Hydrofluorocarbon Emissions Inventory in New York State

Final Report | Report Number 21-24 | July 2021

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Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

Hydrofluorocarbon Emissions Inventory in New York State

Final Report

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Abstract

Building, transportation, and industrial applications throughout New York State use hydrofluorocarbon (HFC) gases for comfort space cooling, food sales and storage, foam, aerosols, and a variety of other processes. HFCs contribute to the State's greenhouse gas (GHG) emissions both directly through refrigerant emissions entering the atmosphere and indirectly through electricity consumption via the operation of space conditioning and refrigeration systemsusing HFC refrigerants. New York State is assessing ways to reduce GHG emissions across a variety of sectors including HFCs to reach the goals within the Climate Leadership and Community Protection Act (Climate Act).

The purpose of this report is to provide the New York State Energy Research and Development Authority (NYSERDA) with an updated and more detailed inventory for HFC gases in the State. The Guidehouse project team developed a thorough bottom-up vintaging model to calculate historical and current HFC consumption and emissions for over 40 end-use categories. The HFC inventory and methodology developed in this project also supported an analysis into how statewide HFC usage is expected to change in future years, and the impacts of potential policies that could be considered to significantly reduce HFC emissions. The results of this analysis will be published as a separate NYSERDA report in the near future.

Keywords

Hydrofluorocarbon, HFC, refrigerant, global warming potential, GWP, air conditioning, refrigeration, heat pump, HVAC, foam, aerosol, solvent, greenhouse gas emissions, phasedown

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Acronyms and Abbreviations

A2L	Refrigerants Classified with Lower Flammability or Mildly Flammable
AC	Air Conditioning
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
BEA	United States Bureau of Economic Analysis
CARB	California Air Resource Board
CBECS	Commercial Building Energy Consumption Survey
CBI	Confidential Business Information
CFC	Chlorofluorocarbons
Climate Act	Climate Leadership and Community Protection Act
CO2e	Carbon Dioxide Equivalent
Com	Commercial
COP	Coefficient of Performance
DEC	Department of Environmental Conservation
DOE	Department of Energy
DX-GSHP	Ground Source Heat Pump with Direct Ground Exchange
EIA	Energy Information Administration
EOL	End of Life
EPA	Environmental Protection Agency
F-gas	Fluorinated Greenhouse Gases
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GW	Gigawatt
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbon
HFO	Hydrofluoro-olefin
HOV	Heat of Vaporization
HP	Heat Pump
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilation, and Air Conditioning
HVAC&R	Heating, Ventilation, Air Conditioning, and Refrigeration
IPCC	Intergovernmental Panel on Climate Change
lb	pound
MMT	Million Metric Tons
MVAC	Motor Vehicle Air Conditioning

NVC	Non-Vapor Compression
ODS	Ozone Depleting Substances
PTAC	Packaged Terminal Air Conditioning
PTHP	Packaged Terminal Heat Pump
RECS	Residential Energy Consumption Survey
Res.	Residential
RMP	Refrigerant Management Program
RTU	Roof Top Unit
SCAQMD	South Coast Air Quality Management District
SEER	Seasonal Energy Efficiency Ratio
SIT	State Inventory Tool
SLCP	Short-Lived Climate Pollutant
SNAP	Significant New Alternatives Policy
TEAP	Technology and Economic Assessment Panel
TRM	Technical Reference Manual
TSD	Technical Support Document
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nation Framework Convention on Climate Change
VRF	Variable Refrigerant Flow
XPS	Expanded Polystyrene

Summary

The purpose of this report is to provide the New York State Energy Research and Development Authority (NYSERDA) with an updated and more detailed inventory for hydrofluorocarbon (HFC) gases in New York State. This report covers a wide variety of HFC end-use categories, including refrigerants used in space conditioning and refrigeration for residential, commercial, industrial, and transport applications, as well as non-refrigerant HFCs used in foams, aerosol propellants, solvents, and fire protection.

Table S-1 summarizes the contents of each section of the report. Guidehouse first reviewed the assessment of HFC emissions in the NYSERDA 2018 New York State Greenhouse Gas Inventory and supporting documentation for the NYSERDA Pathways to Deep Decarbonization in New York State project.[1] Both of these reports are currently being revised by NYSERDA and Department of Environmental Conservation (DEC) to meet the requirements of the Climate Leadership and Community Protection Act (Climate Act). Guidehouse then conducted a thorough literature review of the latest government and industry research into HFC emissions inventories, refrigerant saturations, low global warming potential (GWP) alternatives, and mitigation strategies. Guidehouse also conducted several interviews with industry organizations. This information was used to develop a detailed bottom-up vintaging model to calculate historical, current, and future HFC consumption and emissions for over 40 end-use categories and analyzed potential HFC mitigation scenarios for the State. The HFC inventory and methodology developed in this project also supported an analysis into how statewide HFC usage is expected to change in future years, and the impacts of potential policies that could be considered to significantly reduce HFC emissions. The results of this analysis will be published as a separate NYSERDA report in the near future.

Table S-1. Summary of Each Chapter

Chapter	
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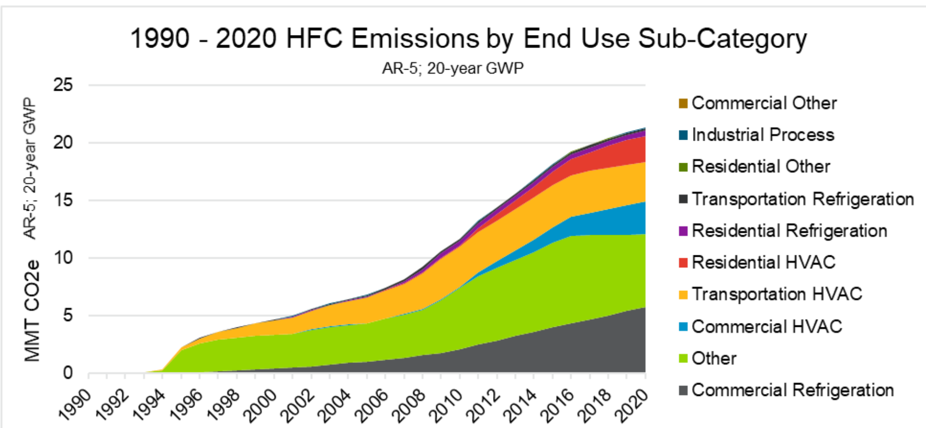
2. HFC Emissions Methodology	Description for the methodology and key data sources used to develop the customized HFC vintaging model for the purpose of updating the emissions inventory for New York State
3. Historical HFC Emissions Inventory	Historical HFC consumption and emissions estimated over 1990–2020 by end-use category, emissions source, and other parameters.
4. Conclusions	Summary of key findings and conclusions
5. References	List of references cited throughout the report
Appendix A. Key Data Inputs and Assumptions	Tables summarizing the Guidehouse model data inputs and assumptions, including sources, GWP values, and scenario assumptions
Appendix B. HFC Emissions Inventory for NYS	Tables summarizing HFC emissions inventory 2005–2020
Appendix C. Source Documentation for the HFC Emissions Model	Provides details for key data sources and assumptions used in the HFC emission model
Appendix D. Comparison of HFC Accounting Practices	Explains HFC accounting methodologies and assumptions from various tools and models

S.1 Historical HFC Emissions Inventory

The foundation for the HFC emissions inventory analysis is an Excel-based vintaging model customized to New York State. For each equipment type, annual HFC consumption and emissions are calculated based on a set of key input assumptions, including refrigerant composition, refrigerant charge size, annual leakage rate, servicing frequency, equipment lifetime, and end-of-life (EOL) loss (i.e., non-recovery) rate. By customizing the input assumptions, a range of business-as-usual growth scenarios, or “reference cases” can be modeled. Against these reference cases, “what-if” scenarios can be modeled to assess the impacts of potential mitigation policies that could be considered to achieve future emission reduction targets.

Results from the Guidehouse model indicate that HFC emissions in New York State have grown from near zero in 1990 to 21.2 million metric tons (MMT) CO_2e (carbon dioxide equivalent) in 2020 (AR-5, 20-year GWP)[2], as shown in Figure S-1. Emission growth was driven by the use of HFCs to replace chlorofluorocarbons/ hydrochlorofluorocarbons (CFCs/HCFCs) as they were phased down (primarily) and economic growth in the State (secondarily). In particular, commercial refrigeration, commercial heating, ventilation, and air conditioning (HVAC), and residential HVAC have all shown large increases since 2005. Once all vintage CFC/HCFC equipment has reached the end-of-life stage, future HFC growth will be slower and reflective of economic growth in the State. HVAC and refrigeration (HVAC&R) categories grew most dramatically after 2010, when HFCs became the predominant refrigerant for stationary cooling applications, replacing ozone depleting substances (OD) refrigerants. HFC use for mobile air conditioning (which began in the 1990s), as well as foams, aerosols, and solvents (subcategory "other") has grown only modestly since 2010 and has already begun declining as these categories transition to lower-GWP options. The estimate of 1990 emissions from this analysis was used by DEC to establish certain Climate Act reduction requirements into regulation.[3] All values from this report will be integrated into an updated GHG inventory report, to be issued by DEC in 2021.

Figure S-1. HFC Emissions by End-Use Subcategory (1990–2020)



S.2 Conclusions

Guidehouse's key conclusions regarding NYS HFC emissions are summarized below.

- HFC emissions in New York State have grown from near zero in 1990 to 21.2 MMT CO_2e in 2020 (AR-5, 20-year GWP), driven by the use of HFCs to replace CFCs/HCFCs as they were phased down (primarily) and economic growth in the State (secondarily). Beyond 2020, as all vintage CFC/HCFC equipment reaches end-of-life, business-as-usual growth in HFC, emissions will be much slower.
- Commercial refrigeration is the largest contributor to HFC emissions in 2020, followed by aerosol propellants and light-duty motor vehicle air conditioning (MVAC). For most categories, annual leakage throughout the equipment lifetime is a much greater source of emissions than end-of-life leakage.

- Commercial and residential HVAC&R systems are the fastest-growing sources of emissions historically and are expected to increase further in future years. Heat pump systems have a relatively small contribution to total emissions in 2020 but are expected to grow substantially as heating electrification increases in the State because heat pump systems, particularly variable refrigerant flow (VRF) systems, have higher refrigerant charge than comparable AC-only systems. Heat pump water heaters are unlikely to be a significant contributor to HFC emissions, assuming leakage rates are similar to other self-contained systems (i.e., very minor).

1 Introduction

The purpose of this report is to provide the New York State Energy Research and Development Authority (NYSERDA) with an updated and more detailed inventory for hydrofluorocarbon (HFC) gases in New York State. Building, transportation, and industrial applications throughout the State use HFCs for comfort space cooling, food sales and storage, foam, aerosols, and a variety of other processes. HFCs contribute to the State's greenhouse gas (GHG) emissions both directly through refrigerant emissions entering the atmosphere and indirectly through the electricity consumption via the operation of space conditioning and refrigeration systems. This report addresses direct HFC emissions associated with the use of HVAC&R equipment and foam and aerosol products in the State, rather than emissions associated with chemical production, electronics, or other categories.

This section introduces the underlying drivers of policy action in New York State, report objectives, technology and market scope, and analysis methodology. The project supports NYSERDA's overall Climate Leadership and Community Protection Act (Climate Act) Integration Analysis, which is ongoing.

1.1 Background

In 2019, New York State committed to ambitious climate goals in the Climate Act, including 100% carbon-free electricity by 2040 and 85% GHG emissions reduction by 2050.[4] Table 1 includes the three GHG emissions reduction requirements: a reduction in statewide emissions of 40% from 1990 levels by 2030, 85% from 1990 levels by 2050, and 100% by 2050 on a net basis. In addition, New York City and other local governments throughout the State have announced their own commitments, including New York City's carbon neutrality goal of 2050. New York State leaders are currently considering potential pathways to reach these goals and are evaluating various economy-wide strategies through the Climate Act Climate Action Council and Advisory Panels.[5]

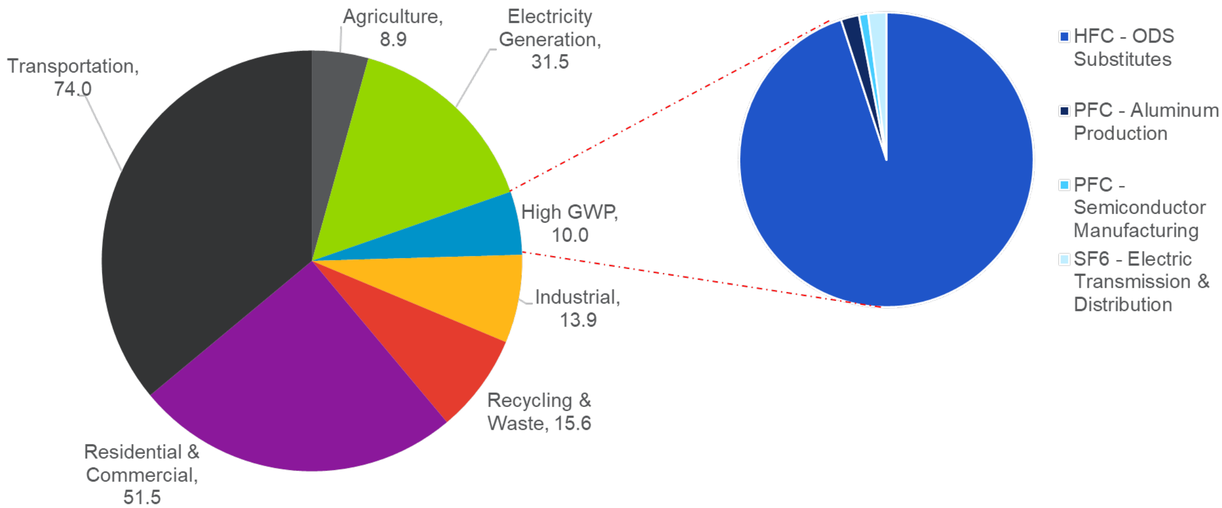
Table 1. Climate Act Timeline and Milestones

Climate Act Timeline and Milestones	
	• Expand to 6 GW of statewide solar capacity
	• Reduction in gross GHG emissions by 40% from 1990 levels • Seventy percent of electric generation from renewable energy • Expand to 3 GW of statewide storage capacity
	• Expand to 9 GW of statewide offshore wind capacity
	• One hundred percent of electrical generation as zero emissions
	• Eighty-five percent reduction in gross GHG emissions (from 1990) • Net zero GHG emissions

Prior to the Climate Act, New York State GHG emissions inventories estimated emissions of carbon dioxide (CO_2), methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons from key segments such as transportation, residential and commercial buildings, electricity generation, industrial processes, and other categories. Figure 1 highlights estimated 2016 emissions as provided in the NYSERDA (2018) New York State Greenhouse Gas Inventory. The Climate Act encompasses additional emissions, such as those associated with the extraction and transmission of imported fossil fuels, as measured on a 20-year global warming potential (GWP) basis. A collection of industrial gases, including HFC refrigerants have relatively small volumetric emissions compared with other sectors but have an outsized impact on statewide emissions due to their significantly higher GWPs. The GWP values for these gases typically have several thousand times greater impact than the equivalent amount of carbon dioxide (carbon dioxide equivalent, or CO_2e). These industrial gases with relatively high GWP values account for approximately 5% of total GHG emissions in NYS today, with the large majority coming from HFC gases used for space conditioning, refrigeration, aerosols, solvents, and other applications. HFCs are the predominant class of refrigerants used today for heating, ventilation, air conditioning, and refrigeration (HVAC&R) in the building, industrial, and mobile fields. HFCs replaced the previous generations of ozone depleting substances (ODS) such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which had a detrimental impact on the ozone layer.

Figure 1. New York State Greenhouse Gas Emissions, 2016

Source: NYSERDA (2018) New York State Greenhouse Gas Inventory Report 1990–2016, 100-year AR4 values



As described above, NYS is assessing ways to reduce GHG emissions per the requirements of the Climate Act. The current pathways discussed focus on renewable and zero-carbon electricity production as the catalyst for emissions reductions in other sectors through electrification of fossil fuel end-uses, such as building heating and road transportation. To reach the ambitious Climate Act requirements, the State must address non-energy GHG emission sources as well, such as from agriculture, wastes, and high GWP substances, which are challenging to address. While these non-energy emission sources are relatively small today, they will constitute a more significant portion of emissions as the emissions from other segments are reduced. Furthermore, electrifying space and water heating in buildings with heat pumps is expected to increase HFC refrigerant usage and emissions in the State, partially counteracting the avoided emissions from eliminating fossil fuel usage.

International, federal, and state agencies are currently exploring opportunities to address HFC consumption and emissions through various policies that target different points in the HFC life cycle. Table 2 maps the different policies considered and their intended impacts on consumption and emissions across the life cycle of HVAC&R systems. As is discussed in Section 3.2, HFC consumption and emissions occur at different stages of the equipment lifecycle for different HVAC&R categories.

Table 2. Potential Hydrofluorocarbon Reduction Policies for A Typical HVAC&R System

Policy Category	Description/Mitigation Option	Mitigation Option Impact on HFC Consumption	Mitigation Option Impact on HFC Emissions
Production	The refrigerant manufacturer produces, stores, and distributes refrigerant to the equipment manufacturer and service technicians. **Mitigation Option**: Prohibit domestic HFC production or imports.	Restricts new HFC supplies and encourages use of alternatives or reclaimed HFCs	Overall emissions would decrease over the equipment lifetime
Consumption in New Equipment	The manufacturer fills (*i.e.*, "charges") the product with refrigerant at the factory. Some systems require field charging of refrigerant. **Mitigation Option**: Restriction on manufacture and sales of new equipment using HFCs.	Restricts HFC use, drives adoption for alternatives	Overall emissions would decrease over the equipment lifetime
Servicing and Leakage for Existing Equipment	A small amount of refrigerant leaks over time through small cracks in the system piping and subassemblies. If a leak is detected, a service technician will repair the leak and replace the lost refrigerant. **Mitigation Option:** Develop requirements for leak detection, mitigation, and reporting.	Reducing leakage would decrease HFC consumption for service	Direct reduction of HFC emissions
End-of-Life Emissions	The full refrigerant charge may be released if the system is damaged or if the system is not properly disposed at the end of its useful life. **Mitigation Option:** Develop requirements for refrigerant recovery and proper disposal.	No direct impact on HFC consumption	Direct reduction of HFC emissions
Use of Reclaimed Refrigerant	The service technician may replace refrigerant that has leaked over time with refrigerant that has been recovered from older systems at end-of-life and reclaimed to applicable standards. **Mitigation Option:** Develop requirements for use of reclaimed refrigerant for service use or for new equipment.	Reduces the demand for new HFC production	No direct impact on HFC emissions, but encourages greater end-of-life recovery

Many of these strategies were first deployed when phasing out the use of CFCs/HCFCs and are familiar to policymakers, manufacturers, and industry organizations. Developing a phasedown schedule for specific HFC end-uses is a common strategy, in which either individual HFCs or refrigerants over a certain GWP limit would no longer be allowed for use in new equipment or applications. This process preserves the use of the HFC refrigerant for servicing existing equipment, and over time achieves HFC reductions as older equipment is replaced with new equipment with lower-GWP refrigerants. New York State's DEC finalized the 6 New York Codes, Rules and Regulations (NYCRR) Part 494 regulation (2020 NYS SNAP Rule[6]) in October 2020 that establishes an HFC phasedown schedule for several end-use categories in refrigeration, chiller, aerosol, and foam segments beginning January 1, 2021.[7] These topics are further discussed throughout the report.

1.2 Report Objectives

This report summarizes the key findings of Guidehouse's analysis into providing a detailed inventory of HFC emission sources and quantities by sector in New York State over 1990–2020. The HFC inventory and methodology developed in this project also supported an analysis into how statewide HFC usage is expected to change in future years, and the impacts of potential policies that could be considered to significantly reduce HFC emissions. The results of this analysis will be published as a separate NYSERDA report in the near future.

1.3 Technology and Market Scope

This report covers a wide variety of HFC end-use categories including refrigerants used in space conditioning and refrigeration for residential, commercial, industrial, and transport applications, as well as non-refrigerant HFCs used in foams, aerosol propellants, solvents, and fire protection. The report also considers newer HFC applications such as heat pump water heaters and clothes dryers, which are expected to increase in adoption commensurate with Climate Leadership and Community Protection Act (Climate Act) goals. Table 3 highlights the HFC end-use categories and sectors included in this analysis.

Table 3. End-Use Sub-Categories and Equipment Types

End Use Sub-Category	Equipment Types
Residential HVAC	Central AC
	Central Heat Pump (HP)
	Window AC
	Ground Source Heat Pump (GSHP)
Residential Refrigeration	Refrigerator / Freezer
	Freezer
Residential Other	Heat Pump Water Heater (HPWH)
	HP Clothes Dryer
	Dehumidifier
Commercial HVAC	Central Split & Package AC, Large
	Central Split & Package AC, Small
	Central Split & Package HP, Large
	Central Split & Package HP, Small
	Room AC / Packaged Terminal AC (PTAC) / Packaged Terminal HP (PTHP)
	GSHP
	Variable Refrigerant Flow (VRF) HP, Large
	VRF HP, Small
	Ductless Split AC
	Ductless Split HP
	Small Chiller
	Medium Chiller
	Large Centrifugal Chiller
Commercial Refrigeration	Refrigerator / Freezer
	Supermarket Racks, Large
	Supermarket Racks, Medium
	Walk-ins/Remote Condensing, Large
	Walk-ins/Remote Condensing, Small
	Self-Contained Display Cases / Reach-ins
	Vending Machines
	Ice Makers
	Refrigerated Warehouse, Medium
	Refrigerated Warehouse, Large
Commercial Other	HPWH
Industrial Process	Industrial Process
Transportation HVAC	Light Duty Vehicles
	Medium Duty Vehicles
	Heavy Duty Vehicles
	Buses
Transportation Refrigeration	Transport Refrigeration
Other	Aerosols, Foams, Solvents, other HFCs

1.4 Project Approach

Table 4 summarizes the content of each section of the report. Guidehouse first reviewed the assessment of HFC emissions in the NYSERDA 2018 NYS GHG Inventory and supporting documentation for the NYSERDA Pathways to Deep Decarbonization in New York State project.[8] Both of these reports are currently being revised by NYSERDA and DEC as part of the Climate Act Integration Analysis project to meet the requirements of the Climate Act.

Guidehouse then conducted a thorough literature review of the latest government and industry research into HFC emissions inventories, refrigerant saturations, low-GWP alternatives, and mitigation strategies. Guidehouse also conducted several interviews with industry organizations. This information was used to develop a detailed bottom-up vintaging model to calculate historical, current, and future HFC consumption and emissions for over 40 end-use categories and analyze potential HFC mitigation scenarios for NYS.

Table 4. Summary of Each Chapter

Chapter	
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Appendix C. Source Documentation for the HFC Emissions Model	Provides details for key data sources and assumptions used in the HFC emission model.
Appendix D. Comparison of HFC Accounting Practices	Explains HFC accounting methodologies and assumptions from various tools and models.

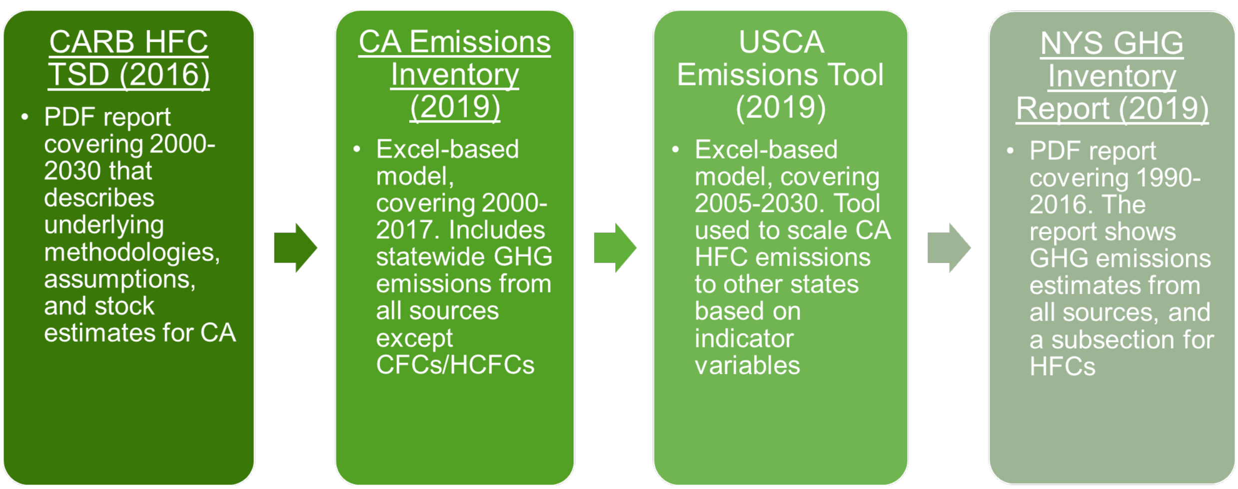
2 Hydrofluorocarbon Emissions Methodology

The following sections describe the methodology and key data sources used to develop the customized HFC vintaging model for the purpose of updating the emissions inventory for New York State. The goal of this analysis was to review previous methods used for the New York State GHG Inventory, identify assumptions and methodologies, and determine areas for improvement in the updated inventory. Appendix A provides a summary of the key data inputs and sources. Appendix B summarizes the historical HFC inventory using both 20-year and 100-year GWP values. The full source documentation for the Guidehouse HFC vintaging model is available in Appendix C.

2.1 Assessment of New York State Current Hydrofluorocarbon Emissions Inventory

As a first step, Guidehouse reviewed the last NYS GHG Inventory Report 1990–2016, and then reverse-engineered the methods for calculating HFC emissions. At a high level, the previous analysis was generated using a tool provided by the California Air Resource Board (CARB) for tracking HFCs across the U.S. A diagram of the modeling process for that tool is shown in Figure 2.

Figure 2. Process Diagram for the NYS GHG Inventory



First, emissions estimates were developed for the state of California using a bottom-up vintaging model, the details of which were presented in the CARB Technical Support Document (TSD). This vintaging model factored in details such as typical refrigerant charge, equipment lifetime, and emission rates due to leakage and end-of-life, among others. Different emissions methodologies were assigned to major equipment categories, including stationary HVACR, mobile HVACR, and the "other" categories such as aerosols and foams. Ultimately, many of the underlying assumptions from the CARB vintaging model were used in Guidehouse's emission model but updated based on the most recent data. Some key updates to these CARB model assumptions include:

- Calculated emissions using a bottom-up approach based on equipment stock estimates in New York State,[9] instead of using a top-down emissions scaling approach (see below).
- Developed differential refrigerant charge size estimates between air-conditioner and heat pump technologies.
- Re-assigned equipment lifetimes based on the NYSERDA Technical Reference Manual.[10]
- Evaluated the historical prevalence of technologies that were not explicitly considered in the CARB inventory (e.g., VRF and ground-source heat pumps).

After emissions estimates were developed for California, the United States Climate Alliance (USCA) tool scaled the California emissions to New York State emissions based on key indicator variables such as state population, commercial building square footage, and vehicle registrations. Emissions were also forecast through the year 2030 based on assumed growth rates in New York State of the key indicator variables. The tool then disaggregates those emissions into 14 different categories, which were retained in the NYS GHG Inventory Report. Guidehouse compared the emissions results from 2020 across those same 14 categories, plus two additional categories for "other" and "water heating/appliances" to calibrate the Guidehouse emission model against the NYS estimates, as shown in Table 5. These values are provided for informational purposes only; differences in methodology, product mapping, and data availability make further comparisons challenging.

Table 5. Emission Comparisons between New York State Inventory and Guidehouse Inventory (MMT CO_2e)

Emissions Category USCA	2020 USCA Estimate	2020 Guidehouse Estimate
Aerosol Propellants	0.75	0.98
Commercial Refrigeration	3.88	3.27
Commercial Stationary AC < 50 lbs	1.31	0.73
Commercial Stationary AC > 50 lbs	0.57	0.65
Foam	0.43	0.90
Industrial Refrigeration	0.16	0.11
Other	--	0.02
Residential (Domestic) Refrigeration	0.10	0.16
Residential Stationary AC Heat Pump	0.23	0.02
Residential Stationary Central AC	1.03	0.87
Residential Stationary Room Unit AC	0.63	0.24
Solvents & Fire Suppressant	0.15	0.28
Transport Heavy-Duty MVAC	0.55	0.11
Transport Light-Duty MVAC	1.46	1.20
Transport Refrigeration	0.30	0.08
Water Heating / Appliances	--	0.03
TOTAL	**11.54**	**9.64**

Note: Emission values in this table based on IPCC AR-4, 100-year GWP values.

2.2 Modeling Approach—Overview

The foundation for the HFC emissions inventory analysis is an Excel-based vintaging model customized to New York State. The Guidehouse vintaging model estimates the annual installed stock, new shipments, and end-of-life (EOL) retirements of HFC-using equipment. Using a bottom-up accounting methodology, the model calculates annual HFC consumption due to new equipment installations and the servicing of existing equipment to replenish refrigerant leakage; as well as annual HFC emissions to the atmosphere due to equipment leakage and disposition at EOL retirement. The model can be used to project future consumption and emissions over a variety of scenarios defined by the user.

For each equipment type, annual HFC consumption and emissions are calculated based on a set of key input assumptions, including refrigerant composition, refrigerant charge size, annual leakage rate, servicing frequency, equipment lifetime, and EOL loss (i.e., non-recovery) rate. Additional general inputs include projected growth rates of key economic indicators (e.g., number of residential housing units, total commercial square footage, and number of vehicle registrations) and saturation rates of main end-uses (e.g., the portion of residential homes with air conditioning).

By customizing the input assumptions, a range of business-as-usual growth scenarios, or "reference cases" can be modeled. Against these reference cases, "what-if" scenarios can be modeled to assess the impacts of potential mitigation policies that could be considered to achieve future emissions reduction targets. The adaptability of the model also allows for a sensitivity analysis of any of the key input assumptions.

Figure 3 shows the key inputs and outputs of the HFC vintaging model.

Figure 3. Key Inputs and Outputs of Hydrofluorocarbon Vintaging Model

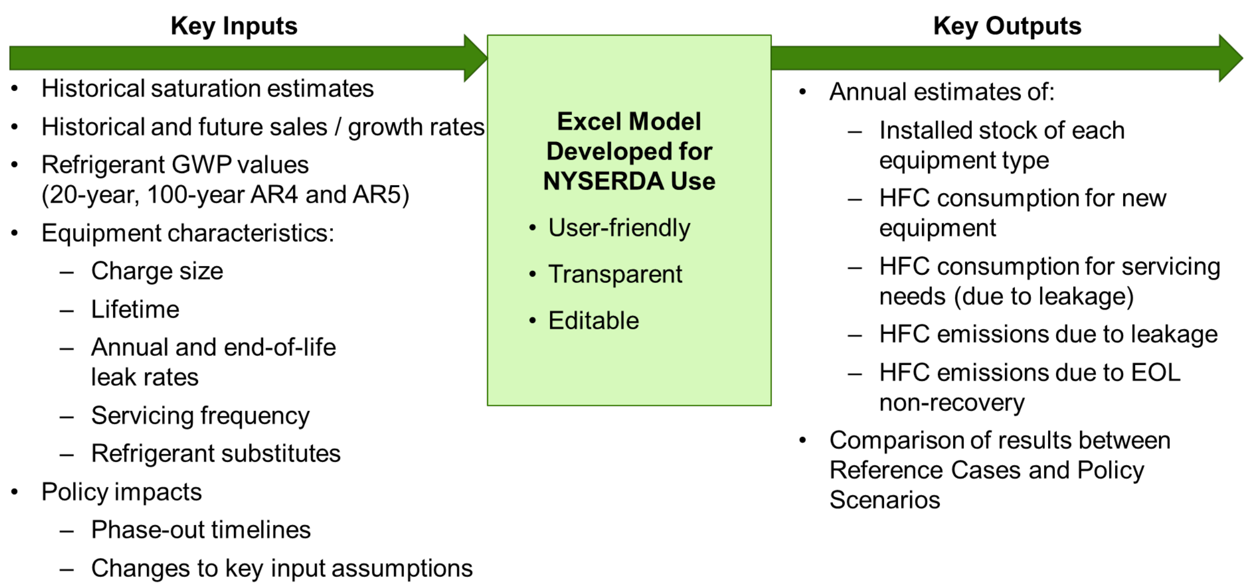
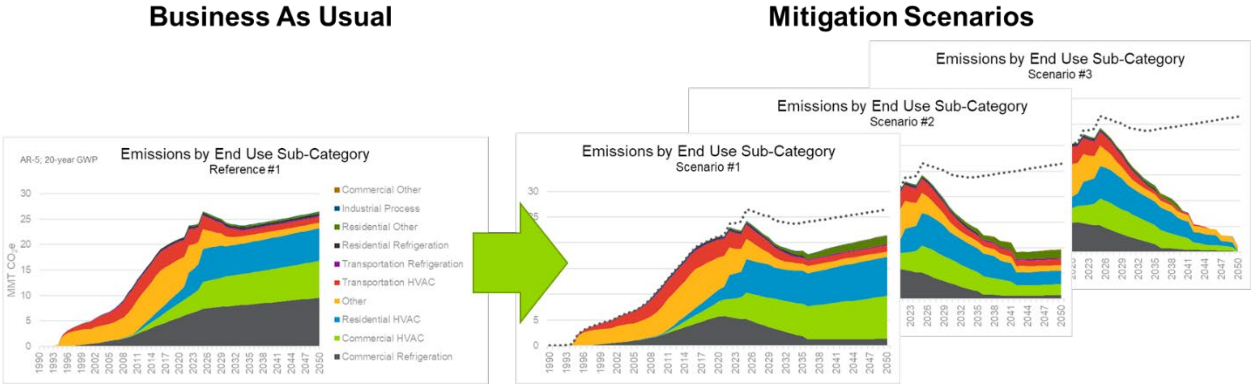


Figure 4 provides an illustrative example of using the outputs of the Guidehouse model to compare results between a reference case and various policy scenarios. Appendix C contains a detailed introduction to the modeling spreadsheet. The HFC inventory and methodology developed in this project also supported an analysis into how statewide HFC usage is expected to change in future years, and the impacts of potential policies that could be considered to significantly reduce HFC emissions. The results of this analysis will be published as a separate NYSERDA report in the near future.

Figure 4. Illustrative Example of Model Outputs



2.3 Equipment Category Mapping

Guidehouse defined an initial list of equipment categories to match the level of granularity from E3's building stock tool for the Climate Act Integration Analysis. Additional categories were created as needed, for example, to align with differentiation in refrigerant charge quantities (e.g., commercial VRF systems) or with specific market segments of interest (e.g., ductless heat pumps). Each equipment category was mapped to existing USCA end-use categories and E3 building stock categories for use in the Climate Act Integration Analysis. As a result, all equipment categories can be incorporated into the existing categories from either USCA or E3. Table 6 shows the mapping between each equipment category in the Guidehouse model and the corresponding category from USCA.

Table 6. Mapping of End-Use Sub-Categories and Equipment Types to USCA Categories

Guidehouse End		
Residential HVAC	Residential Central AC	Residential Stationary Central AC
	Residential Central HP	
	Residential GSHP	Residential Stationary AC Heat Pump
	Residential Window AC	Residential Stationary Room Unit AC
Residential Refrigeration	Residential Refrigerator / Freezer	Residential (Domestic) Refrigeration
	Residential Freezer	
Residential Other	Residential HP Clothes Dryer	(Not Defined)
	Residential Dehumidifier	
	Residential HP Water Heater	

Table 6 continued

Guidehouse End		
Commercial HVAC	Commercial Central Split & Package AC, Large	Commercial Stationary AC > 50 lbs
	Commercial Central Split & Package HP, Large	
	Commercial VRF HP, Large	
	Commercial Chiller, Large Centrifugal	
	Commercial Chiller, Medium	
	Commercial Chiller, Small	
	Commercial Central Split & Package AC, Small	Commercial Stationary AC < 50 lbs
	Commercial Central Split & Package HP, Small	
	Commercial GSHP	
	Commercial VRF HP, Small	
	Commercial Ductless Split AC	
	Commercial Ductless Split HP	
	Commercial Room AC / PTAC / PTHP	
Commercial Refrigeration	Commercial Ice Makers	Commercial Refrigeration
	Commercial Refrigerator / Freezer	
	Com. Self-Contained Display Cases / Reach-ins	
	Commercial Supermarket Racks, Large	
	Commercial Supermarket Racks, Medium	
	Commercial Vending Machines	
	Com. Walk-ins/Remote Condensing, Large	
	Com. Walk-ins/Remote Condensing, Small	
	Commercial Refrigerated Warehouse, Large	Industrial Refrigeration
	Commercial Refrigerated Warehouse, Medium	
Commercial Other	Commercial HP Water Heater	(Not Defined)
Industrial Process	Industrial Process	(Not Defined)
Transportation HVAC	Buses	Transport Heavy-Duty MVAC
	Heavy Duty Vehicles	
	Light Duty Vehicles	Transport Light-Duty MVAC
	Medium Duty Vehicles	
Transportation Refrigeration	Transportation Refrigeration	Transportation Refrigeration
Other	Aerosol Propellants	Aerosol Propellants
	Foams	Foam
	Solvents & Fire Suppressants	Solvents & Fire Suppressant

2.4 Key Modeling Assumptions, Limitations, and Data Sources

The Guidehouse vintaging model incorporates a number of key assumptions and inherent modeling limitations, as summarized in Table 7. Based on the research findings in Task 1.1, Guidehouse updated assumptions and data sources from New York State to develop the more detailed estimates for the vintaging model. Table 7 also describes the data sources and process followed to update each model assumption.

Table 7. Key Model Assumptions, Limitations, and Data Sources

Model		
	• Calculated as saturation rate multiplied by key economic indicator (e.g., number of residential housing units, total commercial square footage). • Saturation rate determined for "base" year using most recent available data (e.g., 2018). • Years prior to base year extrapolated using historical growth rate of economic indicator; assumes constant growth rate over that period. • Future years extrapolated using user-defined annual growth rate of economic indicator.	• Compared NYSERDA residential and commercial baseline studies with data from CARB, U.S. DOE, and the Energy Information Administration (EIA). • Based on these comparisons, developed stock saturation estimates for "base" year. • Extrapolated historical and future stock growth estimates based on projections of key economic indicators.
	• Single lifetime value applied to each equipment type. • Products are assumed to retire at exactly the assigned lifetime (e.g., no distribution of survival time assumed). • Early "catastrophic" loss not considered in the model. • Equipment types that are considered substitutes within the same "main application" must be assigned the same lifetime.	• Assigned equipment lifetimes based on NYSERDA Technical Reference Manual (TRM). • Conducted literature review to assign lifetimes for any equipment categories not considered in the TRM. • Verified equipment lifetimes with other sources such as U.S. DOE rulemakings.
	• Reported in lbs of refrigerant per piece of equipment. • Single representative charge size defined for each type of HFC-using equipment. • "Charge size multiplier" can be applied to alternative refrigerant designs if known to have a smaller or larger charge size.	• Reviewed charge size for existing product categories in CARB TSD. • Conducted literature review to verify certain charge size assumptions from CARB TSD. • Consulted product specification sheets and internal product experts for equipment. categories not covered by CARB (e.g., VRF systems in Section 2.4.1).
	• Constant leak rate assumed across lifetime of equipment. • Users can vary the assumed leak rate of the installed stock each year post-2020.	• Used CARB TSD as primary source. • Conducted literature review and consulted with internal equipment experts for any categories not covered by CARB.

Table 7 continued

Model Parameter	Key Model Assumptions / Limitations	Data Sources and Methodology
End-of-Life Loss Rate	• EOL emissions reflect equipment placed into service one "lifetime" ago, all retiring simultaneously. • Loss rate reflects the fraction of units reaching EOL whose refrigerant is emitted into the atmosphere.	• Used CARB TSD as primary source • Conducted literature review and consulted with internal equipment experts for any categories not covered by CARB.
Service Frequency	• Service interval (in years) defined for each product category.	• Used CARB TSD as primary source. • Conducted literature review and consulted with internal equipment experts for any categories not covered by CARB.
Refrigerant Allocations	• For each equipment type, refrigerant allocations represent the portion of shipments each year containing each refrigerant.	• Used CARB F-Gas ODS-to-HFC Transition Timeline to apportion refrigerant types by equipment category for the period 1990–2020. • Verified HFC apportionment for certain equipment categories through literature review and consultation with internal product experts.
Refrigerant GWP Values	• Different GWP methodologies are available to evaluate results (AR4 vs AR5; 100-year vs 20-year). • CFC and HCFCs assigned GWP value of 0 for HFC inventory purposes11.	• GWP values obtained from AR reports. • Where unavailable, GWP values for HFC blends determined by calculating weighted average of pure components.

Sections 2.4.2 and 2.4.3 describe differences in the overall modeling approach used for the Transportation HVAC & Refrigeration and "Other" categories, due to the unique nature of these categories in comparison to the building HVACR equipment categories.

2.4.1 Charge Size Differences by Equipment Type and Efficiency

Most HFC inventories consider all packaged central residential and commercial HVAC equipment with the same refrigerant charge size regardless of equipment category or efficiency level. Guidehouse reviewed manufacturer product literature to understand whether there are key differences in charge size for heat pump versus cooling-only products and different equipment types (e.g., central split, roof top unit [RTU], variable refrigerant flow [VRF], ground source heat pump [GSHP]). The analysis suggests significant charge size differences between equipment categories, as well as by efficiency level within each category (for some manufacturers).

Table 8 highlights key differences between comparable residential central split-system products. Charge size typically increases with efficiency level due to the use of larger heat exchangers. Heat pumps have higher charge size in comparison to AC-only products due to the addition of components that provide reversible heating functions. There is significant variation by manufacturer based on individual product design decisions.

Table 8. Charge Size Differences between Residential Central Split-System Products

Manufacturer (3 ton central split-systems)*	Standard Efficiency (SEER 13–14) Charge Size (lbs)			Medium Efficiency (SEER 16–17) Charge Size (lbs)			High-Efficiency (SEER >20) Charge Size (lbs)		
	AC	HP	% Increase HP vs AC	AC	HP	% Increase HP vs AC	AC	HP	% Increase HP vs AC
Carrier	4.9	7.7	57%	9.3	13.7	48%	12.7	13.1	3%
Daikin	5.0	7.2	44%	7.1	10.6	49%	9.6	17.0	77%
York	6.0	12.0	100%	**	**	**	7.0	11.0	57%
Average	**5.3**	**9.0**	**69%**	**8.2**	**12.2**	**49%**	**9.8**	**13.7**	**40%**

* Detailed model data for Trane and Lennox products is not publicly available.

** York's medium efficiency models showed the opposite effect, in which the heat pump had a smaller charge size than the AC-only product, and charge size was smaller than standard and high-efficiency models. These products have been excluded from the table because they incorporate different compressor platforms and other significant design changes compared to the other models listed in the table. This highlights how manufacturer design decisions can significantly impact charge size.

2.4.1.1 Charge Size Differences: Commercial RTUs and VRF

Similar to central spit-systems, commercial rooftop units (RTUs) with heat pump function have higher charge than AC-only models, and high-efficiency models have higher charge than standard efficiency models. Variable refrigerant flow (VRF) heat pumps have significantly higher charge than RTUs, assuming typical refrigerant line lengths. VRF models assume 300 ft. of refrigerant lines. Total line length can vary significantly by installation.

Table 9. Charge Size Differences Between Commercial RTU Heat Pumps

Manufacturer (8 ton models)	Standard Efficiency (SEER 13–14) Charge Size lbs.)		Medium Efficiency (SEER 16–17) Charge Size lbs.)		High-Efficiency (SEER >20) Charge Size (lbs.)				
	AC-Only RTU	HP RTU	AC-Only RTU	HP RTU	AC-Only RTU	HP RTU	VRF HP*	VRF w/ Heat Recovery*	VRF w/ HR and Low Ambient*
Average Across Carrier, Daikin, and Mitsubishi	14	21	19	24	22	26	58	61	64

* VRF models assume 300 ft of refrigerant lines. Total line length can vary significantly by installation.

Ground source heat pumps (GSHP) with water/glycol loops have comparable charge size as split-systems (4–6 lbs). GSHP with direct ground exchange (DX-GSHP) with refrigerant have much higher charge sizes, likely similar in magnitude to VRF systems. This type of GSHP is much less common than water/glycol loop systems. E3 has indicated that they do not intend to break-out the different types of GSHPs. Without additional data suggesting that adoption of DX-GSHPs in New York State will significantly rise, these systems were not modeled separately from water/glycol GSHPs.

2.4.1.2 Approach for Modeling Charge Size Differences

The analysis suggests significant charge size differences between equipment categories, as well as efficiency levels within each category. The model incorporates separate stock and charge size differences between AC-only versus heat pump products and key equipment categories (central, GSHP, RTU, VRF) to better align with the E3 pathways modeling. The increasing adoption rate of some of these categories (e.g., GSHP, VRF), and the magnitude of difference in charge size, warrants tracking them separately.

The model does not separately model charge size differences by efficiency level due to (1) uncertainty of future sales estimates for standard, medium, and high-efficiency products in NYS; (2) inconsistent differences in charge size across different manufacturers; and (3) the likelihood of future manufacturer design changes to accommodate low-GWP A2L refrigerants. Guidehouse could consider performing a sensitivity analysis of efficiency level differences based on E3’s pathway modeling on the need for high-efficiency products to meet Climate Act targets.

2.4.2 Transportation HVAC and Refrigeration

Stock estimates for the Transportation HVAC and Transportation Refrigeration categories were determined using a different method than for the building HVACR equipment categories. Whereas building HVACR equipment stock is calculated as a saturation rate multiplied by a key economic indicator (e.g., number of residential housing units), the stock of vehicles is set equal to the number of vehicle registrations as determined by the sources shown in Table 10.

Table 10. Vehicle Stock Assumptions and Data Sources for Transportation HVAC and Refrigeration Categories

Model Parameter	Key Model Assumptions	Data Sources
Vehicle Stock	• Set equal to number of vehicle registrations. • Vehicle registrations determined for "base" year using most readily available data (e.g., 2015 for Transportation HVAC; 2018 for Transportation Refrigeration). • Years prior to base year extrapolated using historical growth rate of vehicle registrations; assumes constant growth rate over that period. • Future years extrapolated using user-defined annual growth rate of vehicle registrations.	• Total vehicle registrations for Transportation HVAC based on E3's estimate of total vehicle stock in 2015. • Vehicle registrations for Transportation Refrigeration based on data from CARB for 2018, scaled to NYS based on population ratio.

Aside from the determination of vehicle stock, the same general modeling assumptions and methodology as described in section 2.4 were used for the Transportation HVAC and Refrigeration categories. In particular, a 15-year average lifetime was assumed across all vehicle categories. As with the building HVAC&R equipment categories, vehicles are assumed to retire at exactly the assigned lifetime (e.g., no distribution of survival time was assumed). Early "catastrophic" loss is not considered in the model. Existing stocks of vehicles with high-GWP refrigerants will continue to emit as long as they remain in service.

The Reference Cases assume that the large majority of light duty and medium duty vehicles have already transitioned to low-GWP alternative refrigerants (e.g., R-1234yf) by 2020, driven in part by corporate average fuel economy "credits" granted to vehicles using R-1234yf instead of the traditional HFC refrigerant beginning in 2010.[12]

2.4.3 Aerosols, Foams, Solvents, and Fire Suppressants

Aerosols, foams, solvents, and fire suppressants collectively comprise the "Other" category in the emissions model. Because of the unique characteristics of each of these categories, they are considered individually and modeled separately from the bottom-up stock-based analysis that is used for the HVACR sectors. For the aerosols, solvents, and fire suppressants sectors, the products are generally assumed to be dispensed within the same year of manufacture, such that there is no stock buildup or rollover to account for, and emissions and consumption are equivalent in each year. The foams sector introduces significant complication because of the wide variety of foam products in which ODS substitutes are used (e.g., spray foam, expanded polystyrene (XPS) foam, flexible polyurethane, etc.). Each of these foam products have a different emissions profile, lifetime, and HFC composition, which would make developing a bottom-up stock analysis significantly more challenging than the residential and commercial equipment categories. Developing a stock estimate for foams also poses a challenge in terms of how they would be quantified (e.g., by volume, by mass, etc.).

To estimate historical emissions for these sectors, Guidehouse used a top-down scaling approach instead of a bottom-up vintaging approach. Guidehouse first used the Environmental Protection Agency (EPA) State Inventory Tool to estimate total national emissions for each of the categories. The national emission numbers were then scaled to New York State using the ratio of State population to national population, which varied in each of the years 1990–2020. This simple scaling process yielded a top-level estimate of emissions for each of the years 1990–2020. The next step was converting the top-level emission estimates from an AR4 100-year GWP methodology to each of the other three GWP methodologies. Information from the 2020 EPA GHG inventory report[13] and the CARB fluorinated greenhouse gases (F-Gas) to ODS Transition tool was used to disaggregate each sector into an assumed distribution of refrigerants used for each sector in each year. Finally, a "weighted GWP ratio" was calculated for each end-use and year in order to convert between AR4 100-year GWP and other methods (e.g., AR5 20-year). This ratio was applied as a multiplier to the top-line emission estimates in each year.

Unlike the equipment categories, for the "Other" categories Guidehouse assumed significant reductions in HFC emissions as part of the business-as-usual Reference Case no. 1 (and all subsequent reference cases and potential mitigation scenarios). According to Guidehouse, discussions with industry representatives, the aerosol and foam industries have already begun transitioning from HFCs to other low-GWP substitutes, and the use of HFCs in these sectors is expected to phase out nearly completely by around 2030. Data from the EPA State Inventory Tool confirms that nationwide HFC emissions from aerosols peaked in 2015 and has steadily declined since then. Accordingly, Guidehouse modeled emissions from the aerosols category as continuing the same rate of decline until reaching zero emissions in 2032. EPA data also shows that HFC emissions from foams appears to have reached a plateau in 2018. Guidehouse modeled emissions from foams as peaking in 2018 and following a downward trajectory that mirrors the upward trajectory leading to the 2018 peak. In contrast to aerosols (in which emissions are assumed to occur in the same year as production/consumption), foams are used as building insulation and other applications with a 30- to 50-year lifetime and emit gases over the lifetime of the foam as well as at building end-of-life (for example, when a building is renovated or demolished). To account for this, the model limits the assumed reduction of HFC emissions from foam to 50% of the 2018 peak value, which is reached in 2028. This reflects an expectation that even after phasing out the use of HFCs by around 2028, the installed "stock" of foam products will continue to emit for another 30 to 50 years.[14]

3 Historical Hydrofluorocarbon Emissions Inventory

This section describes Guidehouse's analysis of historical HFC consumption and emissions in New York State over the period 1990–2020 based on the results generated by the HFC vintaging model developed for this analysis. Appendix A provides a summary of the key data inputs and sources. Appendix B summarizes the historical HFC inventory using both 20-year and 100-year GWP values. The full source documentation for the Guidehouse HFC vintaging model is available in appendix C.

3.1 NYS Hydrofluorocarbon Emissions 2005–2020 by End-Use Category

HFC emissions in New York State have grown from near-zero in 1990 to 21.2 MMT in 2020 (AR-5, 20-year GWP), as shown in Figure 5, driven by the use of HFCs to replace CFCs/HCFCs as the CFCs/HCFCswere phased down (primarily) and economic growth in the state (secondarily). In particular, commercial refrigeration and commercial and residential HVAC have all shown large increases since 2005. Once all vintage CFC/HCFC equipment has reached its end-of-life stage, future HFC growth will be slower and reflective of economic growth in the State. HVAC&R categories grew most dramatically after 2010, when HFCs became the predominant refrigerant for stationary cooling applications, replacing ODS refrigerants. HFC use for mobile air conditioning (which began in the 1990s), as well as foams, aerosols, and solvents ("other") has grown only modestly since 2010 and has already begun declining as these categories transition to lower-GWP options. The estimate of 1990 emissions from this analysis was used by DEC to establish certain Climate Act reduction requirements into regulation.[15] All values from this report will be integrated into an updated GHG inventory report, to be issued by DEC in 2021.

Figure 5. Hydrofluorocarbon Emissions by End-Use Subcategory (1990–2020)

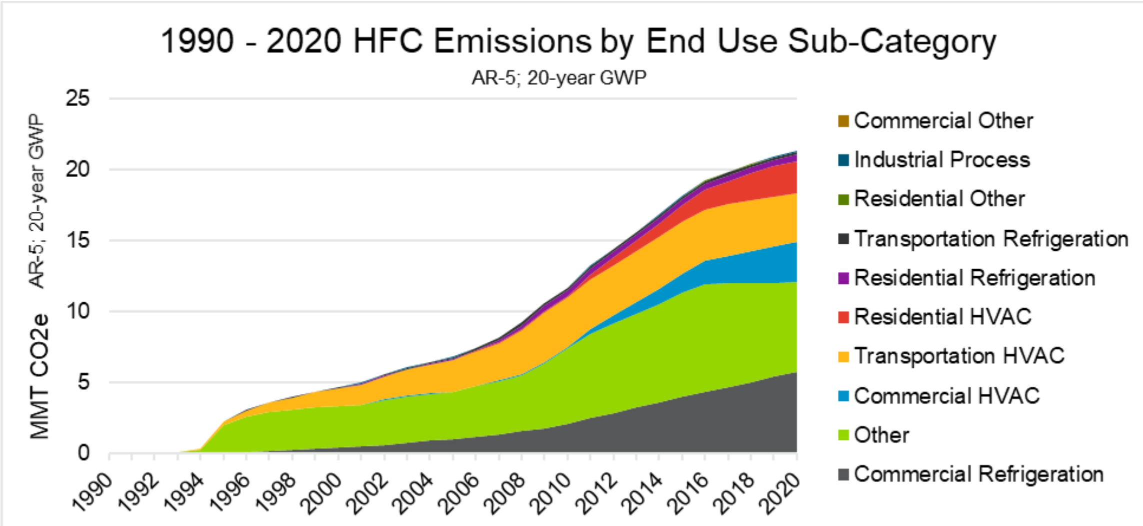


Table 11 summarizes the estimated HFC emissions by category in five-year increments during the period 2005 to 2020.

Table 11. NYS Hydrofluorocarbon Emissions 2005–2020 by End-Use Category, in MMT CO_2e (AR-5 20-year)

End Use Sub-category	2005	2010	2015	2020	2020 % of Total	Notes
Residential HVAC	0.03	0.14	1.16	2.32	10.9%	Includes AC, HP, GSHP, and room products
Residential Refrigeration	0.05	0.40	0.41	0.42	2.0%	Includes refrigerators and freezers
Residential Other	0.00	0.00	0.02	0.06	0.3%	Includes HPWHs and dehumidifiers
Commercial HVAC	0.02	0.05	1.40	2.84	13.3%	Includes AC, HP, PTAC, VRF, ductless, GSHP, and chiller products
Commercial Refrigeration	1.03	2.06	3.98	5.71	26.8%	Includes supermarket, walk-ins, reach-ins, vending machines, icemakers
Commercial Other	0.00	0.00	0.00	0.00	0.0%	Includes HPWHs

End Use Sub-category	2005	2010	2015	2020	2020 % of Total	Notes
Industrial Process	0.01	0.02	0.03	0.04	0.2%	
Transportation HVAC	2.23	3.51	3.62	3.39	15.9%	Light-, medium-, heavy-duty, and buses
Transportation Refrigeration	0.13	0.17	0.18	0.19	0.9%	
Other	3.29	5.35	7.32	6.34	29.8%	Aerosols, Foams, Solvents
Total	**6.79**	**11.70**	**18.12**	**21.31**	**100%**	

3.1.1 Building HVAC Hydrofluorocarbon Emission Subcategories

Residential and commercial central AC-only systems account for the majority of building HVAC emissions today, but heat pump/VRF systems are expected to increase in future years due to heating electrification. As described in Section 2.4.1, the analysis suggests significant charge size differences between equipment categories: heat pumps have 33% greater charge than AC-only products, and VRF systems have at least two times greater charge than other heat pump products. Chillers, packaged terminal air conditioning (PTACs), room ACs, and other self-contained systems have low HFC emissions due to relatively low-leak rates. Many of these end-uses are already transitioning to low- and ultra-low-GWP options, including R-32, R-513A, and R-1234yf.

Table 12 summarizes the 2020 HFC emissions for HVAC applications by equipment type.

Table 12. Hydrofluorocarbon Emissions for HVAC by Equipment Type, 2020 (AR-5, 20-year GWP)

Category	2020 Emissions MMT CO_2e (AR-5 20-year GWP)	% of 2020 HVAC Total
Commercial Central Split & Package AC, Large	0.78	15.1%
Commercial Central Split & Package AC, Small	0.68	13.1%
Commercial Central Split & Package HP, Large	0.15	2.9%
Commercial Central Split & Package HP, Small	0.22	4.4%
Commercial Chiller, Large Centrifugal	0.05	0.9%
Commercial Chiller, Medium	0.02	0.4%
Commercial Chiller, Small	0.33	6.4%
Commercial Ductless Split AC	0.23	4.4%
Commercial Ductless Split HP	0.11	2.1%
Commercial GSHP	0.00	0.1%
Commercial Room AC / PTAC / PTHP	0.03	0.6%
Commercial VRF HP, Large	0.02	0.4%
Commercial VRF HP, Small	0.22	4.3%
Residential Central AC	1.68	32.6%
Residential Central HP	0.10	1.9%
Residential Ductless Split AC (Placeholder)	0.00	0.0%
Residential Ductless Split HP (Placeholder)	0.00	0.0%
Residential GSHP	0.04	0.7%
Residential Window AC	0.50	9.8%
Grand Total	**5.16**	**100.0%**

3.1.2 Building Refrigeration Hydrofluorocarbon Emission Subcategories

Refrigeration systems for supermarkets, cold storage, and food service account for approximately 90% of building refrigeration emissions today (approximately 50% of total building HFC emissions), even though other refrigeration segments have a much larger installed base. Supermarket racks, refrigerated warehouse, and walk-in refrigeration systems have high-leak rates and use high-GWP refrigerants. Most HFC phasedown policies have targeted these segments as high priority for refrigerant phasedown and leakage management. Residential-style refrigerators, freezers, ice makers, vending machines, and other self-contained systems have low HFC emissions due to low-leak rates. Many of these technologies are already transitioning to isobutane (R-600a) or other natural refrigerants with ultra-low-GWP.

Table 13 summarizes the 2020 HFC emissions for refrigeration applications by end-use category.

Table 13. Hydrofluorocarbon Emissions for Refrigeration by Equipment Type, 2020 (AR-5, 20-year GWP)

Equipment Type	2020 Emissions MMT CO_2e (AR-5 20-year GWP)	% of 2020 Refrigeration Total
Commercial Ice Makers	0.01	0.1%
Commercial Refrigerated Warehouse, Large	0.15	2.4%
Commercial Refrigerated Warehouse, Medium	0.03	0.5%
Commercial Refrigerator / Freezer	0.01	0.2%
Commercial Self-Contained Display Cases / Reach-ins	0.07	1.1%
Commercial Supermarket Racks, Large	0.51	8.3%
Commercial Supermarket Racks, Medium	3.08	50.2%
Commercial Vending Machines	0.01	0.1%
Commercial Walk-ins/Remote Condensing, Large	0.66	10.8%
Commercial Walk-ins/Remote Condensing, Small	1.18	19.3%
Residential Freezer	0.06	1.0%
Residential Refrigerator / Freezer	0.36	5.9%
Grand Total	**6.13**	**100.0%**

3.1.3 Transportation and Other Hydrofluorocarbon Emission Subcategories

HFC emissions across transportation and other subsectors have remained relatively flat since 2010, whereas emissions from heat pump water heaters and clothes dryers may increase slightly in future years with building electrification trends. Nevertheless, heat pump water heaters (HPWH) are unlikely to be a significant contributor to HFC emissions if the leakage rates are similar to other self-contained systems (1–2%/yr). Transportation cooling is currently transitioning from the HFC refrigerant R-134a to the ultra-low-GWP refrigerant R-1234yf.

Table 14 summarizes the 2020 HFC emissions for transportation and "other" applications by end-use equipment.

Table 14. Hydrofluorocarbon Emissions for Transportation and Other Equipment by End-Use Equipment (AR-5, 20-year GWP), 2020

Equipment Type	2020 Emissions MMT CO_2e (AR-5 20-year GWP)	% of 2020 Total for Listed Equipment Types
Aerosol Propellants	3.34	33.7%
Commercial Water Heater HP	0.00	0.0%
Foams	2.42	24.4%
Industrial Process	0.04	0.4%
Residential Clothes Dryer HP	0.00	0.0%
Residential Dehumidifier	0.03	0.3%
Residential Water Heater HP	0.02	0.3%
Solvents & Fire Suppressant	0.59	5.9%
Transportation Buses	0.19	1.9%
Transportation Light Duty Vehicles	2.85	28.8%
Transportation Medium Duty Vehicles	0.25	2.5%
Transportation Refrigeration	0.19	1.9%
Grand Total	**9.92**	**100.0%**

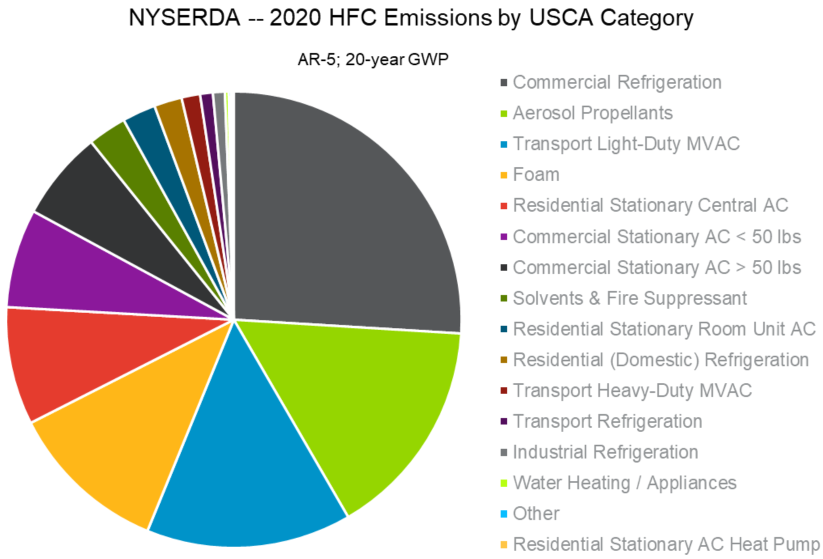
3.1.4 Comparison of Hydrofluorocarbon Emission Categories

Commercial refrigeration and space cooling systems for residential, commercial, and mobile applications account for approximately 70% of statewide HFC emissions. Commercial refrigeration includes supermarket and walk-in systems, which have high-leak rates and high-GWP refrigerants today. Light-duty vehicle emissions should decrease in the future based on current industry transition to R-1234yf. Building AC systems have large installed bases using R-410a and will be challenging to transition to alternatives. Aerosols, foams, and other non-HVAC&R end-uses account for approximately 15% of HFC emissions.

Figure 6 shows the relative breakdown of 2020 HFC emissions by category according to the categories defined by USCA.

Figure 6. Relative Breakdown of 2020 Hydrofluorocarbon Emissions by USCA Category (20-year GWP AR-5)

Listed in clockwise order from largest to smallest:



3.2 Hydrofluorocarbon Emissions by Annual and End-of-Life Leakage

Leakage over equipment lifetime is the greatest source of emissions for most categories. Completely sealed, self-contained systems like residential refrigeration and heat pump water heaters (categorized as "residential other") have very low leakage, resulting in a greater share of end-of-life emissions. Mitigation options can be designed to best address the most prevalent leakage source in each category. For example, California's Refrigerant Management Program (RMP) targets annual leakage in supermarkets and cold storage, whereas a utility recycling program for refrigerators, freezers, room ACs, and HPWHs would target end-of-life leakage.

Figure 7 and 8 show HFC emissions by cause (annual leakage versus end of life) and end-use category in terms of MMT CO_2e and percent of total, respectively.

Figure 7. Hydrofluorocarbon Emissions by Cause and End-Use Category, 2020 (MMT CO_2e AR-5 20-year GWP)

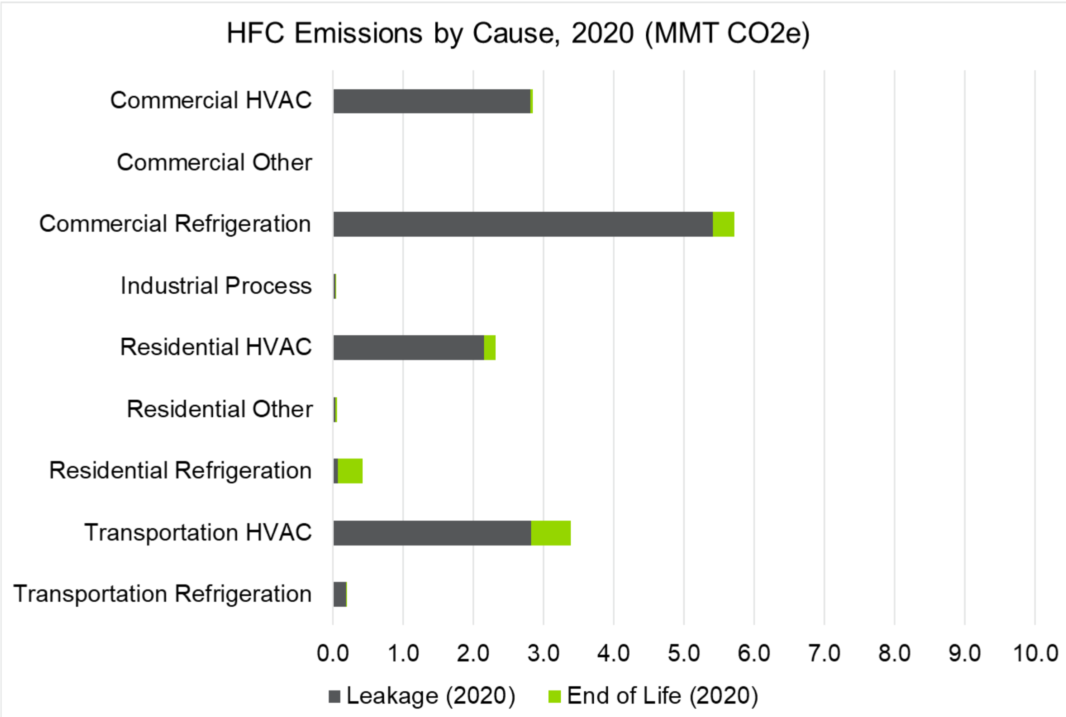
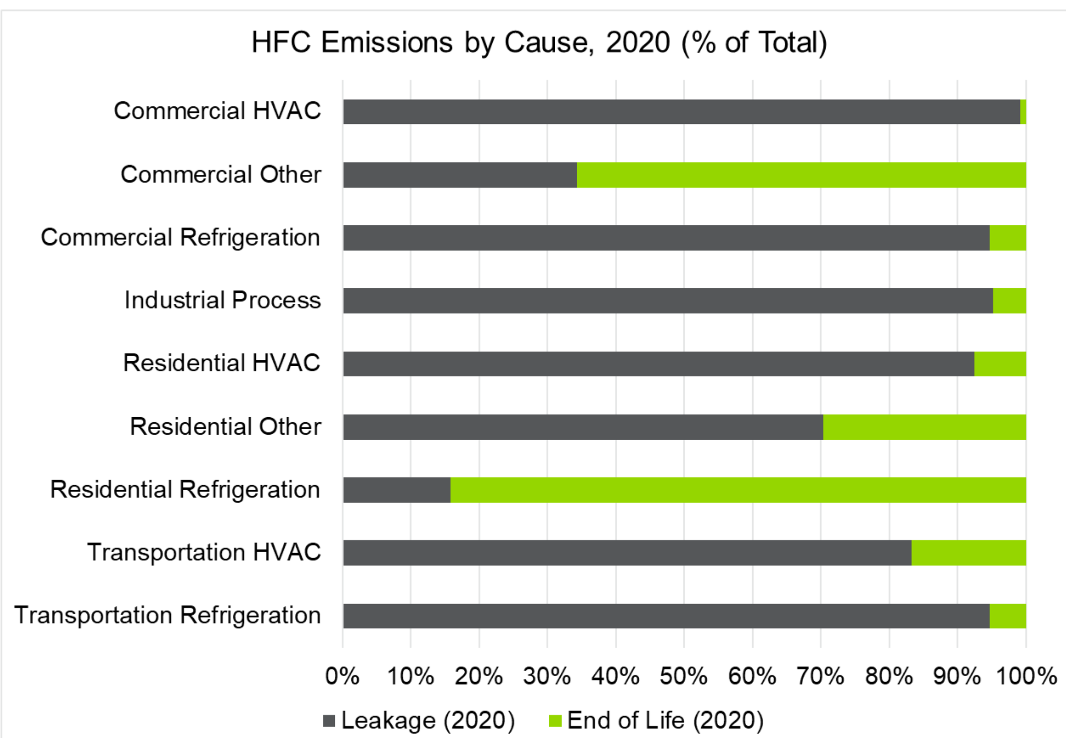


Figure 8. Hydrofluorocarbon Emissions by Cause and End-Use Category, 2020 (% of total) (AR5 20-year GWP)



3.3 Comparison of AR4 100-year and AR5 20-year Inventories

The Climate Act analysis requires 20-year GWP values, whereas 100-year GWP values are important for historical tracking and discussions with industry stakeholders. Historically, AR4 100-year GWP values have been used in GHG inventories. The Guidehouse model provides the ability to view results using any of the four GWP methodologies listed in Table 15, in order to assist DEC in meeting the Climate Act requirement to publish the Inventory Report in AR5 20-year GWP. In this report, future projections of HFC consumption/emissions is based on AR5 20-year GWP. Table 15 compares 2020 HFC emissions by subcategory across 100-year and 20-year GWP values for AR4 and AR5.

Table 15. Hydrofluorocarbon Emissions by Subcategory MMT CO_2e, 2020

Category	AR4-100	AR5-100	AR4-20	AR5-20
Commercial Refrigeration	3.38	3.36	5.40	5.71
Other	2.15	2.04	6.34	6.34
Commercial HVAC	1.38	1.28	2.90	2.84
Transportation HVAC	1.31	1.19	3.50	3.39
Residential HVAC	1.13	1.04	2.36	2.32
Residential Refrigeration	0.16	0.15	0.43	0.42
Transportation Refrigeration	0.08	0.08	0.19	0.19
Residential Other	0.02	0.02	0.06	0.06
Industrial Process	0.02	0.02	0.04	0.04
Commercial Other	0.00	0.00	0.00	0.00
TOTAL	**9.63**	**9.19**	**21.22**	**21.31**

AR5 20-year GWP values results in significantly higher emissions than AR4 100-year values. There are only minor changes in GWP values for individual gases between Intergovernmental Panel on Climate Change (IPCC) AR4 & AR5.

4 Conclusions

This section summarizes Guidehouse's key findings and conclusions for the historical and current HFC inventory in New York State. In addition, Guidehouse identified areas of the analysis that could be enhanced with additional research.

4.1 Project Summary

The purpose of this report is to provide NYSERDA with an updated and more detailed inventory for HFC gases in New York State. This report covers a wide variety of HFC end-use categories including refrigerants used in space conditioning and refrigeration for residential, commercial, industrial, and transport applications, as well as non-refrigerant HFCs used in foams, aerosol propellants, solvents, and fire protection.

Guidehouse first reviewed the current NYS HFC emission inventory and supporting documentation for the Climate Act Integration Analysis project. Guidehouse then conducted a thorough literature review of the latest government and industry research into HFC emissions inventories, refrigerant saturations, low-GWP alternatives, and mitigation strategies. Guidehouse also conducted several interviews with industry organizations. This information was used to develop a detailed bottom-up vintaging model to calculate historical, current, and future HFC consumption and emissions for the over 40 end-use categories and analyzed potential HFC mitigation scenarios for the State.

The HFC inventory and methodology developed in this project also supported an analysis into how statewide HFC usage is expected to change in future years, and the impacts of potential policies that could be considered to significantly reduce HFC emissions. The results of this analysis will be published as a separate NYSERDA report in the near future.

4.2 Summary of Conclusions

Guidehouse's key conclusions regarding NYS HFC emissions are summarized below:

- HFC emissions in New York State have grown from near-zero in 1990 to 21.2 MMT in 2020 (AR-5, 20-year GWP), driven by the use of HFCs to replace CFCs/HCFCs as CFCs/HCFCs were phased down (primarily) and economic growth in the state (secondarily). Beyond 2020, as all vintage CFC/HCFC equipment reaches end-of-life, business-as-usual growth in HFC emissions will be much slower.

- Commercial refrigeration is the largest contributor to HFC emissions in 2020, followed by aerosol propellants and light-duty MVAC. For most categories, annual leakage throughout the equipment lifetime is a much greater source of emissions than end-of-life leakage.
- Commercial and residential HVAC&R systems are the fastest-growing sources of emissions historically and are expected to increase further in future years. Heat pump systems have a relatively small contribution to total emissions in 2020 but are expected to grow substantially as heating electrification increases in New York State because heat pump systems, particularly VRF systems, have higher refrigerant charge than comparable AC-only systems. Heat pump water heaters are unlikely to be a significant contributor to HFC emissions, assuming leakage rates are similar to other self-contained systems (i.e., very minor).
- Due to the unique characteristics of aerosols, foams, solvents, and fire suppressants, these categories were modeled using a top-down scaling approach instead of a bottom-up vintaging approach.

4.3 Gaps and Areas for Future Research

This section discusses limitations of the analysis due to data gaps and modeling sensitives and outlines future potential research opportunities to address these gaps and additional needs for low-GWP and leak reduction solutions.

4.3.1 Data Gaps and Sensitivities

- The NYSERDA residential and commercial baseline studies provided stock/saturation estimates for NYS in many technology categories, although gaps remain. The residential baseline study uses data collected 2011 to 2014, which is now dated, and Guidehouse's analysis of the survey responses showed significant gaps in those responses. In addition, the commercial baseline study was not comprehensive of all technology categories; in particular, data was missing for supermarket racks, refrigerated warehouses, transportation refrigeration, industrial process cooling, and other segments.
- Estimates for future HFC emissions in sectors outside of building HVAC&R systems, such as aerosols and foams, rely on information provided through expert interviews. Guidehouse has developed these projections through top-line estimates rather than a detailed bottom-up stock analysis, so there is greater uncertainty for these segments than for the building HVACR equipment categories.

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Appendix A. Key Data Inputs and Assumptions

A.1 Key Data Inputs and Resources

The complete set of input assumptions is located within the HFC Emissions Inventory spreadsheet.

Table A-1 lists the methodologies, assumptions, and resources used to inform the key data inputs to the Guidehouse model. The key data inputs are grouped by equipment stock, lifetime, leakage rates/charge size, service frequency, backward growth rates, refrigerant adoption timeline, and GWP values.

Table A-1. Key Model Data Inputs and Resources

Key Data Inputs	Methodology/Key Resources
Equipment Stock	• Stock estimates input for year 2018 (commercial) and 2014 (residential) based on the NYSERDA baseline studies. • All other years 1990–2020 were extrapolated based on appropriate growth indicator (households, commercial square footage, or vehicle registrations). • Stock represents the stock on January 1 at the start of the year. • Sales and retirements derived from stock and growth estimates. • For each equipment type, annual sales by refrigerant type are apportioned using F-Gas ODS to HFC Transition workbook.
Lifetime	• Input in years for each Equipment Type. • CARB Kigali Potential Impact Study (2017) & New York State Technical Reference Manual (2020).
Leakage Rates / Charge Size	• Leakage rates for each Equipment Type input as Annual Leak Rate (%) and End of Life Loss Rate (%). • Charge size is input in pounds. • CARB Kigali Potential Impact Study (2017) supplemented with review of manufacturer literature.
Service Frequency	• Input as “Serviced Every X Years” for each Equipment Type. • A value of 0 indicates the equipment type is never serviced. • A service frequency of one year (every year) is assumed if no data is available to suggest otherwise. • Derived from CARB Kigali Potential Impact Study (2017).

Backward Growth Rates	• Backward annualized growth rates are calculated for various indicators using data from:
	  ○ U.S. Census
	  ○ U.S. BEA
	  ○ EIA (CBECS)
	  ○ NYS Department of Motor Vehicles
	  ○ NYS Department of Transportation

Refrigerant Adoption Timeline	• California F-Gas ODS Substitute Worksheet

Table A-1 continued

Key Data Inputs	Methodology / Key Resources
GWP Values	• AR4 20-year and 100-year GWP from IPCC • AR5 20-year and 100 year-GWP from IPCC • GWP assumptions are made, as appropriate, for refrigerants not listed in IPCC, including: • Weighted averages for blends • Setting 20-year value equal to 100-year value • Setting AR5 value equal to AR4 value • Others

* The complete set of input assumptions is located within the HFC Emissions Inventory spreadsheet.

A.2 Example HFC Refrigerant GWP Values

Table A-2 lists the AR4 20-year and 100-year and AR5 20-year and 100-year global warming potentials of refrigerants. This report discusses results for both AR5 20-year values AR4 100-year values. Twenty-year GWP values are used for New York State policy development and 100-year values are the main choice of GWP values for many industry models and estimations.

Table A-2. HFC Refrigerant GWP Values

Source: IPCC as applied to refrigerant composition information from EPA

Refrigerant	GWP - AR4 20-yr	GWP - AR4 100-yr	GWP - AR5 20-yr	GWP - AR5 100-yr
R-134a	3830	1430	3710	1300
R-410a	4340	2088	4260	1920
R-404A	6010	3922	6437	3940
R-448A	3062	1387	2995	1273
R-32	2330	675	2430	677
R-466A	1872	733	1891	696
R-454B	1606	466	1675	467
R-513A	3748	631	3633	573
R-1234yf	1	4	1	1
R-290 (Propane)	3	3	3	3
R-600 (Isobutane)	3.3	3.3	3.3	3.3
R-744 (CO_2)	1	1	1	1
R-717 (Ammonia)	0	0	0	0

* The complete set of input assumptions is located within the HFC Emissions Inventory spreadsheet.

Appendix B. HFC Emissions Inventory for New York State

B.1 HFC Emissions Inventory—20-year GWP (AR5)

Table B-1. HFC Emissions Inventory 2005–2020 (20-year GWP)

Category	2005	2010	2015	2020	% of 2020	Notes
Res. HVAC	0.03	0.14	1.16	2.32	10.9%	Includes AC, HP, GSHP, and room products
Res. Refrigeration	0.05	0.40	0.41	0.42	2.0%	Includes refrigerators and freezers
Res. Other	0.00	0.00	0.02	0.06	0.3%	Includes HPWHs and dehumidifiers
Com. HVAC	0.02	0.05	1.40	2.84	13.3%	Includes AC, HP, PTAC, VRF, ductless, GSHP, and chiller products
Com. Refrigeration	1.03	2.06	3.98	5.71	26.8%	Includes supermarket, walk-ins, reach-ins, vending machines, icemakers
Com. Other	0.00	0.00	0.00	0.00	0.0%	Includes HPWHs
Industrial Process	0.01	0.02	0.03	0.04	0.2%	
Transport. HVAC	2.23	3.51	3.62	3.39	15.9%	Light-, medium-, heavy-duty, and buses
Transport. Refrig.	0.13	0.17	0.18	0.19	0.9%	
Other	3.29	5.35	7.32	6.34	29.8%	Aerosols, Foams, Solvents
TOTAL					**100%**	

* Because "Other" category is estimated through scaling of emissions and not bottom-up modeling of refrigerant consumption, a 20-year GWP value is unable to be determined for this category; therefore, 100-year values were used instead.

B.2 HFC Emissions Inventory—100-year GWP (AR4)

Table B-2. HFC Emissions Inventory 2005–2020 (100-year GWP)

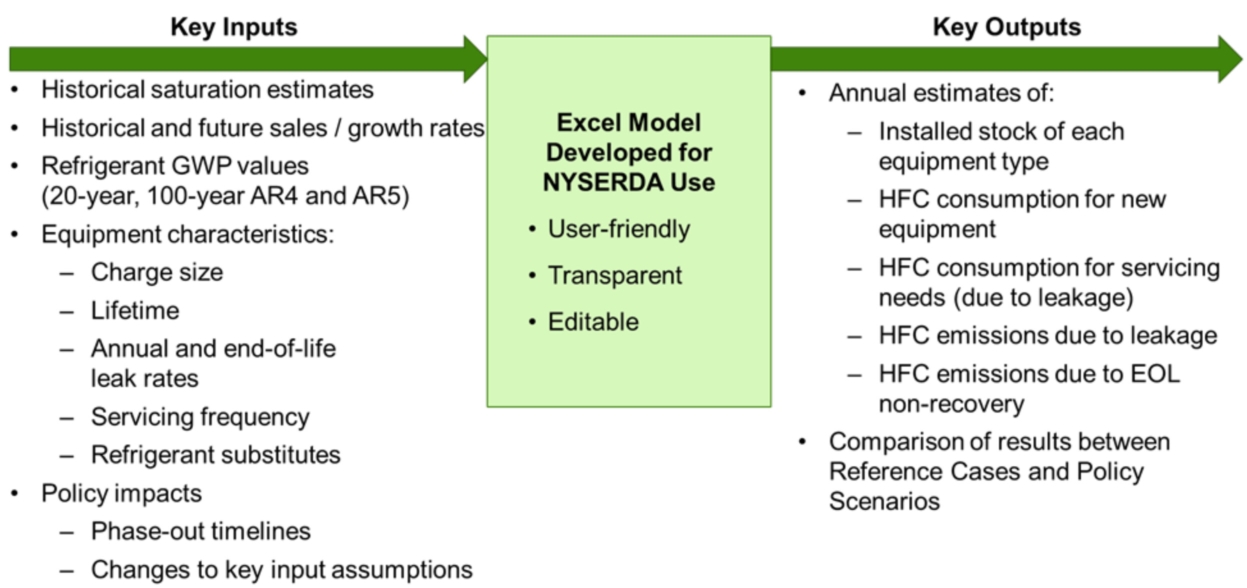
Category	2005	2010	2015	2020	% of 2020	Notes
Residential HVAC	0.01	0.07	0.57	1.13	11.8%	Includes AC, HP, GSHP, and room products
Residential Refrigeration	0.02	0.16	0.16	0.16	1.7%	Includes refrigerators and freezers
Residential Other	0.00	0.00	0.01	0.02	0.3%	Includes HPWHs, dehumidifiers
Commercial HVAC	0.01	0.03	0.68	1.38	14.3%	Includes AC, HP, PTAC, VRF, ductless, GSHP, and chiller products
Commercial Refrigeration	0.58	1.18	2.34	3.38	35.0%	Includes supermarket, walk-ins, reach-ins, vending machines, icemakers
Commercial Other	0.00	0.00	0.00	0.00	0.0%	Includes HPWHs
Industrial Process	0.00	0.01	0.01	0.02	0.2%	
Transportation HVAC	0.86	1.35	1.40	1.31	13.6%	Light-, medium-, heavy-duty, and buses
Transportation Refrigeration	0.06	0.08	0.08	0.08	0.9%	
Other	1.22	1.93	2.51	2.15	22.3%	Aerosols, Foams, Solvents
Total	**2.77**	**4.80**	**7.76**	**9.64**	**100%**	Includes AC, HP, GSHP, and room products

Appendix C. Source Documentation for the HFC Emissions Model

The foundation for the HFC emissions inventory analysis is an Excel-based vintaging model customized to New York State. The vintaging HFC Emissions Model estimates the annual installed stock, new shipments, and end-of-life (EOL) retirements of HFC-using equipment. Using a bottom-up accounting methodology, the model calculates annual HFC consumption due to new equipment installations and the servicing of existing equipment to replenish refrigerant leakage; as well as annual HFC emissions to the atmosphere due to equipment leakage and disposition at EOL retirement. The model can be used to project future consumption and emissions over a variety of scenarios defined by the user.

The figure below shows the key inputs and outputs of the model. The following sections provide the sources of data inputs used in the HFC Emissions Model.

Figure C-1. HFC Emission Model Inputs and Outputs



C.1 Refrigerant Specifications

This section of the model defines the GWP of baseline HFC refrigerants and of potential low-GWP refrigerant alternatives. Four different GWP values are defined for each refrigerant: IPCC 4th Assessment Report (AR4) 20-year, AR4 100-year, 5th IPCC Assessment Report (AR5) 20-year, and AR5 100-year. The refrigerants listed represent the most common refrigerants in use and the most promising low-GWP alternative refrigerants for each equipment type modeled. Table C-1 provides the primary sources used to define the 20-year and 100-year GWP values for each refrigerant.

Table C-1. Sources for GWP Values

GWP Value	Source
AR4 20-year	IPCC 4th Assessment Report (2007), Table 2.14[16]
AR4 100-year	
AR5 20-year	IPCC 5th Assessment Report (2013), Table 8.A.1[17]
AR5 100-year	

- For some of the refrigerants, 20-year or 100-year GWP values are not available from the IPCC reports. For 20-year GWP values not defined in the IPCC reports, the 100-year GWP is used (as noted in the spreadsheet). For 100-year GWP values not defined in the IPCC reports, the Bitzer's Refrigerant Report 20, Table 6 is used as an alternative source.[18]
- GWP values are not defined (i.e. defined as 0) for CFC and HCFC refrigerants, since emissions of these refrigerants are not intended to be accounted for in this model.

C.1.2 Refrigerant Blend Composition Sources

- The GWP values for HFC and HFC/HFO refrigerant blends were estimated by calculating a weighted average of the GWP of the pure refrigerants comprising each blend. The source for the refrigerant blend composition is the U.S. Environmental Protection Agency (EPA) webpage "Compositions of Refrigerant Blends."[19] The sources for the 20-year and 100-year GWP values for the pure refrigerants within in the blends are listed in Table 2-2 above.

C.1.3 Refrigerant Allocation to Equipment Types

- For each equipment type, refrigerant allocations represent the portion of shipments each year containing each refrigerant. The CARB F-Gas ODS-to-HFC Transition Timeline spreadsheet (provided by NYSERDA) was the primary source used to apportion refrigerant types by equipment category for the historical period 1990–2020.
- For some equipment categories, HFC apportionments were verified through additional literature review and consultation with internal product experts.
- For future years 2020–2050, the 2020 allocation was maintained for years leading up to the year of assumed transition to a low-GWP alternative. The assignment of low-GWP refrigerants for each category are based on the current commercial availability of low-GWP alternatives for certain equipment types, or knowledge of the most promising low-GWP alternatives as described in industry research publications. For example, Guidehouse modeled the transition for residential refrigerators to R-600 and mobile AC systems to R-1234yf based on industry expectations and regulations.
- For equipment types in which the future transition to low- and ultra-low-GWP refrigerants is still uncertain, Guidehouse selected representative refrigerants with GWP values that reflect the most likely approximate GWP values of a future low-GWP refrigerant to be used in such equipment (e.g., < 10 GWP, < 750 GWP, < 1500 GWP). For example, for some equipment categories R-1234yf (with a GWP value of 1) is assigned as the max tech option as a means for representing a near-zero GWP value, even if flammability concerns or other technical limitations would prevent the use of R-1234yf itself in such equipment.

C.2 Equipment Specifications

This section of the model defines the key characteristics of each equipment category that relate to HFC emissions. These input specifications are used throughout various calculation tabs in the model.

C.2.1 Lifetime

- For most equipment types, Guidehouse used the lifetimes available in the NYSERDA *New York Standard Approach for Estimating Energy Savings from Efficiency Programs (Version 7)*, available in Appendix P.[20]
- For some of the equipment types not available in the NYSERDA report, Guidehouse used the lifetime available from CARB (used in their modeling) from the 2017 report *Estimates and Methodology used to Model Potential Greenhouse Gas Emissions Reductions in California from the Global Hydrofluorocarbon (HFC) Phase-down Agreement of October 15, 2016, in Kigali, Rwanda*, available in Table A6.[21]
- For a few equipment types (e.g., Freezers, Mini-Splits, Beverage Merchandisers), Guidehouse used lifetime data reported in the U.S. Energy Information Administration's *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies* (2018),[22] which primarily relies on data from U.S. DOE Appliance Standards rulemakings.

- For some equipment types (e.g., residential GSHP), the assigned lifetime represents the same lifetime as the other substitutes within the same main application category, despite there being a different lifetime estimate provided from one of the sources described above. To provide the capability to reflect the future electrification of buildings, the model incorporates the concept of equipment substitutions for "main applications". For example, central AC, central HP, and GSHP are categorized under the main application of "residential whole-home AC". Due to the stock accounting structure of the model, equipment types that are categorized as substitutes for the same main application must be assigned the same lifetime in order to maintain consistency among the installed stock, new shipments, and end-of-life calculations in each year. The definition of equipment lifetime has minimal impact on the calculated emissions because: 1) for most product categories, annual emissions are dominated by the leakage rate from the installed stock, which is not affected by product lifetime; 2) defining a different product lifetime would shift the future year in which new equipment placed into service in a specific year reaches end-of-life, but such a shift would not substantially change the number of units reaching end-of-life in any given year.

C.2.2 Charge Size

- For most equipment types, Guidehouse used charge size data available from CARB from the 2017 report Estimates and Methodology used to Model Potential Greenhouse Gas Emissions Reductions in California from the Global Hydrofluorocarbon (HFC) Phase-down Agreement of October 15, 2016, in Kigali, Rwanda, available in Table A3.[23]
- For equipment types not available in the CARB report, assumptions and estimates are used to fill in gaps, as noted in the 'source' column. Generally, charge sizes are assumed to be the same as other similar equipment types. For a few equipment types, charge size was taken from product specification sheets available online and verified by consulting internal product experts at Guidehouse.
- Additional research was done to estimate charge size differences for heat pumps and variable refrigerant flow heat pumps relative to air conditioners by comparing manufacturer specifications for large HVAC manufacturer products on the market. Based on this research, Guidehouse estimated that the charge size for heat pumps is 33% more than an equivalent air conditioner, and the charge size for variable refrigerant flow heat pumps is 100% more (i.e., twice the size) than the equivalent air conditioner charge size. Refer to Section 2.1.5 in the report for more information on this analysis.

C.2.3 Leak Rates and End-of-Life Loss

- For most equipment types, Guidehouse used leak rate and end of life loss rate data available from CARB from the 2017 report Estimates and Methodology used to Model Potential Greenhouse Gas Emissions Reductions in California from the Global Hydrofluorocarbon (HFC) Phase-down Agreement of October 15, 2016, in Kigali, Rwanda, available in Table A3.[24]

- For equipment types not available in the CARB report, assumptions and estimates are used to fill in gaps, as noted in the 'source' column. Generally, leak rates and end of life loss are assumed to be the same as other similar equipment types. In these cases, Guidehouse also conducted a literature review and consulted with internal equipment experts to verify findings.

C.2.3 Service Frequency

- Service frequency was derived from data available from CARB in the Estimates and Methodology used to Model Potential Greenhouse Gas Emissions Reductions in California from the Global Hydrofluorocarbon (HFC) Phase-down Agreement of October 15, 2016, in Kigali, Rwanda, available in Table A3.[25] Based on the average charge, average annual leak rate, and average charge at the end of life in the CARB resources, the service frequency assumed by CARB could be derived.
- A service frequency of 1 (every year) is assumed if no data is available to suggest otherwise. A service frequency of 0 is assigned to equipment types that are unlikely to ever be serviced (e.g. residential refrigerators).

C.2.4 Equipment Capacity

- Equipment capacity is provided as an average estimated range for each equipment type and is primarily used for informational and comparison purposes only. Equipment capacity is not directly used in downstream calculations. Capacity ranges were derived from CARB in the *Estimates and Methodology used to Model Potential Greenhouse Gas Emissions Reductions in California from the Global Hydrofluorocarbon (HFC) Phase-down Agreement of October 15, 2016, in Kigali, Rwanda*, available in Table A3.[26] These equipment ranges were also compared with the available data in the NYSERDA Residential[27] and Commercial[28] Baseline studies.

C.3 Growth Indicators

Growth indicators are used to estimate the growth in stock of each equipment type in New York State. Each equipment type is assigned to one of four different growth indicators: residential housing units, commercial business square footage, vehicle registrations (generally), and transport refrigeration vehicle registrations. For each growth indicator, a reference value was determined for a specific year, and then a historical growth rate was applied to extrapolate values for the entire historical period 1990–2020. Although some of the data sources (e.g., Census data) provide annual values that could be used directly, the model requires a constant growth rate as one of the parameters in the calculation that extrapolates the initial shipment values for year 1990 from stock estimates in year 2018 (as described further below). All of the growth indicator values are provided in the model.

C.3.1 Reference Value for Each Growth Indicator

- For residential housing units, the reference value is defined for 2018 based on data from the US Census Bureau data for New York State.[29]
- For commercial business square footage, the reference value is defined for 2018 based on data from the NYSERDA Commercial Baseline Study (Vol 1) (pages 6 and 130).[30]
- For vehicle registrations (generally), the reference value is defined for 2015 based on data from the NY Department of Motor Vehicles from the E3 Transportation Stock CLCPA.[31]
- For transportation refrigeration vehicle registrations, the reference value is defined for 2018 based on data from the CARB Emissions Inventory Methodology and Technical Support Document (page 10), which was scaled to New York State based on the ratio of population in each state.[32]

C.3.2 Historical Growth Rate

- For residential housing units, the historical growth rate for the period 1990–2020 (0.44%) was calculated as the average annual growth rate from 1990 to 2015 using data on the number of housing units in NYS from the US Census Bureau.[33] [34]
- For commercial business square footage, the historical growth rate for the period 1990–2020 was calculated as the average annual growth rate from 1990 to 2015 using data scaled down from the Mid-Atlantic from U.S. EIA's Commercial Building Energy Consumption Surveys (CBECS) from 1992, 1995, 1999, 2003, and 2012.[35] Because CBECS data is only available for certain years, gap years were extrapolated using a linear regression.
- For vehicle registrations (both general and for transportation refrigeration specifically), the historical growth rate for the period 1990–2020 was calculated as the average annual growth rate from 2007 to 2015 using vehicle registration data from the NY Department of Motor Vehicles.[36]

C.4 Equipment Stock

This section of the model provides estimates of the total stock values in New York State for each modeled equipment type. The sources for the baseline year are provided in sections 2.4.10 to 2.4.12 and the future projected stock values are calculated using the growth indicators described in section 2.3.

C.4.1 Commercial Stock

- The primary source for commercial equipment stock data is the 2018 NYSERDA Commercial Baseline Study (Vol 1).[37] The data in this study is provided as a saturation per commercial business in NY, so the total number of units of each type of equipment was calculated for 2018 by multiplying the saturation value of each equipment type by the total number of NY businesses in 2018 (367,223). For certain equipment categories that contain equipment of different sizes (e.g., small, medium, or large commercial chillers), the stock breakdown by size was approximated from the available data in the baseline study that broke out the stock proportion by equipment capacity. For a few equipment type breakdowns that were not available from the baseline study, the breakdowns were determined using data from the California equipment units available in the CEC EPIC Low-GWP NVC analysis (from the CARB TSD).
- To verify the accuracy of these stock estimates, the equipment stock for each equipment type from the NYSERDA Commercial Baseline Study was compared with the stock data from CARB and the stock data from CBECS 2012 (using the microdata tables)[38] for the Mid-Atlantic region. The data was normalized by population in those NYS, California, and the Mid-Atlantic regions in the years the data was collected for comparison.
    - Based on this analysis, the equipment numbers for refrigerated warehouses, commercial residential-style refrigerator/freezers, and refrigerated vending machines were updated by scaling the CBECS 2012 data for the Mid-Atlantic to NYS based on population.
- The number of supermarket rack refrigeration equipment units was estimated using the number of supermarkets in NYS multiplied by the average saturation per store (four per store).

C.4.2 Residential Stock

- The primary source for the residential equipment stock data is the 2015 NYSERDA Residential Statewide Baseline Study of New York State, which collected data on single-family and multifamily housing units from 2011 to 2014.[39] The data was provided as the raw survey responses with weights that were used to calculate the total equipment stock in NYS in 2014. The weighted units were divided by the total households represented in the survey (6,930,295) to estimate a saturation rate for each equipment type. Finally, these saturations were multiplied by the total number of residential households in 2014, according to US census data[40] (8,219,287) to determine the total stock values.
- To verify the accuracy of these stock estimates, the equipment stock for each equipment type from the NYSERDA Residential Statewide Baseline Study of New York State was compared with the stock data from CARB and the stock data from RECS 2015 (using the microdata tables)[41] for the Mid-Atlantic region. The data was normalized by population in those NYS, California, and the Mid-Atlantic in the years the data was collected for comparison. No additional data adjustments were found to be necessary based on this analysis.

C.4.3 Vehicle Stock

- Vehicle registration data is available from the NY Department of Motor Vehicles from the E3 Transportation Stock CLCPA.[42]
- For transportation refrigeration units, stock was estimated using data from the CARB Emissions Inventory Methodology and Technical Support Document (page 10), which was scaled from 2014 California to 2018 New York State based on the ratio of population.[43]

C.5 Saturation Rate

- Saturation rate (defined as a decimal) represents the number of equipment stock units per market growth indicator (e.g., number of refrigerators per household, or number of commercial vending machines per million square feet of commercial space). Saturation rate is defined at the "main application" level.
- The initial saturation rates were determined for the year 2018 for the commercial equipment and 2014 for the residential equipment, corresponding to the available data from the NYSERDA baseline studies in those years, as described above.
- For vehicle categories, the concept of building saturation does not apply, so the saturation rates are defined as 1.0.

Appendix D. Comparison of HFC Accounting Practices

Guidehouse conducted a literature review to assess the methodologies and assumptions of several HFC emissions accounting practices. This section provides details around HFC accounting methodologies and assumptions from various tools and models and a comparison of key assumptions across the different methodologies. Many of the methodologies and assumptions in HFC accounting methods are derived from the EPA Vintaging Model or IPCC Guidelines.

D.1 US EPA Vintaging Model (2018)[44]

D.1.1 Overview

- Within the five sectors (refrigeration and air-conditioning, foams, aerosols, solvents, and fire-extinguishing) there are 67 independently modeled end-uses. As ODS are phased out, a percentage of the market share originally filled by the ODS is allocated to each of its substitutes.
- Models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment.
- Synthesizes data from: ODS Tracking System, the Greenhouse Gas Reporting Program, and Significant New Alternatives Policy (SNAP) program. Additional published sources, conference proceedings, coordination with trade associations and companies are also referenced.
- Methodology: *Step 1* Gather historical data, *Step 2* Simulate the implementation of new, non-ODS technologies, *Step 3* Estimate emissions of the ODS substitutes. (Additional approach details: screening method, method for purchased gases, material balance method, simplified material balance method).

D.1.2 Major Assumptions/Limitations

- The model requires information on the market growth for each of the end-uses, a history of the market transition from ODS to alternatives, and the characteristics of each end-use such as charge sizes and loss rates.
- The simulation is considered to be a “business-as-usual” baseline case, and does not incorporate measures to reduce or eliminate the emissions of these gases other than those regulated by U.S. law or otherwise common in the industry. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment.
- Full public disclosure of the inputs to the Vintaging Model would jeopardize the security of the Confidential Business Information (CBI) that has been entrusted to the EPA.

D.2 CARB (2016)[45]

D.2.1 Overview

- CARB has implemented detailed inventory estimations based on comprehensive research completed by CARB staff and studies completed by CARB contractors. Historical net consumption of each ODS was first compiled at a detailed product and equipment level to establish the basis for future emissions.
- The following emission categories are included in the CARB Greenhouse Gas (GHG) Emission Inventory: Refrigeration and air conditioning (AC), aerosol propellants, insulating foam, solvents and fire protection.
- F-gases are estimated using the Tier 2 emission factor approach from the 2006 IPCC Guidelines. The Tier 2 methodology follows two general steps:
    - **Step 1.** Calculate the time series of net consumption of each individual HFC at a detailed product and equipment level as the basis for emission calculations (e.g., inventory of refrigerators, other stationary refrig./AC equipment, appliance foams, pipe insulation, etc.).
    - **Step 2.** Estimate emissions using the activity data and resulting bank calculations derived from Step 1 and either emission factors that reflect the unique emission characteristics related to various processes, products and equipment (Tier 2a) or, relevant new and retiring equipment data at the sub-application level to support a mass balance approach (Tier 2b).

D.2.2 Major Assumptions/Limitations

- Emissions were estimated using activity data, equipment specific storage capacity, maintenance and recharging assumptions, and emission factors that reflect the individual characteristics of the various equipment types, processes, and products.
- F-gas emissions are organized into ten broad categories with 29 detailed sub-categories (details in link).
- Emissions of each individual F-gas is reported by subcategory on a mass and CO_2-equivalent basis.

D.3 IPCC (2006)[46]

D.3.1 Overview

- Inventory compilers in different countries can search the IPCC Emissions Factor Database if national data is difficult to obtain.
- Contains Tier 1 A/B and Tier 2 A/B Methodologies that result in estimates of actual emissions rather than potential emissions. Approach A is emission-factor approach and Approach B is mass-balance approach.
    - **Tier 1:** data aggregation is at a more aggregated application level (refrigeration, AC, etc.). Uses composite emission factors based on weighted averages of known sub-application emission factors.

- **Tier 2:** data aggregation is at the sub-application level (e.g. categories that make up AC). Determine emission factors based on circumstances surrounding sub-applications in their specific countries.

D.3.2 Major Assumptions/Limitations

- Takes into account time lag between consumption of ODS substitutes and emission
- Accounts for the potential development of banks (amounts of chemical accumulated throughout lifecycle).
- Includes assumptions for product lifetimes, first year losses, annual losses, default emission factors, end of life emission %, charge (when applicable), activity data, and uncertainty assessment, on the application and sub-application level.

D.4 American Carbon Registry (2015)[47]

D.4.1 Overview

- Sectors eligible under this methodology are 1) the use of reclaimed HFC refrigerants and 2) use of zero/low-GWP alternative technologies.
- This methodology is based on a robust data set, including United Nations Environment Programme, Technical Options Committee for Refrigeration, Air Conditioning and Heat Pumps, the U.S. EPA Vintaging Model, the U.S. EPA GreenChill Partnership, the CARB Offsets Methodology for Destruction of Ozone Depleting Substances, and the 2006 IPCC Guidelines.
- Avoided emissions generated under this Methodology from the use of reclaimed HFC refrigerants would be considered within direct emissions.
- For the reclaimed HFC refrigerant Methodology, the baseline emissions are defined for a specific HFC refrigerant by the weighted-average emission rate for the equipment in which that refrigerant is typically used.
- Additional references: Methodology for Advanced Refrigeration Systems (2018),[48] Methodology for Certified Reclaimed HFC Refrigerants (2018).[49]

D.4.2 Major Assumptions/Limitations

- Uses a conservative estimate for R-22 reclaim rate (8.9%).
- Average annual emissions rates for major refrigeration and AC end-use categories come from US EPA Vintaging Model and 2006 IPCC Guidelines.
- Under any scenario, percentage of supermarkets in the US with advanced, low-GWP refrigeration systems is negligible.
- For refrigerants that are predominantly used in 1 application, the average emission rate for that refrigerant is the average emission leak rate for that application.

D.5 United Nation Framework Convention on Climate Change (UNFCCC)[50]

D.5.1 Overview

- Annex 1 parties should use the methodologies provided in the 2006 IPCC Guidelines and report Actual Emissions of HFCs by chemical.
- Non-Annex 1 parties are encouraged but not required to express HFC emissions as either potential or actual.
- Potential Emissions should be estimated using the Tier 1 approach of IPCC Guidelines.
- Actual Emissions should be estimated using the Tier 2 approach of IPCC Guidelines and reported on a gas-by-gas basis.

D.5.2 Major Assumptions/Limitations

- Base year is typically 1990 within UN programs.
- The inventory data are provided in the annual GHG inventory submissions by Annex I Parties and in the national communications and biennial update reports by non-Annex I Parties.[51]

D.6 State Inventory Tool (2018)[52]

D.6.1 Overview

- EPA's State Inventory Tool (SIT) is an "top-down" interactive spreadsheet model designed to help states develop GHG emissions inventories and provides a streamlined way to update or complete an inventory.
- There is no input data required for consumption of substitutes for ozone-depleting substances because emissions of HFCs from ODS substitutes can be estimated by apportioning national emissions to each state based on population. Therefore, the emissions factors and activity data for these sources are not required.

D.6.2 Major Assumptions/Limitations

- The methods used and the sectors covered are the same as those in the U.S. GHG Inventory.[53]
- The SIT only allows scaling of HFC emissions based on state population.
- No inputs are required for consumption of ODS substitutes, only for HCFC-22.

D.7 Comparison of Key HFC Accounting Models

Table D-1. Comparison of Assumptions for HFC Accounting Models

Assumption	EPA Vintaging Model (2018)	CARB (2016)	IPCC (2006)	NYS (2019)
1. Emission Rate	EPA estimates, based on EPA Vintaging Model Version 4.4, recent market research, and expert judgement.	Emission factors that reflect the individual characteristics of the various equipment types, processes, and products are referenced from various sources.	Can be derived from actual measurements of products or equipment at a national level during various phases of their lifecycle (country-specific) or can be inferred from wider regional or global sub-applications (default). The most significant emission factors are included in the Emissions Factor Database (EFDB) administered by IPCC.	Follows CARB methodology.
2. GWP Values	100-year values from IPCC Fourth Assessment Report (AR4) (source).	100-year values from IPCC AR4 (source).	Most recent values - IPCC AR5.	Follows CARB methodology.
3. Equipment Stock Estimates	Market for each equipment type is assumed to grow independently, according to annual growth rates.	Uses EPA Vintaging model.	Detailed accounting for imports and exports of refrigerant and equipment details included in link. Inventory compilers should account for imports and exports of both chemicals and equipment. This will ensure that they capture the actual domestic consumption of chemicals and equipment.	Emission stocks scaled from CA inventory using USCA tool on a $MMTCO_2e$ basis Most categories scaled by population, some scaled by households and technology penetration. Light duty vehicles scaled by vehicle registrations.

Table D-1 continued

Assumption	EPA Vintaging Model (2018)	CARB (2016)	IPCC (2006)	NYS (2019)
4. Size Assumption per Equipment	Primary research and Confidential Business Information (CBI)	New equipment and materials are assumed to use the same amount and type of F-gas as used in baseline years and previous years, until adopted regulations prohibit the use of specific F-gases in new equipment and materials. Example: equipment profiles for 12 specific types and sizes of refrigeration and AC equipment were developed using SCAQMD Rule 1415 reporting data from approximately 6,000 systems in 2,000 facilities over reporting years. Each profile includes refrigerant types used, average refrigerant charge size, and average annual loss. Some profiles for HFC use in refrigeration and AC equipment were augmented by U.S. EPA Vintaging Model estimates.	Estimates for charge (kg) for refrigeration and air-conditioning systems are based on information contained in UNEP RTOC Reports. In the given ranges, use a lower value for developed countries and high value for developing countries.	Follows CARB methodology
5. Annual Leak Rate per Equipment	Primary research and CBI	Assume a linear reduction each year from 2011 to 2021 until the lower limit of 10 percent leak rate is achieved. Annual leak rates and equipment end-of-life loss rates remain the same as baseline years, unless acted upon by exterior forces such as regulations that have been adopted at the state or national level. Leak rate assumptions are checked against actual reported data to CARB Refrigerant Management Program, then revised and updated annually.	Annual leakage from the refrigerant banks represents fugitive emissions, i.e., leaks from fittings, joints, shaft seals, etc. but also ruptures of pipes or heat exchangers leading to partial or full release of refrigerant to the atmosphere. Information contained in UNEP RTOC Reports.	Follows CARB methodology
6. Lifetime	Primary research and CBI	The equipment end-of-life (EOL) retirement for a given year is modeled using an appliance and equipment survival curve based on equipment retirement ages. Data on the retirement ages of very large commercial refrigeration and AC equipment were not available, so it was assumed that commercial equipment follows a similar functional life and survival curve as smaller equipment.	Estimates for equipment lifetime for refrigeration and air-conditioning systems are based on information contained in UNEP RTOC Reports. In the given ranges, use a lower value for developed countries and high value for developing countries.	Follows CARB methodology

Table D-1 continued

Assumption	EPA Vintaging Model (2018)	CARB (2016)	IPCC (2006)	NYS (2019)
7. End of Life Leakage	Primary research and CBI	The normal distribution of functional life and retirement age, or "survival curve", was applied to the emission equations for all refrigeration and AC equipment.	Estimates for end of life emission factors for refrigeration/AC systems are based on info in UNEP RTOC Reports Methodology and values for recovery efficiency and initial charge remaining used to calculation end of life leakage included in link.	Follows CARB methodology
8. Other	The HFC default refrigerant is the one assumed to represent the single highest share of installed refrigerants for a particular equipment type according to the U.S. EPA Vintaging Model.	F-gas emissions are assumed to increase proportionally to population, unless data indicates otherwise. For years 2012 and later, they use the California Department of Finance (DOF) population projections showing a 0.75 percent annual growth rate in California through 2030.	N/A	Follows CARB methodology

Endnotes

1 These reports can be found at https://climate.ny.gov/Climate-Resources

2 GHG emissions under the Climate Act use AR-5, 20-year GWP values. 2020 emissions are 9.6 MMT CO2e when measured using AR-4, 100-year GWP

3 6 NYCRR Part 496 Statewide GHG Emission Limits

4 New York State Climate Act https://climate.ny.gov/

5 New York State Climate Action Council https://climate.ny.gov/Climate-Action-Council

6 NYS adopted prohibitions on new equipment and products previously promulgated by the U.S. Environmental Protection Agency Significant New Alternatives Policy (SNAP) Program. https://www.dec.ny.gov/regulations/119032.html

7 The October 14, 2020 Notice of Action adopted regulatory provisions previously promulgated by the U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) Program, which were partially vacated in 2017. This rule adopted prohibitions on certain HFC substances in the specific end-uses identified by the EPA as having safe and available alternatives. https://www.dec.ny.gov/regulations/119032.html

8 These reports can be found at https://climate.ny.gov/Climate-Resources

9 See Appendix A and Appendix C for details on equipment stock estimates and other input assumptions.

10 New York State Joint Utilities. 2019. "New York State Technical Resource Manual: New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs." Version 7. April 15, 2019. https:/www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/TRM%20Version%207%20-%20April%202019.pdf

11 This project focuses on consumption and emissions of HFCs rather than for CFCs and HCFCs. The Guidehouse model was designed to track the installed stock of HVAC&R systems using ODS refrigerants starting in 1980 to accurately model the overall stock of equipment and the anticipated shipments and demands for HFC models following ODS restrictions in the 1990s. To accurately model the consumption and emissions for ODS, the model would need to be updated to begin tracking ODS installed base and shipments much earlier than 1980 to capture at least one complete lifetime of all HVAC&R equipment categories by the 1990s. Furthermore, ODS refrigerants are not tracked in most GHG inventories because of the assumed global phasedown in the Montreal Protocol.

12 EPA established a "credit" program to incentivize certain air conditioning technologies in mobile vehicles as part of a final rule published in the Federal Register on May 7, 2010. See 75 FR 25323.

13 U.S. Environmental Protection Agency. 2020. "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2018." April 2020. https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf

14 This analysis relied on expert interviews to project how foam consumption and emissions will change over time and does not break out the specific HFC alternatives in the same manner as for HVAC&R equipment. Furthermore, the analysis does not consider any health impacts related to the use of HFOs or other HFC alternatives for foams and other end-use sectors.

15 6 NYCRR Part 496 Statewide GHG Emission Limits

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[24] Ibid

[25] Ibid

[26] Ibid

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