S. EPA. "Environmental Justice." *Epa.gov*, 4 Mar. 2021, www.epa.gov/environmentaljustice.

U.S. EPA. "HCPA and NAA Petition to Reinstate HFC Prohibitions for Aerosol Propellant from SNAP Rules 20 and 21 under AIM Act." *Regulations.gov*, 15 Jul. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0037.

U.S. EPA. "IIAR Petition for Technology Transitions June 3 2021." *Regulations.gov*, 11 Jun. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0033.

U.S. EPA. "IIAR Petition for Technology Transitions May 23 2022." *Regulations.gov*, 21 Jun. 2022, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0055.

U.S. EPA. "Information Collection Request Supporting Statement Part A." *Regulations.gov*, 15 Dec. 2022, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0643-0066.

U.S. EPA. “Methylene Chloride; TSCA Review and Risk Evaluation.” *Regulations.gov*, 2016, https://www.regulations.gov/docket/EPA-HQ-OPPT-2016-0742.

U.S. EPA. “NRDC IGSD CDPHE Petition Reinstate SNAP 20 - 21 HFC Prohibitions April 13 2021.” *Regulations.gov*, 28 Apr. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0007.

U.S. EPA. “Petitions for Technology Transitions.” Epa.gov, 2023, https://www.epa.gov/climate-hfcs-reduction/petitions-technology-transitions.

U.S. EPA. “Proposed Endangerment Finding for Greenhouse Gases under the Clean Air Act (CAA).” *Regulations.gov*, 2009, https://www.regulations.gov/docket/EPA-HQ-OAR-2009-0171.

U.S. EPA. “Proposed Rule and Related Materials for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2.” *Epa.gov*, 2015, https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-and-related-materials-greenhouse-gas.

U.S. EPA. “Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Policy Program.” *Regulations.gov*, 20 Jul. 2015, https://www.regulations.gov/document/EPA-HQ-OAR-2014-0198-0238.

U.S. EPA. “Protection of Stratospheric Ozone: New Listings of Substitutes; Changes of Listing Status; and Reinterpretation of Unacceptability for Closed Cell Foam Products under Significant New Alternatives Policy Program; and Revision of Clean Air Act Section 608 Venting Prohibition for Propane.” *Regulations.gov*, 1 Dec. 2016, https://www.regulations.gov/document/EPA-HQ-OAR-2015-0663-0114.

U.S. EPA. “Response to Comments, Technical Support Documents, and Memorandums.” *Regulations.gov*, 5 Oct. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0044-0227.

U.S. EPA. “States' AIM Act Petition July 15 2021.” *Regulations.gov*, 19 Jul. 2021, https://www.regulations.gov/document/EPA-HQ-OAR-2021-0289-0038.

U.S. EPA. “Summary of the Toxic Substances Control Act.” Epa.gov, 2022, https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

U.S. EPA. “Suppliers of Industrial GHGs and Products Containing GHGs.” *Epa.gov*, https://www.epa.gov/ghgreporting/suppliers-industrial-ghgs-and-products-containing-ghgs.

U.S. EPA. “Tetrachloroethylene (perchloroethylene); TSCA Review and Risk Evaluation.” *Regulations.gov*, 2016, https://www.regulations.gov/docket/EPA-HQ-OPPT-2016-0732.

U.S. EPA. “Toxic Substances Control Act (TSCA) Science Advisory Committee on Chemicals Review of Risk Evaluation for Carbon Tetrachloride (CCl4, Carbon tet).” *Regulations.gov*, Jan. 2020, https://www.regulations.gov/docket/EPA-HQ-OPPT-2019-0499.

U.S. EPA. “Toxic Substances Control Act (TSCA) Science Advisory Committee on Chemicals Review of Risk Evaluation for Methylene Chloride.” *Regulations.gov*, 2019, https://www.regulations.gov/docket/EPA-HQ-OPPT-2019-0437.

U.S. EPA. “Toxic Substances Control Act (TSCA) Science Advisory Committee on Chemicals Review of Risk Evaluation for Perchloroethylene.” *Regulations.gov*, 2020, https://www.regulations.gov/docket/EPA-HQ-OPPT-2019-0502. *Regulations.gov*, 2020, https://www.regulations.gov/docket/EPA-HQ-OPPT-2019-0500.

U.S. EPA. “Toxic Substances Control Act (TSCA) Science Advisory Committee on Chemicals Review of Risk Evaluation for Trichloroethylene.”

U.S. EPA. “Trichloroethylene; TSCA Review and Risk Evaluation.” *Regulations.gov*, 2016, https://www.regulations.gov/docket/EPA-HQ-OPPT-2016-0737.

U.S. EPA. *Air Toxics Screening Assessment, 2019 AirToxScreen*. https://www.epa.gov/AirToxScreen/2019-airtoxscreen.

U.S. EPA. *Chemical Data Reporting under the Toxic Substances Control Act*. https://www.epa.gov/chemical-data-reporting.

U.S. EPA. *Greenhouse Gas Reporting Program (GHGRP).* https://www.epa.gov/ghgreporting.

U.S. EPA. *Enforcement and Compliance History Online (ECHO) database.* https://echo.epa.gov/.

U.S. EPA. EPA Report EPA-430-R-16-002. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*. Apr. 2016, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014.

U.S. EPA. *Federal Registry Service (FRS) National Data Set, https://www.epa.gov/frs/epa-frs-facilities-state-single-file-csv-download.*

U.S. EPA. *Guidance on Considering Environmental Justice During the Development of Regulatory Actions.* May 2015, https://www.epa.gov/sites/default/files/2015-06/documents/considering-ej-in-rulemaking-guide-final.pdf.

U.S. EPA. *ICLUS Tools and Datasets (Version 1.3 and 1.3.1)*, EPA/600/R-09/143F. 2010, https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=205305.

U.S. EPA. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2014*, EPA 430-R-16-002. Apr. 2016, https://www.energy.gov/sites/prod/files/2018/02/f49/EPA%202016_GHG-Inventory.pdf.

U.S. EPA. *Plan EJ 2014.* Sep. 2011, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100DFCQ.PDF?Dockey=P100DFCQ.PDF.

U.S. EPA. *Regulatory Impact Analysis for the Proposed Revisions to the Emission Guidelines for Existing Sources and Supplemental Proposed New Source Performance Standards in the Municipal Solid Waste Landfills Sector.* 2015b, https://www.epa.gov/sites/default/files/2020-07/documents/landfills_ria_final-eg-nsps_2016-07.pdf.

U.S. EPA. *Regulatory Impact Analysis of the Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector*. EPA-452/R-15-002, Aug. 2015b, https://www.epa.gov/sites/default/files/2020-07/documents/oilgas_ria_proposed-nsps_2015-08.pdf.

U.S. EPA. *Risk Analysis to Support Potential Revisions to Underground Storage Tank (UST) Regulations*. Aug. 2011, https://www.regulations.gov/document/EPA-HQ-UST-2011-0301-0189.

U.S. EPA. *Suppliers of Industrial GHGs and Products Containing GHGs.* https://www.epa.gov/ghgreporting/suppliers-industrial-ghgs-and-products-containing-ghgs.

U.S. EPA. *Technical Guidance for Assessing Environmental Justice in Regulatory Analysis*. Jun. 2016, www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.

U.S. EPA. *Toxics Release Inventory Program*. https://www.epa.gov/toxics-release-inventory-triprogram/tri-data-and-tools.

U.S. EPA. *Vintaging Model*. *Version VM IO_v4.4_02.04.16*. 2016.

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

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

Wheaton, William D., "Synthesized Population Databases: A US Geospatial Database for Agent-Based Models." *RTI Press Methods Report*, no. MR-0010-0905, doi: 10.3768/rtipress.2009.mr.0010.0905.

Wheaton, William D. *2010 U.S. Synthetic Population Version 1*, RTI International.

World Meteorological Organization (WMO). *Scientific Assessment of Ozone Depletion: 2018*, World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 58, Geneva, Switzerland, 2018, *https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf*.

Velders, G.J.M., et al. "Projections of hydrofluorocarbon (HFC) emissions and the resulting global warming based on recent trends in observed abundances and current policies." *Atmospheric Chemistry and Physics*, vol. 22, no. 9, 2022, pp. 6087–6101, doi: 10.5194/acp-22-6087-2022.