Market Characterization of the U.S. Aerosols Industry, U.S. Motor Vehicle Air Conditioning Industry, U.S. Commercial Refrigeration Industry, and U.S. Foams Industry

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Acronyms and Abbreviations

CAA	Clean Air Act
CFC	chlorofluorocarbon
CG	compressed gases
CO_2	carbon dioxide
COP	coefficient of performance
CRP	Cooperative Research Program
CSPA	Consumer Specialty Products Association
DOE	Department of Energy
DPI	dry powder inhaler
EC	European Commission
EPA	Environmental Protection Agency
EU	European Union
FMEA	Failure Mode and Effect Analysis
GHG	greenhouse gas
GM	General Motors
GVWR	gross vehicle weight rating
GWP	global warming potential
HC	Hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbons
HFE	hydrofluoroether
HFO	hydrofluoroolefin
MDI	metered dose inhalers
MT	metric ton
MVAC	motor vehicle air conditioner
NHTSA	National Highway Traffic Safety Administration
NPRM	notice of proposed rulemaking
OCF	one component foams
ODS	ozone-depleting substance
OEM	original equipment manufacturer
SAE	Society of Automotive Engineers
SIP	State Implementation Plan
SNAP	Significant New Alternative Policy
SUV	sports utility vehicle
VOC	volatile organic compound
XPS	extruded polystyrene

Executive Summary

This report characterizes the current state of the U.S. market for the industries that are anticipated to be impacted by EPA's Final Rule "Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Policy Program." This report includes information on the aerosols industry, the light-duty motor vehicle air conditioning industry, portions of the commercial refrigeration industry, and the foams industry. Historically, each of these industries has relied on ozone depleting substances (ODS), which are substances that destroy the stratospheric ozone layer that shields the Earth from the sun's harmful ultraviolet radiation. Each chapter of this document characterizes one of these industries in terms of the market size and companies, historical and current use of ODS and alternatives, the availability of climate-friendly alternatives, and barriers to transitioning to those alternatives.

In support of the Notice of Proposed Rulemaking (NPRM), EPA made available four individual market characterizations: "Market Characterization of the U.S. Aerosols Industry," "Market Characterization of the Motor Vehicle Air Conditioning Industry," "Market Characterization of the U.S Commercial Refrigeration Industry," and "Market Characterization of the U.S. Foams Industry." These documents are available at regulations.gov in docket EPA-HQ-OAR-2014-0198. This report is a compilation of the four individual market characterizations and the content has been updated to reflect information provided to EPA during the public comment period.

The U.S. Aerosols Industry

1. Introduction

Aerosols use liquefied or compressed gas to propel active ingredients in liquid, paste, or powder form and many also contain a solvent. The propellant is emitted during use. Historically, a variety of propellants and solvents have been available to formulators. Hydrocarbons (HCs) (e.g., propane, isobutane, blends) and compressed gases (e.g., CO_2, N_2O, compressed air) have long been used. Prior to 1978, CFCs were predominantly used by the aerosol industry. CFCs were excellent propellants because of their ability to produce a fine spray; they are non-flammable, could be stored under low pressure, and, for the most part, do not react with other ingredients.[1] In 1973 chemists Sherwood Rowland and Mario Molina began studying effects of CFCs on the earth's atmosphere. They discovered that CFCs were stable enough to migrate to the stratosphere and that the chlorine atoms contained in these molecules could break down large amounts of ozone in the stratosphere. In 1975, a major manufacturer of household aerosol products eliminated CFC propellants over concerns for depletion of the Earth's ozone layer. In 1978, the United States banned CFC propellants.

As a result of the ban on CFC propellants, consumer products were reformulated or replaced with a variety of not in kind substitutes, such as pump sprays and solid or roll-on deodorants, and alternatives such as HCs, compressed gases, oxygenated organic compounds, and HCFCs. However, HCFCs are controlled substances under the *Montreal Protocol on Substances that Deplete the Ozone Layer*, and subject to regulation under the CAA including a phaseout of production and import. Sale and distribution of aerosols using HCFCs was banned in 1994 with few exceptions.

HCFC propellants have been or are being replaced with a range of alternatives including HFCs (e.g., HFC-134a, HFC-152a), HCs, compressed gases, and not-in-kind alternatives. In solvent uses, CFC and HCFCs have been or are being replaced by HFC-4310mee, HFC-365mfc, HFC-245fa, HCs, oxygenated organic compounds, and hydrofluoroethers (HFEs). Other low-GWP fluorinated compounds are in use or under development, including HFOs. HFO-1234ze is being used in the aerosol industry.

The remainder of this chapter characterizes the U.S. aerosol sector in terms of market size, key market players, historical and current propellant and solvent use, and the availability of alternative propellants and solvents.

2. Market Characterization

The U.S. aerosol industry is characterized by many product types and applications involving multiple companies and markets. [2] It also can be generally characterized as a North American market rather than a global market. Finished products are not complex to manufacture and require little labor; therefore, domestic production is more affordable than shipping products from overseas (Falcon Safety 2007); however, there has been an increasing amount of exports of aerosol products from major export hubs, such as the European Union,

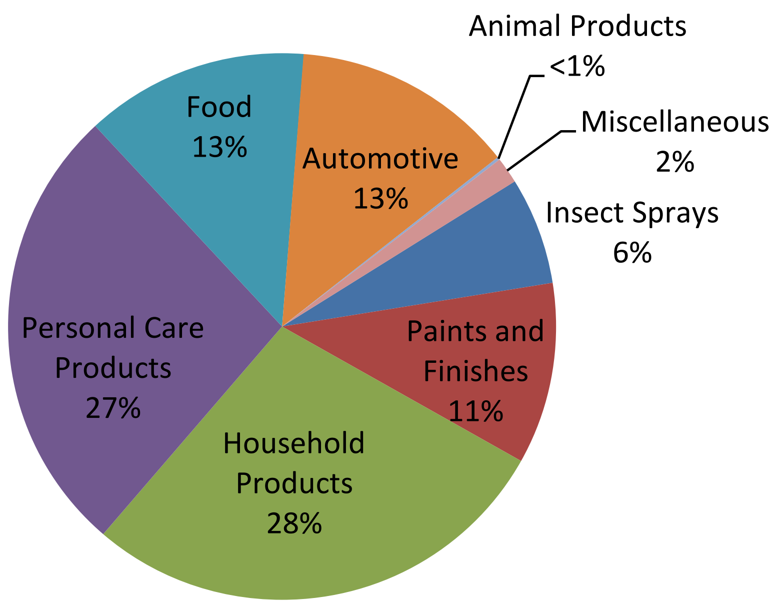
[1] An exception is CFC-11, which hydrolyzes to produce hydrochloric acid (HCl). In aerosol formulations containing water, CFC-12 or a mixture of CFC-12 and CFC-114 was often used (UNC 2014).

[2] NAICS codes were used to the extent possible to determine economic data about the aerosol market; however, the NAICS codes also include a large majority of products which are not aerosols. More detailed NAICS codes (8 to 10 digits) were researched when available.

Argentina, and China (EC 2001; Midwest Aerosol Association 2014). Additionally, the U.S. aerosol market is subject to volatile organic compound (VOC) regulations, and as a result, the United States uses larger volumes of HFCs in aerosol propellants than other markets in the world.

The aerosol market in the United States continues to grow. According to the *2011 Aerosol Pressurized Products Survey* conducted by the Consumer Specialty Products Association (CSPA), approximately 3.8 billion units were filled in 2011 by U.S. producers, which was 36 million units more than the total units filled in 2010 (CSPA 2012). Approximately $15 billion in annual revenue is generated from the sale of aerosol products nationwide. As shown in Figure 1, household and personal care products constitute about half of the aerosol units filled in 2011.

Figure 1: Number of Aerosol Units Filled in 2011 in the United States (CSPA 2012)



The remainder of this section is organized into the three aerosol product categories—consumer, technical, and medical. Information was gathered using a variety of sources, including, market profiles, historical research, and information provided by the aerosol and chemical manufacturing industries.

2.1. Overview of Aerosol Products

The U.S. aerosol industry is comprised of the following three product categories:

- **<u>Consumer Aerosols</u>** – this grouping consists of a wide variety of products using aerosol packaging for personal and household use. Examples include personal care products such as cosmetics, hairspray, body sprays, and deodorants are covered by this category along with a wide variety of other products such as tire inflators and other automotive products (e.g., auto lubricants, brake cleaners); noise horns and safety horns; animal repellants; spray adhesive with various applications; household and office cleaning products; hand-held spray cans; eyeglass and keyboard dusters; consumer freeze sprays (e.g., chewing gum or excrement removal); room fresheners; food dispensing products; and novelty aerosols (e.g., artificial snow, plastic string, noise makers, and cork poppers).
- **<u>Technical Aerosols</u>** – this grouping consists of highly specialized products for sale and use solely in commercial and industrial applications that are not for normal day-to-day use. Technical aerosols

include (but are not limited to) those products exempted from the non-essential products bans under EPA regulations at 40 CFR Part 82, Subpart C.[3] Products include industrial cleaners (e.g., electronic contact cleaners, flux removers, degreasers); pesticides (e.g., certain wasp and hornet sprays, aircraft insecticides), mold release agents, and certain dusters (e.g., for photographic negatives, semiconductor chip manufacture, specimens for observation under electron microscope); and spinnerette lubricant/cleaning sprays. Other miscellaneous products such as industrial spray paints and document preservation sprays are also considered in this category.

- **Medical Aerosols** – this grouping consists of products that are used for healing or medicinal purposes. These include, but are not limited to, products regulated by the U.S. Food and Drug Administration. Medical aerosols include metered dose inhalers for the treatment of asthma and chronic obstructive pulmonary disease, calamine spray, anti-fungals, wart treatments, wound care sprays, freeze or coolant spray for pain relief, spray-on "liquid" bandages, and products for removing bandage adhesives. Although aerosol propellants are used in metered dose inhalers (MDIs), MDIs are not explored in this market characterization because they are not affected by this final rule.[4]

Some applications may be represented in more than one of the above categories. For example, insect sprayers have parallel lines of products with similar end-uses in both technical and consumer applications, one to be used by line workers around electrical lines (i.e., a technical aerosol), and another as household insect repellant (i.e., a consumer aerosol). Additionally, freeze sprays can be a consumer aerosol (e.g., food freeze sprays, animal waste sprays) or a medical aerosol (e.g., wart removers, numbing sprays).

According to the CSPA, around 400 aerosol product-related companies exist in the United States, 12.5% of which are in California (AboutAerosols 2013). These companies include those producing aerosol components (e.g., valves, cans, propellants, and other ingredients), formulating and marketing products in aerosol form, or filling aerosol products (AboutAerosols 2013). An estimated 138 companies have facilities with filling lines in the United States (CSPA 2012).

2.2. Consumer Aerosols

Demand for consumer aerosols in the United States is most concentrated within household products, which continue to rank as the highest production product category, reporting a 2.4% increase from 2010 to 2011 (CSPA 2012). This trend is also true globally; about 90% of the 6.8 billion metal aerosol cans sold worldwide in 2011 were in the beauty and household markets with 27% of sales for household care and 69% of sales for applications in deodorant sprays, insecticides, air fresheners and styling agents (Downey 2012). A number of consumer aerosol products meet niche demands, with overall volume being very small relative to other consumer aerosol products (e.g., boat safety horns). Such products may be purchased but not used for a long period of time (e.g., years), as they may be stored for emergency uses only. Some of the larger end-uses of consumer aerosols are described with further detail in Table 1.

[3] Under the non-essential products ban, all aerosol products, pressurized dispensers and foam products containing, or manufactured with, CFCs and HCFCs—except those specifically exempted by the regulations and those that are listed as essential medical devices by the Food and Drug Administration, at 21 CFR 2.125(e)—are banned from sale and distribution in interstate commerce in the U.S.

[4] CFC-based propellants have historically been used in MDIs for inhalation therapy. A gradual shift toward the use of HFC propellants, including HFC-134a and HFC-227ea, began in the early 1990s. Dry powder inhalers (DPIs) are an alternative to MDIs; these delivery systems do not require a propellant and have been in use for more than 20 years. Although DPI use is on the rise and accounts for about one-third of all inhaled medication, it is recognized that both DPIs and HFC MDIs play important roles in inhalation therapy.

Table 1. Market Characterization for Consumer Aerosols

Product	Major Producers	Key Market Information	Propellants[1]	Solvents[1]
Air Fresheners	• Henkel AG & Co. • KGaA • Procter & Gamble • Reckitt Benckiser Inc. • SC Johnson & Son	• U.S. market grew by 3.4% in 2011 (Research and Markets 2012a) • Value of $1.8 million with total revenue of $770 million • Pump/aerosol air fresheners account for 44% of market's total value in 2011 (Research and Markets 2012a)	• HCs • HFC-152a • Not-in-kind • Compressed gases (CGs)	U
Deodorants/ Anti-perspirants	• Procter & Gamble • Unilever • Colgate Palmolive • Dial Corporation • Lever Brothers • Revlon • Church and Dwight	• Spray deodorants account for 14% of North America's deodorant sales (Downey 2012). • U.S. deodorants market generated total revenues of $2.5 billion in 2009, at a compound annual growth of 4.8% from 2005-2009 (Research and Markets 2012b)	• HCs • HFC-152a • Not-in-kind •	U
Household Cleaners[5]	• Procter & Gamble • Chase Products Co. • The Clorox Company • SC Johnson & Son • Church and Dwight • Reckitt Benckiser Inc.	• Household products continue to rank as the highest production product per unit of aerosol cans filled, reporting a 2.4% increase from 2010 to 2011 (CSPA 2012)	• HCs • CGs • Dimethyl ether	U
Hair Spray	• Alberto-Culver Company • Kao Brands • Procter & Gamble • Unilever	• Approximately 303 million aluminum and steel containers of hair spray were filled in 2011 as reported by 97 U.S. company facilities (CSPA 2013) • In 1999, HFC-152a was used in approximately 31.7 million hair sprays based on a review of 62 products (ICF 1999) • Pump sprays account for 44% of the market (HHS 2013)	• HCs • HFC-152a •	U
Tire Inflators	• ITW Global Brands • Valvoline, Co. • Radiator Specialty Company • Warren Distribution, Inc. • Hutchinson Tires	U	• HCs • Dimethyl ether HFC-134a	U
Brake Cleaners	• Sprayaway, Inc. • Trak Auto Corporation	U	• CO_2	• Perchloro-ethylene

[5] This category in the CSPA survey contains a large number of products, including room deodorants and disinfectants, cleaners for glass, oven, rug, fabric, wall, tile etc., laundry products, waxes and polishes, and other household products (e.g., shoe polishes, dyes, leather dressings, fuels, drain openers, antistatic sprays, caulking and sealing compounds).

Product	Major Producers	Key Market Information	Propellants[1]	Solvents[1]
Safety Horns	• Falcon Safety	• According to Falcon Safety, signal horns do not use HFC-152a because of safety concerns; HCs are safer for these applications than HFC-152a. • One manufacturer makes about 100,000 horns per year and 100,000 refills a year (Falcon Safety 2007)	• HCs • HFC-134a • HFO-1234ze	U
Dusters	• Falcon Safety • Sprayaway	• The duster spray market has increased steadily with the advent of digitalization in the United States, but is now a mature market (Falcon Safety 2007) • One manufacturer makes 500,000 – 1 million cans (10 ounces) per year charged with HFC-134a and 11 million cans per year charged with HFC-152a (Falcon Safety 2007) • CSPA estimated that in 2008, approximately 1,300 metric tons (MT) of HFC-134a (14%) and 8,300 MT of HFC-152a (86%) were used as propellants in dusters (CSPA 2008).	• HFC-134a • HFC-152a • HCs • Dimethyl ether	Not Applicable

U indicates that information is not readily available.

[1] Based on production of new units in the United States in 2014

2.3. Technical Aerosols

Many of the products within the technical aerosols category, defined above, including aircraft maintenance products, wasp and hornet sprays, and spinnerette lubricant sprays, are highly specialized products that fill niche market demands. Table 2 below presents a summary of the major producers, historically used propellants and solvents, and currently used propellants and solvents for commonly-used technical aerosols.

Table 2: Market Characterization for Technical Aerosols

Product	Major Producers	Key Market Information	Propellants		Solvents	
			Historical	Current (2014)	Historical	Current (2014)
Degreasers	• CRC Industries • ITW, Inc. • Micro-Care • Miller-Stephenson • Price-Driscoll Corporation • SprayOn, Inc. • Zep Commercial	U	• CFC-11/CFC-12 mixture • Methyl chloroform	• HFC-134a • HFC-152a • HCs • Compressed gases	• CFC-11 • CFC-113 • HCFC-225ca/cb	• Chlorinated solvents • *trans*-Dichloroethylene • HFC-43-10mee • HFC-365mfc • HFC-245fa • HFE-7100 • HFE-7200 • n-Propyl bromide • Dimethyl ether • Petroleum distillates

Product	Major Producers	Key Market Information	Propellants		Solvents	
			Historical	Current (2014)	Historical	Current (2014)
						• Oxygenated organic compounds
Aircraft Maintenance Products	• 3M Company • GLI Aviation Products • ITW, Inc. • LHB Industries	• Non-flammability is a critical characteristic	• HCFC-22 • CO_2	• CO_2 • Not-in-kind	• HCFC-141b	• HFE-7100 and blends • HFC-43-10mee • *trans*-Dichloro-ethylene • Not-in-kind • Petroleum distillates • Oxygenated organic compounds
Wasp and Hornet Sprays[6]	• Amrep, Inc. • LTC Products	U	• HCFC-22 • CO_2 • HCs	• CO_2 • Nitrogen	• Methyl chloroform	• Petroleum distillates • Water
Spinnerette Lubricant Sprays[7]	• ALFA • G. D. Silicones Tania International • ITW, Inc. • Price-Driscoll Corporation	• Specialty product with only four manufacturers – small percentage of the product line • In 1998, one company was selling 20,000 cans per year and another manufactured 100,000 cans per year (ICF 1998).	• CFC-12 • HCFC-22	• HFC-134a	• CFC-114	• n-Propyl bromide • Dimethyl ether • Methyl siloxanes
Brake Cleaners	• Sprayaway, Inc. • Trak Auto Corporation	U	U	• CO_2	• Methyl chloroform	• Perchloroethylene

[6] Wasp and hornet sprays are often used by industrial users, such as public utility workers, for use on high-tension power lines.
[7] Spinnerettes are used for the production of synthetic fibers (e.g., nylon). They are steel structures with many tiny holes through which melted resin is passed to form a spun fiber. Lubricants are applied to the spinnerette to facilitate spinning and prevent the fibers from sticking to the accumulated resin on the block (ICF 1998).

Product	Major Producers	Key Market Information	Propellants		Solvents	
			Historical	Current (2014)	Historical	Current (2014)
Flux Removers[8]	• CRC Industries • ITW, Inc. • Micro-Care • Miller-Stephenson • Petroferm, Inc.	U	• CFC-12	• HFC-134a	• CFC-11 • CFC-113 • Methyl chloroform • HCFC-141b • HCFC-225ca/cb	• HFC-4310mee • HFC-245fa • *trans*-Dichloro-ethylene • Chlorinated solvents • n-Propyl bromide • Oxygenated organic solvents
Document Preservation Sprays[9]	• Preservation Technologies	U	• CFC-12 • HCFC-22	• CO_2 • HCs	• CFC-113 • HCFC-141b	• Petroleum distillates
Dusters[10]	• CRC Industries • Falcon Safety • MG Chemicals • SprayOn, Inc.	U	U	• HFC-134a	Not applicable	Not applicable
Lubricant Sprays[11]	• Amrep, Inc. • Price-Driscoll Corporation	U	U	• HCs • CO_2 • Nitrogen	• HCFC-141b	U
Mold Release Agents	• Amrep, Inc. • Price-Driscoll Corporation • Sprayon	U	• CFC-12 • HCs • CO_2	• HCs • CO_2 • HFC-134a • not-in-kind	• CFC-11 • CFC-113 • HCFC-141b	• Methylene chloride • Perchloroethylene • HCs • Oxygenated organic solvents • Water

U indicates that information is not readily available. Sources: ICF (1998); CSPA (2008); HHS (2013).

2.4. Medical Aerosols

Limited information is available regarding the market size for medical aerosols, including liquid bandages, freeze sprays (i.e., wart removers), calamine sprays, anti-fungal sprays, and bandage adhesive and remover. There are not-in-kind alternatives currently available for most of these medical aerosols, including lotions and pump sprays; however, some medical aerosols rely on the cooling effect of the aerosol propellant evaporating off of

[8] Flux removers are used to clean excess flux and solder residue from circuit boards and electrical components.

[9] Document preservation sprays are deacidification sprays that neutralize the acid in paper that causes paper to weaken and become brittle over time.

[10] Dusters that fall under the technical aerosols category include more specialized dusters used for applications such as photographic negatives, semiconductor chip manufacture, and specimens for observation under electron microscope.

[11] Lubricants reduce friction, heat, and wear when applied to the surfaces between moving parts. They are mainly used to repair and maintain electronic equipment and reduce friction between mechanical parts. Cleaner lubricants remove dirt and dust while simultaneously applying a protective layer of grease on a given surface (ICF 1998). Examples of applications include aircraft maintenance and electrical, electronic or photographic equipment.

skin (e.g., freeze sprays). Table 3 provides a summary of the major producers and gases historically and currently used as propellants and solvents in medical aerosols, as available.

Table 3: Market Characterization Summary for Medical Aerosols

Product	Major Producers	Key Market Information	Propellants		Solvents	
			Historical	Current	Historical	Current
Liquid Bandages	• Amerisource Bergen Corporation • Johnson & Johnson Consumer Companies, Inc. • NMS Technologies • Prestige Brands, Inc.	U	Not applicable	• HCs • not-in-kind	U	• Oxygenated organic solvents
Freeze Sprays[12]	• Merck & Co., Inc. • Prestige Brands, Inc.	U	• CFCs	• HCs • Liquefied petroleum gas • Dimethyl ether • not-in-kind	U	• Oxygenated organic solvents
Calamine Spray	• Johnson & Johnson Consumer Companies, Inc.	U	• CFC-11/12 mixture • CFC-12 • HCFC-22	• HCs • Dimethyl ether • not-in-kind	• Methylene chloride • HCFC-141b	• Oxygenated organic solvents
Anti-fungal Sprays	• MSD Consumer Care, Inc.	U	• CFC-11/12 mixture • CFC-12 • HCFC-22	• HCs • Dimethyl ether • not-in-kind	• Methylene chloride • HCFC-141b	• Oxygenated organic solvents
Bandage Adhesive and Remover	• ARI • Medline Industries, Inc. • Pac-Kit Safety Equipment	U	• CFCs	• HCs • DME • not-in-kind	• CFC-113	• Oxygenated organic solvents

Sources: HHS (2013); Good Guide (2013); EPA (2013a); Proctor & Gamble (1973); EPA (1990); Gertrude Fisher (1978)
U indicates that information is unavailable.

3. Sector Background

Historically, a variety of propellants and solvents have been available to aerosol formulators. While HCs (e.g., propane, isobutane, blends) and CGs (e.g., CO_2, N_2O, compressed air) have always had a market presence, before 1978, CFCs and other ODS were the predominant propellants and solvents used by the aerosol industry because of their excellent mixing, solvating, and dispersing properties. CFC-12 was the most popular propellant while other CFCs (e.g., CFC-11 and -113) and methyl chloroform were often used as solvents in aerosols. CFCs were excellent as propellants because of their ability to produce a fine spray; they were non-flammable, could

[12] Freeze sprays include both wart removing freeze sprays and topical coolant sprays for pain alleviation.

be stored under low pressure, did not react with other ingredients, and were safe to use. CFCs were also excellent solvents because they were effective at dissolving active ingredients used in aerosol products.

In response to the 1978 ban, many consumer products previously using CFCs were reformulated successfully to use non-ODS propellants and solvents or were replaced by not-in-kind alternatives, such as pump sprays or solid and roll-on deodorants. The market trended toward the use of these not-in-kind products, which make up an important share of the market in household and industrial products; however, not-in-kind products often present "trade-offs" to manufacturers in terms of cost, effectiveness, safety, and environmental properties (IPCC 2005), and the number of aerosol products used in the United States continues to grow. In-kind aerosol propellant alternatives also emerged into the market in response to the 1978 ban including HCFCs—notably HCFC-22 as a propellant, and HCFC-141b and HCFC-225ca/cb as solvents—in addition to HCs, compressed gases, and oxygenated organic compounds (e.g., alcohols, ketones, esters).

Section 610 of the 1990 CAA Amendments established the nonessential product bans which addressed most of the remaining uses of CFCs and HCFCs in aerosols and pressurized dispensers.[13] The Nonessential Product Bans in 1993 and 1994 prohibited the sale, distribution, or offer for sale or distribution of all CFC-containing and HCFC-containing aerosols except those specifically exempted. In establishing these bans, the EPA considered the purpose or intended use of the product, the technological availability of alternatives, issues of safety and health, and other relevant factors[14]. Some uses of CFCs in aerosols (such as solvents, active ingredients, or sole ingredients) and certain uses of CFC-based aerosol propellants were exempted from the ban given the lack of alternatives available at the time.

In the 1990s, HCFC propellants began to be replaced with high-GWP HFCs—including HFC-134a—as well as a variety of lower or no global warming potential alternatives, such as HCs, compressed gases, not-in-kind alternatives, and HFC-152a. Similarly, HCFC solvents also began to be replaced by HFC-4310mee, HFC-365mfc, HFC-245fa, HCs, oxygenated organic compounds, and HFEs. The industry overcame technical hurdles with HFCs and HFEs by blending these compounds with substances such as trans-1,2-dichloroethylene to increase solvency. Trans-1,2-dichloroethylene, commonly referred to as "trans," is an aggressive solvent. Because of this characteristic, and because of its flammability, trans is usually combined with other solvents, such as HFCs and HFEs, to form effective azeotropes that are less flammable and less aggressive on precision metal and electronics parts.

Additionally, the U.S. aerosol market is using a larger volume of HFCs in aerosol products relative to aerosol markets globally due to continuously evolving state and federal regulations for VOCs that require manufacturers to limit the amount of VOC (e.g., HCs) in their formulations for various locations of the country. HFCs, such as

[13] Products still using CFCs at the time included plastic party streamers, noise horns (e.g., marine safety noise horns, sporting event noise horns, personal safety noise horns), and cleaning fluids for noncommercial electronic and photographic equipment (e.g., solvent wipes, keyboard dusters, flux removers, and tape and computer disk head cleaners).

[14] EPA exempted the following products from the nonessential product bans: Aircraft pesticides; Medical devices listed in 21 CFR 2.125(e); Lubricants, coatings, or cleaning fluids for aircraft maintenance containing CFCs or HCFCs as solvents; Lubricants, coatings, or cleaning fluids for electrical, electronic or photographic equipment containing CFCs or HCFCs as solvents; Mold release agents containing CFCs and HCFCs as solvents and mold release agents containing HCFC-22 as a propellant; Spinnerette lubricant/cleaning sprays containing CFCs or HCFCs as solvents and/or propellants; Document preservation sprays containing CFCs and HCFCs as solvents; Document preservation sprays containing CFCS or HCFCs as propellants for use on thick books with coated or dense paper, and tightly bound documents, only; Wasp and hornet sprays containing CFCs or HCFCs for use near high-tension power lines only; Lubricants for pharmaceutical and tablet manufacture; Gauze bandage adhesives and adhesive removers; and Red pepper bear repellent sprays which contain CFC-113 as the solvent but which contain no other CFCs.

HFC-152a, are exempt from the definition of VOC in regulations under the CAA addressing the development of State Implementation Plans (SIPs) to attain and maintain the national ambient air quality standard for ozone (40 CFR 51.100(s)), and therefore, can be suitable alternatives to VOCs in states (or municipalities) with VOC restrictions.

VOC regulations often drive propellant and solvent formulation choices in aerosol products. States that regulate the VOC content in consumer products include California, the Ozone Transport Commission or "OTC" states (Virginia to Maine), and the Lake Michigan Air Directors Consortium, or "LADCO" states (Illinois, Indiana, Michigan, Ohio, and Wisconsin) (Geer 2011; ISSA 2012; Beaver 2011). Individual states such as Texas and Georgia and counties within certain states (e.g., Atlanta metro area and Phoenix) also have VOC regulations (Beaver 2011). VOC regulations can affect the entire aerosol formulation—the solvent system must match the propellant formulation, and if one component changes, the entire formulation is affected.

Different products have different VOC limits, which can vary based on local regulations. For example the VOC limit for hairspray cannot exceed 80 percent (on a weight percent basis) according to EPA regulation. However, in California and other states with VOC regulations, the limit cannot exceed 55 percent; for aerosol deodorants, EPA has a 20 percent VOC limit, but California and other states only allow a 0-10 percent limit (ISSA 2012).

Although on occasion differing formulations have been designed for the same product in different locales, it is often not practical for an aerosol manufacturer to change the aerosol formulation of the same product to address varying VOC regulations (i.e., no-VOC, low-VOC, and high-VOC formulations). Therefore, to comply with VOC regulations in one state or area (e.g., if HFC-152a is the only option in California), a manufacturer may use the same VOC exempt substitute in all formulations of one product across the United States, which increases the use of HFCs nationally for some products.

3.1. Aerosol Propellants

The U.S. aerosol industry has already made significant progress in adopting a variety of propellants and not-in-kind alternatives to ODS propellants; however, high-GWP HFC propellants continue to occupy a portion of aerosol products on the market, particularly in personal consumer products and auto products. Table 4 illustrates a sample of household aerosol products containing propellants queried from the U.S. Department of Health and Human Services Household Product Database (HHS, 2013). Based on this sampling, personal care (which are also the largest continued user of HFC propellants) and household and home office products make up the majority of aerosol products currently manufactured.

Table 4: Sample of Propellants in Aerosol Products from the U.S. HHS Household Products Database[a]

Category (Total Sample Size)	Propellant Type	Percentage of Products in Sample by Propellant Type
Arts and Crafts (74)	HFC-134a	1%
	Hydrocarbons	96%
	Dimethyl ether	3%
Auto Products (130)	HFC-134a	12%
	HFC-152a	3%
	Hydrocarbons	72%
	Carbon dioxide	2%
	Dimethyl ether	11%
Home Maintenance (154)	HFC-134a	6%
	Hydrocarbons	76%
	Dimethyl ether	16%
Household and Home Office (364)	HFC-134a	1%
	HFC-152a	3%
	Hydrocarbons	86%
	Compressed Gas	6%
	Dimethyl ether	3%
Personal Care (285)	HFC-134a	<1%
	HFC-152a	35%
	Dimethyl ether	18%
	Hydrocarbons	46%
Pesticides (92)	HFC-152a	1%
	Hydrocarbons	99%
Pet Care (16)	Hydrocarbons	70%
	Dimethyl ether	30%

[a] Source: HHS (2013).

Note: A query was performed in March 2013 on the aerosol products listed in the U.S. HHS Household Products Database to provide the sampling shown in this table. Products were identified through searches of products containing known aerosol propellants. This table and the U.S. HHS Household Products Database does not provide a comprehensive compilation of all products on the market that utilize aerosol propellants. Rather, this sampling is intended to demonstrate the various aerosol propellants used in 2013 among categories tracked in this database. Different variations of the same product (i.e. air fresheners with different scents or spray paints of different colors) are counted as separate products.

In the early to mid-1990s, ODS propellants in use continued to include CFC-12, CFC-114, HCFC-22, and HCFC-142b because their market presence was in exempted products only. HCFC-22 was the most widely used HCFC propellant in the 1990s with the transition from CFC-12 to HCFC-22 taking place during 1990 and 1991. Beginning in the 1990s the aerosol industry also became far more dependent on HFCs with the introduction of VOC regulations in the 1990s, despite the widespread use of HCs--known VOCs--in aerosol products.

CSPA estimated that in 2008, the majority of products using HFC-152a were consumer products (e.g., hairsprays, dusters, deodorant body sprays, antiperspirants, and deodorants) with total use equal to 21,417 metric tons (MT), and the majority of products using HFC-134a being technical products (e.g., tire sealant/inflators and degreasers) with total use of 3,242 MT (CSPA 2008).

3.2. Aerosol Solvents

Table 5 illustrates a sample of household aerosol products containing solvents queried from the U.S. Department of Health and Human Services Household Product Database (HHS 2013). As shown, most types of aerosol products require solvents such as alcohols and hydrocarbons. Water is also a commonly used solvent; however, those products are not reflected in the table below due to it being difficult to isolate aerosol products using water as a solvent from those containing water for other purposes.

Table 5: Sample of Solvents in Aerosol Products from the U.S. HHS Household Products Database

Category (Total Sample Size)	Solvent Type	Percentage of Product in Sample by Solvent Type
Arts and Crafts (111)	Hydrocarbons	47%
	Oxygenated Organic Solvents	50%
	Chlorinated Organic Solvents	4%
Auto Products (163)	Hydrocarbons	37%
	Oxygenated Organic Solvents	45%
	Chlorinated Organic Solvents	17%
Home Maintenance (72)	Hydrocarbons	44%
	Oxygenated Organic Solvents	35%
	Chlorinated Organic Solvents	19%
Household and Home Office (97)	Hydrocarbons	71%
	Oxygenated Organic Solvents	24%
	Chlorinated Organic Solvents	5%
Personal Care (3)	Hydrocarbons	100%
Pesticides (19)	Hydrocarbons	100%
Pet Care (2)	Hydrocarbons	100%

Source: HHS (2013).

Note: A query was performed in March 2013 on the aerosol products listed in the U.S. HHS Household Products Database to provide the sampling shown in this table. Products were identified through searches of products containing known aerosol solvents. This table and the U.S. HHS Household Products Database do not provide a comprehensive compilation of all products on the market that utilize aerosol solvents. Rather, this sampling is intended to demonstrate the various aerosol solvents used in 2013 among categories tracked in this database. Different variations of the same product (i.e. air fresheners with different scents or spray paints of different colors) are counted as separate products.

Aerosol solvent applications historically used CFC-11, CFC-113, methyl chloroform, and HCFC-141b. CFC-11 was used in precision and general mold release agents exclusively as a diluent,[15] not as an active ingredient in solvent applications. CFC-113 served as both a diluent and active ingredient (i.e., in electronics solvent cleaners and as a diluent in mold release agents and lubricants). Methyl chloroform was more widespread in its use (i.e., as a diluent in applications such as water and oil repellants, tire shiners, insecticides, and mold release agents and as a solvent in electric motor cleaners, spot removers, and brake cleaners). Information on the use of HFCs, such as HFC-43-10mee and HFC-365mfc, in the aerosol solvent market is not readily available; however, it is expected to be minimal (IPCC 2005).

4. Climate-Friendly Alternatives

A variety of alternatives are available to replace HCFC, HFC-134a and HFC-152a propellants and HCFCs, HFC-4310mee, HFC-365mfc, and HFC-245fa solvents used in aerosols. Many alternatives have an established market presence because of the direct transition from CFCs and HCFCs to hydrocarbons, oxygenated organic compounds, and not-in-kind alternatives. Lower-GWP fluorinated compounds are also in use or under development, including HFOs. Table 6 below summarizes the status of several climate-friendly alternatives for aerosol propellants and aerosol solvents under SNAP and available information on use in the United States.

[15] A diluent is a type of solvent used to weaken the strength of a particularly aggressive solvent.

Table 6: Overview of Climate-friendly Alternatives

Alternative	Overview
Aerosol Propellants	
C3-C6 Hydrocarbons (propane, n-butane, isobutane)	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States
Dimethyl Ether	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States
Not-in-kind devices	• Acceptable under SNAP • Widely used alternative to aerosolized products in consumer, technical, and medical aerosols
Compressed Gases (carbon dioxide, air, nitrogen, nitrous oxide)	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States
HFO-1234ze(E)	• Acceptable under SNAP • Available in the U.S. market as of 2012
Aerosol Solvents	
C5-C20 Hydrocarbons (pentane, hexane, heptane)	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States
HFE-7000, HFE-7100, HFE-7200, HFE-347pcf2	• Acceptable under SNAP • Widely used in the U.S. market (HFE-347pcf2 still emerging in the U.S. market) in technical aerosols
Solstice™-1233zd(E) (also known as *trans*-1-chloro-3,3,3-trifluoroprop-1-ene)	• Acceptable under SNAP • Available in the U.S. market as of 2013
MPHE	• Acceptable under SNAP
Oxygenated Organic Compounds (esters, ethers, alcohols, and ketones)	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States
Water	• Acceptable under SNAP • Widely used in consumer, technical, and medical aerosols in the United States

Many companies have already transitioned to non-HFC propellants and solvents; however, technical, financial, and practical barriers have existed for some products that have prevented the complete transition away from HFCs in aerosols. The European aerosol industry has adopted a Code of Practice against using HFCs whenever feasible with only a small number of technical aerosols that do not have safe, practical, economic or environmentally acceptable alternatives using HFCs. These include products used in maintenance, repair, cleaning, testing, disinfecting, manufacturing, installation and other applications where a non-flammable formulation is required for safety reasons (EAF 2013).

In the United States, HFCs are often the propellant and/or solvent of choice to address product-related performance and flammability concerns when VOCs are restricted, although water is also a widely-used solvent in such cases. Replacements to HFCs are typically not drop-in replacements since the entire formulation must be evaluated and potentially changed. Safety considerations are another factor for this industry when evaluating alternative formulations. In undergoing a transition to certain replacements (e.g., flammable or more toxic compounds), workplace environmental controls may be a large expense for a company if they do not already have them in place. Liability insurance and associated plant safety requirements will increase if transitioning to the use of a flammable propellant or solvent. Several additional factors must be examined when reformulating including safety hazards (e.g., toxicity, corrosiveness, irritants, cancer/reproductive harm, flammability), container corrosion, properties of the propellant (e.g., vapor pressure, flash point, solubility in water, boiling point), efficacy, and cost (Geer 2011).

The use of HFCs is considered by the U.S. aerosol industry to be flat to declining, and compared to other sectors where HFCs are used (e.g., refrigeration, AC, foams) total use is on a smaller scale.

The U.S. Motor Vehicle Air Conditioning Industry

1. Introduction

Motor vehicle air conditioners (MVACs) cool the passenger compartment of light-duty vehicles (i.e., passenger cars), light-duty trucks, heavy-duty vehicles, off-road vehicles, buses, and passenger rail vehicles. The MVAC sector historically relied on CFC-12, and to a more limited extent, HCFC-22 in passenger rail and buses, both of which are ODS. In advance of the 1996 phaseout of CFC-12 and the continued phaseout of HCFCs, the U.S. MVAC industry largely transitioned away from ODS by 1994, relying most heavily on the high-GWP HFC refrigerant, HFC-134a. While HFC-134a remains the most predominant refrigerant used in new cars today, lower-GWP alternatives are entering the U.S. market in newly manufactured light-duty vehicles. This is facilitated by EPA approval of alternatives under the SNAP program and the availability of air conditioning credits to enable companies to meet the U.S. fuel economy standards for light-duty vehicles and trucks.

The remainder of this chapter characterizes the MVAC sector for light-duty vehicles and trucks manufactured and sold in the United States in terms of market size, key market players, historical and current refrigerant use, the availability of alternative refrigerants, and barriers to transitioning to alternative refrigerants. Light-duty vehicles and trucks are the most numerous of the vehicle types, and the only types of vehicles affected by this rulemaking.

2. Market Characterization for Light-Duty Vehicles

This section presents available market data on automobile and MVAC manufacturers. The majority of vehicle manufacturers assemble and install their own MVAC systems, while a limited number may purchase assembled MVAC systems. Because almost all cars sold in the United States are equipped with an air conditioning system, vehicle production, import and export, and sales data are used to characterize the light-duty MVAC market in the United States.

2.1. Overview of Light-Duty Vehicles and Trucks

Definitions and fleet estimates of light-duty vehicles and trucks are provided below.

- **Light-duty vehicles** include standard and large passenger cars, which meet the criteria outlined in 40 CFR 86.1803-01, which defines light-duty vehicles as a passenger car or passenger car derivative capable of seating 12 passengers or less, and categorized as Class 1 vehicles with gross vehicle weight rating less than 6,000 lbs (EPA 2010a). Typical light-duty vehicles include passenger cars, minivans, sports utility vehicles (SUVs), pick-up trucks, and utility vans (EPA 2011a). These vehicles represent the largest use of MVAC.
- **Light-duty trucks** are defined as vehicles with gross vehicle weight rating less than 8,500 lbs, or between 8,500 and 10,000 lbs that meet the criteria outlined in 40 CFR 86.1803-01, which defines a light-duty truck as any motor vehicle rated at 8,500 pounds gross vehicle weight rating (GVWR) or less which has a vehicle curb weight of 6,000 pounds or less, a basic vehicle frontal area of 45 square feet or less, and which is: (1) Designed primarily for purposes of transportation of property or is a derivation of such a vehicle, (2) Designed primarily for transportation of persons and has a capacity of more than 12 persons, or (3) Available with special features enabling off-street or off-highway operation and use. Vehicles in

this category are categorized as Class 2A vehicles and include truck-based station wagons, minivans, full size pick-up trucks, and full-size SUVs (EPA 2011a; DOT 2013a).

Fleet estimates (i.e., the number of vehicles in use) within the United States are summarized in Table 7 below, based on readily available literature.

Table 7. Light-Duty Vehicle and Truck Fleet Size Estimates

Year	Number of Light-Duty Vehicles and Trucks	Source
2010	239,812,000[a]	Ward's (2011)
2010	237,129,000	ICCT (2012)
2011	233,841,000[b]	DOT (2013a)

[a] Includes 118,946,744 cars and 120,865,240 commercial vehicles.

[b] Includes light-duty vehicles (192,513,278 short wheel base and 41,328,144 long wheel base).

2.2. Vehicle Manufacturers

Available 2011 U.S. Census data on the U.S. vehicle manufacturing industry is provided in Table 8, including information on total shipment values, number of employees, number of establishments, and number of companies/firms.

Table 8. 2007 Census Data on the Vehicle Manufacturing Industry

Industry	NAICS code	Total Value of Shipments* ($1,000)	Number of Employees	Number of Establishments	Number of Companies/Firms
Automobile and Light-Duty Motor Vehicle Manufacturing	336111	84,727,558	65,436	188	174
Light Truck and Utility Vehicle Manufacturing	336112	154,035,538	84,806	90	66

*Value of shipments is defined as received or receivable net selling values, free on board plant (exclusive of freight and taxes), of all products shipped as well as all miscellaneous receipts, such as receipts for contract work performed for others, installation and repair, sales of scrap, and sales of products bought and sold without further processing.

Known light-duty vehicle and truck manufacturers within the United States are listed below. The companies listed were identified during literature review while developing this report, and do not necessarily represent an inclusive list of all companies manufacturing within the United States. (Lowe et al. 2010; Nielsen et al. 2010; EPA 2011a)

- BMW
- Fiat Chrysler Automobile (FCA)
- Ford
- General Motors (GM)
- Honda
- Hyundai
- Kia
- Mazda
- Mercedes-Benz
- Mitsubishi
- Nissan
- Subaru
- Toyota
- Volkswagen
  Volvo

The largest light-duty vehicle and truck manufacturers in the United States are GM, Ford, and FCA. The "Detroit Three" are headquartered in the Detroit, Michigan area, with the majority of their U.S. plants located in the Great Lakes region, and the remainder primarily located in southern states (International Trade Administration 2010).

2.2.1. Vehicle Production

Production estimates for the U.S. vehicle manufacturing industry by vehicle type are presented in Table 9.

Table 9. Estimated Number of Light-Duty Vehicles and Trucks Produced Annually in the United States

Year	Production		
	Light-Duty Vehicles	Light-Duty Trucks	Total
2005	4,284,391	7,249,964	11,534,355
2006	4,340,673	6,525,355	10,866,028
2007	3,895,684	6,583,451	10,479,134
2008	3,755,039	4,701,500	8,456,539
2009	2,229,656	3,333,408	5,563,064
2010	2,781,947	4,776,365	7,558,312
2011	3,019,848	5,388,169	8,408,017
2012	4,106,991	5,937,229	10,044,220
2013	4,357,929	6,446,965	10,804,894

Sources: OICA (2014), BEA (2014), Automotive News (2008, 2009, 2011, 2012), DOT (2014)

2.2.2. Imports and Exports Market

The U.S. import and export markets for light-duty vehicles and trucks are significant. Foreign markets accounted for nearly 70% of Ford vehicles sold in 2007 and 64% of GM's total sales in 2008. Canada was the top export destination, with exports of $17 billion, followed by Germany ($3.6 billion), Saudi Arabia ($2.95 billion), China ($2.91 billion), and Mexico ($2.8 billion) (International Trade Administration 2011). In 2013, over 20% of the vehicles produced in the United States were exported to approximately 180 countries, representing over $52 billion (Association of Global Automakers 2014a). International automakers, which contribute to approximately 45% of all U.S. vehicle production, exported nearly 800,000 vehicles to more than 60 countries in 2013 (AGA and AIADA 2014). Exports vary broadly among the major manufacturers in the United States. GM, Ford, and FCA have traditionally exported most successfully to the Middle East and Central and South America while BMW and Mercedes-Benz use their U.S. facilities to satisfy the full global demand for their SUVs. Japanese manufacturers are increasingly exporting vehicles from the United States to Central and South America (Alliance of Automobile Manufacturers 2014).

The United States imports more vehicles by volume and value than any other country. In 2010, Mexico, Canada, Germany, Japan, and Korea accounted for 93% of all U.S. light-duty vehicle imports; Mexico and Canada alone accounted for 48% of U.S. light-duty vehicle imports (International Trade Administration 2011).

Vehicle import and export estimates for the U.S. industry by vehicle type are presented in Table 10. The International Trade Administration (2014) provided both import and export data of light-duty vehicles and trucks; however, the data combined light-duty vehicles and trucks. To disaggregate the data into light-duty vehicles and trucks, the annual ratio of light-duty vehicles to trucks that are produced based on the production data (Table 9) was applied to the total, which is roughly 40 percent light-duty vehicles and 60 percent light-duty trucks each year.

Table 10. Estimated Number of Vehicles Imported and Exported by the United States

Year	Imports			Exports		
	Light-duty Vehicles	Light-duty Trucks	Total	Light-duty Vehicles	Light-duty Trucks	Total
2005	2,453,820	4,143,277	6,597,097	471,291	795,774	1,267,065
2006	2,940,203	4,409,859	7,350,062	578,822	868,144	1,446,966
2007	2,656,448	4,478,232	7,134,680	614,905	1,036,606	1,651,511
2008	2,883,764	3,603,015	6,486,779	703,188	878,572	1,581,760
2009	1,746,438	2,598,200	4,344,638	405,610	603,432	1,009,042
2010	2,142,100	3,656,289	5,798,389	513,368	876,254	1,389,622
2011	2,165,210	3,845,539	6,010,749	571,669	1,015,316	1,586,985
2012	2,838,986	4,105,171	6,944,157	738,183	1,067,412	1,805,595
2013	2,879,909	4,271,187	7,151,096	781,700	1,159,338	1,941,038

Source: International Trade Administration (2014)

2.2.3. Vehicle Sales

Estimates of U.S. light-duty vehicle and light-duty truck sales are presented in Table 11. In 2010, sales by foreign manufacturers accounted for approximately 54% of the U.S. market of light-duty vehicle sales; Japanese manufacturers decreased their market share to 38.8% in 2010, from 40.5% in 2009 while German manufacturers increased their market share from 7.3% to 7.6% and Korean manufacturers' market share grew from 7.1% to 7.7% (International Trade Administration 2011). In 2013, foreign manufacturers' share of U.S. vehicle sales accounted for more than 59% of the U.S. market (Association of Global Automakers 2014b).

Table 11. U.S. Sales of Light-Duty Vehicles and Trucks

Year	Sales		
	Light-duty Vehicles	Light-duty Trucks	Total
2005	7,667,066	9,288,400	16,955,466
2006	7,820,854	8,766,721	16,587,575
2007	7,618,413	8,399,807	16,018,220
2008	6,813,369	6,345,806	13,159,175
2009	5,400,890	4,940,454	10,341,344
2010	5,635,433	5,829,948	11,465,381
2011	6,089,422	6,603,650	12,693,072
2012	7,241,900	7,166,834	14,408,734
2013	7,585,800	7,946,200	15,532,000

Source: Ward's Automotive Group (2011 & 2013), BEA (2014)

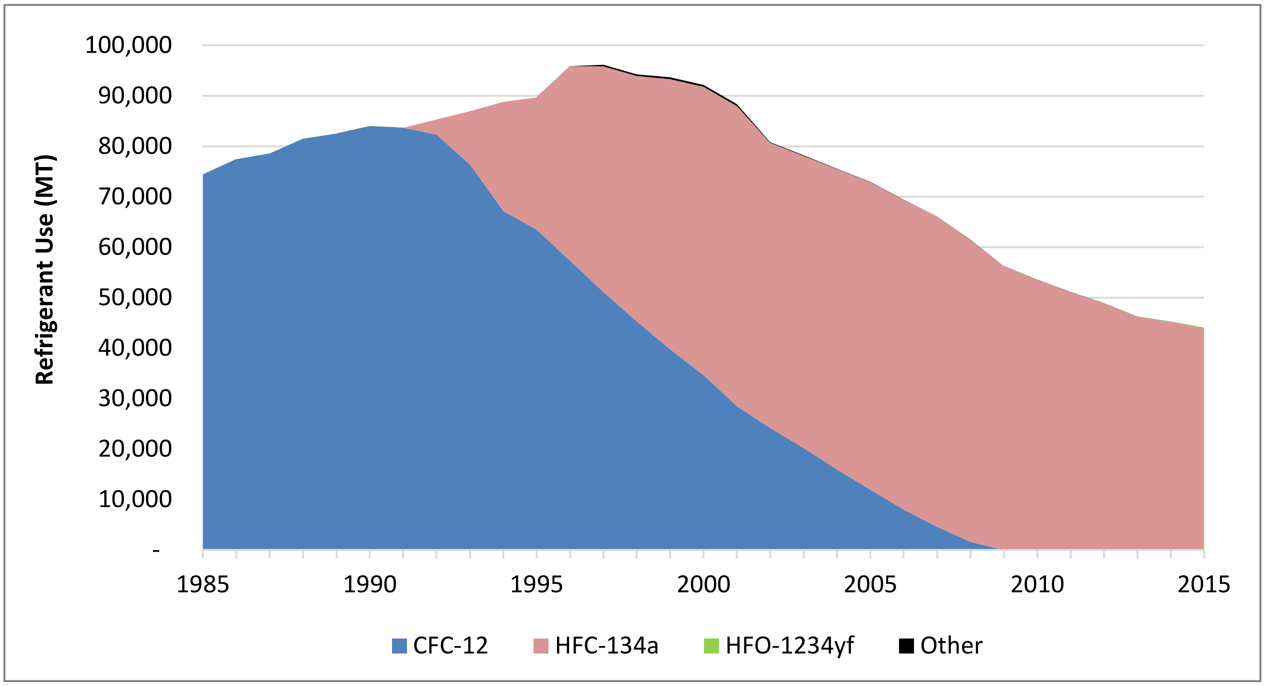
3. Sector Background

MVAC systems have been in widespread production in the United States since the 1960s. As of 2012, more than 98% of passenger vehicles sold in the United States were estimated to contain MVAC systems (ICCT 2012). This section provides an overview of MVAC use in light-duty vehicles and trucks, including a description of the vehicle types and fleet estimates, and their historical refrigerant use.

3.1. Refrigerant Use in Motor Vehicle Air Conditioning

Historically, the light-duty MVAC sector relied on the ODS refrigerant CFC-12. Automobile manufacturers transitioned to the non-ozone depleting alternative HFC-134a in the mid-1990s. HFC-134a, like its predecessor, is a potent greenhouse gas that contributes to climate change. HFC-134a, which has a GWP of 1,430 (IPCC 2007), is the predominant refrigerant used today, as illustrated in Figure 2.

Figure 2: U.S. Light-Duty Vehicle and Truck MVAC Refrigerant Use Over Time*



* "Other" includes <1% of the market consisting of a variety of blends.
Source: EPA Vintaging Model 2014.

The overall decrease in consumption shown in Figure 2 has been driven by several factors: EPA's Vintaging Model is based on actual stock and sales of cars/trucks through 2013, and there was a fairly significant drop in sales around 2008-2009 due to the U.S. and global recession. That coupled with modeled decreases in the HFC-134a MVAC light-duty vehicle charge size in 2002 and again in 2007 contribute to the decreases in refrigerant use seen in the figure. Charge size decreases also occurred for light-duty trucks in 2003 and 2006. Estimates of conventional (ODS or HFC) MVAC charge sizes from various sources are shown in Table 12. The average lifetime of light-duty vehicles and trucks in the United States is currently estimated to be 11.5 years (Auto Care Association 2015).

Table 12. Average Light-Duty Vehicle and Truck MVAC Charge Sizes for Conventional (ODS/HFC) Systems

Refrigerant Charge Size (kg)	Sources
0.6 - 0.8	ICCT (2012)
0.4 - 1.2	RTOC (2010)
0.4 – 0.8	EIA (2012a)
0.77- 0.95	EPA (2011a)

Under the SNAP program EPA has found acceptable, subject to use conditions, three MVAC refrigerants with lower GWPs: HFC-152a, hydrofluoroolefin (HFO)-1234yf, and carbon dioxide (CO_2) (R-744). None of these alternatives deplete the ozone layer and all have significantly lower GWPs than CFC-12 or HFC-134a. Table 13 shows the relative GWPs of these MVAC refrigerants and whether or not they are ozone depleting. Today, there are cars on the road in the United States using CFC-12, HFC-134a, and HFO-1234yf.

Table 13. Environmental impacts of MVAC refrigerants

MVAC refrigerant	GWP	Ozone depleting?
CFC-12	10,900	Yes
HFC-134a	1,430	No
HFC-152a	124	No
HFO-1234yf	4	No
CO_2 (R-744)	1	No

Source: IPCC (2007)

Transition away from HFC-134a to these climate-friendly alternatives is likely being enhanced by the joint regulations promulgated by the EPA and Department of Transportation's National Highway Traffic Safety Administration (NHTSA), which established GHG and fuel economy standards for light-duty vehicles and trucks. As established by EPA's Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards, vehicle manufacturers may earn credits toward meeting the GHG standards by improving air conditioning systems. Both direct and indirect credits are available. Credits can be earned directly by reducing emissions through improved leak control and/or use of a lower-GWP refrigerant. Indirect credits can be earned through improvements to technologies that increase efficiency and result in decreased consumption of fuel to provide mechanical power to the MVAC system. The EPA regulations allows vehicle manufacturers to generate direct leakage credits of up to 13.8 and 17.2 g/mi CO_2eq and indirect efficiency credits of up to 5.0 and 7.2 g/mi CO_2eq for cars and trucks, respectively, towards compliance with the industry fleet-wide average standard projected to be 163 g/mi CO_2eq in model year 2025 (77 FR 62,624).

Transition to climate-friendly alternatives has already begun in the United States based on these credits. Transition is also occurring widely in the European Union (EU), prompted by the EU Directive on Mobile Air Conditioning (MAC Directive) (2006/40/EC). The EU MAC Directive requires that, as of January 1, 2013,[16] all new model type vehicles be sold with an MVAC refrigerant with a GWP no greater than 150; beginning January 1, 2017 this requirement will apply to all new vehicle sales.

4. Climate-Friendly Alternatives

This section summarizes information on climate-friendly refrigerant alternatives for MVAC that have been found acceptable subject to use conditions under EPA's SNAP program. This section also provides limited information on other alternatives under development in the United States and globally.

[16] Originally, the EU MAC Directive requiring MVACs in all newly type-approved vehicles to use a refrigerant with a GWP no greater than 150 was to be effective in 2011; however, this date was postponed to January 1, 2013.

Table 14. Overview of Climate-Friendly Alternatives Approved by SNAP

Alternative	SNAP Listing Status	Global Use Status
HFC-152a	• Acceptable subject to use conditions in 2008	• Prototype vehicles have been tested • Under evaluation in secondary loop systems in demonstration project in India • No known use in light-duty vehicles
HFO-1234yf	• Acceptable subject to use conditions in 2011	• Used in several light-duty vehicle models in the United States, Canada, and Europe • Market share increasing annually in the United States • Under evaluation in secondary loop systems in demonstration project in India
CO_2	• Acceptable subject to use conditions in 2012	• Used outside the United States in buses • No known use in light-duty vehicles; under evaluation by several European car manufacturers

4.1. HFC-152a

While prototype vehicles have been tested with HFC-152a, and there was on-going development as of 2010, no automobile manufacturers have adopted this refrigerant to date. According to ICCT (2012), however, at least one manufacturer reported that good engineering design could address technical barriers, though cost and efficiency would still present challenges to bringing it to the market. According to the same report, other sources have indicated that HFC-152a exhibits good cooling performance and cost, especially when incorporating the latest technological advancements; still, the system would require significant space in the engine compartment which would pose a challenge in many vehicle models today. HFC-152a is currently under evaluation for use in a secondary loop system in a demonstration project in India funded by the Climate and Clean Air Coalition. The project will focus on evaluating the use of refrigerants in secondary loop systems in climates with long, hot, and frequently humid cooling seasons with high fuel prices (Andersen et al. 2015).

HFC-152a exhibits moderate flammability and is characterized as an A2 refrigerant by ASHRAE. Under the 2008 SNAP listing, EPA established the following conditions for use: (1) Engineering strategies and/or devices shall be incorporated into the system such that foreseeable leaks into the passenger compartment do not result in R-152a concentrations of 3.7% v/v or above in any part of the free space inside the passenger compartment for more than 15 seconds when the car ignition is on, and (2) manufacturers must adhere to all the safety requirements listed in the Society of Automotive Engineers (SAE) Standard J639, including unique fittings and a flammable refrigerant warning label as well as SAE Standard J2773, "Refrigerant Guidelines for Safety and Risk Analysis for Use in Mobile Air Conditioning Systems."

4.2. HFO-1234yf

The number of cars using HFO-1234yf globally is expected to exceed 2 million by the end of 2014 (Automotive World 2014). DuPont, a producer of HFO-1234yf, has stated that 7 million vehicles are estimated to be on the road by year end 2015 (DuPont 2014). Approximately 60 different light-duty vehicle models designed to use HFO-1234yf in the United States and Europe are manufactured by 28 different vehicle brands (Honeywell 2014). In the United States, a number of vehicle models are sold with HFO-1234yf or will be within the 2015 model year, including the Cadillac XTS, Chevrolet Spark EV, BMW i3 and i8, Chrysler 200, Chrysler 300, Dodge Challenger, Dodge Charger, Dodge Dart, Dodge Durango, Jeep Cherokee, Jeep Wrangler, Ram 1500, Fiat 500 and 500L, Alfa Romeo 4C, Honda Fit EV, Tesla Model S, Range Rover, Range Rover Sport (Crowell 2015; FCA 2015).

In 2014, Honeywell announced a supply agreement with Asahi Glass Company (AGC) Ltd. to increase production of HFO-1234yf in mid-2015, and they plan to construct a new production plant in Geismar, Louisiana (Automotive World 2014). In 2013, Arkema announced its construction of a new HFO-1234yf production plant, which is anticipated to begin production in 2016 (Arkema 2013). HFO-1234yf is currently distributed in 40 counties, including the EU member states, the United States, Saudi Arabia, Turkey, Israel, and the United Arab Emirates (DuPont 2014).

HFO-1234yf is mildly flammable, and is classified by ASHRAE as an A2L refrigerant. Under the 2011 SNAP decision and a March 2012 subsequent rule, EPA established two required use conditions for HFO-1234yf used in a newly manufactured MVAC system for passenger cars and light-duty trucks: (1) HFO-1234yf MVAC systems must adhere to all of the safety requirements of SAE J639 (adopted 2011), including requirements for a flammable refrigerant warning label, high-pressure compressor cutoff switch and pressure relief devices, and unique fittings. For connections with refrigerant containers for use in professional servicing, use fittings must be consistent with SAE J2844 (revised October 2011). And (2) manufacturers must conduct Failure Mode and Effect Analysis (FMEA) as provided in SAE J1739 (adopted 2009). Manufacturers must keep the FMEA on file for at least three years from the date of creation. Under its Cooperative Research Program (CRP), SAE International found the risk of fire to be “very small compared to the risks of a vehicle fire from all causes and well below risks that are commonly viewed as acceptable by the general public.”

4.3. Carbon Dioxide

In March 2013, several German car manufacturers announced plans to develop MVACs using CO_2 (R-744) refrigerant, though light-duty vehicles using CO_2 are not in production today (AMN 2013). CO_2 is in use in MVAC systems in buses outside of the United States (EIA 2014). The use of CO_2 as a refrigerant in MVAC systems poses challenges due to its high operating pressure. The peak pressure of CO_2 operating systems is approximately 2,000 psi compared to 450 psi in HFC-134a systems (EPA & NHTSA 2012). The refrigerant’s energy performance has been questioned, with some studies claiming performance to be similar if not better than HFC-134a, and others reporting poorer performance at high ambient temperatures (EIA 2012a, CARB 2011, ICCT 2012).

When EPA listed CO_2 as acceptable for use in 2012, the SNAP program established the following conditions of use: (1) engineering strategies and/or mitigation devices shall be incorporated such that in the event of refrigerant leaks the resulting CO_2 concentrations do not exceed the STEL of 30,000 ppm averaged over 15 minutes in the passenger free space and the ceiling limit of 40,000 ppm in the passenger breathing zone; (2) OEMs must keep records of the tests performed for a minimum period of three years demonstrating that CO_2 refrigerant levels do not exceed the STEL of 30,000 ppm averaged over 15 minutes in the passenger free space, and the ceiling limit of 40,000 ppm in the breathing zone; and (3) the use of CO_2 in MVAC systems must adhere to the standard conditions identified in SAE Standard J639 (EPA 2012b).

4.4. Other Alternatives (Not Currently Listed by SNAP)

Additional alternatives are under development and/or in use outside of the United States; however, these alternatives have not, to date, been listed as acceptable by the SNAP program. Many of these are flammable. The SNAP program prohibits the use of flammable refrigerants in MVAC unless a particular refrigerant is specifically listed as acceptable subject to use conditions. HFC-152a and HFO-1234yf are the only flammable refrigerants EPA has listed as acceptable subject to use conditions for use in MVAC systems (Appendix B to subpart G of 40 CFR part 82).

A range of unsaturated fluorocarbon blends have recently emerged as potential alternatives for refrigerants used in MVAC systems. While the majority of these are still under development, unsaturated fluorocarbons have exhibited promising results thus far; the use of blending may offer flexibility in overcoming technical and financial barriers. Two blends in particular, AC5 and AC6 (also classified as R-444A and R-445A, respectively) are under development. AC5 is a blend of 12% HFC-32, 5% HFC-152a, and 83% HFO-1234ze (by weight); AC6 is a blend of 6% CO_2, 9% HFC-134a and 85% HFO-1234ze. The GWPs of AC5 and AC6 are 92 and 130, respectively (SAE undated).

AC5 is expected to have similar performance to R-134a and similar flammability characteristics to HFO-1234yf, whereas AC6 is expected to have a somewhat higher refrigeration capacity than HFC-134a and reduced flammability compared to HFO-1234yf (SAE undated). That said, both AC5 and AC6 have an A2L flammability rating under ASHRAE. To date, research has been conducted on the design and manufacture of prototype charging equipment using AC6 (PRWeb 2013); however, concerns exist with the servicing and recovery of such zeotropic refrigerant blends because the blend composition varies with temperature and pressure during the refrigeration cycle (SAE 2013). Additional concerns include selective leakage of the CO_2 component of AC6 due to its high pressure. A leakage model from SAE's Cooperative Research Program shows there would be just a 5% performance loss if the CO_2 level dropped from 6% to 2% (SAE 2013).

The potential for use of hydrocarbons in MVAC systems is still being researched, and there is not yet agreement on its suitability. According to TEAP (2013), due to safety (flammability) concerns, use of hydrocarbons for MVACs in light-duty vehicles and trucks is not anticipated to receive support from any car company and would remain marginal. Hydrocarbons have the highest flammability rating given by ASHRAE, A3. Some sources report that certain hydrocarbon refrigerants could have benefits due to their relatively low charge size (e.g., 200-300 g), higher cooling performance, and higher coefficient of performance (COP) than HFC-134a and HFO-1234yf (Obrist Engineering 2011; Greenpeace 2012). According to Expert Group (2013), a consulting firm in Australia, hydrocarbons are currently used in about 8% of MVAC systems in passenger and light commercial vehicles in Australia. As previously mentioned, the SNAP program has listed all flammable refrigerants as unacceptable for use in MVAC systems, unless specifically exempted. To date, EPA has not yet received sufficient information on any hydrocarbon refrigerant to find their use acceptable in MVAC.

The U.S. Commercial Refrigeration Industry

1. Introduction

Commercial refrigeration systems historically relied on synthetic ODS refrigerants—CFCs and HCFCs—both of which deplete the stratospheric ozone layer and contribute to climate change. The U.S. commercial refrigeration market transitioned away from ODS in response to the 1996 phaseout of CFCs and the on-going phaseout of HCFCs. The transition was primarily to HFCs, which are not ODS but typically have high GWPs. Today, lower-GWP alternatives, discussed below, have entered or are expected to enter the U.S. market, facilitated by acceptability listings under EPA's SNAP program.

The remainder of this chapter characterizes the portions of the U.S. commercial refrigeration sector affected by this final rule in terms of equipment types and manufacturers, market size, historical and current refrigerant use, and the availability of climate-friendly alternative refrigerants.

2. Market Characterization

It is estimated that in 2013 over 6 million commercial refrigeration systems[17] were in use in the United States. In addition, it is estimated that roughly 600,000 new systems were sold into the market (DOE 2009). Since the purpose of this document is to characterize refrigerant use in commercial refrigeration applications affected by this rulemaking, only systems and/or components that directly contain refrigerant are discussed, and only the manufacturers of such equipment are identified.[18] Also, only end-users of systems that are most likely to be retrofitted with a different refrigerant at some point during the lifetime of the equipment are included.[19]

2.1. Overview of Commercial Refrigeration Systems

Commercial refrigeration systems include reach-in refrigerators and freezers, beverage coolers, food service equipment, packaged walk-in food storage equipment, refrigerated vending machines, ice makers, water coolers, soda fountains/beer dispensers, remote condensing units, and supermarket (i.e., rack) systems, and an overview of each of these systems is provided in the sections that follow. Because ice makers, very low temperature refrigerators and freezers, water coolers, and soda fountains/beer dispensers are not affected by this rulemaking, they are not characterized in this document.

Commercial refrigeration systems generally can be categorized into two groups: stand-alone (i.e., self-contained)[20] and remote refrigeration systems. Self-contained systems integrate all components within their structure, while remote refrigeration systems consist of various components that are linked through a refrigerant piping network, such as supermarket rack systems and remote condensing units.

[17] Excludes ice machines and refrigerated vending machines.

[18] Manufacturers of display cases and walk-ins that are connected to a rack system are excluded from this discussion since the choice of the refrigerant used in such equipment is determined by the rack system owner or operator.

[19] Systems that are more likely to be retrofitted include remote condensing unit systems and rack systems.

[20] The terms stand-alone and self-contained are used interchangeably in this document.

2.1.1. Reach-In Refrigerators/Freezers and Beverage Coolers

Reach-in refrigerators and freezers and beverage coolers are self-contained systems with the refrigeration system located within the unit. These systems are commonly used in convenience stores, small markets, specialty stores, bars, and restaurants as well as in large supermarkets in spaces that are not easily accessible to the rack system refrigerant lines or when movability of the system is desired. These systems are often characterized by their operating temperature (e.g., medium vs. low), door type (e.g., transparent, solid, without), and orientation (e.g., horizontal, semivertical, vertical). Example images of these systems are provided in Figure 3 below.

Figure 3. Example Images of Reach-In and Beverage Coolers (DOE 2009)

2.1.2. Food Service Equipment

Refrigerated food service equipment is a type of self-contained system used to maintain the temperature of food products prior to and while serving them in foodservice settings (DOE 2009). Such equipment is predominantly found in restaurants, hotels, convenience stores, supermarkets, schools, and other facilities where food is served. Common categories of equipment include preparation tables, worktop tables, and buffet tables. Example images of food service equipment are provided in Figure 4.

Figure 4. Example Images of Food Service Equipment (DOE 2009)

2.1.3. Packaged Walk-In Food Storage Equipment

Walk-in food storage equipment (i.e., packaged walk-in refrigerators and freezers) are another type of self-contained unit that is commonly used in convenience stores, cafeterias, florists, restaurants, and bars. Larger in both size and capacity than reach-in coolers, such units are generally located outside of the sales area and only accessible to equipment owners and store employees via an access door. These units generally consist of a large, heavily insulated box with a dedicated refrigeration system that is mounted either on the roof or wall of the insulated room and is configured such that the condenser has access to the outside of the room and the evaporator has access to the inside of the room (DOE 2009). These units are classified as self-contained (stand-alone) because they are pre-charged, shipped as a single package, and are ready to operate upon connection to a power supply. In 2008 there were approximately 755,000 walk-in coolers and freezers in use in the United States, including both packaged units and built-up systems that use a remote condensing unit (as discussed in Section 2.1.5) (DOE 2009). Example images of packaged walk-in coolers and freezers are provided in Figure 5.

Figure 5. Example Images of a Packaged Walk-in with a Mounted Refrigeration System (DOE 2009)

2.1.4. Refrigerated Vending Machines

Refrigerated vending machines are another type of self-contained system used to sell a variety of products, including cold drinks in cans or bottles, ice cream, milk, cold drinks in cups, and perishable food items (e.g., prepared sandwiches). Hot beverages may also be provided via a heat-pump or through recycled waste heat from the refrigeration cycle, particularly for dual hot/cold beverage vending machines (Fuji Electric 2003; Coca-Cola 2015). Vending machines are predominantly located in offices, numerous types of public locations, and plants and factories (DOE 2009). In 2008 there were approximately 3.8 million vending machines in use in the United States (DOE 2009). Example images of refrigerated vending machines are shown in Figure 6 below.

Figure 6. Example Images of Refrigerated Vending Machines (DOE 2009; AMS 2015)

2.1.5. Remote Condensing Units

Remote condensing units are a type of remote commercial refrigeration system that are commonly used in convenience stores, drug stores, hotels, cafeterias, specialty food stores, restaurants, and bars to cool a walk-in or row of reach-ins. They may also be used in supermarkets to cool walk-ins that are not otherwise connected to the rack system. They consist of one or two compressors and a condenser assembled into a modular system, which is then connected to a unit cooler located inside a walk-in or to a row of reach-ins. In most cases, the remote condensing unit is located on the building rooftop or outside at ground level (DOE 2009). While similar in size and function to packaged (i.e., self-contained) walk-in food storage equipment (see Section 2.1.3 above), remote condensing units are assembled and charged on-site before going into operation. In 2008 there were approximately 755,000 walk-in coolers and freezers in use in the United States, including both packaged units (as discussed in Section 2.1.3) and built-up systems that are cooled by a remote condensing unit (DOE 2009). Example images of remote condensing units are provided below in Figure 7. An example image of a unit cooler that might be placed inside a walk-in room is provided in Figure 8.

Figure 7. Example Image of an Outside Remote Condensing Unit (DOE 2009; Master-Bilt 2014)

Figure 8. Example Image of a Typical Walk-In Unit Cooler (DOE 2009)

2.1.6. Supermarket Rack Systems

Supermarket (i.e., rack) systems are a type of remote commercial refrigeration systems that are most commonly used in large retail food operations (hence the name "supermarket systems") including warehouse clubs and superstores. They are custom designed and complex to install, and consist of racks of multiple compressors and other components that are connected to a remote condenser and linked to display cases, reach-ins, and walk-ins through a piping network. They come in a variety of designs including centralized, distributed, indirect, and cascade.[21] These systems can also be designed to additionally provide air conditioning, for example, in offices and break rooms located in a supermarket. About 37,500 supermarkets in the United States in 2013 (FMI 2014) plus an additional 11,000 supercenters, warehouses, and other retail food stores are assumed to use one or more rack systems to meet their cooling needs (EPA Vintaging Model 2014). The key components of a rack system—which include compressor racks, condensers, display cases, and walk-ins—are discussed in more detail below.

Condensers

Typically located outside, the condenser is a part of the refrigeration system that transfers heat from the refrigerant to the surrounding air or a water supply. Air-cooled condensers are more commonly used in supermarket rack systems, although water-cooled condensers and evaporative condensers may also be applied.

[21] See http://www2.epa.gov/greenchill/advanced-refrigeration for descriptions of commonly used system designs.

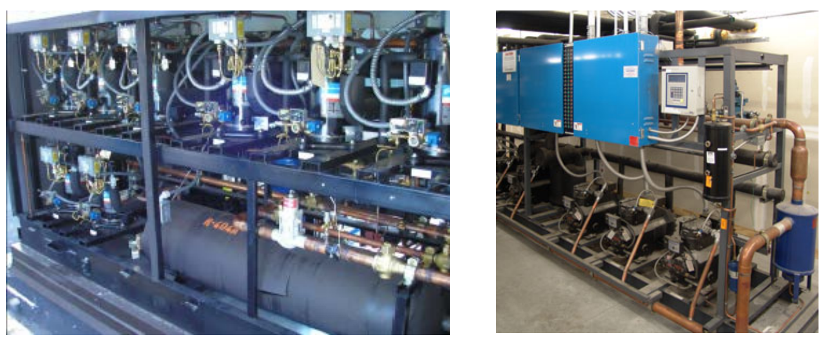
According to the DOE (2009), a typical supermarket has one condenser per refrigeration circuit, or four condensers per supermarket. An example of an air-cooled condenser is shown below in Figure 9.

Figure 9: Example Image of a Condenser (Heatcraft 2013)

Compressor Racks

Compressor racks are configurations of paralleled-connected compressors commonly located in a machinery room. It is estimated that supermarkets use on average four compressor racks with three to five compressors per rack (DOE 2009). Example images of compressor racks are provided below in Figure 10.

Figure 10: Example Images of a Compressor Rack (DOE 2009; Hillphoenix 2013)



Display Cases

Display cases that are part of a rack system are used in supermarkets and other retail food establishments to attractively display food or beverages to consumers. Similar to reach-in refrigerators and freezers, display cases vary by temperature and orientation. Example images of display cases are provided below in Figure 11.

Figure 11. Example Images of Display Cases (DOE 2009)

Walk-In Coolers and Freezers

Walk-in coolers and freezers are large, insulated refrigerated spaces with access doors large enough for people to enter. Walk-ins are used for food storage and merchandising in the food service and food sales applications. While some walk-ins are cooled by a remote condensing unit, either mounted on the unit or located outside (as discussed in sections 2.1.3 and 2.1.5, respectively), walk-ins that are found in supermarkets are generally connected to and cooled by the rack system. A report developed for the DOE (2009) estimates that in 2008 there were 245,000 walk-in coolers and freezers in use in the United States that are cooled by a supermarket rack system. With annual sales estimated at 10,000 and accounting for systems reaching end-of-life, it is estimated that in 2013 there were 250,000 systems in use. An example image of merchandising doors open to the sales floor that would be placed on one side of the walk-in room, is provided in Figure 12. An example image of a unit cooler that might be placed inside a walk-in room is provided above in Figure 8.

Figure 12. Example Image of a Walk-In with Merchandising Doors (DOE 2009)

2.2. Equipment Manufacturers

Leading manufacturers of self-contained systems and remote refrigeration systems are summarized in Table 15 below.[22] Since remote systems are installed on-site and are made up of numerous components that are often manufactured separately, the manufacturers of remote systems that are specified in the table may actually only manufacturer one or more component of such systems. In contrast, since self-contained systems are pre-assembled, only manufacturers that sell fully assembled self-contained systems are specified in the table; companies that manufacture only components of self-contained systems are not included.

Manufacturers were identified based mainly on information gathered by DOE (2013a; 2013b; 2009) and comments received on the NPRM. Since a different set of companies manufacture vending machines than other self-contained systems, vending machine manufacturers are designated separately in Table 15.

Table 15: Manufacturers of Commercial Refrigeration Systems by Type

Company Name[a]	Self-Contained Systems		Remote Systems[b]
	Reach-Ins, Beverage Coolers, Food Service Equipment, Packaged Walk-In Food Storage Equipment	Vending Machines	
Aladdin Temp-Rite	X		
Arctic Air	X		
Arctic Star	X		
Arneg USA	X		
Automated Merchandising Systems, Inc.		X	
Bally Refrigerated Boxes			X
Beverage-Air	X		

Company Name[a]	Self-Contained Systems		Remote Systems[b]
	Reach-Ins, Beverage Coolers, Food Service Equipment, Packaged Walk-In Food Storage Equipment	Vending Machines	
Bitzer			X
Carlyle			X
Century Refrigeration			X
Continental Refrigerator	X		
Copeland			X
Crown Tonka			X
Cubigel			X
Danfoss			X
Delfield	X		
Dixie-Narco		X	
Duke Manufacturing	X		
Edina Technical Products		X	
Federal Industries	X		
Heat Transfer Products Group DBA Russell			X
Hillphoenix	X		X
Howard/McCray	X		
Howe Corporation			X
Hoshizaki America	X		X
Hussmann	X		X
InterMetro Industries	X		
KeepRite			X
Kelvinator	X		
Killion Industries	X		
Kolpak			X
Krack			X
Kysor/Warren			X
McCall Refrigeration	X		
Master-Bilt Products	X		X
Multi-Max Vending		X	
Northland Refrigeration	X		
Parker-Hannifan			X
Peerless of America, Inc.			X
Randell	X		
RPI Industries, Inc.	X		
Royal Vendors		X	
SandenVendo America	X	X	
Sanyo			X
Scotsman	X		
Seaga Manufacturing	X	X	
Secop			X
Silver King	X		
So-Low	X		

Company Name[a]	Self-Contained Systems		Remote Systems[b]
	Reach-Ins, Beverage Coolers, Food Service Equipment, Packaged Walk-In Food Storage Equipment	Vending Machines	
Southern Case Arts	X		
Structural Concepts Corp.	X		
Sub-Zero	X		
Tecumseh			X
Thermal-Rite/International Cold Storage	X		X
Tor Rey Refrigeration	X		
Traulsen	X		
Trenton Refrigeration Products			X
True Manufacturing	X		
Turbo Air	X		
Unilever	X		
Victory Refrigeration	X		
Wittern Group		X	
Zero Zone	X		X

[a] The companies listed do not necessarily represent an inclusive list of all manufacturers of commercial refrigeration systems in the United States. Parent companies are not listed due to frequent consolidations and other acquisitions.
[b] Includes manufacturers of components of remote systems, such as compressors, compressor racks, condensers and condensing units.
Sources: DOE (2013a); DOE (2013b); DOE (2009); comments on NPRM available at regulations.gov in docket EPA-HQ-OAR-2014-0198

2.3. Equipment Owners Performing System Retrofits

As previously mentioned, some commercial refrigeration systems—including remote condensing unit systems and rack systems—have the potential to be retrofitted with a different refrigerant mid-way through their lifetime. The decision to retrofit a system is generally made by the owner or operator of the equipment. Refrigerant retrofits do not typically take place unless at least one component of the system (e.g., a remote display case or condenser) needs to be replaced or upgraded. Due to the cost of retrofitting relative to purchasing a new self-contained system or vending machine, it is assumed that retrofits are not performed on those systems. While remote condensing unit systems are more likely to be retrofitted, they are only commonly retrofitted if there is an economic incentive to do so. Similarly, supermarkets are most likely to retrofit their rack systems if there is a financial benefit for doing so. Such retrofits are common today as the industry phases out HCFCs, particularly HCFC-22. Recovered HCFC-22 from retrofitted or retired systems is commonly used by supermarkets to service their other HCFC-22 equipment. As the availability of HCFC-22 decreases, the incentive to retrofit or replace HCFC-22 systems will increase for some companies. However, the actual impact of future HCFC-22 supplies on retrofit activity is uncertain due to variation in the refrigerant use profiles and specific circumstances of individual companies.

3. Sector Background

3.1. Refrigerant Use in Commercial Refrigeration

Commercial refrigeration systems have historically relied on synthetic refrigerants including CFCs, HCFCs, HFCs, and blends of these chemicals sometimes mixed with small portions of hydrocarbons. Today, although less common, non-fluorinated alternatives are additionally in use in the commercial refrigeration sector (e.g., ammonia, carbon dioxide, and hydrocarbons). Unsaturated HFCs (i.e., HFOs as well as HFOs blended with other refrigerants) are also being tested and are expected to enter the market soon.

A summary of the commonly used, non-ODS refrigerants listed as acceptable under SNAP for commercial refrigeration systems characterized in this document is provided below in Table 16, presented in order from largest to smallest GWP. Some refrigerants are generally used only in new equipment (denoted by "N" in the table), while other refrigerants are generally used only as a retrofit refrigerant (i.e., a refrigerant used to replace a different refrigerant in existing equipment) (denoted by "R" in the table). As shown, some refrigerants are used in both new equipment and as a retrofit in existing equipment.

Table 16: Non-ODS Refrigerants Commonly Used in Commercial Refrigeration by Equipment Type

Refrigerant	GWP*	Equipment Category**		
		Stand-Alone	Remote Condensing Units	Supermarket Rack Systems
R-507A	3,985	N	N	N, R
R-404A	3,922	N	N	N, R
R-422A	3,143		R	R
R-422D	2,729		R	R
R-422B	2,526		R	R
R-438A	2,264		R	R
R-427A	2,138		R	R
R-407A	2,107		N, R	N, R
R-407F	1,825		N, R	N, R
R-407C	1,774		N, R	N, R
HFC-134a	1,430	N	N	N
R-290	3.3	N		
R-744	1	N	N	N

*GWPs from IPCC (2007)

** R = used as a retrofit; N = used in new equipment. These designations are based on common use, not SNAP listing status.

Source: Based on RTOC (2011) and GreenChill Partnership Data (2013).

Although there are significantly fewer remote refrigeration systems (i.e., condensing units and rack systems) in the market relative to self-contained systems, the majority of refrigerant consumed in the United States in commercial refrigeration is used to charge or refill remote refrigeration systems.

3.1.1. Stand-Alone Systems

As previously discussed, the types of stand-alone (self-contained) systems characterized in this report include reach-in refrigerators and freezers, beverage coolers, food service equipment, packaged walk-in food storage equipment, and refrigerated vending machines. These systems historically used refrigerants CFC-12 and HCFC-22. Today, HFC-134a is the most commonly used refrigerant in self-contained systems, with R-404A also commonly used in low temperature applications (e.g., freezers, ice machines) and some high-capacity systems. Propane (R-290) and to a lesser extent isobutane (R-600a) have recently started to be used in retail food self-contained refrigerators and freezers (e.g., reach-in refrigerators and freezers, and beverage coolers), following listing by SNAP as being acceptable subject to use conditions in December 2011 and April 2015. R-744 (carbon dioxide, CO_2), which was listed as acceptable under SNAP for use in retail food refrigeration in September 2009, is currently used in beverage coolers. More recently, R-744 has started to be used in vending machines, following SNAP listing in 2012. A summary of the ODS substitute refrigerants commonly used today in self-contained systems, along with their corresponding estimated charge size, is provided below in Table 17.

Table 17: Non-ODS Refrigerants Typically Used in Self-Contained Systems by System Type

System Type	Refrigerants	Typical Charge Size Range (kg)[a]
Reach-In Refrigerators and Freezers	HFC-134a, R-404A, R-290	0.2 – 3.0
Beverage Coolers	HFC-134a, R-290, R-744	0.2 – 3.0
Food Service Equipment	HFC-134a, R-404A, R-290	0.2 – 3.0
Packaged Walk-In Food Storage Equipment	R-404A	0.8 – 1.3
Vending Machines	HFC-134a, R-404A, R-744	0.2 – 3.0

[a] Charge size is influenced by both the system capacity and the refrigerant type.
Source: RTOC (2011); EPA (2010d); Heatcraft (2004).

Due to their small charge size, the amount of refrigerant used to fill new self-contained equipment represents a small portion of total refrigerant consumed by the commercial refrigeration sector.

Although HFCs continue to dominate the market, this trend is starting to change for equipment types that may now use R-290 (e.g., reach-in refrigerators and freezers, beverage coolers, and food service equipment) and R-744 (e.g., beverage coolers and vending machines). For example, Unilever and Ben & Jerry's installed R-290 ice cream freezers (i.e., reach-in freezers) in 21 stores in the United States in 2009 and announced plans to install 700 more units in 2012. As of 2012, PepsiCo had also installed 35 R-290 beverage coolers across North America. Additionally, many supermarket chains, including Fresh & Easy and H-E-B, have deployed self-contained R-290 units. Coca-Cola has committed to installing only HFC-free equipment beginning in 2015 and as of 2014 had already installed over one million HFC-free units globally (including beverage coolers and vending machines)—the majority of which use R-744.

3.1.2. Remote Refrigeration Systems

As previously discussed, remote commercial refrigeration systems can be categorized into remote condensing unit systems and supermarket rack systems. Similar to self-contained systems, remote refrigeration systems historically used CFC-12, HCFC-22, and some ODS blends (e.g., R-502, R-401A, R-402A, and R-408A). Today, new remote systems largely rely on HFCs although both HFCs and many ODS refrigerants still remain in use in existing equipment. Ammonia (R-717) and carbon dioxide (R-744), both of which are acceptable under SNAP for use in large retail food equipment, are also used and gaining market share. A summary of non-ODS refrigerants currently used in remote condensing unit and supermarket rack systems is provided below in Table 18. A more detailed description of refrigerant use by system type is provided in the sections that follow.

Table 18: Non-ODS Substitute Refrigerants Used in Remote Refrigeration Systems by System Type

System Type	Refrigerants in Use	Typical Charge Size Range (kg) [a]
Remote Condensing Unit Systems	HFC-134a, R-404A, R-407A, R-407C, R-407F, R-422A, R-422B, R-422D, R-427A, R-438A, R-507A	0.5 – 20
Supermarket Rack Systems	HFC-134a, R-404A, R-407A, R-407C, R-407F, R-422A, R-422B, R-422D, R-427A, R-438A, R-507A, R-717, R-744	300 – 1,800

[a] Charge size is influenced by the system capacity, system design, and the refrigerant type.
Sources: RTOC (2011); EPA (2010d); GreenChill Partnership Data (2013).

Remote Condensing Units

Remote condensing units historically used HCFC-22. While many HCFC-22 systems still remain in use today, newly manufactured systems primarily use R-404A or HFC-134a. Other HFC blends—including R-407A, R-407C, R-407F, and R-507A—are also available. Remote condensing units may be retrofitted but retrofits are generally only done if the system is experiencing high leakage and the cost of replacing the leaked refrigerant is high. In such cases, an R-407 series or R-422 series refrigerant is most commonly used, although other retrofit refrigerants (e.g., R-427A, R-438A) are also available.

Supermarket Rack Systems

Supermarket rack systems historically used CFC-12, R-502, HCFC-22, and other HCFC blends in a centralized design. While many of these systems remain in use today, some have been retrofitted to replace the ODS refrigerant with an HFC blend (e.g., R-404A, R-422A, R-422B, R-422D, R-427A, R-438A, R-507A). For newly manufactured systems, HFC refrigerants (e.g., R-404A, R-507A, R-407A, R-407C, R-407F) dominate the market.

Many of the newly manufactured systems additionally employ alternative designs such as secondary loop systems, which use secondary fluids, such as R-744 or glycol to indirectly cool the refrigerated space, allowing for a relatively low HFC charge size. Another alternative design is a cascade system, which consists of two independent rack systems that share a common cascade heat exchanger which allows for the use of R-744 on the low temperature side. While an HFC is most commonly used as the refrigerant on the high temperature side, it is also feasible to use other refrigerants, e.g. R-717, on the high temperature side, thereby eliminating the use of the HFC.

In 2012, the first R-717/R-744 cascade system was installed in the United States in an Albertsons supermarket in Carpinteria, California. This milestone was followed in 2013 by the installation of the first 100% CO_2 (R-744)-based rack system in a Hannaford supermarket in Turner, Maine. This system is a transcritical CO_2 system, in which CO_2 is used as the primary refrigerant and operates at a high pressure to accommodate the low critical temperature of CO_2. Additional transcritical CO_2 systems have been installed in a Walgreens store in South Evanston, Illinois; a Whole Foods Market in Brooklyn, New York; a Whole Foods Market in Berkeley, California; a Whole Foods Market in San Jose, California; a Kroger in Holland, Ohio; a Sprouts store in Dunwoody, Georgia; and a Pick 'n Save supermarket in Menomonee Falls, Wisconsin. Installation of new supermarket rack systems that use R-744 and possibly R-717 as the primary refrigerant are expected to continue to grow in the United States. For example, the Lackland Air Force Base Commissary in San Antonio, Texas is currently in the process of replacing its old refrigeration system with an R-717/R-744 cascade system. This system is expected to go into operation in the summer of 2015.

4. Climate-Friendly Alternatives

Although not a significant portion of the market today, a variety of climate-friendly refrigerant alternatives (e.g., hydrocarbons, CO_2, ammonia, and HFOs (often blended with HFCs)) are available for use or expected to be available for use in the near-term in each of the commercial refrigeration system types described in this document. Table 19 below summarizes the status of lower-GWP alternatives in the United States by system type.

Table 19: Overview of Status of Climate-Friendly Alternatives by System Type

System Type	Hydrocarbons	CO_2	Ammonia	HFOs and HFC/HFO Blends
Stand-Alone (i.e., Self-Contained) Units: Reach-In Refrigerators and Freezers, Beverage Coolers, Food Service Equipment, and Packaged Walk-In Food Storage Equipment	• Acceptable under SNAP subject to use conditions (2011; 2015) • Gaining market share in the United States • Commonly used outside the United States	• Acceptable under SNAP (2009) • Used in glass-door beverage coolers	• Acceptable under SNAP (1996) with a secondary loop; no known use	• R-450A acceptable under SNAP (2014) • R-513A acceptable under SNAP (2015) • R-448A acceptable under SNAP for low-temperature equipment (2015) • R-449A acceptable under SNAP for low-temperature equipment (2015)
Vending Machines	• Acceptable under SNAP (2015) • Used outside the United States; limited testing in the United States	• Acceptable under SNAP (2012) • Gaining market share in the United States	• Not acceptable under SNAP; no known use	• R-450A acceptable under SNAP as retrofit (2014) and for new equipment (2015) • R-513A acceptable under SNAP (2015)
Remote Condensing Units	• Not acceptable under SNAP; no known use	• Acceptable under SNAP (2009) • Used outside the United States	• Acceptable under SNAP (1996) with a secondary loop • Used historically in industrial applications but not currently used commercially	• R-450A acceptable under SNAP (2014) • R-513A acceptable under SNAP (2015) • R-448A acceptable under SNAP (2015) • R-449A acceptable under SNAP (2015)

System Type	Hydrocarbons	CO_2	Ammonia	HFOs and HFC/HFO Blends
Supermarket Rack Systems	• Not acceptable under SNAP: no known use	• Acceptable under SNAP (2009) • First 100% CO_2 system installed in the United States in 2013 • Commonly used outside the United States • Also used in secondary loop systems or cascade designs in the United States	• Acceptable under SNAP (1996) with a secondary loop • First system installed in the United States in 2012	• R-450A acceptable under SNAP (2014) • R-450A in use in a supermarket in Spain • R-513A acceptable under SNAP (2015) • R-448A acceptable under SNAP (2015) • R-449A acceptable under SNAP (2015)

The U.S. Foams Industry

1. Introduction

Foams are plastics (such as polyurethane or polystyrene) that are manufactured using blowing agents to create bubbles or cells in the material's structure. The foam plastics manufacturing industries, the markets they serve, and the blowing agents used are extremely varied. Foams are used as insulation in a range of equipment and products, including refrigerated appliances (e.g., household refrigerators and freezers, laboratory and medical equipment, commercial refrigeration equipment), refrigerated trucks ("reefers") and other refrigerated transport systems, buildings (e.g., walls, roofs, floors), and pipes. Foams are also used to provide buoyancy (e.g., flotation devices, boat frames), and as cushioning in products, (e.g., steering wheels, furniture, shoes).

Historically, a variety of CFCs and HCFCs have been used as foam blowing agents because of their favorable chemical properties. Used in the production of foam, certain blowing agents may lead to environmental damage when released to the atmosphere at the time of foam manufacture, during product use, and/or at product disposal. In particular, CFC and HCFC blowing agents deplete the ozone and have very high GWPs. HFCs, which have more recently been adopted in the U.S. market to replace CFCs and HCFCs, also have high GWPs but do not damage the ozone layer. Other blowing agents that are both ozone- and climate-friendly have also been used and are increasingly being adopted.

The remainder of this chapter characterizes the U.S. foams sector in terms of market size and companies, historical and current blowing agent use, and the availability of climate-friendly alternatives.

2. Market Characterization

This section provides an overview of foam types and end-uses, and the foams market today. Additional general sector information on the market size, sales, and employment is also provided, as available.

2.1. Overview of Foam Types and End-Uses

Foams are characterized as "closed-cell" or "open-cell." Closed-cell foams have completely enclosed/discrete cells which encase the blowing agent used to create the cells during the foam production process; as a result, the blowing agent remains intact in the foam product (with only small amounts emitted during the production process) and is slowly emitted over the product lifetime and at or after (i.e., post-life emissions) disposal (if not properly recovered and destroyed). Conversely, in open-cell foams, each cell is connected to another cell and is not completely enclosed; thus, most or all blowing agent is emitted during the manufacture/production of the foam-containing product. Closed-cell foams are generally used in insulating and buoyancy applications, whereas open-cell foams are most often used in cushioning applications.

Foams can also be classified by the primary polymer used in production. Specifically, there are four foam types that have traditionally relied upon ODS, as described below.

- **Polystyrene** foam is the largest foam market in the United States, based on revenue. This foam type is estimated to represent approximately 52% of the revenue generated from all foam manufacture.[23] In

[23] Based on the 2012 data presented in IBIS (2012a) and IBIS (2012b). See details in Section **2.2.2**.

terms of quantity of foam generated, however, polystyrene is second to polyurethane, and represents approximately 30% of all foam (BCC Research 2010). Polystyrene foam is categorized as either "extruded" or "expanded," based on how it is manufactured. Extruded polystyrene (XPS) foam is manufactured by an extrusion process at elevated temperatures, which offers improved thermal properties. XPS includes boardstock (or 'board'), billet, and sheet foam; board and billet foam is often manufactured for construction applications, although XPS billet is also manufactured for buoyancy and insulating pipe applications. Sheet foam is typically manufactured for packaging purposes with thermal requirements. Expanded polystyrene is blown from beads of polystyrene which contain a blowing agent (typically a hydrocarbon such as pentane for extruded sheet foam, and a hydrocarbon or a hydrofluorocarbon for extruded boardstock). The beads are blown into hot moulds to create blocks and moulded shapes, typically for packaging applications.

- **Polyurethane** generates less revenue than polystyrene foam but represents 52% of the total quantity of foam generated by weight (BCC Research 2010). The technology was developed in the early 1930s and has since been the predominant foam type due to its versatility. Polyurethane foams can be formulated to achieve a range of properties (e.g., density, resilience) for different applications; it can be flexible or rigid. Rigid polyurethane foam is most often used in insulating applications, which represents the most significant use of this foam type. Rigid polyurethane spray foam used in construction insulation applications can be further characterized into three distinct categories: (1) high-pressure two component foam, (2) low-pressure two-component foam, and (3) one component foam (OCF). Flexible foams are most often used in non-insulating applications, specifically in the furniture industry and the automotive industry. Polyisocyanurate is chemically similar to polyurethane and is used in some of the same rigid thermal applications, and thus is often grouped with polyurethane foam. While it is less resilient than polyurethane, polyisocyanurate does offer improved fire performance and greater rigidity.

- **Polyolefin** foam represents less than 10% of the foam manufactured in the United States by weight (BCC Research 2010). Polyolefin foam is a polymer produced from a simple olefin. The two most common polyolefin foams are polyethylene and polypropylene, taken from the name of the olefin used to produce them: ethylene or propylene. Polyolefin foams have similar properties to XPS foam and are generally used in similar applications. This foam type, however, offers additional resilience which often makes it the foam type of choice in packaging applications.

- **Phenolic** foam accounts for less than 10% of all foam manufactured in the United States by weight (BCC Research 2010). This type of foam is very rigid, typically more so than polyurethane or polyisocyanurate. This foam type includes insulation board and bunstock, or 'blocks.' The rigidity characteristic of phenolic foams has historically made them unacceptable where vibration or thermal shock is a consideration. However, more recent developments have led to improved resilience, fire performance, as well as the best thermal performance of all foam types. This foam type is commonly used in insulating applications, specifically pipe sections, walls, roofs, and cold stores.

Table 20 summarizes the foam types and common application.

Table 20: Foam Types and Applications

Foam Type	Product Type	Open or Closed Cell	Insulating Applications							Non-insulating Applications					
			Domestic Appliances	Commercial Appliances	Pipe Section	Wall and Door/ Window Frames	Floor	Roof	Transportation	Cold Stores	Transportation	Furniture	Packaging	Buoyancy	Shoe Soles
Polyurethane	Boardstock (includes polyisocyanurate) (rigid)	closed				√	√	√							
	Appliance(rigid)	closed	√	√											
	Spray (rigid)	closed		√	√	√		√		√				√	
	Slabstock (rigid)	closed	√	√	√	√			√	√				√	
	Continuous and Discontinuous Block (rigid)	closed			√			√[a]	√	√			√[b]	√[a]	
	Injected / Pipe-in-Pipe (rigid)	closed			√										
	Continuous and Discontinuous Sandwich Panel (rigid)	closed				√		√	√	√					
	One Component Foam (OCF)	open				√									
	Slabstock and Moulded (flexible)	open				√[c]					√	√	√		√
	Integral Skin (flexible)	open									√	√	√		√
Polystyrene	Extruded Sheet	closed											√		
	Extruded Boardstock and Billet	closed			√	√	√	√	√	√				√	
	Expanded	closed				√	√	√					√		
Phenolic	Boardstock	closed				√		√							
	Panel	closed				√		√		√					
	Disk Block	closed			√					√					
Polyolefin (polyethylene, polypropylene)	Board	closed					√						√		
	Pipe	closed			√										

Source: UNEP (2010a), Jeffs (2013).
[a] For continuous blocks only.
[b] For discontinuous blocks only.
[c] Acoustic insulation.

2.2. Foam Market

For the purposes of this characterization, the foams market supply chain is divided into two separate groups: suppliers and systems houses. Suppliers produce the chemicals used in the manufacture of foams, which includes blowing agents and polyols,[24] while systems houses manufacture the foam. Large systems houses may purchase these chemicals from suppliers and then formulate their own blend of polyol and blowing agent and/or use additives, such as fire retardants, catalysts, and surfactants to produce foam that meets their product specifications. In contrast, small systems houses may purchase pre-blended or "fully formulated" polyols from suppliers to produce foam in favor of simpler operating conditions. Spray foam, on the other hand, is created on a jobsite by combining equal volumes of two chemicals, commonly referred to as A-side and B-side. A-side is the isocyanate component of the foam while B-side is a mixture of polyols, fire retardants, blowing agents, catalysts, and other additives. These two chemicals react and expand at the point of application. A-side is manufactured by suppliers, or chemical manufacturing companies, while the B-side formulation is developed by systems houses (SPFA 2013). In addition, depending on the application and the market, two-component spray foam can be applied either in a high-pressure two-component system using a liquid blowing agent and a high-pressure pump, or in a low-pressure two-component system using a gaseous blowing agent that provides propulsion in place of a pump.

2.2.1. Blowing Agent and Polyol Suppliers

Companies known to supply blowing agents[25] in the United States include:

- Albemarle
- Arkema
- Chevron Phillips
- Dow Chemical
- Chemours
- Dyplast Products
- ExxonMobil
- Foam Supplies Inc.
- Great Lakes
- Honeywell
- Lambiotte & Cie
- Mexichem
- Plenco
- Solvay

Companies known to supply polyols to the foam manufacturing industry include Invista (formerly Kosa), Huntsman, and Dow Chemicals (ICF 2003b, UNEP 2010a).

2.2.2. System Houses

Some of the major system houses for polyurethane, polystyrene, and phenolic foams are summarized in Table 21 by foam type and market share. Information on major foam system houses in the polyolefin market was not readily available.

[24] A compound containing multiple alcoholic hydroxyl groups.

[25] Foam blowing agents can be either chemical or physical blowing agents. The blowing agent suppliers listed here are for physical blowing agents. SNAP program listings are for substitutes in types of foam that historically have used CFCs or HCFCs as physical blowing agents.

Table 21. Major Foam System Houses

Market	Major Foam System Houses (% Market Share in 2012)
Polyurethane	Carpenter Co. (25.6%); Johnson Controls Inc. (25%); FXI Foamex Innovations (13.4%); Vitafoam Inc. (1.9%)
Polystyrene	Reynolds Group Ltd. (26.2%); Dart Container Corporation (18.8%); Solo Cup Company (5.9%); The Dow Chemical Company (4.8%)
Phenolic	Plenco (Plastics Engineering Company), Dyplast Products, Ashland, Borden Chemical, H.D. Fuller, Georgia Pacific, Resinoir, Sumitomo America, Triquest, and Vantico

Source: IBIS (2012a), IBIS (2012b), and ICF internet research.

Polyurethane system houses include, but are not necessarily limited to, the following. The types of foam produced at these system houses include flexible, rigid and spray, with different systems houses specializing in some or all types of polyurethane foam. [26]

- Bayer (formerly PSI)
- BASF
- Carpenter Co.
- Elliot Company
- Foam Supply Inc.
- FXI Foamex Innovations
- Gaco
- General Coatings
- Iso Tech
- Huntsman
- Hydroseal
- Johnson Control Inc.
- NCFI
- SWD Urethane
- UCSC
- Utah Foam Products
- Vitafoam Inc.

Source: ICF International (2003), Bayer (Undated), BASF (2010).

Manufacturers of XPS boardstock and billet include:

- BASF
- Dow
- Owens Corning
- Kingspan (formerly Pactiv Building Products)

2.3. Foam Sector Revenue and Employment

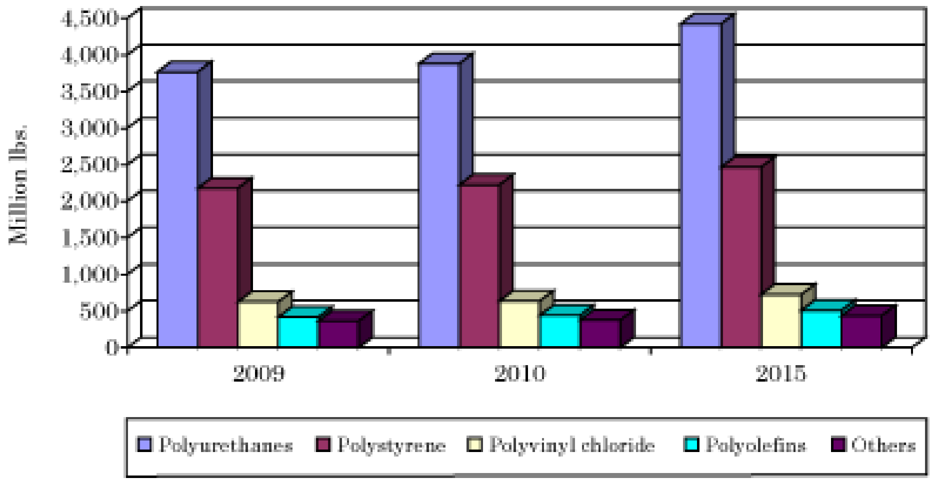
Several market reports were reviewed to assess the foams industry by end-use. According to the data available in these market reports, in 2012, the foam market was estimated to gross between $12.0 and $17.3 billion (IBIS [2012a, 2012b] and Barnes [2013a, 2013b]). [27] Of this, the polystyrene sector represented more than 50% of the industry, based on gross revenue. The same year, the industries for polyurethane and other types of foams employed between 25,700 and 27,300 people and grossed between $6.4 and $8.6 billion (IBIS 2012a, Barnes 2013b); the polystyrene industry employed about 25,000 people and grossed between $5.7 and $8.7 billion (IBIS 2012b, Barnes 2013a). Notably, these 2012 estimates of the number of employees and businesses are significantly lower than those provided for 2007 by the U.S. Census; the reason for this discrepancy is unclear.

[26] Parallel information on phenolic, polyolefin, and polystyrene (besides XPS boardstock and billet) system houses was not available, although it is known that Dow serves as a major system house for polystyrene foams. Companies listed do not necessarily represent an inclusive list of all polyurethane system houses in the United States.

[27] 2012 is the most recent year for which market data is available. This estimate is based on the highest gross revenues cited for each foam type across the available reports; the lower bound is estimated at $12.0 billion, based on Barnes (2010) and Barnes (2012).

Annual foam production estimates by polymeric foam type (which include PU, polyolefins, polystyrene, and other foam types) are illustrated in Figure 13. The data are based on two different reports, BCC Research (2010) and ACC (2012) but show consistent estimates for polyurethane production in 2010 at slightly less than four billion pounds.

Figure 13: Polymeric Foam U.S. Market Estimate by Resin Family, 2009-2005 (million pounds)



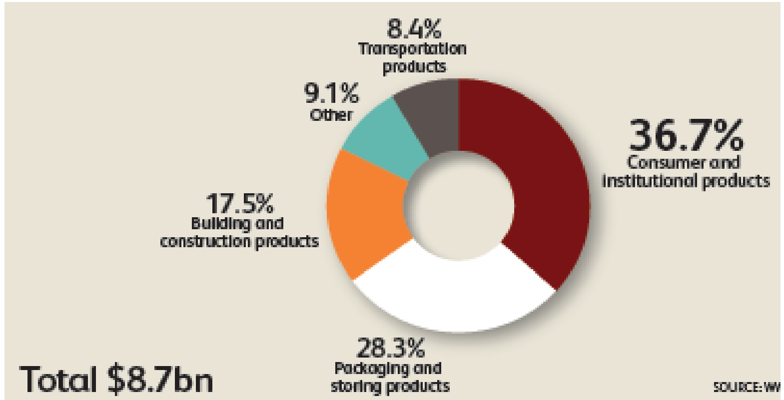
Source: BCC Research (2010).

Additional market information was available for the polyurethane industry from the American Chemistry Council. In 2010, the polyurethane industry directly created 37,700 jobs, paying $2.0 billion in wages to its employees, and generated $19.7 billion in revenues. Indirectly, this industry created and supported 164,900 additional jobs and generated $40.1 billion in output. Overall, the polyurethane industry supports 202,600 jobs through various activities including raw materials purchasing, equipment and services. Based on these figures, more than four jobs are created upstream or indirectly for each job in the polyurethanes industry, totaling five jobs in the economy for each job in polyurethanes (ACC 2012).

2.4. Foam Applications

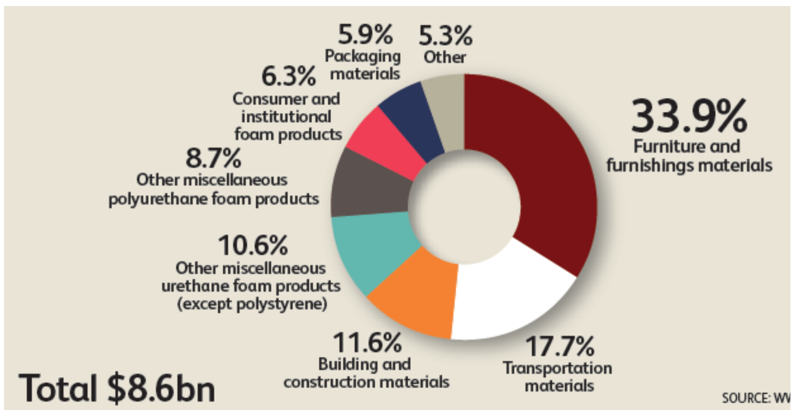
More detailed information on foam product segmentation/application is shown below. Figure 14 illustrates the product segmentation of the polystyrene market as a percentage of the overall revenue, followed by Figure 15, which illustrates the product segmentation of polyurethane as well as polyolefin, phenolic, and other foam products. In contrast, Table 22 provides segmentation of polyurethane product by product weight. The inclusion of other foam types may explain the significant differences in the product/end-use categories, notably furniture and transportation, between Figure 14 and Figure 15.

Figure 14: 2012 Polystyrene Product Segmentation*



Source: IBIS (2012b).
*Consumer and institutional products include polystyrene foam cups, plates, bowls and cutlery for household and commercial use.

Figure 15: 2012 Polyurethane and Other Product Segmentation



Source: IBIS (2012a).

Table 22: 2010 Polyurethane Production by Application/Product Type*

	Million Pounds	% of Total
Building and Construction	1,432	38%
Transportation and Marine	770	20%
Furniture and Bedding	730	19%
Appliances	230	6%
Packaging	172	5%
Footwear	19	1%
Other End-Use**	428	11%
Total	3,781	100%

Source: ACC (2012).
*Includes minor production of non-foam products, such as adhesives and coatings.
**Includes marine, tank, and pipe uses.

3. Sector Background

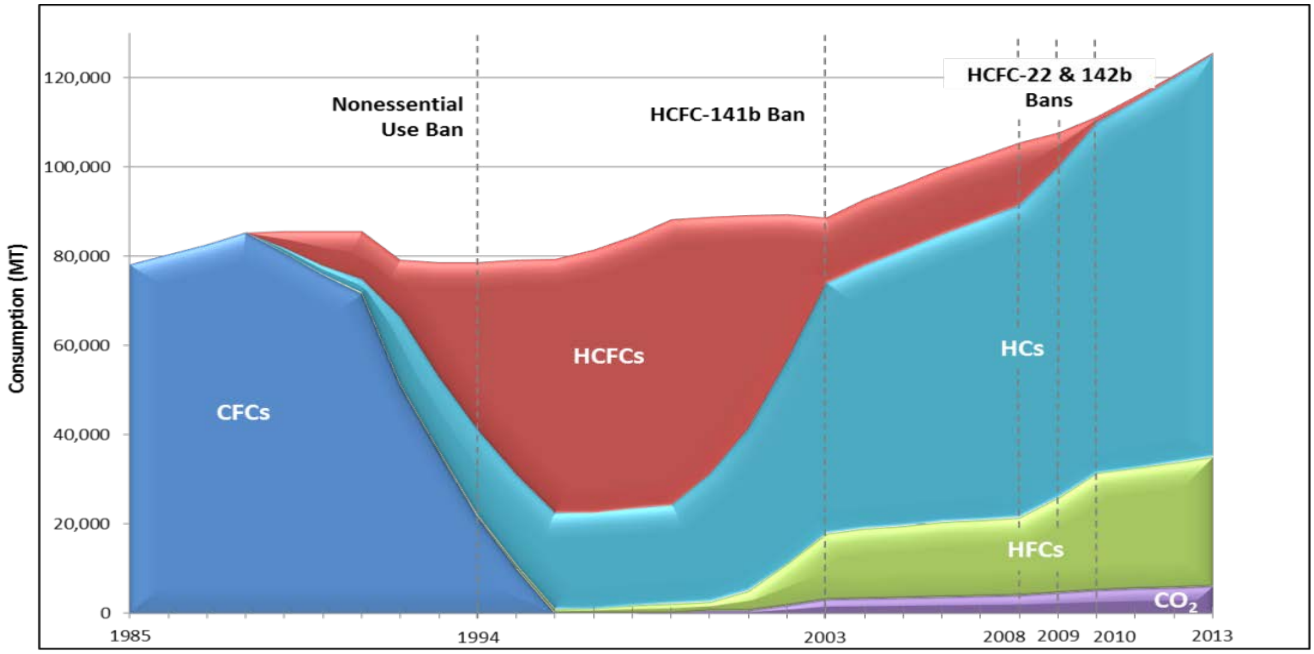
Most foam types were historically produced in the United States with CFC blowing agent, due to their relative abundance and favorable chemical properties. CFC-11 was the predominant blowing agent, followed by CFC-12, and CFC-113 in niche applications. One exception to this is expanded polystyrene, which has never used ODS blowing agents (ICA 2014).

Historically, a variety of CFCs and HCFCs have been used as foam blowing agents because of their favorable chemical properties. The Nonessential Product Bans in 1993 and 1994 under section 610 prohibited the sale, distribution, or offer for sale or distribution of all foam products containing or manufactured with CFCs and HCFCs, except insulating foams.[28] This ban included **open-cell foams**, often used for non-insulating purposes, because they emit most or all of the blowing agent at the time the foam is blown or within the first year. Flexible slabstock and moulded polyurethane foam, which represent the greatest blowing agent use of all flexible foam types, transitioned from CFCs to HCs. Integral skin polyurethane foams, however, transitioned briefly to HCFC-141b, and then to CO_2 and HFC-134a. One component foams (OCF) also transitioned briefly to HCFCs, namely HCFC-22 and HCFC-141b, before fully transitioning to HFC-134a, HFC-152a, and HCs.

In the early 1990s many **closed-cell foams** transitioned largely to HCFCs—particularly HCFC-141b and HCFC-142b, and to a lesser extent, HCFC-22. Nearly a decade later, in 2003, the United States phased out production and import of HCFC-141b and in November 2004, the use of HCFC-141b was listed as unacceptable under the SNAP Program. In addition, EPA proposed an unacceptability determination in November 2005 and issued a final unacceptability determination in March 2007, which specified that existing users of HCFC-22 and HCFC-142b must transition by March 1, 2008, for most uses. EPA provided an additional 18 months for this transition for marine flotation foam, allowing its use until September 1, 2009 and EPA allowed until January 1, 2010 for the transition for extruded polystyrene boardstock and billet. Following the phaseout of HCFCs, these applications transitioned largely to HFCs—primarily HFC-134a, HFC-152a, and HFC-245fa, and more recently HFC-365mfc and blends of HFC-227ea and HFC-365mfc. A number of closed cell foam applications also transitioned from CFCs directly to non-fluorinated alternatives that are both non-ozone depleting and low-GWP—namely to HCs (cyclo-pentane and n-pentane) and CO_2 (with water). The United States' transition away from the use of ODS to other blowing agents is illustrated in Figure 16.

[28] 40 CFR 82.62 defines foam insulation products as those "containing closed cell rigid polyurethane; closed cell rigid polystyrene boardstock foam; closed cell rigid phenolic foam; or closed cell rigid polyethylene foam when such foam is suitable in shape, thickness, and design to be used as a product that provides thermal insulation around pipes used in heating, plumbing, refrigeration, or industrial process systems."

Figure 16: United States Blowing Agent Use from 1985 to 2013 (MT)



Source: EPA Vintaging Model 2014.

4. Climate-Friendly Alternatives

A range of climate-friendly alternatives have been found to be acceptable under the SNAP program for use as foam blowing agents including hydrocarbons[29], carbon dioxide, water, and methyl formate. Other acceptable lower-GWP fluorinated compounds in use include HFO-1234ze and *trans*-1-chloro-3,3,3-trifluoroprop-1-ene (Solstice 1233zd(E)). Additional alternatives are also under development, such as HFO-1336mzz(Z) (Formacel-1100) and methylal.

The U.S. foam industry has made significant progress in adopting climate-friendly alternatives. HCs and to a lesser extent carbon dioxide, have been almost fully adopted in many foam end-uses. However, there are some foam applications, such as spray foam, where transition has been slower due to specific concerns such as safety considerations related to the particular application.

Over 65% of the U.S. market today already uses climate-friendly blowing agent alternatives. Additional climate-friendly options are expected to be available in the near-term for end-uses which have thus far encountered barriers to transition (e.g., flammability, insulation performance). Table 23 summarizes available information on the status of use and SNAP listing of several climate-friendly alternative blowing agents by end-use. One-component foam is not recognized as a distinct end-use under the SNAP program; thus, it is not included separately in the table.

[29] Specifically, light saturated hydrocarbons with three to six carbons (C3-C6) including propane, butane, isobutane, n-pentane, cyclopentane, isopentane, and hexane and its isomers.

Table 23: Overview of Climate-Friendly Alternatives and SNAP Listing Status by Foam Type[1]

Foam End-use	HCs	CO_2	Water	Unsaturated HFCs and HCFCs	Methylal	Methyl Formate/ ecomate™
Flexible Polyurethane: Slabstock and Moulded	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994)	• SNAP-approved (1999) • Widely in use	• Solstice 1233zd(E) SNAP-approved (2014) • HFO-1336mzz(Z) SNAP-approved (2014)	• SNAP-approved (2014)	• SNAP-approved (2000) • Under industry evaluation; trials in progress
Rigid Polyurethane and Polyisocyanurat: Boardstock	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994)	• SNAP-approved (1999)	• Solstice 1233zd(E) SNAP-approved (2012) • HFO-1336mzz(Z) SNAP-approved (2014) • Under regulatory and/or industry evaluation; trials in progress	• SNAP-approved (2014)	• SNAP-approved (2000)
Rigid Polyurethane: Appliance	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994)	• SNAP-approved (1999)	• Solstice 1233zd(E) SNAP-approved (2012); gaining market share • HFO-1234ze SNAP- approved (2009); no known use • HFO-1336mzz(Z) SNAP-approved (2014)	• SNAP-approved (2014)	• SNAP-approved (2000) • No known use
Extruded Polystyrene: Sheet	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994) • Some use	• SNAP-approved (1999)	• NA	• NA	• SNAP-approved (2006)[2]
Rigid Polyurethane: Spray	• NA[3]	• SNAP-approved (1994) • Some use	• SNAP-approved (1999)	• Solstice 1233zd(E) SNAP-approved (2012); gaining market share • HFO-1336mzz(Z) SNAP-approved (2015)[4] • HFO-1234ze SNAP- approved (2009); no known use; development ongoing for low-pressure formulation	• NA	• SNAP-approved (2006)[2]

Foam End-use	HCs	CO_2	Water	Unsaturated HFCs and HCFCs	Methylal	Methyl Formate/ ecomate™
Polyolefin	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994)	• SNAP-approved (1999)	• HFO-1234ze SNAP- approved (2010)	• NA	• SNAP-approved (2006)[2]
Extruded Polystyrene: Boardstock and Billet	• SNAP-approved (1994)	• SNAP-approved (1994) • Some use	• SNAP-approved (1999)	• HFO-1234ze SNAP-approved (2009)	• NA	• SNAP-approved (2006)[2]
Rigid Polyurethane: Slabstock and Other	• SNAP-approved (1994)	• SNAP-approved (1994) • Some use	• SNAP-approved (1999)	• HFO-1234ze SNAP-approved (2010) • Solstice 1233zd(E) SNAP-approved (2012) • HFO-1336mzz(Z) SNAP-approved (2014)	• SNAP-approved (2014)	• SNAP-approved (2000)
Rigid Polyurethane: Commercial Refrigeration	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994) • Some use	• SNAP-approved (1999)	• HFO-1234ze SNAP-approved (2009) • Solstice 1233zd(E) SNAP-approved (2012) • HFO-1336mzz(Z) SNAP-approved (2014)	• SNAP-approved (2014)	• SNAP-approved (2000) • Some use
Phenolic Insulation Board and Bunstock	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1994)	• SNAP-approved (1999)	• HFO-1234ze SNAP-approved (2009) • HFO-1336mzz(Z) SNAP-approved (2014)	• NA	• SNAP-approved (2006)[2]
Polyurethane: Integral Skin	• SNAP-approved (1994) • No known use	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1999)	• HFO-1234ze SNAP-approved (2010) • Solstice 1233zd(E) SNAP-approved (2012)	• SNAP-approved (2014)	• SNAP-approved (2000)
Rigid Polyurethane: Sandwich Panels (Continuous and Discontinuous)	• SNAP-approved (1994) • Widely in use	• SNAP-approved (1999) • Some use	• SNAP-approved (1999)	• Solstice 1233zd(E) SNAP-approved (2012) • HFO-1234ze SNAP-approved (2009) • HFO-1336mzz(Z) SNAP-approved (2014)	• SNAP-approved (2014)	• SNAP-approved (2000)

NA = Not applicable. The SNAP program has not received a submission and/or made a determination for the specified end-use.
[1]Earliest SNAP listing dates are indicated in this table.
[2] Listed as acceptable under the brand name ecomate™ and not listed for methyl formate.
[3] Listed as acceptable under the brand name Exxsol blowing agents, and not listed for light saturated C3-C6 hydrocarbons.
[4]Listed as acceptable for use in high-pressure two-part spray foam only.

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