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REPORT

INDIA'S HFC PHASE-DOWN PATHWAYS

AUTHORS:

R. S. Agarwal, *Professor, Indian Institute of Technology Delhi (Retired)*
Gerry George, *NRDC India*
Akash Goenka, *NRDC India*

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LIST OF ABBREVIATIONS

A5 Parties	Article 5 Parties
GHG	Greenhouse Gas
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFA	Hydrofluoroalkane
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
KIP	Kigali HFC Implementation Plan
LDV	Light Duty Vehicle
LRM	Lifecycle Refrigerant Management
MAC	Mobile Air Conditioning
MDI	Metered Dose Inhaler
MLF	Multilateral Fund
MT	Metric ton
$MTCO_2eq$	Metric tonne of carbon dioxide equivalent
PFAS	Per- and Poly-fluoroalkyl Substances
RAC	Room Air Conditioner
SLS	Secondary Loop System
UNEP	United Nations Environment Programme
VRF	Variable Refrigerant Flow

EXECUTIVE SUMMARY

The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) agreed on 16 September 1987, and which entered into force on 1 January 1989, is widely regarded as the most successful multilateral environmental agreement. Originally designed to protect the stratospheric ozone layer, the Protocol expanded its scope in 2016 to address ozone-safe greenhouse gas (GHG) emissions by adopting an Amendment to the Montreal Protocol at Kigali, Rwanda, to include hydrofluorocarbons (HFCs), used as refrigerants, propellants, and foam blowing agents, as controlled substances and phasing down HFCs as per agreed schedules.

India ratified the Kigali Amendment to the Montreal Protocol in September 2021. As a result, India's HFC-dependent sectors—including cooling (space cooling, mobile air conditioning (MAC), cold-chain, commercial and industrial refrigeration), aerosols, and limited use for polyurethane foams—must transition to lower-global warming potential (GWP) HFC alternatives. Under the Kigali schedule, India is required to freeze its baseline HFC consumption by 1 January 2028, and reduce it from 2032 through 2047.

This report presents a practical approach to phasing-down HFCs, based on a comprehensive sector-by-sector analysis of India's HFC consumption for the period 2020–2050. The bottom-up analysis is based on the best available data, supplemented with industry intelligence and stakeholder consultations.

- **Business-As-Usual Scenario (BAU Scenario):** This scenario reflects a continuation of current HFC usage trends and preferences. The BAU scenario assumes that there's no new transition to lower-GWP HFC alternatives in the future.
- **Intervention Scenario 1 (INT Scenario 1):** This Montreal Protocol compliance scenario models a transition to HFC alternatives with lower-GWPs that are both technologically and economically viable for the Indian industry, undertaken in full alignment with the Kigali Amendment. This scenario assumes a timely adoption of alternatives to ensure complete compliance with India's Kigali Amendment HFC phase-down schedule with greater environmental benefit.
- **Intervention Scenario 2 (INT Scenario 2):** Like INT Scenario 1, this Montreal Protocol compliance scenario models a transition to lower-GWP HFC alternatives that are technologically and economically viable. However, the transition starts a little later than INT Scenario 1. This scenario is included as a comparative case to highlight the environmental benefit of timely and proactive action, as modelled in INT Scenario 1.

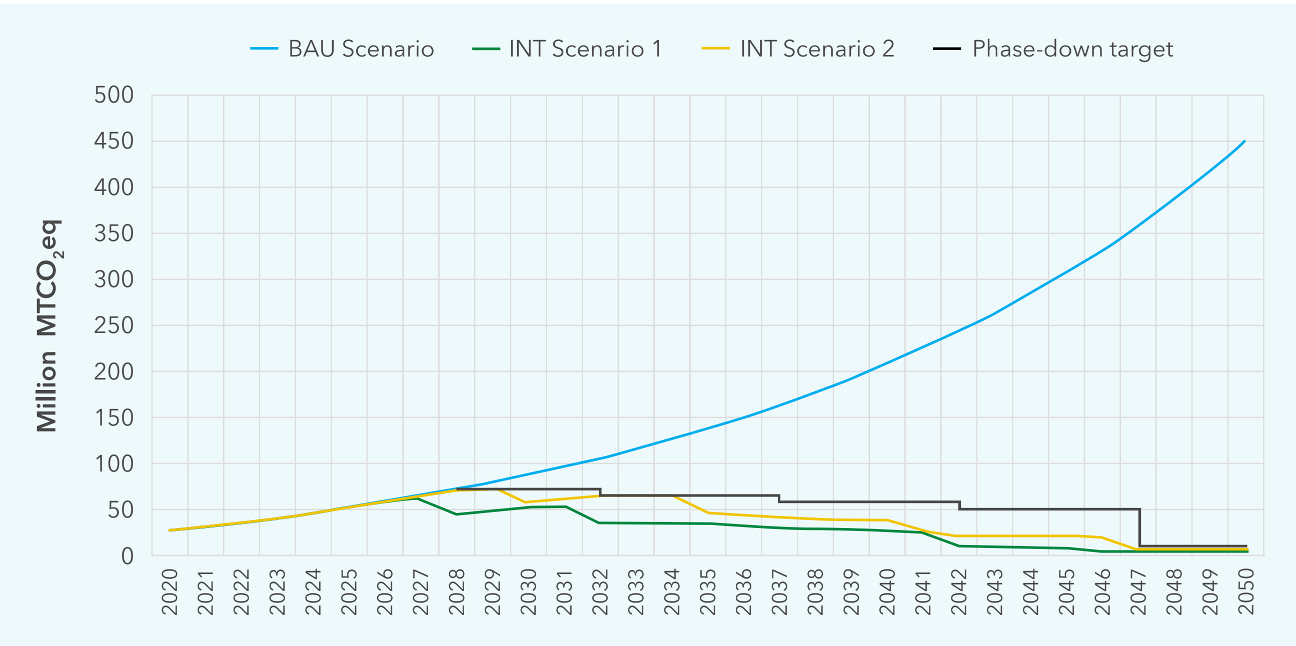
Key findings include:

- **HFC consumption in the BAU Scenario:**
  - India's HFC consumption in the BAU Scenario is estimated to increase ~9x from ~47,000 metric tons (MT) in 2025 to ~4,14,000 MT in 2050.
  - Manufacturing new equipment and servicing existing ones comprise ~60% and ~40%, respectively, of the current consumption (i.e., for 2025).

- In terms of metric ton of carbon dioxide equivalent ($MTCO_2eq$), India's HFC consumption is estimated to increase ~8x from ~54 million $MTCO_2eq$ in 2025 to ~450 million $MTCO_2eq$ in 2050.
- Space cooling and MAC comprise ~80% of the current HFC consumption.
- R134a and R32, used in the MAC and space cooling sectors, respectively, comprise nearly 70% of the current HFC consumption.

- **Cumulative avoided HFC consumption in INT Scenarios 1 and 2:** INT Scenarios 1 and 2, which incorporate transitions to low-GWP HFC alternatives, are projected to deliver substantial cumulative avoided HFC consumption relative to the BAU Scenario.

  - Between 2028 and 2047, INT Scenario 1 is estimated to avoid ~3.1 billion $MTCO_2eq$, while INT Scenario 2 achieves ~2.8 billion $MTCO_2eq$ in avoided consumption. Overall, INT Scenario 1 offers an additional ~300 million $MTCO_2eq$ of cumulative avoided consumption compared to INT Scenario 2.
  - The cumulative avoided HFC consumption can be attributed to manufacturing new equipment and servicing existing ones by ~60% and ~40%, respectively.
  - Per the figure below, INT Scenario 1 complies with the Kigali Amendment's allowable HFC consumption (i.e., freeze in 2028, 10% reduction in 2032, 20% reduction in 2037 and finally 85% reduction in 2047), sustainably with almost no obsolescence of cooling equipment on account of HFCs for servicing beyond 2047.
  - Per the figure below, INT Scenario 2 also complies with the Kigali Amendment's allowable HFC consumption through effective Lifecycle Refrigerant Management (LRM) measures, especially between 2028 and 2034.



HFC consumption in INT Scenarios 1 and 2

Actions proposed to support the industry in ensuring smooth, effective, and timely implementation of INT Scenarios 1 and/or 2 include: raising awareness among manufacturers about technically and economically viable low-GWP options across different sectors and subsectors, and developing supportive ecosystems for the safe adoption of A2L and A3 flammable refrigerants through harmonized safety standards, workforce training, and certification. An assessment of market readiness for transitioning from HFCs to low-GWP alternatives should be undertaken through industry and stakeholder consultations, leading to the development of a detailed roadmap informed by sectoral inputs. In parallel, India's Ozone Depleting Substances (Regulation and Control) Rules (2000) should be amended to align with the phase-down of HFCs under the Kigali Amendment to the Montreal Protocol. Finally there is a need to develop the Kigali HFC Implementation Plan (KIP) Stage I for accessing financial and technical assistance for eligible enterprises from the Multilateral Fund (MLF).

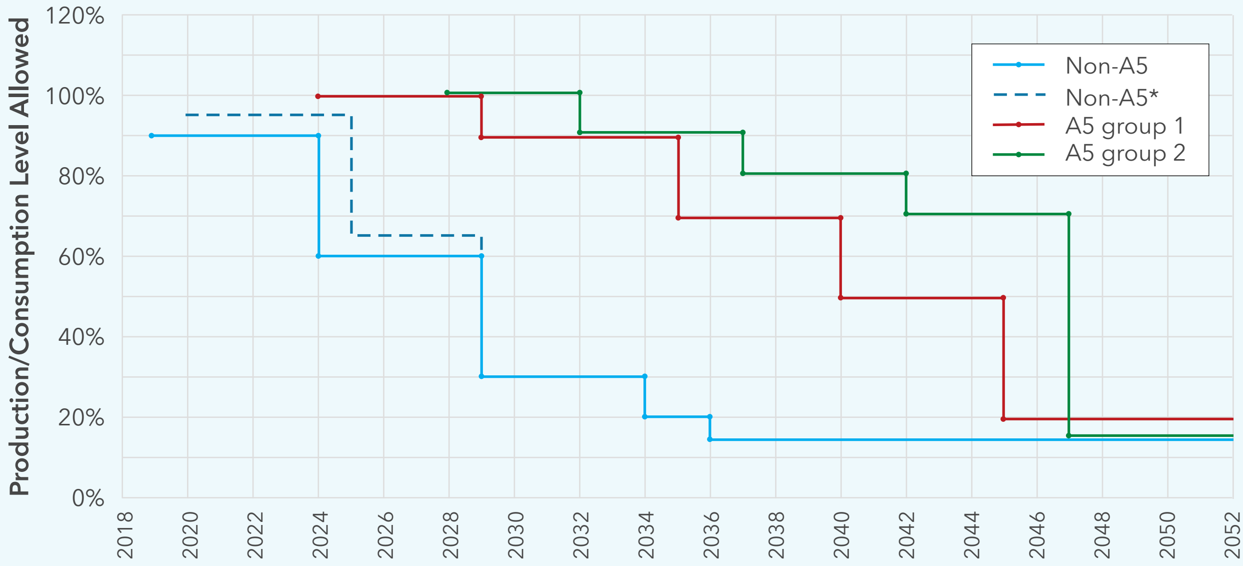
The report acknowledges ongoing debates on Per- and Polyfluoroalkyl Substances (PFAS), a group of over 15,000 chemicals—including some HFC alternatives—known for their health risks. While some countries are exploring regulations to curb their use, PFAS are not yet controlled under the Montreal Protocol. The report therefore limits the use of low-GWP PFAS alternatives, employing them only where non-PFAS options are unavailable or not yet mature. Since adding PFAS to the Protocol would require a lengthy amendment process, the transition under the Kigali Amendment will proceed independently of these PFAS discussions.

India's relatively low current HFC demand reflects the limited penetration of cooling appliances. Rising temperatures, economic growth, urbanisation, and recently lowered Goods and Services Tax on cooling equipment, will drive rapid market expansion in the coming decades. This creates both a challenge and an opportunity: without intervention, HFC consumption will rise sharply; but with strategic transitions to low-GWP alternatives—most of which are already available—India can align with its Kigali obligations while expanding access to cooling. Timely action is critical. Early adoption of alternatives, supported by strong government and industry collaboration, can ensure compliance, minimise climate impacts, and unlock additional avoided consumption through the mainstreaming of good LRM practices and associated circular economy policies. As India develops its KIP, the coming decade represents a decisive window to shape the country's cooling future in a climate-resilient and sustainable manner.

1. INTRODUCTION

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, originally designed to protect the stratospheric ozone layer, expanded its scope to address greenhouse gas (GHG) emissions by adopting an amendment (at its XXVIII meeting in October 2016 in Kigali, Rwanda) that included hydrofluorocarbons (HFCs) as controlled substances and mandated a phase-down of production and consumption of HFCs. HFCs are highly potent GHGs, used as refrigerants for air-conditioning and refrigeration, for blowing agents for thermal insulation foams, for metered-dose inhalers for asthma and chronic obstructive pulmonary disease, and for other applications.[1] The projected surface temperature contribution from HFCs (excluding HFC-23) reduces from 0.3–0.5 °C to less than 0.1 °C in 2100 due to entry into force of the Kigali Amendment.[2]

Under the Montreal Protocol, Article 5 (A5) Parties refers to developing countries whose annual calculated level of consumption of the controlled substances in Annex A (chlorofluorocarbons) was less than 0.3 kg per capita on their date of entry into the Protocol or any time thereafter until 1 January 1999. A5 Parties can delay by ten years their compliance with the control measures set out in Articles 2A to 2E with respect to controlled substances. The 1990 Amendment created a fund, funded by non-Article 5 (non-A5) Parties, which are developed countries with earlier phaseout and phasedown schedules, to finance the agreed incremental costs of conversion to alternatives to controlled substances for eligible A5 Parties. The same principle and financing is also applied to the phase-down of HFCs under the Kigali Amendment. Figure 1 shows the phase-down schedules of non-A5 and A5 Parties; A5 Parties are further split for the HFC phase-down into two groups: Group 1 (the majority of developing countries) and Group 2 (Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates). As of 31 October 2025, 169 parties have ratified the Kigali Amendment.[3]



Non-A5 Baseline = Average HFC for 2011–2013 + 15% of HCFC baseline.
Non-A5* Baseline = Average HFC for 2011–2013 + 25% of HCFC baseline.
A5 – Group 1 Baseline = Average HFC for 2020–2022 + 65% of HCFC baseline.
A5 – Group 2 Baseline = Average HFC for 2024–2026 + 65% of HCFC baseline.

Figure 1: HFC consumption reduction schedule[4]

India is an A5 Group 2 Party and ratified the Kigali Amendment in September 2021.[5] A5 Group 2 Parties' baseline HFC consumption is calculated as the sum of its average HFC consumption for 2024-2026 and 65% of its hydrochlorofluorocarbon (HCFC) consumption baseline. Per the phase-down schedule shown in Table , this baseline consumption should be frozen by 1 January , 2028, and then reduced gradually from 1 January 2032 to 1 January 2047.

Table 1: HFC phase-down schedule for A5 Group 2 Parties

Base level	Average HFC consumption for 2024-2026 + 65% of HCFC consumption baseline
Freeze	January 1, 2028
10% reduction	January 1, 2032
20% reduction	January 1, 2037
30% reduction	January 1, 2042
85% reduction	January 1, 2047

According to the India Cooling Action Plan[6], India's refrigerant-based cooling demand is projected to increase ~8x to over 950 million tons of refrigeration by 2037–38, compared to 2017–18 levels. This growth is expected to drive a ~6.5x rise in refrigerant demand over the same period. However, compliance with the Kigali Amendment means that this growing demand cannot be addressed by continued reliance on HFCs. India's HFC-dependent sectors—namely the cooling sector (where HFCs serve as refrigerants), the aerosol sector (where HFCs are used as propellants), and limited use in the foam sector—will be required to transition to lower-global warming potential (GWP)[i] alternatives.

This report estimates:

- India's HFC consumption[ii] (in metric ton (MT) and metric ton of carbon dioxide equivalent (MTCO_2eq)) across the cooling, aerosol, and foam sectors for 2020-2050 under business-as-usual;
- India's HFC consumption under different intervention scenarios, including a scenario that models a transition to HFC alternatives with lower-GWPs that are both technologically and economically viable for the Indian industry, undertaken in complete alignment with the Kigali Amendment; and
- The cumulative avoided HFC consumption under different intervention scenarios with respect to the business-as-usual scenario.

The analysis draws on the best available data, supplemented by the latest intelligence from industry sources and stakeholder consultations. Particular care has been taken to capture the diversity of India's HFC demand patterns across different end-use applications, technology options, and market dynamics. Results are therefore presented at a granular sectoral and sub-sectoral level, allowing for a nuanced understanding of where transitions to lower-GWP alternatives are most feasible and where challenges may arise. This level of detail is intended to maximize the practical utility of the findings in guiding the design, sequencing, and implementation of India's Kigali HFC Implementation Plan (KIP), while also supporting alignment with broader national developmental goals.

i GWP is a metric defined by the Intergovernmental Panel on Climate Change to compare the warming impact of different greenhouse gases relative to carbon dioxide (CO_2 = 1) over a time period (100-year period in this case).

ii Consumption = Production (if any) + Imports - Exports

2. METHODOLOGY

2.1 Scope

This analysis covers the HFC-consuming sectors and sub-sectors shown in Table 2. The study covers the period from 2020 to 2050, thereby extending beyond the official HFC phase-down schedule for India (2028–2047) on both the earlier and later years, to capture existing conditions before the start of the phase-down as well as the longer-term impacts that continue even after its completion. All years presented in this analysis are calendar years, i.e., from 1 January to 31 December.

Table 2: The HFC-consuming sectors and sub-sectors covered in this analysis

Sector	Sub-sectors / Equipment	Notes
Refrigerant use HFC[iii] for the cooling sector		
Space Cooling	Room Air Conditioner (RAC), Variable Refrigerant Flow (VRF), Chiller, Packaged Air Conditioner	Chillers do not include low-pressure centrifugal chillers using R123, which is a hydrochlorofluorocarbon (HCFC), already transitioning to non-HFCs such as R514A or R1224yd (Z) or R1233zd(E).
Mobile Air Conditioning (MAC)	Light Duty Vehicle (LDV), Bus, Train & Metro	India's vehicle scrapping policies and the growing penetration of electric vehicles have been incorporated into the analysis.
Cold-chain	Cold Storage, Packhouse, Ripening Chamber, Reefer Vehicle	
Commercial Refrigeration	Standalone Refrigeration Unit, Condensing Unit (Chiller)	Domestic refrigeration is not considered since 100% manufacturing of domestic refrigerators has already transitioned to R600a, which is a natural refrigerant. Super/hypermarkets have been precluded from this analysis due to their low presence in India, and the lack of sufficient data.
Industrial Refrigeration		This includes only industrial process chillers.
Non-refrigerant use HFC		
Aerosol	Metered Dose Inhaler (MDI), Personal Care Product	HFCs are used as propellants in the aerosol sector. The transition from HFCs is underway even in the MDI subsector.
Foam		This sector has already converted to ultra-low-GWP blowing agents as of 1 January 2020. Still, a small quantity of HFCs is used as blowing agents in the thermal insulating foam sector by a few manufacturers for some applications.

iii Refrigerants are denoted with 'R'. For example, HFC32 when used as a refrigerant, is denoted as R32.

2.2 Scenarios

The analysis is carried out under three scenarios:

- **Business-As-Usual Scenario (BAU Scenario):** This scenario reflects a continuation of current HFC usage trends and preferences. The BAU scenario assumes that there's no new transition to lower-GWP HFC alternatives in the future.
- **Intervention Scenario 1 (INT Scenario 1):** This Montreal Protocol compliance scenario models a transition to HFC alternatives with lower-GWPs that are both technologically and economically viable for the Indian industry, undertaken in full alignment with the Kigali Amendment. This scenario assumes a timely adoption of alternatives to ensure complete compliance with India's Kigali Amendment HFC phase-down schedule with greater environmental benefit.
- **Intervention Scenario 2 (INT Scenario 2):** Like INT Scenario 1, this Montreal Protocol compliance scenario models a transition to lower-GWP HFC alternatives that are technologically and economically viable. However, the transition starts a little later than INT Scenario 1. This scenario is included as a comparative case to highlight the environmental benefit of timely and proactive action, as modelled in INT Scenario 1.

2.3 Estimating India's HFC Consumption (MT) in the BAU Scenario

The consumption of HFCs (MT)[iv] was estimated bottom-up using a spreadsheet model that utilized the input parameters shown in Table 3. It includes the HFC consumption for manufacturing new equipment and servicing existing ones.

Table 3: Input parameters utilized to estimate HFC consumption (MT) in the BAU Scenario

Input parameter	Source
For cooling, aerosol, and foam sectors	
The past and current market status, and future projections	The past and current market status and sub-sector-specific growth rates were ascertained using the following data sources. Due to varying levels of data availability across sectors, the authors made certain assumptions based on expert consultations. • Ministry of Environment, Forest and Climate Change's India Cooling Action Plan[7] (for the cooling sector only) • Bureau of Energy Efficiency's impact assessment reports for the financial years 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, and 2022-23[8] (for the cooling sector only) • Government, industry, and academic publications[9, 10, 11, 12, 13, 14, 15, 16] • Estimates based on industry consultations (for cooling, aerosol, and foam sectors)

iv MT is a useful unit for industry players, including equipment manufacturers and refrigerant producers, to consistently track the production and consumption of different HFC types regardless of their climate impact.

Input parameter	Source
The HFCs used and their proportion in new sales	The HFCs used and their proportion in new sales were determined based on • Bureau of Energy Efficiency's demand analysis for cooling by sector[17] (for the cooling sector only) • Industry consultations (for cooling, aerosol, and foam sectors)
For the cooling sector	
Refrigerant charge per unit of equipment for manufacturing new equipment, i.e., the total quantity (mass) of refrigerant required to fill and operate a single piece of equipment at its designed capacity	These input parameters were sourced from the Bureau of Energy Efficiency's demand analysis for cooling by sector[18] and verified through industry consultations.
Refrigerant charge per unit of equipment for servicing existing equipment. i.e., the total quantity (mass) of refrigerant required to refill a single piece of equipment to its proper operating level during maintenance	
Equipment life, i.e., the period over which a piece of equipment performs its intended function effectively and reliably, under normal operating conditions and with proper maintenance	
Service rate, i.e., the share of the equipment stock (i.e., the total number of functional units currently installed and available for use) serviced in a year	

2.4 Estimating India's HFC Consumption (MTCO2eq) in the BAU Scenario and INT Scenarios 1 and 2

India's HFC consumption in MTCO2eq[v] under the BAU Scenario was derived[vi] from its HFC consumption in MT and the specific HFCs' GWP values sourced from the United Nations Environment Programme's (UNEP) Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer[19]. The bottom-up estimates were validated top-down using India's past HFC consumption reported to the UNEP Ozone Secretariat[20]. India's HFC consumption (MTCO2eq) under INT Scenarios 1 and 2 was estimated based on the transitions from HFCs to low-GWP HFC alternatives shown in Table 4.

The study acknowledges ongoing debates on Per- and Polyfluoroalkyl Substances (PFAS)[vii], a group of over 15,000 chemicals—including some HFC alternatives—known for their health risks. While some countries are exploring regulations to curb their use, PFAS are not controlled under the Montreal Protocol. Our analysis therefore limits the use of low-GWP PFAS alternatives, employing them only where non-PFAS options are unavailable or not yet mature.

v MTCO2eq is useful for monitoring compliance with the Kigali Amendment to the Montreal Protocol; it helps understand the climate impact across HFC types.

vi HFC consumption (MTCO2e) = HFC consumption (MT) x GWP

vii PFAS are a large group of manmade chemicals often referred to as toxic "forever" chemicals. PFAS chemicals are extremely resistant to break down in the environment.

Table 4: The HFC transitions modelled in INT Scenarios 1 and 2

Sector / Sub-sector	HFC used in the BAU Scenario [GWP]	HFC transition modelled in INT Scenarios 1 and 2 [GWP; more properties of potential HFC alternatives utilized in INT Scenarios 1 and 2 are included in Appendix A.]	Transition year[viii] modelled in INT Scenario 1	Transition year modelled in INT Scenario 2
Space Cooling				
RAC	R32 [675], R410A [2088]	R32 → R290 [3] R410A → R290 [3]	2032	2035
VRF	R410A [2088]	R410A → R32 [675]	2028	2030
		R32 → X[ix] X could potentially be R454C [148] or R455A [148].	2042	2042
Medium-pressure Centrifugal Chiller	R134a [1430]	R134a → R1234ze(E) [7]	2028	2030
Screw Chiller	R134a [1430]	R134a → R1234ze(E) [7]	2028	2030
Scroll Chiller	R407C [1774], R410A [2088]	R407C → X R410A → X X could potentially be R32 [675] or R454C [148] or R455A [148].	2028	2030
Packaged Air Conditioner	R410A [2088], R407C [1774]	R410A → R32 [675] R407C → R32 [675]	2028	2030
		R32 → X X could potentially be R454C [148] or R455A [148].	2042	2042
MAC				
LDV	R134a [1430]	R134a → R1234yf[x, 21] [4]	2028	2030
Bus	R407C [1774]	R407C → X X could potentially be R290 [3] in top-mounted SLS.	2032	2035
Train & Metro	R407C [1774]	R407C → R454B [466]	2032	2035
Cold-chain				
Cold Storage	R404A [3922], R134a [1430]	R404A → R717 [0] R134a → R717 [0]	2028	2030

viii The HFC transition has been modelled from January 1 of the transition year.
ix X denotes an as-yet unidentified low-GWP refrigerant; X's GWP has been assumed to be 150 for the purposes of this analysis.
x LDV could further transition from R1234yf to R290 in the secondary loop system (SLS) at a later stage, especially for the electric vehicles, if safety issues are addressed.

Sector / Sub-sector	HFC used in the BAU Scenario [GWP]	HFC transition modelled in INT Scenarios 1 and 2 [GWP; more properties of potential HFC alternatives utilized in INT Scenarios 1 and 2 are included in Appendix A.]	Transition year[viii] modelled in INT Scenario 1	Transition year modelled in INT Scenario 2
Packhouse	R404A [3922], R134a [1430]	R404A → R717[xi] [0] R134a → R717 [0]	2028	2030
Ripening Chamber	R134a [1430]	R134a → R717 [0]	2028	2030
Reefer Vehicle	R404A [3922], R134a [1430], R407C [1774]	R404A → R1234yf [4] R134a → R1234yf [4] R407C → X X could potentially be R290 [3] or R152a [124] in the SLS.	2028	2030
Commercial Refrigeration				
Standalone Refrigeration Unit	R404A [3922], R134a [1430]	R404A → R290 [3] R134a → R290 [3]	2028	2030
Condensing Unit (Chiller)	R404A [3922], R134a [1430]	R404A → R290[xii] [3] R134a → R290 [3]	2028	2030
Industrial Refrigeration				
Industrial Refrigeration	R404A [3922]	R404A → R717 [0]	2028	2030
Aerosol				
MDI	HFA134a[xiii] [1430], HFC227ea [3220]	HFA134a → HFC152a [124] HFC227ea → HFC152a [124]	2042	2047
Personal Care Product	HFC152a [124]	HFC152a → Hydrocarbon Aerosol Propellant [3]	2028	2030
Foam				
Foam	HFC245fa [1030], HFC365mfc [794]	HFC245fa → Ecomate[xiv] [0] HFC365mfc → Ecomate [0]	2028	2030

xi Packhouses and ripening chambers could potentially transition to R455A and R454C (instead of R717) from R404A and R134a, but they have not been modelled in this study.

xii Condensing units could potentially transition to R455A and R454C (instead of R290) from R404A and R134a, but they have not been modelled in this study.

xiii HFA134a is the same chemical as HFC134a. When used as a propellant in medical inhalers, the pharmaceutical industry often refers to it as HFA134a (Hydrofluoroalkane).

xiv Potential alternatives to Ecomate include water, cyclopentane, and Hydrofluoroolefins (HFOs) such as HFO1233zd(E), HFO1336mzz(Z), and HFO1234ze.

3. RESULTS & DISCUSSION

3.1 BAU Scenario

HFC consumption (MT): India's HFC consumption in the BAU Scenario is estimated to increase ~9x from ~47,000 MT in 2025 to ~4,14,000 MT in 2050 (Figure 2). Manufacturing new equipment and servicing existing ones comprise ~60% and ~40%, respectively, of the current consumption ((i.e., for 2025). Space cooling and MAC comprise ~80% of the current HFC consumption (Figure 3). R32 and R134a are the dominant HFCs used currently (Figure 4).

HFC consumption ($MTCO_2eq$): India's baseline HFC consumption is calculated at the sum of its average HFC consumption for 2024-2026 and 65% of its HCFC consumption baseline[22], which is estimated to be ~73 million $MTCO_2e$.[xv, xvi]. In the BAU Scenario, India's HFC consumption is estimated to increase ~8x from ~54 million $MTCO_2eq$ in 2025 to ~450 million $MTCO_2eq$ in 2050 (Figure 5). The current HFC consumption is dominated by space cooling and MAC (Figure 6). Manufacturing new equipment and servicing existing ones comprise ~60% and ~40%, respectively, of the current HFC consumption. R134a and R32 comprise nearly 70% of the current HFC consumption (Figure 7). Sector-wise details are included below, and sub-sector-wise details are included in Appendix B:

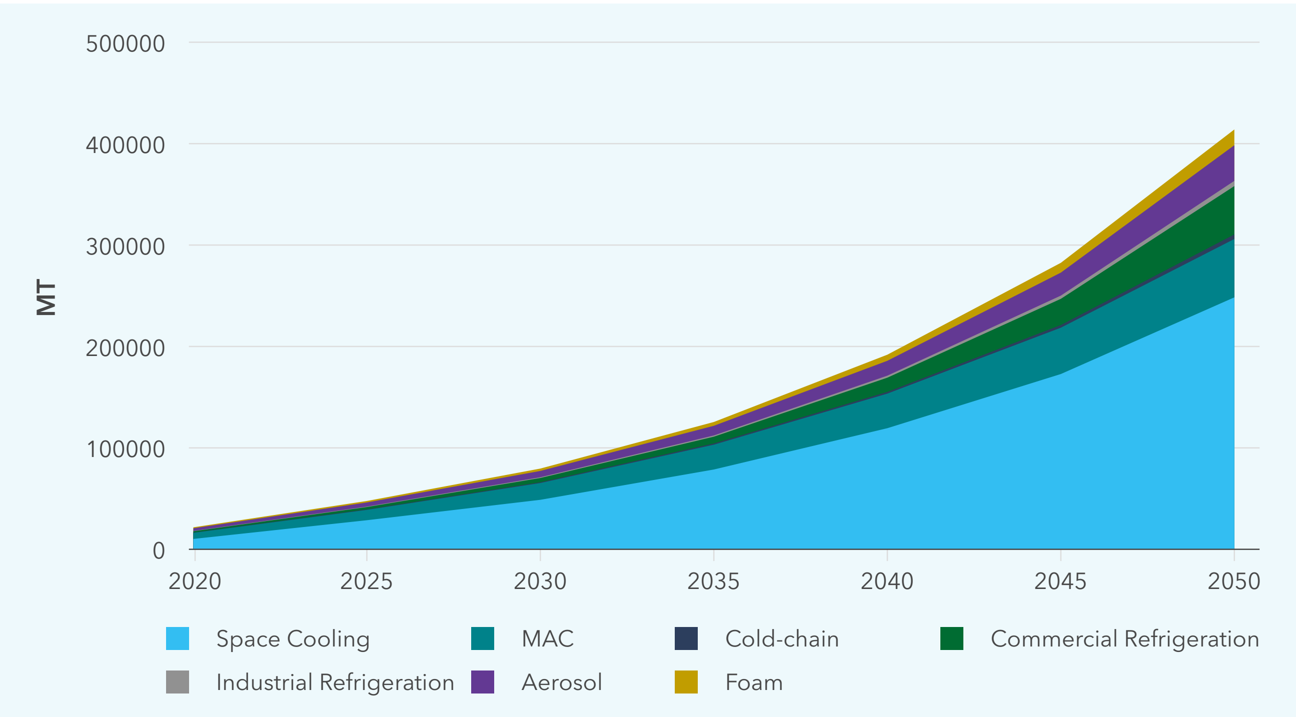


Figure 2: HFC consumption (MT) by sector in the BAU Scenario

xv India's baseline HFC consumption = Average HFC consumption for 2024-2026 + 65% of HCFC baseline = 53.2 + 19.6 = 72.8 million $MTCO_2eq$

xvi The actual baseline will be based on the data reported by the Ozone Cell of the Ministry of Environment, Forest, and Climate Change.

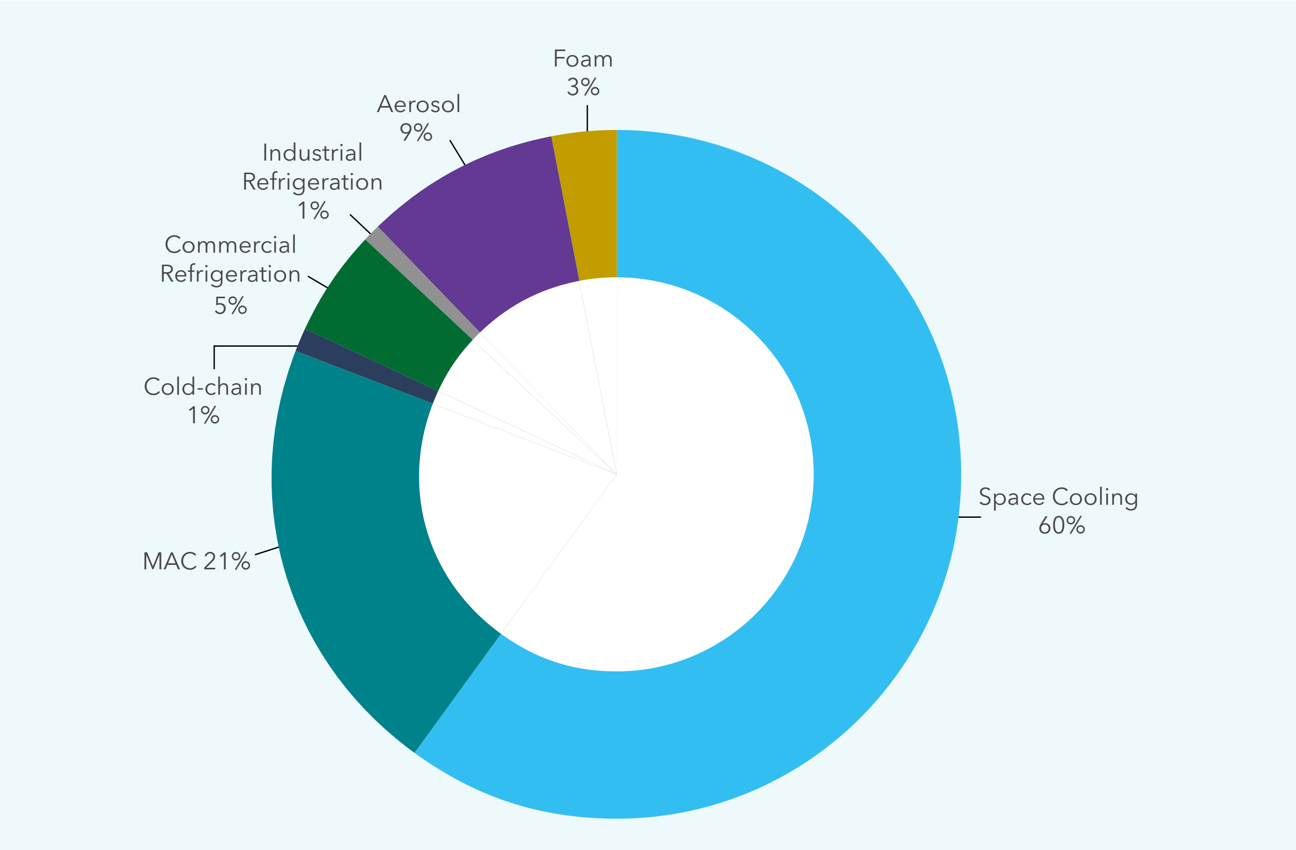


Figure 3: HFC consumption (MT) by sector for 2025

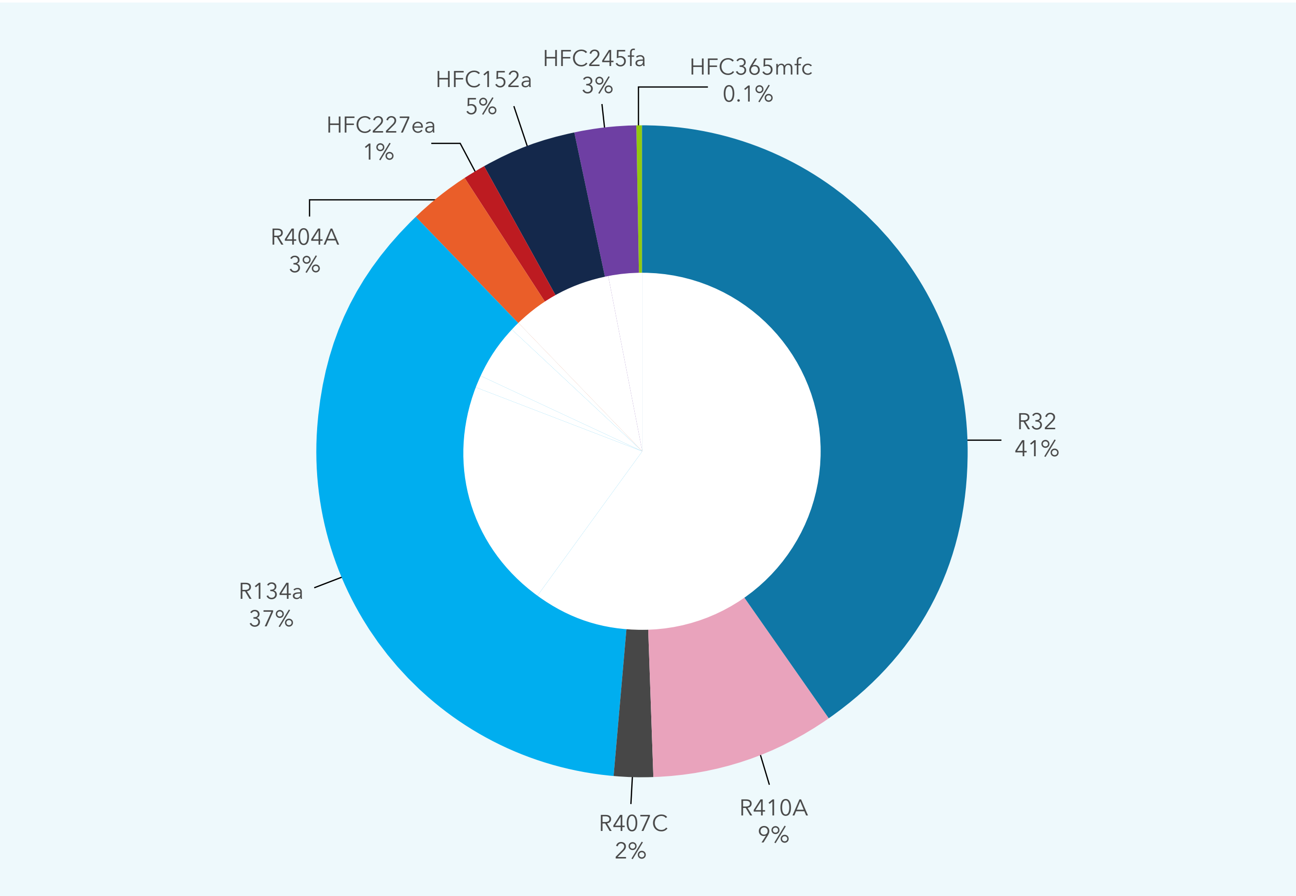


Figure 4: HFC consumption (MT) by chemical for 2025

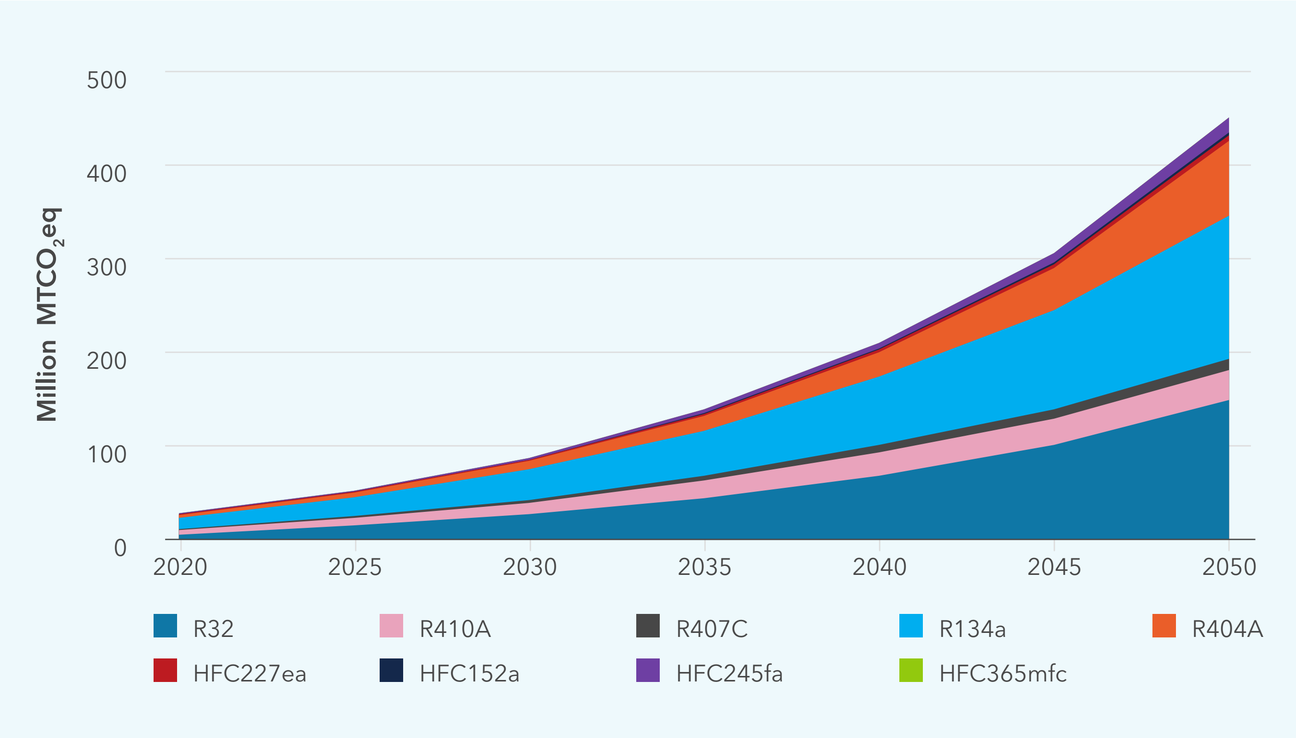


Figure 5: HFC consumption (MTCO2eq) by chemical in the BAU Scenario

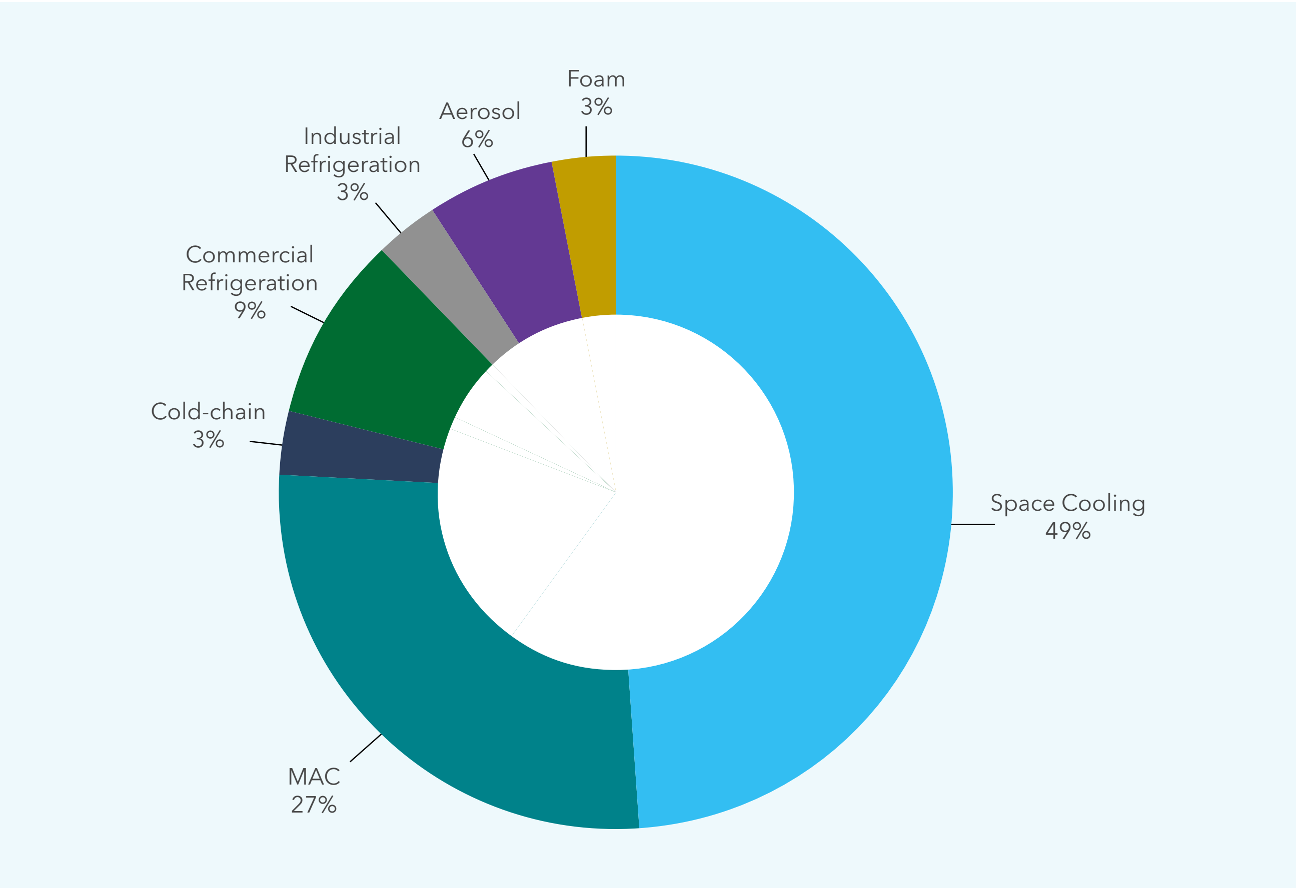


Figure 6: HFC consumption (MTCO2eq) by sector for 2025

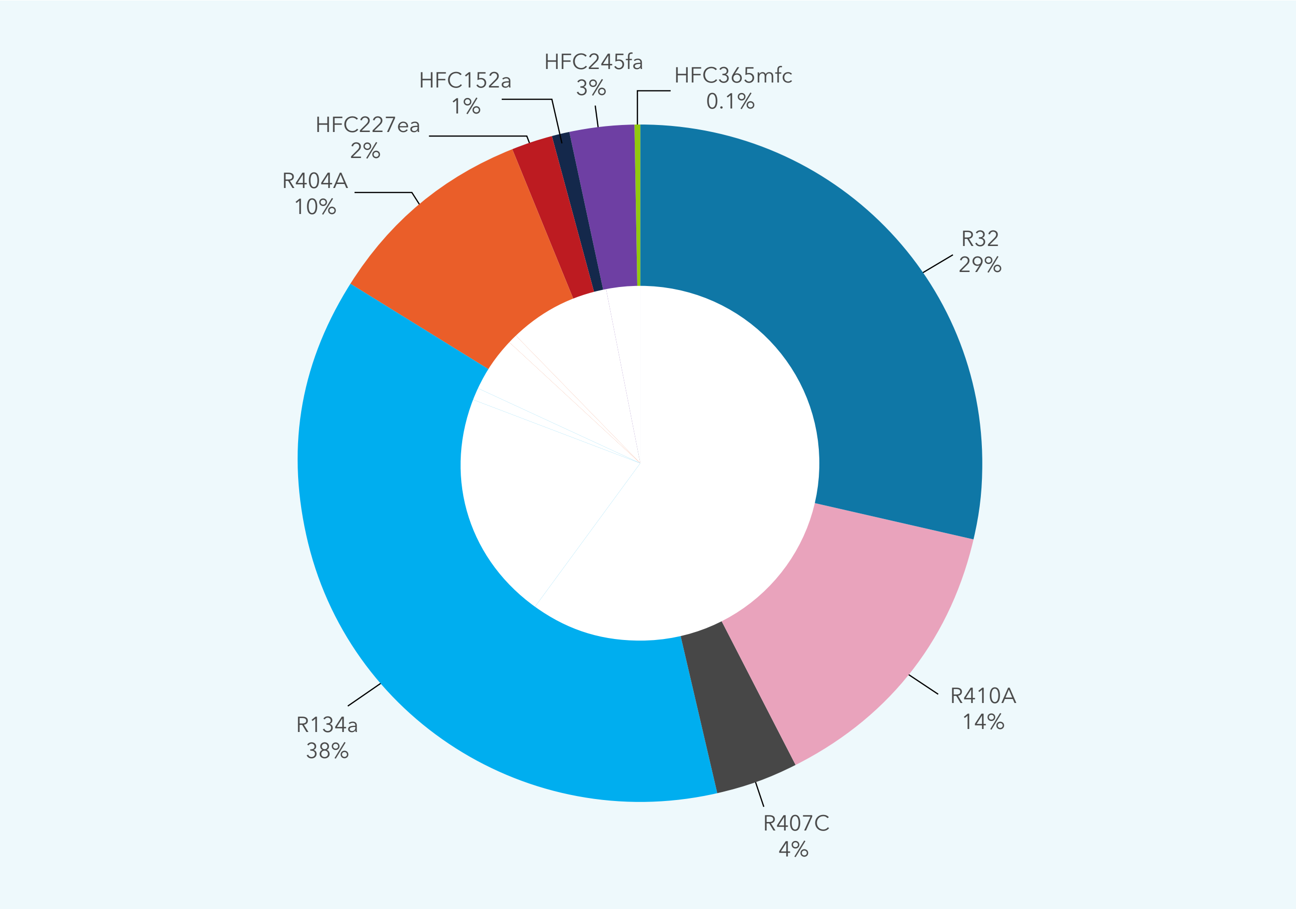


Figure 7: HFC consumption ($MTCO_2eq$) by chemical for 2025

3.1.1 Space Cooling

HFC consumption (MT): As shown in Figure 8, HFC consumption for space cooling is expected to increase ~9x from ~28,000 MT in 2025 to ~2,40,000 MT in 2050. Manufacturing new equipment and servicing existing ones comprise ~65% and ~35%, respectively, of the current consumption. This is expected to change slightly by 2050, i.e., ~60% for manufacturing new equipment and ~40% for servicing existing ones in 2050. R32 is the dominant HFC used in space cooling, followed by R410A, R134a, and R407C. HFC consumption for space cooling is likely to be dominated by RACs at ~80% through 2050, followed by VRF, chillers, and packaged ACs.

HFC consumption ($MTCO_2eq$): As shown in Figure 9, HFC consumption from space cooling is expected to increase more than 7x from ~26 million $MTCO_2eq$ in 2025 to ~200 million $MTCO_2eq$ in 2050. R32, R410A, R134a, and R407C continue being used in the BAU Scenario.

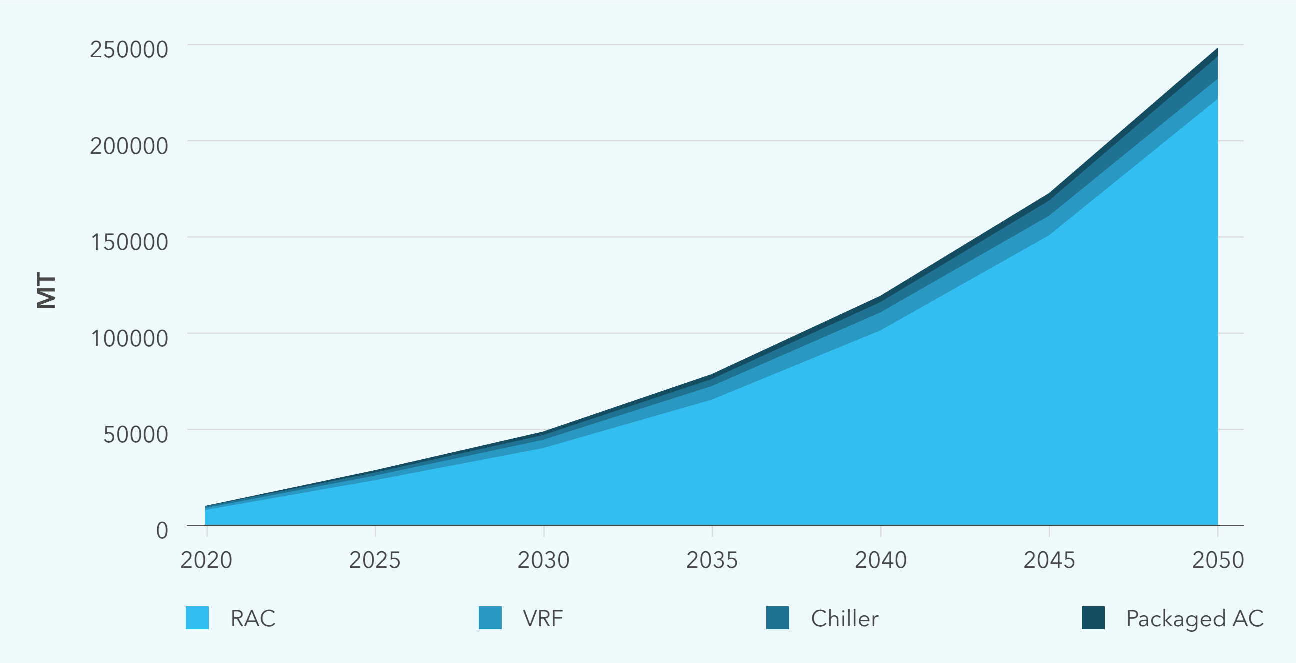


Figure 8: HFC consumption (MT) for space cooling in the BAU Scenario

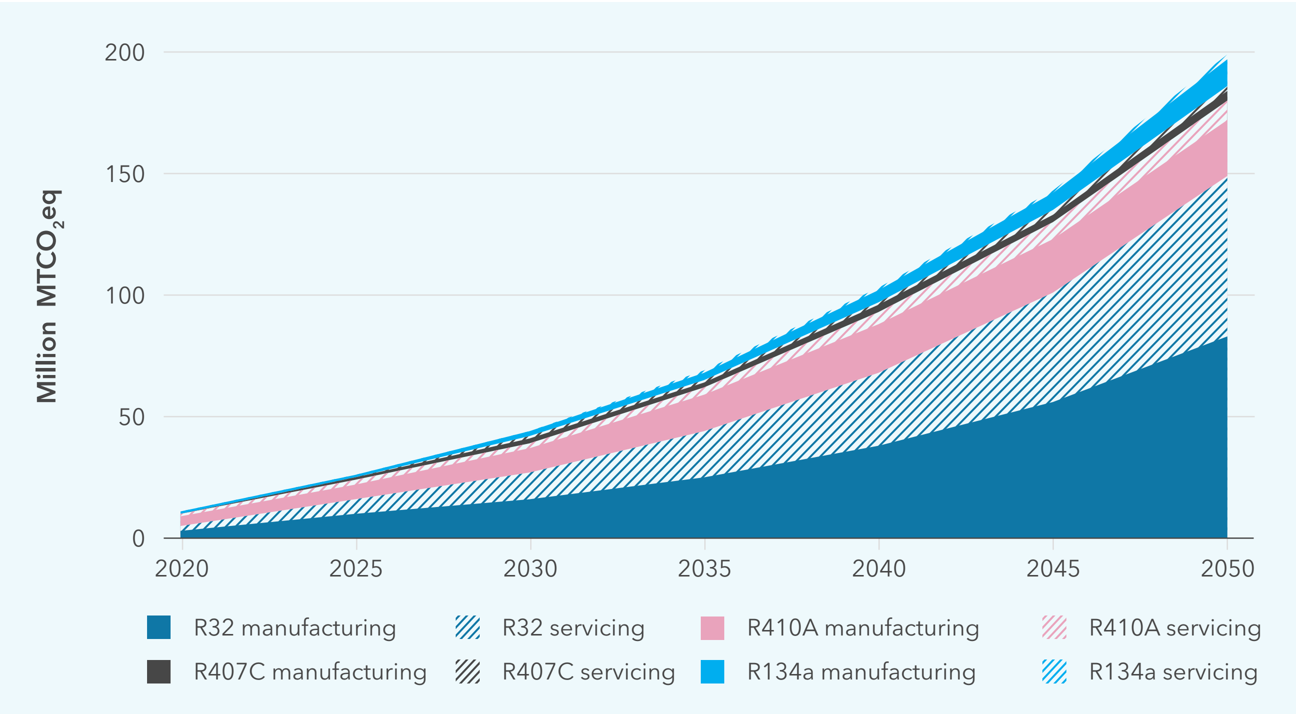


Figure 9: HFC consumption ($MTCO_2eq$) from space cooling in the BAU Scenario

3.1.2 Mobile Air Conditioning

HFC consumption (MT): As shown in Figure 10, HFC consumption for MACs is expected to increase more than 5x from ~10,000 MT in 2025 to ~57,500 MT in 2050. Manufacturing new equipment and servicing existing ones comprise ~35% and ~65%, respectively, of the current consumption. This share is expected to remain the same by 2050. R134a is the HFC used for air-conditioning LDVs, whereas R407C is used for air-conditioning buses, trains, and metros. HFC consumption for MAC is likely to be dominated by LDVs at more than 95% through 2050.

HFC consumption (MTCO2eq): As shown in Figure 11, HFC consumption from MAC is expected to increase more than 5x from ~15 million $MTCO_2eq$ in 2025 to ~83 million $MTCO_2eq$ in 2050. R134a and R407C continue being used in the BAU Scenario.

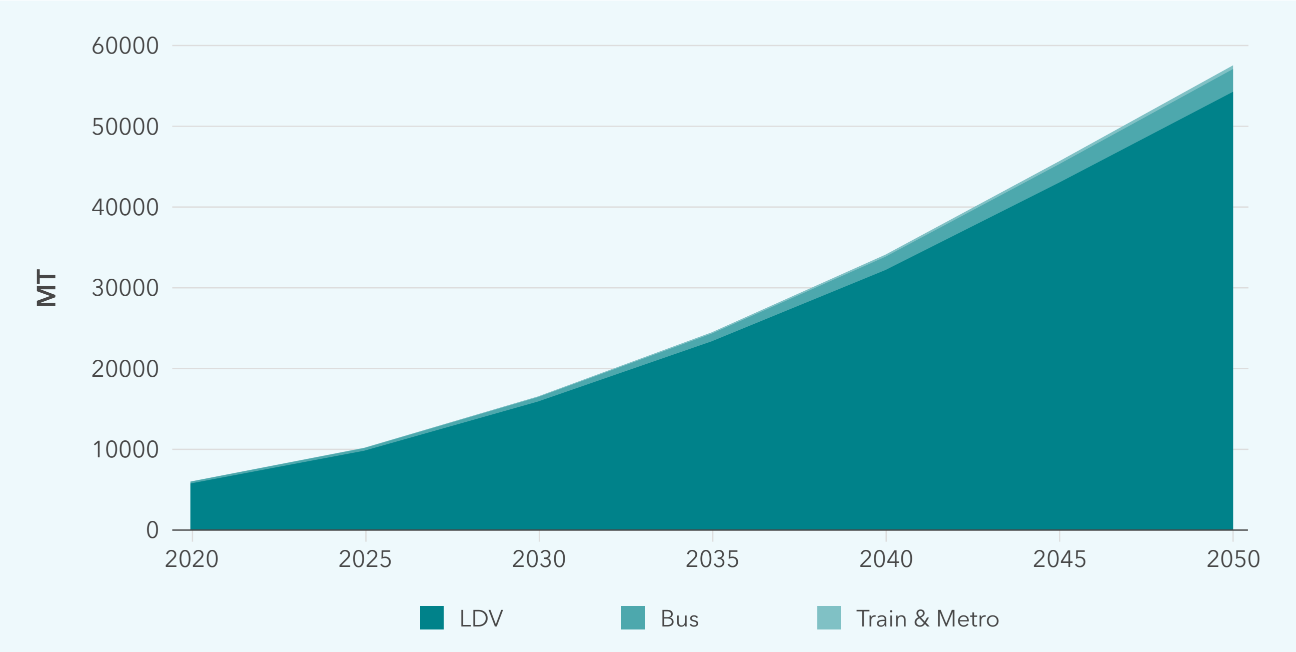


Figure 10: HFC consumption (MT) for MAC in the BAU Scenario

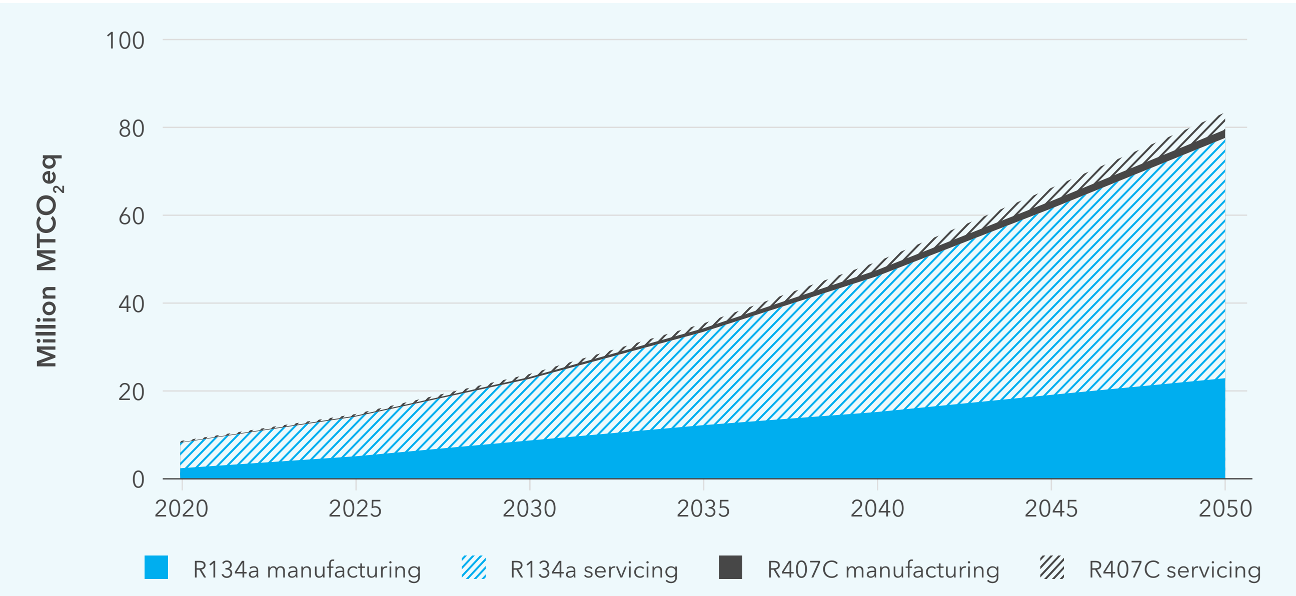


Figure 11: HFC consumption ($MTCO_2eq$) from MAC in the BAU Scenario

3.1.3 Cold-chain

HFC consumption (MT): As shown in Figure 12, HFC consumption for the cold-chain sector is expected to increase ~9x from ~500 MT in 2025 to ~4,400 MT in 2050. Manufacturing new equipment and servicing existing ones comprise ~40% and ~60%, respectively, of the current consumption. This is expected to change slightly by 2050, i.e., ~45% for manufacturing new equipment and ~55% for servicing existing ones in 2050. R404A is the dominant HFC used in the cold-chain sector, closely followed by R134a. HFC consumption for the cold-chain sector is likely to be dominated by cold storages and packhouses.

HFC consumption (MTCO2eq): As shown in Figure 13, HFC consumption from the cold-chain sector is expected to increase ~8x from ~1.5 million $MTCO_2eq$ in 2025 to ~12 million $MTCO_2eq$ in 2050. R404A, R134a, R407C continue being used in the BAU Scenario.

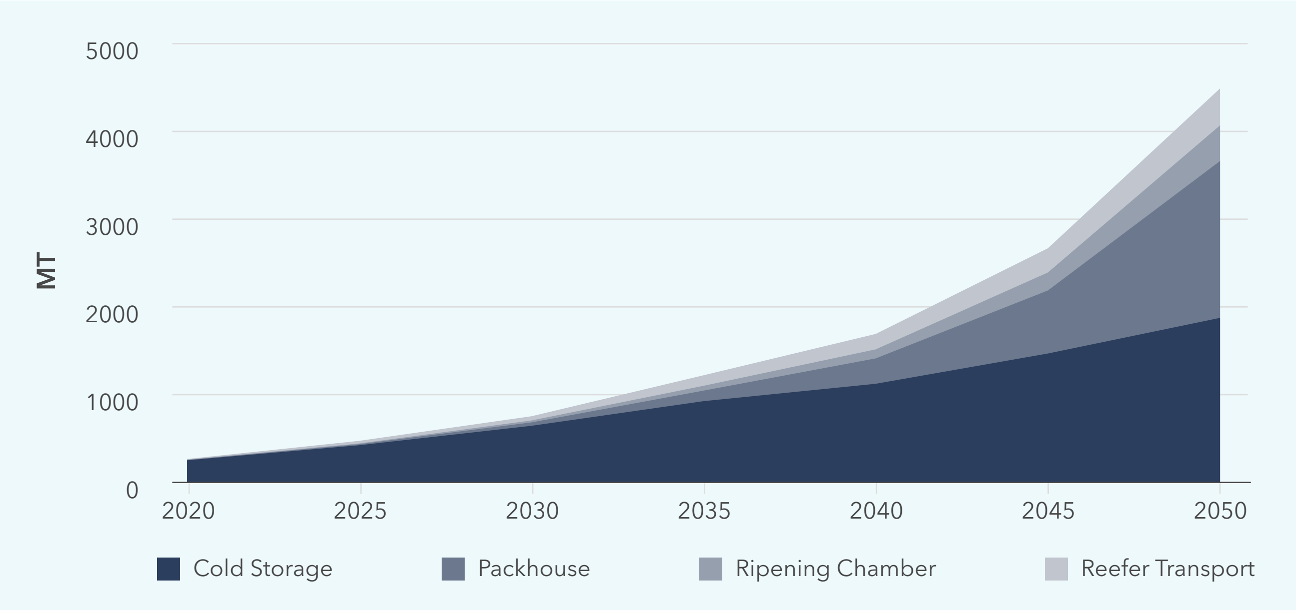


Figure 12: HFC consumption (MT) for the cold-chain sector in the BAU Scenario

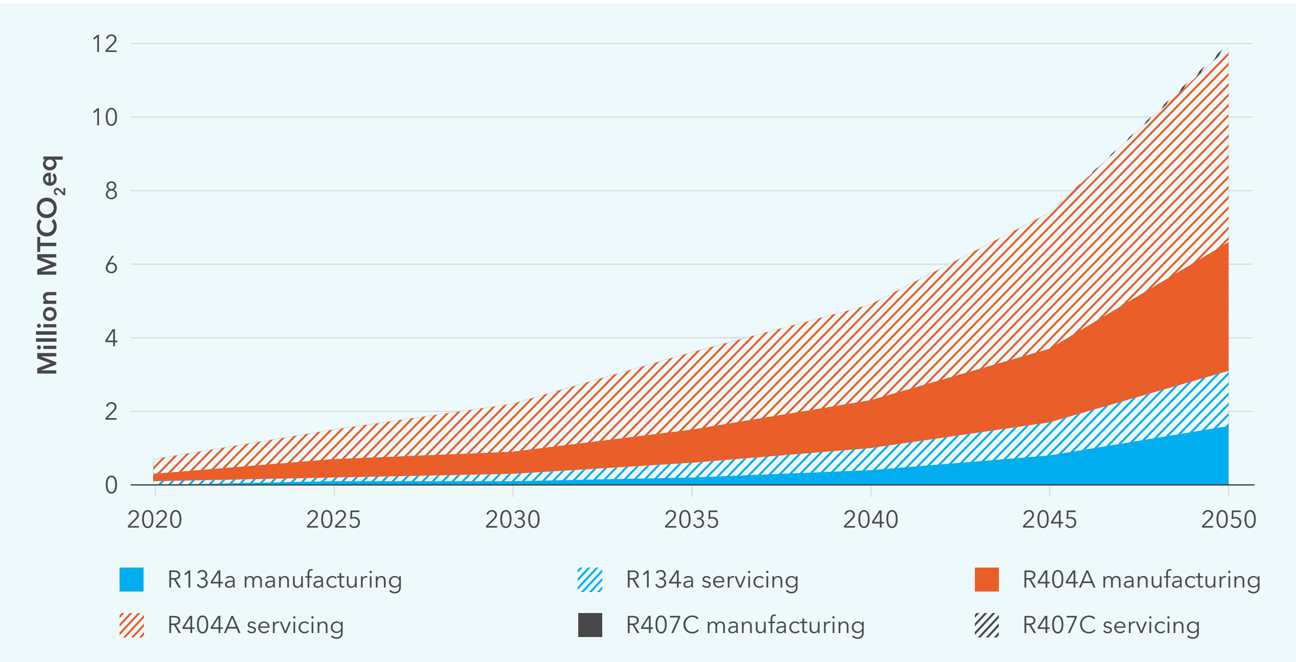


Figure 13: HFC consumption ($MTCO_2eq$) from the cold-chain sector in the BAU Scenario

3.1.4 Commercial Refrigeration

HFC consumption (MT): As shown in Figure 14, HFC consumption for commercial refrigeration is expected to increase ~21x from ~2,300 MT in 2025 to ~48,000 MT in 2050. The split between manufacturing new equipment and servicing existing ones is nearly equally. This share is expected to remain roughly the same by 2050. R134a is the dominant HFC used in commercial refrigeration, followed by R404A. HFC consumption for commercial refrigeration is likely to be dominated by standalone refrigeration units.

HFC consumption (MTCO2eq): As shown in Figure 15, HFC consumption from commercial refrigeration is expected to increase ~21x from ~4.7 million MTCO2eq in 2025 to ~100 million MTCO2eq. R134a and R404A continue being used in the BAU Scenario.

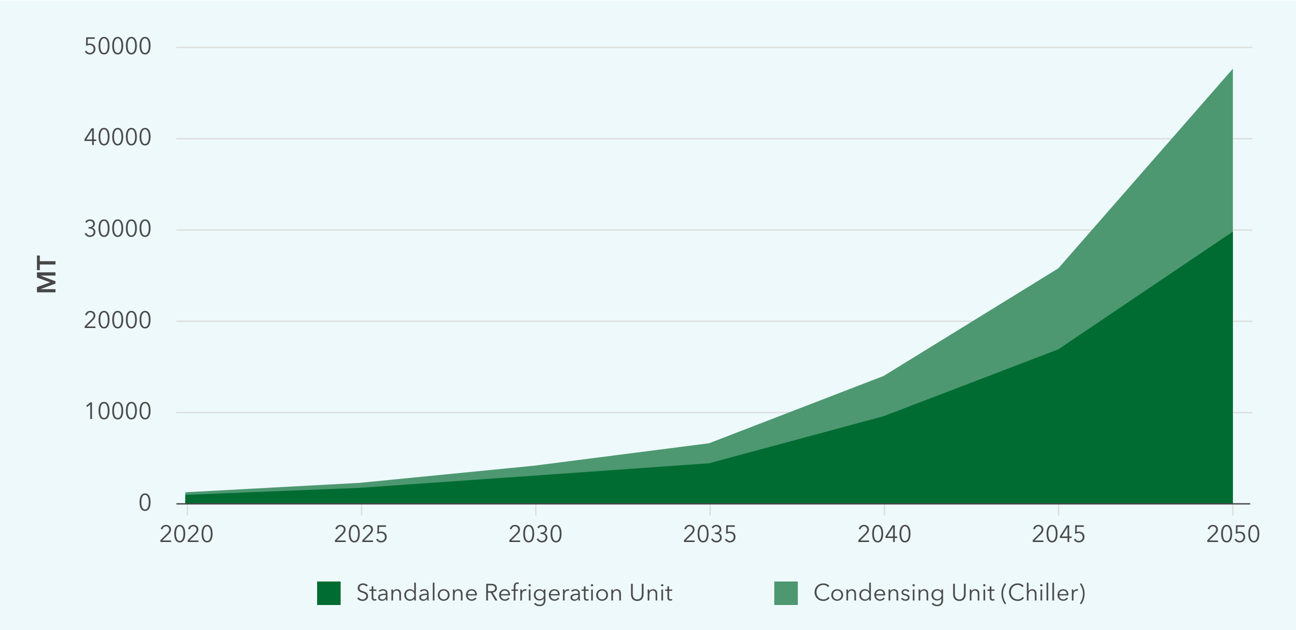


Figure 14: HFC consumption (MT) for commercial refrigeration in the BAU Scenario

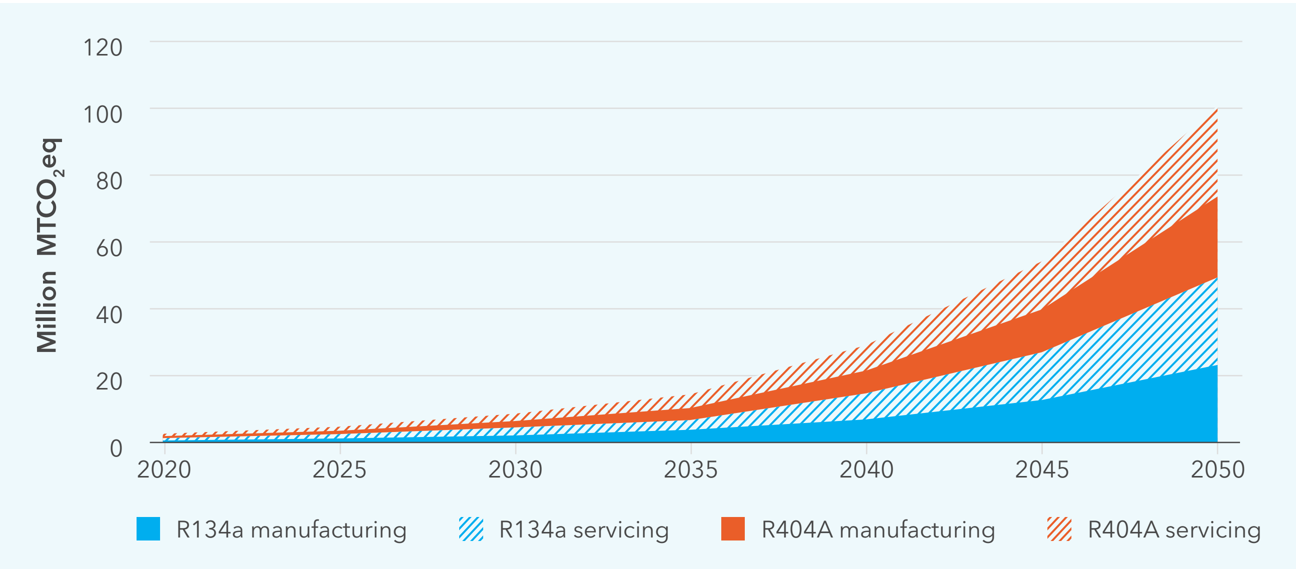


Figure 15: HFC consumption (MTCO2eq) from commercial refrigeration in the BAU Scenario

3.1.5 Industrial Refrigeration

HFC consumption (MT): As shown in Figure 16, HFC consumption for industrial refrigeration is expected to increase nearly 11x from ~460 MT in 2025 to ~5,100 MT in 2050. The split between manufacturing new equipment and servicing existing ones is nearly equal. This share is expected to remain roughly the same by 2050. R404A is used for industrial refrigeration.

HFC consumption (MTCO2eq): As shown in Figure 17, HFC consumption from industrial refrigeration is expected to increase ~11x from ~1.8 million MTCO2eq in 2025 to ~20 million MTCO2eq in 2050. R404A continues being used in the BAU Scenario.

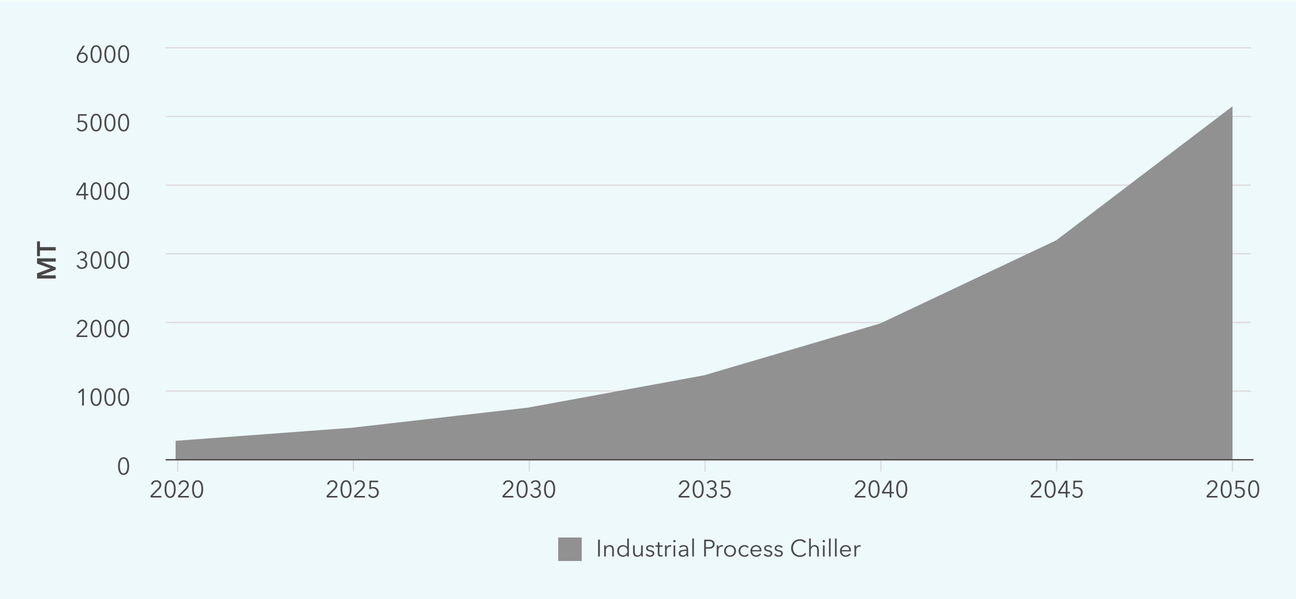


Figure 16: HFC consumption (MT) for industrial refrigeration in the BAU Scenario

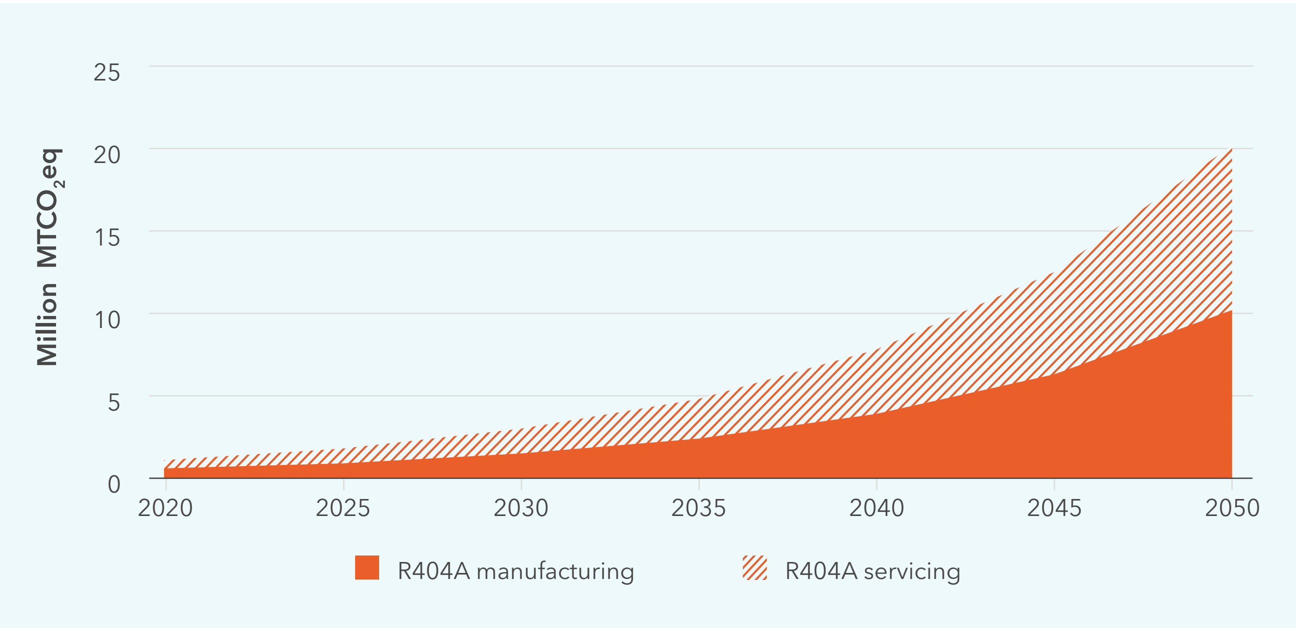


Figure 17: HFC consumption ($MTCO_2eq$) from industrial refrigeration in the BAU Scenario

3.1.6 Aerosol

HFC consumption (MT): As shown in Figure 18, HFC consumption for aerosols is expected to increase ~9x from ~4,000 MT in 2025 to ~35,000 MT in 2050. HFC152a is the dominant HFC used for aerosols, followed by HFA134a and HFC227ea. HFC consumption for aerosols is likely to be dominated by personal care products.

HFC consumption ($MTCO_2eq$): As shown in Figure 19, HFC consumption from the aerosol sector is expected to increase ~6x from ~3.3 million $MTCO_2eq$ in 2025 to ~19 million $MTCO_2eq$ in 2050. HFA134a, HFC227e, and HFC152a continue being used in the BAU Scenario.

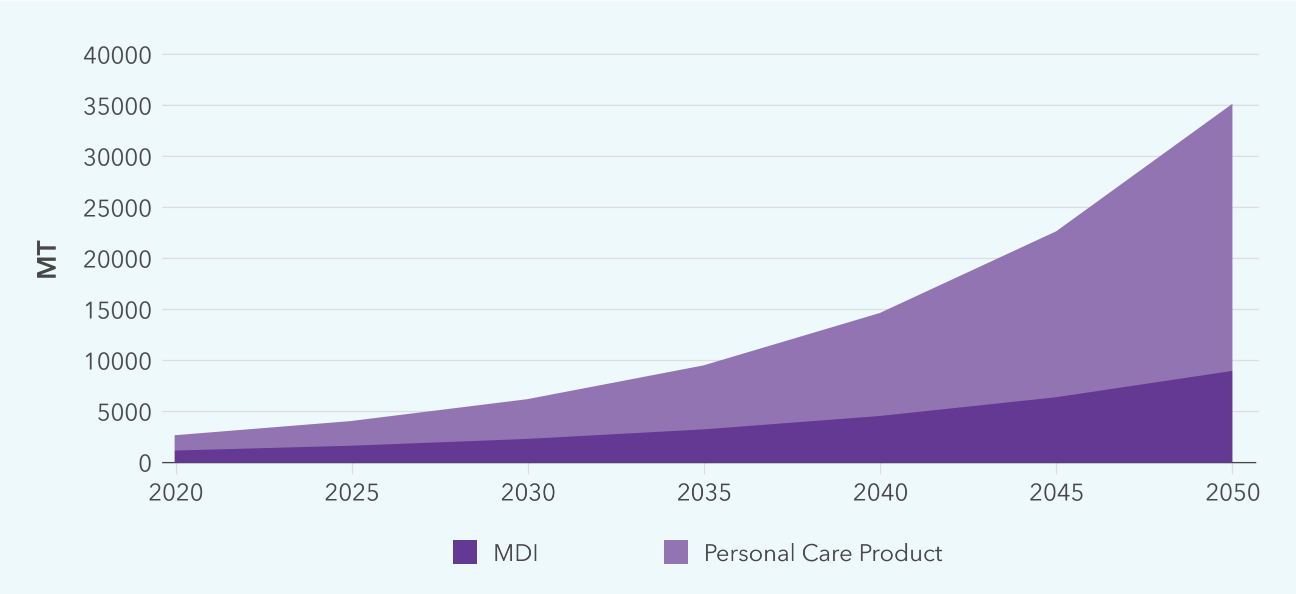


Figure 18: HFC consumption (MT) for the aerosol sector in the BAU Scenario

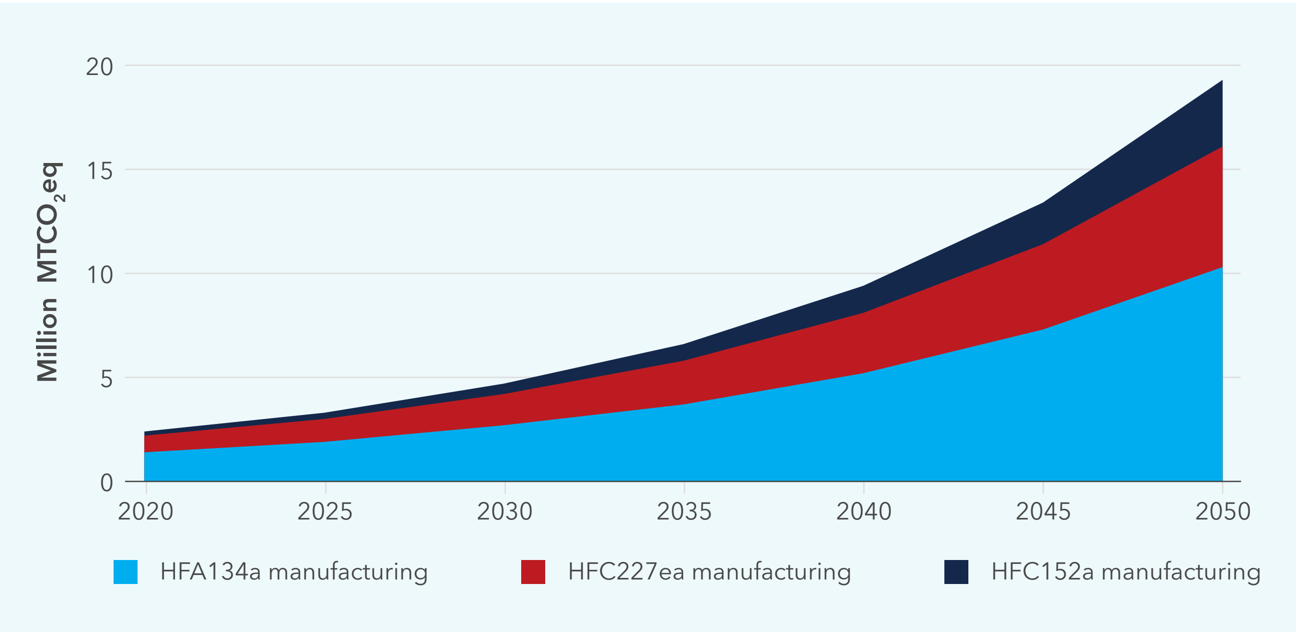


Figure 19: HFC consumption ($MTCO_2eq$) from the aerosol sector in the BAU Scenario

3.1.7 Foam

HFC consumption (MT): As shown in Figure 20, HFC consumption for the foam sector is expected to increase more than 10x from ~1,400 MT in 2025 to ~15,500 MT in 2050. HFC245fa is the dominant HFC used in the foam sector, followed by HFC365mfc.

HFC consumption ($MTCO_2eq$): As shown in Figure 21, HFC consumption from the foam sector is expected to increase more than 10x from ~1.5 million $MTCO_2eq$ in 2025 to ~16 million $MTCO_2eq$ in 2050. HFC245fa and HFC365mfc continue being used in the BAU Scenario.

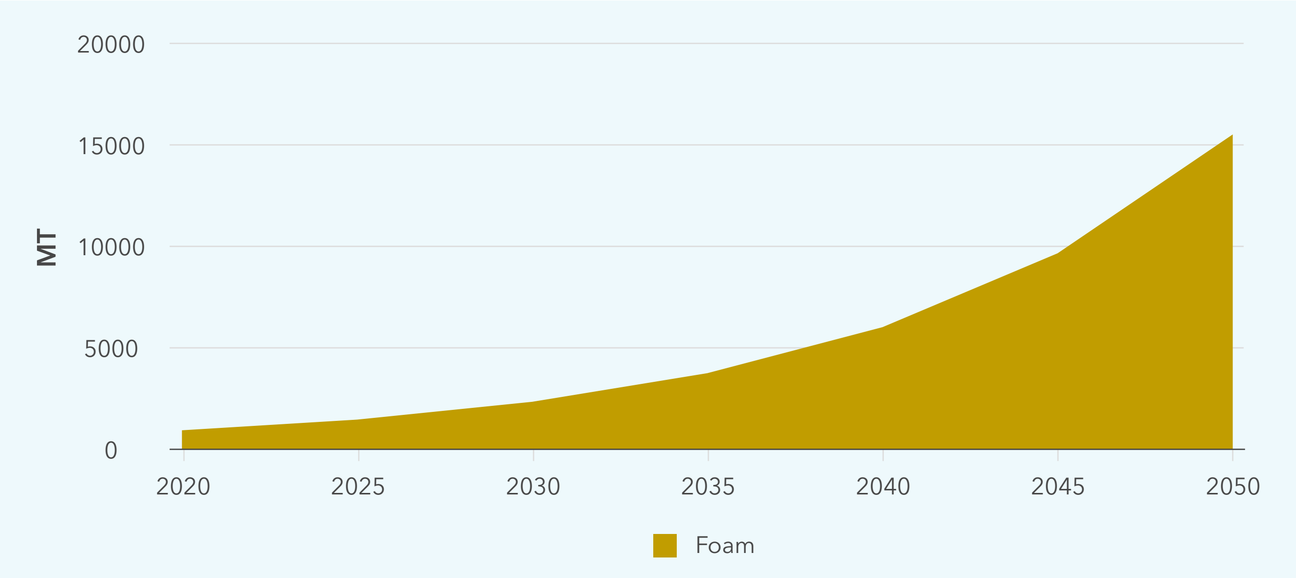


Figure 20: HFC consumption (MT) for the foam sector in the BAU Scenario

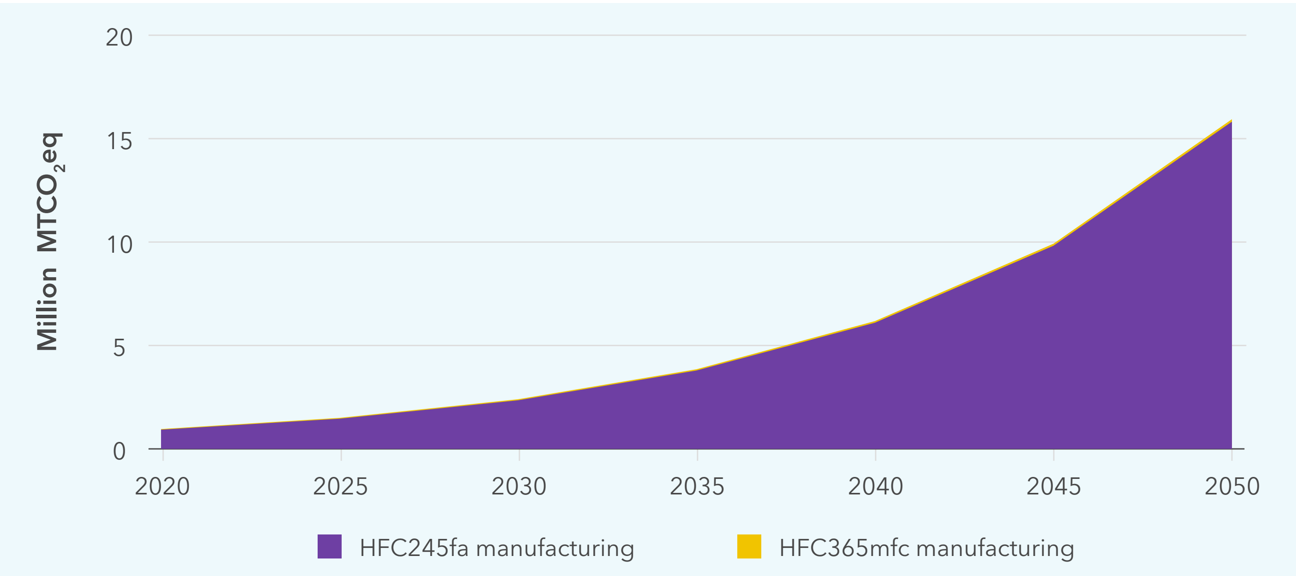


Figure 21: HFC consumption ($MTCO_2eq$) from the foam sector in the BAU Scenario

3.2 INT Scenarios 1 and 2

INT Scenarios 1 and 2, which incorporate transitions to HFC alternatives as outlined in Table 4, are projected to deliver substantial cumulative avoided HFC consumption relative to the BAU Scenario. Between 2028 and 2047[xvii], INT Scenario 1 is estimated to avoid ~3.1 billion $MTCO_2eq$, while INT Scenario 2 avoids ~2.8 billion $MTCO_2eq$. The cumulative avoided HFC consumption can be attributed to manufacturing new equipment and servicing existing ones by ~60% and ~40%, respectively. As illustrated in Figure 22, INT Scenario 1 aligns fully with the Kigali Amendment's phase-down schedule. INT Scenario 2 also complies with the Kigali Amendment's allowable HFC consumption through effective Lifecycle Refrigerant Management (LRM) measures, especially between 2028 and 2034. Overall, INT Scenario 1 offers an additional ~300 million $MTCO_2eq$ of cumulative avoided consumption compared to INT Scenario 2.

xvii For India, the Kigali phase-down schedule spans the period from 2028 to 2047.

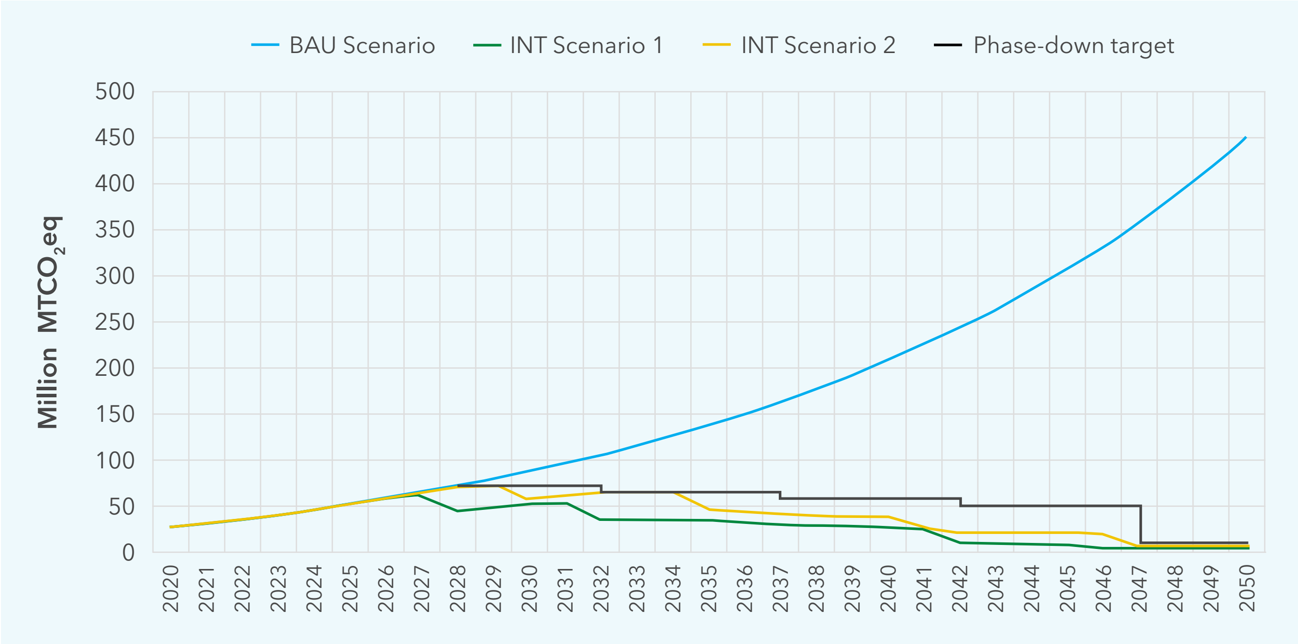


Figure 22: HFC consumption in INT Scenarios 1 and 2

Table 5 summarizes India's Kigali phase-down targets alongside the projected HFC consumption, estimated allowable consumption, and consumption under INT Scenarios 1 and 2.

Table 5: India's Kigali phase-down targets alongside the projected HFC consumption under INT Scenarios 1 and 2

Year	HFC consumption in the BAU scenario (million MTCO2eq)	Phase-down target	Allowable HFC Consumption (million MTCO2eq)	HFC consumption in the INT 1 scenario (million MTCO2eq)	HFC consumption in the INT 2 scenario (million MTCO2eq)
2028	72.4	Freeze baseline	72.8	45.4	70.5
2032	105.9	90% of baseline	65.5	36.1	63.0
2037	163.3	80% of baseline	58.2	30.1	42.0
2042	244.1	70% of baseline	50.9	10.6	22.7
2047	357.4	15% of baseline	10.9	5.5	7.6

The effective implementation of INT Scenarios 1 and 2 will require establishing a streamlined regulatory framework, including amending India's Ozone Depleting Substances (Regulation and Control) Rules (2000) to align with the phase-down of HFCs under the Kigali Amendment to the Montreal Protocol, and facilitating timely access to MLF funding to support eligible enterprises in accelerating the adoption of low-GWP technologies. Specific actions are proposed in Table 6.

Table 6: Specific actions proposed to support the implementation of INT Scenarios 1 and 2

Sector / Sub-sector	Proposed actions
Space Cooling	
RAC	• Expand availability of energy-efficient R290 compressors. • Promote micro-channel heat exchangers. • Develop and scale certified technical training programs.
VRF	• Optimize larger-capacity units by modular design. • Plan for converting to future low-GWP around 2042.
Medium-pressure Centrifugal Chiller	• Facilitate and accelerate the ongoing transition.
Screw Chiller	• Facilitate and accelerate the ongoing transition.
Scroll Chiller	• Improve accessibility of patented refrigerant blends. • Address cost optimization for low-GWP refrigerants. • Plan for first conversion to R32 and subsequent low-GWP options.
Packaged Air Conditioner	• Facilitate and accelerate the ongoing transition.
MAC	
LDV	• Encourage adoption of low-GWP refrigerants, as the shift is already underway for export markets.
Bus	• Enable system redesigns to meet enhanced safety standards.
Train & Metro	• Improve availability and cost-effectiveness of R454B and other refrigerants.
Cold-chain	
Cold Storage	• Design and deploy low-charge systems suitable for small facilities.
Packhouse	• Maintain and enhance standard ammonia-based safety systems. • Develop and scale certified technical training programs.
Ripening Chamber	• Maintain and enhance standard ammonia-based safety systems. • Develop and scale certified technical training programs.
Reefer Vehicle	• Support system redesign for R290 adoption. • Align with MAC best practices.
Commercial Refrigeration	
Standalone Refrigeration Unit	• Support ongoing transition to low-GWP refrigerants.
Condensing Unit (Chiller)	• Encourage system redesigns to enhance safety.
Industrial Refrigeration	
Industrial Refrigeration	• Promote system redesigns for safer low-GWP adoption.
Aerosol	
MDI	• Support development of emerging low-GWP technologies.
Personal Care Product	• Expand use of Hydrocarbon Aerosol Propellants safely. • Strengthen safety protocols at filling sites.
Foam	
Foam	• Start converting from HFC blowing agents to the already widely used ultra-low-GWP blowing agents in India as early as possible.

4. CONCLUSION

India's current HFC consumption remains relatively low due to the limited penetration of cooling appliances. However, given the country's very high temperatures and the growing need to expand access to cooling, the market for refrigerant-based cooling products is expected to grow significantly in the coming decades. As a growing economy, India must ensure a productive and comfortable environment for its people to thrive and contribute to national development. The combination of a low baseline HFC consumption and high anticipated growth will coincide with India's obligation to phase-down HFCs under the Kigali Amendment. To address this unique trajectory, the present study examined two scenarios for a sustainable HFC phase-down: the first (INT Scenario 1) envisions a strategic transition to low-GWP alternatives beginning in 2028, while the second (INT Scenario 2) starts in 2030. Both scenarios rely primarily on known alternatives and seek to minimize the number of conversions to HFC alternatives except in select subsectors.

While INT Scenario 1 represents the ideal pathway, it may face implementation challenges without adequate industry readiness and sufficient financial and technical assistance through the Multilateral Fund (MLF). INT Scenario 2 could temporarily result in higher HFC consumption than Kigali targets allow; however, this can be mitigated by prioritizing sectors such as MAC, commercial refrigeration, and industrial refrigeration where technology transition readiness is high. The MAC sector, already adopting R1234yf in global markets, has seen slower progress in part due to ongoing PFAS-related concerns, though it is important to note that PFAS are not controlled under the Montreal Protocol. Non-fluorinated alternatives such as R290 in a secondary loop architecture is being considered for the MAC sector by some global manufacturers but will require additional ecosystem support (e.g., safety standards, technician training) for mass commercialization in India and a transition to that alternative will likely occur later than the 2028. Similarly, the RAC subsector, a major consumer of HFCs, has been scheduled for a later transition due to the lack of energy-efficient compressors for ultra-low-GWP refrigerants such as R290. The industry will be advised that while converting from HFCs to low-GWP technologies, it is necessary to maintain and/or enhance the energy efficiency of appliances/equipment through various ways, including redesign and the use of energy-efficient system components.

As India prepares to operationalize the Kigali Amendment and develop its KIP, there is a critical window of opportunity for government and industry to initiate early stakeholder engagement and interventions. Beyond transitioning to low-GWP alternatives, significant reductions in HFC consumption can also be achieved by promoting good LRM practices. Acting within this decade will allow India to curb potential growth in HFC consumption while enabling the cooling, aerosol, and foam sectors to expand sustainably and without constraint.

APPENDIX

Appendix A

The properties of potential HFC alternatives used in INT Scenarios 1 and 2 consolidated from various sources[23, 24, 25, 26]

HFC alternative	GWP	Safety class	Normal Boiling Point (°C)	Temperature glide (°C)	PFAS yield	Energy efficiency (EE)
R290	3	A3	-42.1	0	No (0)	EE > R134a EE > R404A
R32	675	A2L	-51.7	0	No (0)	EE > R410A EE > R407C
R454C	148	A2L	-45.8	8.2	Yes (Unknown)	
R455A	148	A2L	-52.0	12.5	Yes (Unknown)	
R1234ze (E)	7	A2L	-19.0	0	Yes (2%-30%)	EE < R134a
R1234yf	4	A2L	-26.1	0	Yes (100%)	EE < R134a
R454B	466	A2L	-50.7	0.9	Yes (Unknown)	EE < R407C
R717	0	B2L	-33.34	0	No (0)	EE > R404A
HFC152a	124	A2	-24.0	0	No (0)	
Hydrocarbon Aerosol Propellant	3	A3	Varies from -42.1 to -11.7	NA	No (0)	
ECOMATE	0	A3	31.5	NA	No (0)	EE < HFC245fa
HFO-1233zd(E)	4	A1	-18.3	NA	No (0)	
HFO-1336mzz (Z)	2	A1	33.4	NA	Yes (Unknown)	
HFO-1234ze	7	A2L	-19.0	0	Yes (Unknown)	
Cyclopentane	3	A3		NA	No (0)	
Water	0	A1	100	NA	No (0)	

Appendix B

HFC consumption by sector and sub-sector in the BAU Scenario
(Note: HFCs used in 2025, continue being used in the BAU Scenario through 2050.)

Sector / Sub-sector	HFCs used in 2025	HFC consumption in 2025 (MT)	HFC consumption in 2025 (million MTCO2eq)	HFC consumption in 2050 (MT)	HFC consumption in 2050 (million MTCO2eq)
Space Cooling	R32 R410A R407C R134a	28,679	26.4	248,443	199.8
RAC	R32 R410A	23,480	16.6	22,1827	151.3
VRF	R410A	2,372	5.0	10,477	21.9
Chiller	R410A R407C R134a	1,599	2.5	11,610	18.0
Packaged Air Conditioner	R410A R407C	1,228	2.3	4,528	8.6
MAC	R134a R407C	10,197	14.7	57,550	83.4
LDV	R134a	9,825	14.0	54,273	77.6
Bus	R407C	321	0.6	2,816	5.0
Train & Metro	R407C	51	0.09	461	0.82
Cold-chain	R134a R404A R407C	474	1.5	4,490	12.1
Cold Storage	R134a R404A	424	1.4	1,875	6.1
Packhouse	R134a R404A	12	0.03	1,787	4.43
Ripening Chamber	R134a	8	0.01	406	0.58
Reefer Vehicle	R134a R404A R407C	30	0.07	421	0.99

Sector / Sub-sector	HFCs used in 2025	HFC consumption in 2025 (MT)	HFC consumption in 2025 (million MTCO2eq)	HFC consumption in 2050 (MT)	HFC consumption in 2050 (million MTCO2eq)
Commercial Refrigeration	R134a R404A	2,301	4.7	47,665	100.8
Standalone Refrigeration Unit	R134a R404A	1,753	3.4	29,820	57.5
Condensing Unit (Chiller)	R134a R404A	548	1.3	17,844	43.3
Industrial Refrigeration	R404A	466	1.8	5,148	20.2
Aerosol	HFA134a HFC227ea HFC152a	4,071	3.3	35,159	19.3
MDI	HFA134a HFC227ea	1,655	3.0	8,985	16.1
Personal Care Product	HFC152a	2,416	0.30	26,174	3.25
Foam	HFC245fa HFC365mfc	1,464	1.5	15,515	15.9

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