California Environmental Protection Agency

Air Resources Board

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California's High Global Warming Potential Gases Emission Inventory

Emission Inventory Methodology and Technical Support Document

State of California
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Air Quality Planning and Science Division

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Acknowledgments

This document was developed by the following Air Resources Board staff members:

Glenn Gallagher
Bela Deshpande, Ph.D.

With

Pamela Gupta
Manager of Greenhouse Gas Reduction Strategy Section, Research Division

Anny Huang, Ph.D.,
Manager of Emission Inventory Analysis Section, Air Quality Planning and Science Division

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INTRODUCTION

Ozone depleting substances (ODS) are a class of compounds being phased out under the Montreal Protocol and the Clean Air Act Amendments of 1990. ODS include a number of fluorinated gases (F-gases) such as chlorofluorocarbons (CFCs), halons, carbon tetrachloride, hydrochlorofluorocarbons (HCFCs), and methyl chloroform. Historically, ODS were used in applications such as refrigeration and air conditioning equipment, solvent cleaning, foam production, sterilization, fire suppression, and aerosol containers. Hydrofluorocarbons (HFCs) and perfluorinated compounds (PFCs) are the primary replacement for ODS, and are collectively known as "ODS substitutes". The emissions of ODS substitutes have been increasing as they are increasingly phased in. ODS substitutes have global warming potentials much higher than that of carbon dioxide.

Emissions of ODS substitutes occur when they are intentionally released into the atmosphere during normal product use (e.g., from fire extinguishers or aerosol cans), when they leak out of equipment such as refrigerators and air conditioning units, or upon disposal and destruction of equipment end-of-life (if the ODS substitutes are not collected and destroyed). Estimating these emissions is difficult because the sources are diffuse and the emissions occur over the equipment lifetime. The California Air Resources Board (ARB) has implemented detailed inventory estimations based on comprehensive research completed by ARB staff and studies completed by ARB contractors. Historical net consumption of each ODS was first compiled at a detailed product and equipment level to establish the basis for future emissions. Emissions were estimated using activity data, equipment-specific storage capacity, maintenance and recharging assumptions, and emission factors that reflect the individual characteristics of the various equipment types, processes, and products.

This document provides detailed methodology used to calculate emissions of ODS substitutes in California from 2000 to the present, along with projected emissions through 2030. This document is prepared in support of the Short-Lived Climate Pollutant (SLCP) Strategy developed pursuant to Senate Bill (SB) 605 (Lara, Chapter 523, Statutes of 2014), which requires ARB to develop a plan for reducing F-gases with a lifetime of several decades. The following emission categories are included in the ARB Greenhouse Gas (GHG) Emission Inventory: Refrigeration and air conditioning (AC), aerosol propellants, insulating foam, solvents and fire protection.

General Methodology of Emission Estimation and Forecasting

F-gases are estimated using the Tier 2 emission factor approach from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The Tier 2 methodology follows two general steps:

Step 1. Calculate the time series of net consumption of each individual HFC at a detailed product and equipment level as the basis for emission calculations (e.g., inventory of refrigerators, other stationary refrigeration/AC equipment, appliance foams, insulated panels, pipe insulation, etc.).

Step 2. Estimate emissions using the activity data and resulting bank calculations derived from step (i), and either emission factors that reflect the unique emission characteristics related to various processes, products and equipment (Tier 2a) or, relevant new and retiring equipment information at the sub-application level to support a mass balance approach (Tier 2b).

I. Emission categories and sub-categories

F-gas emissions are organized into ten broad categories with 29 detailed sub-categories, as listed in Table 1 below. Emissions of each individual F-gas is reported by subcategory on a mass and CO_2-equivalent basis.

Table 1. F-gas emission categories and sub-categories

Emission Category	Emission Sub-Category
Aerosol propellants (MDI)	Metered Dose Inhalers (MDI)
Aerosol propellants (non-MDI)	Consumer Product and Commercial/Industrial Aerosol Propellants
Commercial Refrigeration and AC Large (> 50-lb systems)	Centralized system ≥2,000 lbs.
	Centralized system 200-<2,000 lbs.
	Centrifugal chiller ≥2,000 lbs.
	Centrifugal chiller 200-<2,000 lbs.
	Chiller - packaged 200-<2,000 lbs.
	Cold storage ≥2,000 lbs.
	Cold storage 200-<2,000 lbs.
	Process cooling ≥2,000 lbs.
	Refrigerated condensing units 50-< 200 lbs.
	Unitary AC 50-<200 lbs.
Commercial Refrigeration and AC Small (≤ 50-lb systems)	Refrigerated condensing units ≤ 50 lbs.
	Unitary AC (≤ 50-lb)
Fire Protection	Fire Suppressants
Foam, Insulating	Foam (appliance, building, refrigeration equipment, transport, marine buoyancy)
Industrial	Industrial Solvents
	Semiconductor Manufacturing
	Sulfur Hexafluoride uses
Medical	Medical Sterilants
Mobile and Transport	Light Duty (LD) Vehicle AC
	Heavy Duty (HD) Vehicle (non-Bus) AC
	Bus AC
	Off-road Heavy Duty Vehicle
	Transport Refrigerated Units (TRUs) including rail cars
	Refrigerated Shipping Containers
	Ships (Marine Vessels)
Residential	Residential refrigerator-freezer (appliance)
	Residential AC Window AC units (Residential)

II. Calculation method and inputs

In order to estimate emissions, it was first necessary to assign an emissions profile for each sub-category. Sub-categories are assigned a simple or complex calculation methodology.

Simple Calculation

Emission estimates for many refrigeration and AC equipment categories are based on of available equipment information, refrigerant charge amount, and leak rates using the following general formula:

Equation 1. General equation for refrigeration and AC equipment

*Emissions (lbs.) = [number of units (equipment) in use] * [average F-gas charge (lbs./unit)] * [average annual leak or loss rate]*

*+ [number of units reaching end-of-life (EOL)] * [average F-gas charge at EOL (lbs./unit)] * [average loss rate at EOL]*

Table 2 shows input factors used to estimate emissions. The methodology and data used to determine the input factors are further described in subsequent supporting sections of this methodology paper.

Table 2. Input factors and emission calculations for refrigeration and AC

Equipment Type or Emissions sub-sector	**Units in CA in 2014 [(a)]**	**Ave. Charge (amount) of F-gas in lbs.**	**Ave. Annual Leak (loss) Rate**	**Annual Loss in lbs. [(a)] (units* charge* loss rate)**	**EOL units in 2014 [(a)]**	**Ave. Charge (amount) in lbs. at EOL**	**Ave. EOL Loss Rate**	**EOL Loss in lbs. [(a)] (units* charge* loss rate)**	**total loss in lbs. [(a)] (annual + EOL)**
Refrigeration Large Centralized System ≥ 907.2 kg (2,000 lbs.)	840	3,635	16.6%	506,864	45	2,871	20%	25,839	532,703
Refrigeration Medium Centralized System 90.7-< 907.2 kg (200-< 2,000 lbs.)	23,720	704	17.6%	2,939,003	1,265	577	20%	145,981	3,084,984
AC Large Centrifugal Chiller ≥ 907.2 kg (2,000 lbs.)	5,165	3,978	2.3%	472,567	205	3,887	20%	159,367	631,934
AC Medium Centrifugal Chiller 90.7-< 907.2 kg (200-< 2,000 lbs.)	1,630	1,007	1.4%	22,980	65	993	20%	12,909	35,889
AC Chiller - Packaged 90.7-< 907.2 kg (200-< 2,000 lbs.)	10,190	526	6.9%	369,836	410	490	20%	40,180	410,016
Refrigeration Large Cold Storage ≥ 907.2 kg (2,000 lbs.)	150	7,929	15.9%	189,107	6	5,788	20%	6,946	196,052
Refrigeration Medium Cold Storage 90.7-< 907.2 kg (200-< 2,000 lbs.)	420	494	18.9%	39,214	20	316	20%	1,264	40,478
Refrigeration Process Cooling ≥ 907.2 kg (2,000 lbs.)	105	5,242	10.0%	55,041	4	4,718	20%	3,774	58,815
Refrigerated Condensing units 22.7-≤ 90.7 kg (50-≤ 200 lbs.)	77,700	122	15.0%	1,421,910	3,100	122	20%	75,640	1,497,550
Unitary AC 22.7-≤ 90.7 kg (50-≤ 200 lbs.)	73,400	100	11.3%	829,420	3,900	89	20%	69,420	898,840

Equipment Type or Emissions sub-sector	Units in CA in 2014 [a]	Ave. Charge (amount) of F-gas in lbs.	Ave. Annual Leak (loss) Rate	Annual Loss in lbs. [a] (units* charge* loss rate)	EOL units in 2014 [a]	Ave. Charge (amount) in lbs. at EOL	Ave. EOL Loss Rate	EOL Loss in lbs. [a] (units* charge* loss rate)	total loss in lbs. [a] (annual + EOL)
Refrigerated Condensing Units ≤ 22.7 kg (50-lbs. or less)	314,500	31.4	15.0%	1,481,295	12,600	27	34%	115,668	1,596,963
Refrigerated stand-alone display cases	686,200	7.1	0%	0	27,500	7.1	100%	195,250	195,250
Refrigerated vending machines	524,400	0.66	0%	0	28,000	0.66	100%	18,480	18,480
Unitary A/C ≤ 22.7 kg (50-lbs. or less) (central)	2,533,600	15.1	10.0%	3,825,736	143,000	12.1	56%	968,968	4,794,704
Commercial AC (window unit)	649,600	1.54	2.0%	20,008	43,300	1.17	100%	50,661	70,669
Residential Appliance (refrigerator-freezer)	17,718,700	0.34	1.0%	60,244	1,013,000	0.29	77%	226,203	286,446
Residential A/C (central)	7,231,000	7.5	10.0%	5,423,250	386,000	5.3	80%	1,636,640	7,059,890
Residential A/C (window unit)	3,725,000	1.54	2.0%	114,730	248,000	1.17	100%	290,160	404,890
Transport Refrigerated Units (TRUs)	58,100	20.7	18.3%	220,089	4,600	17.4	15%	12,006	232,095
Refrigerated Shipping Containers	51,400	33.1	5.0%	85,067	15,360	33.1	19%	96,851	181,918

a) Red font represents the quantities that are expected to change every year. Blue font represents the loss calculated.

Complex Calculation

The remaining F-gas categories not shown in Table 2 have no simple formula to calculate emissions, and required more detailed analysis. For example, AC refrigerant emissions from mobile vehicles employed two detailed vehicle emission models known as the ARB EMissions FACtor model (EMFAC) (CARB, 2011a), and the OFFROAD model (CARB, 2007a). Refrigerant emissions from marine vessels represented a particular challenge because there were five different ship types analyzed, and a lack of information on the number of days each ship type spent in California waters. Insulating foam emissions were estimated as a result of a three-year study by Caleb Management Services for ARB, where the foam emissions were estimated for 19 distinct categories of insulating foam.

These emission estimate methodologies are described in their respective sections:

- Mobile vehicle AC
- Ships (marine vessels)
- Aircraft AC
- Rail AC
- Metered Dose Inhaler (MDI) aerosol propellant
- Consumer product (and commercial/industrial) aerosol propellants
- Fire suppressants
- Insulating foam
- Semiconductor manufacturing
- Solvents
- Medical sterilants
- Sulfur hexafluoride

III. Emission projection through 2030

The F-gas inventory and projection is updated annually to incorporate the best available data. Projected emissions use current emission factors, projected equipment inventory and known changes that will occur (due to regulation). The following assumptions are made for projected emissions of F-gases:

Population as the Default Growth Surrogate

The number of pieces of equipment using F-gases increases each year in proportion to population growth in California. For example, an increase in population of one percent corresponds to a one percent increase in the number of new refrigeration and AC units used in the state. Therefore, F-gas emissions are assumed to increase proportionally to population, unless data indicates otherwise. For years 2012 and later, we use the California Department of Finance (DOF) population projections showing a 0.75 percent annual growth rate in California through 2030 (DOF, 2014).

Annual Leak Rate

Annual leak rates and equipment end-of-life loss rates remain the same as baseline years, unless acted upon by exterior forces such as regulations that have been adopted at the state or national level. For example, the baseline leak rate of large centralized refrigerated systems containing 2,000 or more pounds of refrigerant was found to be 21 percent annually (SCAQMD, 2008 and 2012). However, research conducted for the ARB Refrigerant Management Program (RMP) found that a lower annual leak rate of 10 percent was achievable through best management practices as required by the RMP (CARB, 2009d). This methodology assumes that the lower leak rates expected from the RMP can be achieved within ten years of program implementation. Therefore, if the baseline leak rate in 2011 was 21 percent annually, the annual leak rate could be reduced to 10 percent in 2021 and each year thereafter. We assume a linear reduction each year from 2011 to 2021 until the lower limit of 10 percent leak rate is achieved.

Leak rate assumptions are checked against actual reported data to the ARB Refrigerant Management Program, then revised and updated annually. A constant projected leak rate is assumed for all refrigeration and AC equipment not subject to federal record keeping requirement or state regulations, which include all equipment containing less than 50 pounds of refrigerant. Though future refrigerant cost increases may incentivize faster leak repair, no data exists to predict the future price of refrigerants, therefore, potential changes in maintenance could not be estimated at this time.

New Equipment

F-gases used in new equipment and materials were assessed and summarized by the U.S. EPA as part of their emissions calculations estimated through the Vintaging Model (U.S. EPA, 2008). New equipment and materials are assumed to use the same amount and type of F-gas as used in baseline years and previous years, until adopted regulations prohibit the use of specific F-gases in new equipment and materials (exceptions are described at the end of this section). For example, CFCs were banned from all new uses beginning in

1995, with special use exemptions for medical dose inhalers. HCFCs were banned in new equipment and use beginning in 2010. From 2010 to 2030, we assume that ODS substitutes are used in new equipment and materials in the same proportion each year, unless regulations prohibit specific HFCs from new use.

The U.S. EPA Significant New Alternatives Policy (SNAP) Program adopted F-gas regulations on July 22, 2015 that will prohibit the use of certain high-GWP HFCs in new uses for specific applications (U.S. EPA, 2015). SNAP is estimated to reduce future California HFC emissions an additional ten percent from previous baseline levels. The SNAP Program requirements have been incorporated into updated California ODS Substitutes emissions projections through 2030, with the SNAP requirements summarized below. The details of the SNAP requirements are shown in Appendix 1.

Aerosol propellants: HFC-125, HFC-134a, and HFC-227ea are prohibited as of January 1, 2016. Exceptions are for medical dose inhalers and some technical and aerospace applications.

Insulating foam: Specific foam expansion agents are prohibited in new uses with prohibition start dates between January 1, 2017 and January 1, 2021, depending upon the foam type. Although no GWP limits are cited by the SNAP rule, the functional effect will be to ban all foam expansion agents with a GWP greater than 150 by 2021.

Light-duty motor vehicle air-conditioning: HFC-134a is prohibited beginning with model year 2027 and all subsequent models. Note that this does not affect the projected emissions using our methodology because we have already assumed that HFC-134a will not be used in new light-duty vehicles beginning with model year 2017, due to the Federal Clean Car Incentive Program that incentivizes low-GWP air-conditioning in light-duty vehicles.

Retail food refrigeration: SNAP functionally prohibits all refrigerants with a GWP greater than 2500 for new supermarket systems beginning January 1, 2017; and for remote condensing units (smaller refrigeration units) beginning January 1, 2018. For self-contained or stand-alone units, the requirement begins January 1, 2019 for smaller systems, and January 1, 2020 for larger systems and low-temperature systems.

Vending machines: SNAP functionally prohibits all refrigerants with a GWP greater than 1300 for new units beginning January 1, 2019. The likely replacements have low GWPs between one and ten.

Exceptions to the assumption that no change in F-gases are made without regulatory drivers: Insulating foam has increasingly been produced using low-GWP foam expansion agents such as methyl formate, CO_2 and hydrocarbons for the past decade without any regulatory requirements (Caleb, 2010). The lower cost of non-HFC foam expansion agents appears to be the driver behind the decreasing use of HFCs. The methodology includes both the required SNAP changes as well as the voluntary changes and trends as researched by Caleb Management Services for ARB (Caleb, 2010).

In 2004, several companies formed a partnership called "Refrigerants Naturally" which made a commitment to using only low-GWP refrigerated vending machines and small self-contained display cases for food and soft drinks. As of 2015, there has been a significant increase in low-GWP refrigeration used in the vending machines and self-contained display cases. These changes made in advance of any regulatory requirement have been incorporated into the methodology.

I. General methods and data sources

This section describes the methodology used to calculate emissions for all stationary refrigeration and AC equipment and emission categories. Annual emissions for a given year were calculated using the following equation:

Equation 2. Annual emissions for a given year

*Emissions (lbs.) = [number of units in use] * [average F-gas charge (lbs./unit)] * [average annual leak or loss rate]*
*+ [number of units reaching end-of-life (EOL)] * [average F-gas charge (lbs./unit)] * [average loss rate at EOL]*

The emissions in pounds are converted into metric tonnes. The metric tonnes are then multiplied by the GWP of the F-gas (using IPCC Fourth Assessment Report GWP values) to calculate metric tonnes of carbon dioxide equivalents.

The main data source for stationary refrigeration and AC equipment was refrigerant usage and loss data provided by the South Coast Air Quality Management District (SCAQMD) and analyzed by ARB to develop emission profiles for each sub-category of equipment (CARB, 2009d). Equipment profiles for 12 specific types and sizes of refrigeration and AC equipment were developed using SCAQMD Rule 1415 (Reduction of Refrigerant Emissions from Stationary Refrigeration and Air Conditioning Systems) reporting data from approximately 6,000 systems in 2,000 facilities over reporting years 2002-2010 (SCAQMD, 2008; SCAQMD, 2012). Each profile includes refrigerant types used, average refrigerant charge size, and average annual loss. Some profiles for HFC use in refrigeration and AC equipment were augmented by U.S. EPA Vintaging Model estimates, as SCAQMD Rule 1415 did not apply to HFC refrigerants until 2011.

The average recovery and loss of refrigerant at equipment end-of-life were derived from an ARB contracted study conducted by Armines Center for Energy and Processes (Armines, 2009), U.S. EPA Vintaging Model estimates (US EPA, 2008), and United Nations Environment Programme (UNEP) reports (UNEP 2006b, and 2010b).

The number of units was estimated by extrapolating Rule 1415 business and equipment data to statewide estimates. A methodology to estimate numbers of refrigeration and AC equipment in use, and the numbers and types of facilities using the refrigeration or AC equipment was developed by ARB, and is described in the Initial Statement of Reasons for the ARB Refrigerant Management Plan Rule for stationary refrigeration systems (CARB, 2009d). The data from SCAQMD were extrapolated statewide by 1) developing equipment type emission profiles, 2) linking equipment to specific business types, and 3) estimating the number of refrigerant-using facilities within a specific Standard Industrial Classification (SIC) code or North American Industrial Classification System (NAICS) code.

II. Average lifetime and end-of life emissions

The equipment end-of-life (EOL) retirement for a given year is modeled using an appliance and equipment survival curve based on equipment retirement ages. Studies available on equipment and appliance retirement age indicate a normal distribution curve represents actual appliance and equipment retirement ages (Calabrese, 2004; Lawless, 2003; Weibull, 1951; Welch and Rogers, 2010). Using retirement age data and regression curves, it is shown that appliances begin to retire almost immediately after their year of manufacture, with the longest tail-end of equipment functioning until 200 percent of the average lifetime of the equipment. The normal distribution of functional life and retirement age, or “survival curve”, was applied to the emission equations for all refrigeration and AC equipment. Data on the retirement ages of very large commercial refrigeration and AC equipment were not available; therefore, it was assumed that commercial equipment follows a similar functional life and retirement age curve (“survival curve”) as smaller equipment. See Figure 1 below for a comparison of equipment survival curves.

Figure 1. Equipment end-of-life function curve

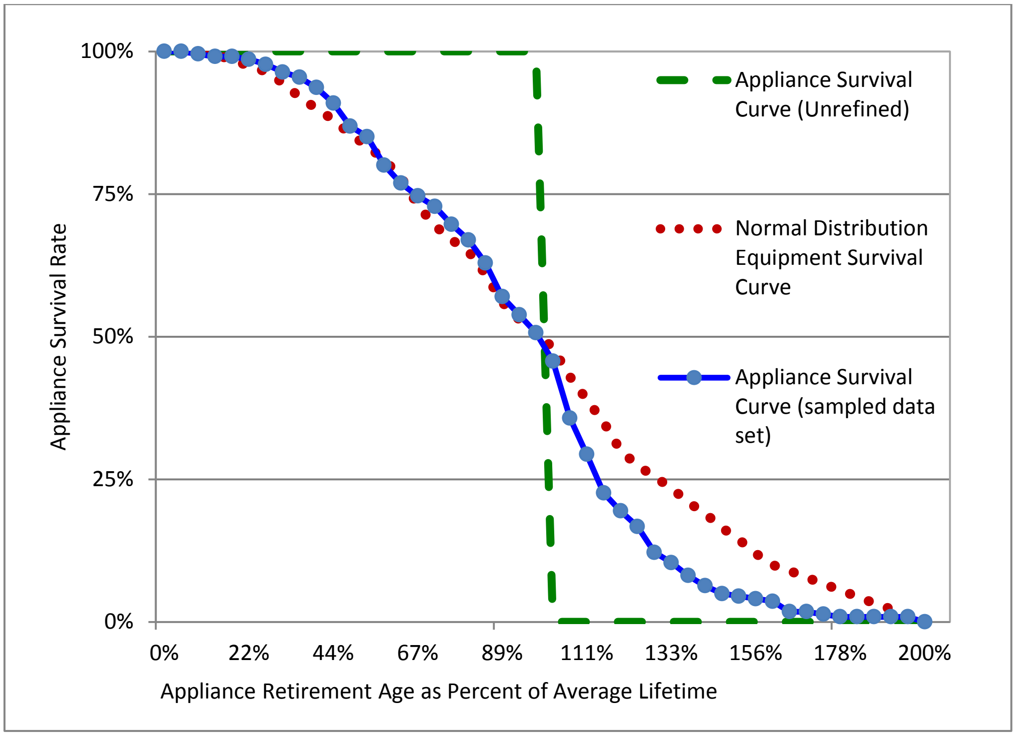

Figure 1 shows survival curves that include an unmodified, unrefined "curve" used, shown as a dashed green line, where all equipment is in use until average lifetime is reached, at which time all equipment reaches end-of-life. The normal distribution survival curve is shown as a red dotted line. For comparison purposes, an average lifetime curve for household appliances (refrigerator-freezers) as sampled is shown as a blue line with blue dots, which compares closely to the normalized survival curve (Calabrese, 2004).

III. Commercial refrigeration and air conditioning

An inventory of GHG emissions was developed for the commercial refrigeration and AC category in the development of the ARB Stationary Refrigerant Management Program regulation adopted in December 2009. The methodology used to estimate baseline and future emissions is detailed in the regulation's Initial Statement of Reasons (ISOR) Appendix B for California Facilities and Greenhouse Gas Emission Inventories (CARB, 2009d). The following is a brief summary of the methodology used.

Reports submitted by facilities to the South Coast Air Quality Management District (SCAQMD) to comply with Rule 1415, "Reduction of Refrigerant

Emissions from Stationary Refrigeration and Air Conditioning Systems" (SCAQMD, 2008; SCAQMD, 2012) formed the basis for developing emission profiles using the following input data:

- Numbers and types of refrigeration and AC equipment used in California,
- Refrigerant capacity in pounds,
- Annual loss (leakage) rates, and
- Types of refrigerant used and their distribution for each equipment type.

Equipment profiles were developed for 12 sub-types of refrigeration and AC equipment, each with its own profile of refrigerant types, average refrigerant charge size, and average annual loss. The SCAQMD Rule 1415 did not apply to HFC refrigerants until 2010; therefore, distribution of HFC refrigerants was derived from U.S. EPA Vintaging Model (U.S. EPA, 2008). End-of-life loss rates were derived from a study by Armines Center for Energy and Processes (Armines, 2009), U.S. EPA Vintaging Model estimates (U.S. EPA, 2008), and UNEP reports (UNEP 2006b, and 2010b).

The category for "commercial refrigeration, 50-pounds charge size or less" was further broken out into the following types of equipment:

- Refrigerated condensing units (centralized or distributed systems)
- Refrigerated stand-alone display cases
- Refrigerated vending machines

AC units containing 50 pounds or less of refrigerant were also exempt from Rule 1415 reporting, as were all residential refrigeration and AC systems. Therefore, the primary source of data for these smaller units was the research conducted by Armines Center for Energy and Processes (Armines, 2008). To determine emissions from AC units containing less than 50 pounds of refrigerant, it was necessary to further divide this category into central AC units used in commercial buildings, central AC units used for residential, and window AC units (commercial and residential units). Refrigerant emissions are directly proportional to the number of equipment in use, and the number reaching end-of-life each year. Armines Center for Energy and Processes estimated that the growth in sales of refrigeration equipment was 1.7 percent annually between 1990 and 2007, and the growth in sales of AC equipment was 2.5 percent annually between 1990 and 2007.

Due to the economic downturn of the late 2000s, the refrigeration equipment sales rates were adjusted downwards beginning in 2007. Although food sales are resilient to economic downturns, it was assumed that sales of new refrigeration equipment for food manufacturing, distribution, storage, and retail sales would decrease proportionally to food sales which accounts for inflation adjustment. Food sales were estimated by the United States Department of Agriculture (USDA) to increase only 0.6 percent in 2007, and decrease one percent annually in 2008 and 2009 (USDA, 2012) although the decrease was estimated to be slightly less at 0.5 percent annually in 2009 by the Food Marketing Institute (IFT, 2009). The USDA also estimated that food sales adjusted for inflation were estimated to increase 1.5 and 1.4 percent annually in 2010 and 2011. To simplify future growth estimates, we assume that refrigeration equipment sales (and emissions) increase proportionally to population growth in California, estimated at 0.75 percent annually for the foreseeable future, based on projected population growth through 2030 (CA DOF, 2011).

The AC equipment sales rates were also adjusted to the economic downturn beginning in 2007. Based on US Department of Commerce (DOC) wholesale trade surveys, we used the wholesale trade surveys for NAICS code 42 (Wholesale Trade) as the closest approximation for the more specific NAICS code that includes AC sales, NAICS 421730 "Warm air heating & air-conditioning equipment and supplies wholesale". Inflation-adjusted refinements made to the historic 2.5 percent annual increase in the AC sales growth rate were as follows: no increase or decrease in 2007, 7.2 percent decrease in 2008, 17.0 percent decrease in 2009, and a 4.3 percent annual increase in both 2010 and 2011 (US DOC, 2012; BLS, 2012). For 2012 and future years, a 1.3 percent annual growth is estimated for this category, representing half of the traditional growth rate in this category.

As detailed in the ARB Refrigerant Management Program Initial Statement of Reasons (CARB 2009d), emissions in this category were assumed to decrease by 2020 due to the regulations enacted as part of the program. It is estimated that large stationary refrigeration systems (2,000 pounds or more) can achieve a leak rate of ten percent or less annually by 2016, and medium systems (200 – 2,000 pounds) can achieve a leak rate of ten percent or less annually by 2018. Stationary refrigerant systems with 50 to 200 pounds of refrigerant charge can achieve an annual leak rate of five percent or less annually by 2020. As the inventory is updated, actual leak rates derived from annual reporting to ARB will be used to replace the estimated future leak rates.

We do not assume any decreases in two categories that do not have to register or report with the Refrigerant Management Program: small refrigeration equipment containing less than 50 pounds of refrigerant, and commercial stationary air-conditioning equipment of any size. Stationary commercial air-conditioning equipment currently achieves low leak rates of less than seven percent annually for systems greater than 200 pounds, 11 percent annually for AC systems between 50 and 200 pounds, and ten percent annually for AC systems less than 50 pounds. The annual leak rate of 15 percent is expected to continue for refrigeration equipment containing less than 50 pounds.

IV. Residential stationary refrigeration and AC

Residential refrigerator-freezer emission estimates are derived from ARB funded research conducted by ICF International (ICF, 2011) and analysis of potential rulemaking for residential refrigerators (CARB, 2008d), with additional data on numbers of units in use and disposed of annually, average unit lifetime, and refrigerant usage data (Calabrese, 2004; Welch and Rogers, 2010; Wethje, 2007; and Westberg, et al., 2007). The GHG contribution from refrigerator-freezer waste insulating foam is included in the separate emission category of insulating foam.

Refrigerant emissions from refrigerant-freezers are directly proportional to the number of units used or disposed of annually, which is in turn directly related to the number sold for use in California in a given year. Refrigerant-freezer appliance use is estimated to have grown 2.8 percent annually between 1990 and 2007. During 2008 through 2011 sales are estimated to decline by 1.5 percent per year on average due to the recession (ICF, 2011). Sales are expected to remain flat from 2012 through 2015, when sales are projected to increase proportional to expected population growth of 0.75 percent annually. Future emission inventories will verify and update these assumptions as needed.

Residential air-conditioning GHG emissions were based on equipment numbers and emission profiles (Armines, 2009), supplemented by Vintaging Model data (US EPA, 2008) and UNEP reports (UNEP, 2002b; UNEP, 2006a; UNEP, 2010b), and applying the emissions calculation methodology used for the small AC systems used in commercial facilities (CARB, 2009d). The growth in window units and their emissions were estimated at an increase of 0.1 percent annually, and the growth in central units and their emissions were estimated at 2.5 percent annually (Armines, 2009). The projected growth rate was adjusted for years 2008 through 2020 due to the economic downturn, especially in housing starts which account for many of the residential AC new sales. The same downward adjustments used for refrigerator-freezers were made for years 2008 through 2014, and the same growth estimates were used for 2014 through 2020.

METHODOLOGY FOR MOBILE AC AND TRANSPORT REFRIGERATION

Estimating emissions from mobile air conditioning (MAC) systems sources and transport refrigeration requires a different methodology than used for stationary refrigeration and AC equipment, although the general emissions calculation uses the same principle as that used for stationary sources. A unique challenge for MAC is to take into account the many technological improvements that have occurred since 2000, and those that are expected to occur by 2020. For the transport refrigeration categories, one of the main challenges is to determine how much time a highly mobile piece of equipment spends in California during a year.

The following ODS substitutes emission categories are included in this section:

- MAC systems for light- and heavy-duty on-road vehicles, buses, and off-road vehicles and equipment
- Refrigerated shipping containers
- Transport refrigerated units
- Shipping (marine vessels)
- Aircraft
- Rail AC

I. Mobile AC (MAC) and transport refrigeration for on and off-road vehicles

Refrigerant emissions from MAC systems occur as assembly loss, regular leakage, irregular loss due to accidents, stone hits, component failure, service loss, and end-of-life loss.

MAC emissions were based on a comprehensive emissions model developed by ARB staff and research funded by ARB in the development of potential regulations to reduce GHG emissions from motor vehicle air conditioning (MVAC) sources (Tremoulet et al., 2008; Baker et al., 2010; CARB, 2006; CARB, 2008a). The basis of the refrigerant emissions is from vehicle data analyzed through the ARB emissions models EMissions FACtor (EMFAC) and OFFROAD. Vehicle emission profiles were developed for light duty and heavy duty vehicles, buses, and off-road heavy duty vehicles.

Table 3 is a partial summary of the types of data and analysis used to determine MAC emissions.

Table 3. Mobile AC categories and emissions data summary

Mobile AC sectors	**Units in CA in 2014** [e]	**Ave. Charge (amount) of F-gas in lbs.**	**Ave. Annual Leak (loss) Rate**	**Ave. EOL Loss Rate**	**total loss in lbs. (annual + EOL)** [e]
Mobile Vehicle AC (MVAC) Light-Duty Vehicles	23,200,000	1.52 – 3.02 [a]	10.1% - 13.1% [b]	30%	3,919,000
MVAC Heavy-Duty Vehicles (non-bus)[c]	1,130,000	variable	0.79 lbs./yr	0.12 lbs./yr	1,138,000
MVAC Off-road Heavy-Duty Vehicles[c]	310,000	variable	0.79 lbs./yr	0.12 lbs./yr	179,000
MVAC Buses[d]	57,000	variable	2.55 lbs./yr	0.40 lbs./yr	289,000

a) The average charge size for light-duty vehicles between model years 1965 through 2007 was 3.02 lbs. Beginning model year 2008, light-duty vehicle AC systems were manufactured with a significantly reduced average refrigerant charge of 1.52 lbs.
b) The average annual loss rate for vehicle model years 1965 through 2007 was 13.1%. Beginning model year 2008, light-duty vehicle AC systems were estimated to lose on average 10.1% of their refrigerant charge annually.
c) For heavy-duty vehicles, both on-road (non-bus) and off-road, the average emissions are based on mass-balance computations derived from ARB emissions models EMFAC and OFFROAD. The average emissions from leakage are 0.79 lbs./year and annualized end-of-life losses are 0.12 lbs./year, for a total annualized average loss 0.91 lbs./year per vehicle for heavy-duty vehicles (on-road and off-road).
d) For buses, the same note as above, except the average emissions from annual leakage are 2.55 lbs./year and annualized end-of-life losses are 0.40 lbs./year, for a total annual average loss of 2.95 lbs./year per bus.
e) Red font represents the quantities that are expected to change every year. Blue font represents the emissions calculated.

To estimate the emissions of HFC-134a from light-duty vehicles, a model has been developed by ARB to balance the amount of refrigerant added into an MVAC system (mass-in) and the amount of refrigerant emitting from or pulled out of the system (mass-out) over the system's lifespan. The mass out of the system would become emissions to the environment unless it is recovered for recycling, reclamation, or destruction. The model parameterizes all the mass-in and mass-out terms except the number of AC service in the system's lifespan. The resulting mass balance equation is then solved for the number of AC service. The mass-out terms, together with the number of AC service, are then used to estimate refrigerant emissions

An average HFC-134a leak rate suggested in a ARB study for heavy-duty vehicles and in-use bus fleet (Baker et al., 2010) is scaled up to account for other types of emissions using the same ratio of leak rate to overall emission factor for light-duty vehicles estimated by the lifetime mass balance model.

II. Refrigerated shipping containers

Refrigerated shipping container (RSC) emissions at California ports were estimated from the methodology and refrigerant loss as outlined in a white paper prepared by ARB staff (CARB, 2009c). It was significantly improved and refined by the additional research project funded by ARB (Dwyer, 2012). The methodology is essentially the same as that used for other refrigeration equipment, using refrigerant charge size, average leak rates, and refrigerant loss at end of life.

The Dwyer study determined that RSCs are managed extremely well due to the high value of their cargo, and that they leaked very little in the first few years of their use. By the end of their useful life, which is 10 years on average, they were leaking 10 percent of their refrigerant each year, for an average leak rate over the equipment lifetime of 5 percent annually. The RSC end-of-life emissions were different than other refrigeration/AC equipment, in that they were determined to be of two distinct types of EOL loss: 1) Loss at the time of planned decommissioning, and 2) catastrophic loss due to accidental damage.

The average refrigerant charge of 15 kg is 33.1 lbs., and due to the excellent management of the typical RSC, it is believed that they have a full refrigerant charge at their end-of-life. The refrigerant recovery at the container's planned decommissioning was estimated at 85 percent recovery, for a loss of 15 percent at EOL. However, a 100 percent catastrophic loss of refrigerant occurred when RSCs were involved in an accident that breached the refrigeration equipment. It was estimated that the accident rate, resulting in total loss of refrigerant, is about 0.5 percent of RSCs annually, with about half occurring on their way to California that would be counted as CA emissions, for a total loss accident rate of 0.25 percent.

RSCs are highly transient pieces of equipment. The number of units in California was estimated by first converting the 1.66 million containers that were in California during the baseline emission year of 2010 for an average stay of 10 days, which resulted in annual "full-time equivalents". 1,666,000 containers * 10 days/365 days/year = 45,640 "full-time equivalent" containers/year.

The annual growth rate of emissions between 2000 and 2008 was estimated to be the same as the growth in the number of refrigerated shipping container traffic to California, at 7 percent per year (Dwyer, 2012). Growth between 2008 and 2010 was estimated at 3 percent annually, and post 2010 growth was conservatively assumed at no more than 1.5 percent annually. Based on the post-2010 growth rate in shipping container traffic, the number of "full-time equivalent” refrigerated shipping containers in California was 51,400 units in 2014. Based on the RSC study data, the weighted EOL loss average of 15 percent for decommissioned units and 100 percent for units reaching EOL by accident was 19 percent on average for each EOL unit.

The following emissions equation was used to determine RSC emissions:

Equation 3. Emissions from refrigerated shipping containers

*Emissions (lbs.) = [number of full-time-equivalent RSCs in CA * average F-gas charge (lbs.)/unit * average annual leak rate]*

*+ [number of units reaching end-of-life (EOL) from planned decommissioning * average F-gas charge (lbs.)/unit * average loss rate at decommissioning EOL]*

*+ [number of units reaching EOL through accident * average F-gas charge (lbs.)/unit * catastrophic loss rate from EOL as a result of an accident]*

III. Transport Refrigerated Units (TRUs)

TRU emissions were developed from the number of equipment estimated in TRU regulation support documents (CARB, 2003), TRU data reported to ARB by the regulated sources (CARB 2012b), and TRU regulation staff analysis on average refrigerant charge (CARB, 2011b). The TRU category includes the following sources and emission factors:

Table 4. Transport Refrigerated Unit (TRU) input factors and emission calculations [(a)]

TRU type	**Units in 2014** [(b)]	**Time in CA**	**Charge size (lbs.)**	**Annual Leak rate**	**EOL units in 2014** [(b)]	**EOL charge size (lbs.)** [(a)]	**EOL loss rate**
Large refrigerated trailers over 25 feet	25,885	100%	22.0	24%	1,991	16.7	15%
Mid-size refrigerated trailers between 11 and 25 feet	6,781	100%	12.0	24%	522	9.1	15%
Mid-size refrigerated trailers between 11 and 25 feet (out-of-state)	106,721	12.5%	12.0	24%	8,209	9.1	15%
Refrigerated vans less than 11 feet	246	100%	4.0	24%	19	3.0	15%
Refrigerated shipping containers not in ports	7,320	100%	33.1	5%	665	31.4	15%
Refrigerated shipping containers not in ports (out-of-state)	29,124	12.5%	33.1	5%	2,648	31.4	15%
Rail cars	7,189	12.5%	33.1	24%	553	25.2	15%
Weighted average	**58,110**	**n/a**	**20.7**	**18.3%**	**4,623**	**17.4**	**15%**

a) For TRUs, it is assumed that during the last year of its useful life, no top-off of refrigerant occurs. The calculation for EOL charge size = Charge size - (charge size * annual leak rate).
b) Red font represents the quantities that are expected to change every year.

The number of TRUs for each type was available for years 2000 through 2010. The numbers of TRUs were further analyzed by placing them into two separate categories: 1) TRUs used in-state (completely or almost completely), and 2) TRUs registered out-of-state, but occasionally used within the state. It was assumed that TRUs registered in the state were used completely within the state. For those TRUs entering from out-of-state, it was assumed that the time they spent in state was proportional to California's share of national population, which was 12.5 percent during the baseline year. Thus, the number of out-of-state TRUs used occasionally within the state was converted to “full-time equivalents” based on the number of out-of-state TRUs registered for use within California.

The charge size and types of refrigerant used were also referenced against U.S. EPA and UNEP information (US EPA, 2006; UNEP, 1999). Refrigerant loss rates were from research by D. Godwin (Godwin, 2003), with additional input from Dutch transport research (Bouma, 2003). Because TRU refrigerant losses at EOL are poorly quantified, they were estimated to be the same as refrigerated shipping containers comparable in size and function to the TRU systems (Dwyer, 2012).

Refrigerant emissions from TRUs are assumed to be directly proportional to TRU traffic and numbers in use, although idled or mothballed TRUs can still leak refrigerant if it has not been removed from the system. Measured data from the ARB TRU program was used to estimate emissions between 2000 and 2010, which averaged a two percent annual growth rate. Due to a slowing economy, it was assumed that no growth would occur between 2010 and 2015, with an assumed growth rate of one percent annually for years 2016 through 2030. These assumptions will be checked against actual TRU numbers in use in California as reported to ARB annually.

IV. Ships (Marine vessels)

The same formula used to estimate refrigerant emissions for stationary equipment was used to estimate ship refrigerant emissions. Eight separate types of ship refrigeration or AC systems were identified. Ship categories are listed in Table 5 below.

Table 5. Ship refrigeration and AC categories and emissions data summary

Ship Type	Units in 2014 (full-time-equivalents) [(a)]	Charge size (lbs.)	Annual leak rate
Merchant ships (direct refrigeration)	67	441	40%
Merchant ships (indirect refrigeration)	8	110	20%
Naval ships	15	441	40%
Large fishing vessels (25 meters or longer) (direct refrigeration)	9	3,977	40%
Large fishing vessels (25 meters or longer) (indirect refrigeration)	4	1,989	20%
Small fishing vessels (less than 25 meters)	515	36.5	39%
Cruise ship AC	5.5	13,228	40%
Cruise ship refrigeration	5.5	882	40%

a) A "full-time-equivalent" approach was used to normalize the mobile and transitory nature of shipping, where the number of hours (in California waters) for each type of vessel was aggregated, then divided by 8,760 hours per year to derive the number of full-time "ship-years" in California waters. Red font represents the quantities that are expected to change every year

Refrigerant emission factors from ships (marine vessels) greater than 25 meters long or more than 100 gross tonnes) were based upon UNEP data for average refrigerant charge sizes, annual leak rates, and distribution of refrigerant types (UNEP, 2006a; UNEP, 2010b). The UNEP data were used for large marine vessels including merchant ships and navy ships. Two sub-categories of merchant ships, large fishing vessels and cruise ships, had more specific emission factors as derived by W. Schwarz of Öko-Recherche and J.M. Rhiemeier of Ecofys, 2007. Another sub-category not large enough to be classified as a merchant ship is the small fishing vessel category, less than 25 meters long. For this category, the Öko-Recherche and Ecofys emission factors were used. Annual leak rates will be updated as more recent UNEP reports and other studies become available.

The number of large marine vessels and the time they spent within 12 miles of shore in California waters, ports, and harbors were determined from data reported to ARB as part of the California shipping emissions reduction program, and analyzed using the ARB Marine Model, version V2.3J (CARB, 2012a).

For each marine vessel category, the number of hours spent in California waters, harbors, and ports were aggregated. The aggregate hours were divided by 8,760 hours per year (24 hours/day * 365 days/year) to calculate the number of “ship-year-equivalents”, before average annual leak rates could be applied. Average refrigerant leak rates were expected to occur at a constant rate throughout the year.

The standard refrigerant equipment emissions formula was thus adapted for marine vessels as follows for each vessel type:

Equation 4. Refrigerant emissions from marine vessels

Marine vessel emissions (lbs.) = Average refrigerant charge (lbs.)/ship * average annual leak or loss rate * total ship-year equivalents

Additional Marine Vessel Data Used: Data on cruise ship port calls to California were included in the ARB Marine Model as part of the aggregated data that were combined with merchant ship port calls, and were not shown separately. The emission factors used for cruise ships were obtained from the U.S. Department of Transportation (US DOT, 2006). The average amount of time cruise ships spend in California waters is not known with certainty; therefore, the average time used is from the ARB Marine Model for merchant ships. To avoid double-counting, the number of cruise ships were deducted from the aggregate number of merchant ships.

Similarly, the numbers of large fishing vessels were included in the ARB Marine Model, but as the emission factors are different from those of other merchant ships, it was necessary to estimate the number of large fishing vessels separately from aggregated merchant ship data, using the 2007 Öko-Recherche analysis (Schwarz and Rhiemeier, 2007). The number of smaller fishing vessels (less than 25 meters in length) is not included in the ARB Marine Model; these fishing vessel numbers were estimated using a separate data source (CARB, 2007b). Emission factors are from Öko-Recherche (Schwarz and Rhiemeier, 2007).

The ARB Marine Model also does not include Navy ships. Data on the number of Navy ships in CA ports were derived from the U.S. Naval list of ships and their homeports (US Navy, 2012). The amount of time Navy ships spent in port or harbor was not available, likely due to security concerns; therefore, a conservative factor of 25 percent of time spent at the home port was applied. Only those ships with a home port assignment in California were included. According to UNEP analysis, Navy ships have the same average refrigerant emissions profile as merchant ships (UNEP, 2006a, and 2010b).

Emissions were calculated for baseline years 2002, 2007, 2008, and 2010. Interpolation was used for years between 2002 and 2010 not previously estimated. Emissions are proportional to the amount of ship time spent in California waters, which is correlated with shipping traffic and trade. Therefore, growth or decrease in emissions was linked to shipping traffic data as collected by the ARB Marine Model. For years previous to 2002, the annual growth rate of 2 percent between 2002 and 2008 was applied to back-cast emissions. For years 2008 through 2015, it was estimated that shipping traffic and their refrigerant emissions would continue to decline one percent per year. For years 2016 and beyond, it was assumed that shipping traffic would increase to previous levels and continue growing at about one percent per year. These assumptions will be periodically double-checked against collected data for shipping traffic in California waters.

Due to the lack of data available, no EOL emissions from ship refrigerant and AC equipment were estimated. While likely to be greater than zero, it is also likely that with the large average refrigerant charge size of systems used, it is economically desirable to recover all refrigerant in refrigeration and AC equipment prior to disposal or recycling (ICF, 2011), and in accordance with good refrigerant management practice at ports as found by ARB-funded study (Dwyer, 2012). The EOL emissions loss factor will be updated should additional information becomes available.

V. Aircraft air conditioning

Based upon research conducted by W. Schwarz of Öko-Recherche and J.M. Rhiemeier of Ecofys (Schwarz and Rhiemeir, 2007), the refrigerant emissions from aircraft were assumed to be negligible, and were not included in the ARB F-gas inventory. Most aircraft do have AC units, but for flight altitudes greater than 10,000 feet, an HFC-based vapor cycle is not used to cool the aircraft; it is cooled with bleed air from the jet engine. For air-conditioning purposes prior to take-off and after landing, semi-mobile units at the plane docking sites are connected to the plane’s air circulation system. Annual refrigerant emissions from aircraft in the European Union 27 (EU 27) countries were estimated to be less than 400 kilograms per year (Schwarz and Rhiemeier, 2007). With a population of approximately 500 million in EU 27 countries in 2010, these emissions, if scaled to California’ population in 2010 (37.2 million), would be less than 30 kilograms.

VI. Rail Air-conditioning

Due to a lack of data on California’s rail AC emissions, the Öko-Recherche and Ecofys study (Schwarz and Rhiemeier, 2007) for F-gas emissions from

European maritime, aircraft, and rail sectors was used as the best available study on rail AC, which could be used as a proxy for California rail emissions. To correlate European Union member states (EU 27) rail AC emissions to California rail AC emissions, the following assumptions were used and considered reasonable:

- The Öko-Recherche and Ecofys study used for EU-27 rail AC emissions provides reasonably accurate emissions estimates of F-gases from rail AC for the EU-27, in baseline year 2006.
- Rail AC emissions can be correlated to population, on a lbs. emissions/person/year basis.
- The per capita emissions of rail AC have not significantly increased or decreased since 2006.
- The rail AC emissions in California are not significantly greater, per capita, than they are in the EU-27.

The installed refrigerant charge in rail AC in Europe of 2.96 million pounds correlates to an installed charge in California of approximately 178,000 pounds. At an annual leak rate of five percent, the rail AC emissions in California are 8,900 pounds, or 0.05 percent of HFC emissions in the state.

Approximately 30 percent of all F-gas emissions are from non-refrigeration, non-AC categories. The sources of non-refrigerant F-gases are diverse and each source requires a separate methodology for estimating its F-gas emissions, as described in the following sub-sections.

I. Metered dose inhalers (MDI) aerosol propellants

Estimates based on the US EPA Vintaging Model (US EPA, 2008) were the initial source of data for F-gas emissions from MDI aerosols. The Vintaging Model inputs are proprietary and emission results are not speciated, they are expressed in teragrams of carbon dioxide equivalents ($TgCO_2e$). Scaling national Vintaging Model estimates to state population, emissions from this category for baseline year 2010 were estimated to be 0.3 $MMTCO_2e$ HFCs for California. Because the Vintaging Model aggregates emissions and groups them as total HFC, it was necessary to further speciate usage by actual F-gas used, to develop a usage "distribution profile".

The primary data source for MDI aerosol speciation was the Department of Health and Human Services rule making (DHHS, 2005). Speciation assumptions were also compared to available MDI information cited in IPCC and UNEP reports (IPCC/TEAP, 2005; UNEP, 2010a). Speciation profiles for MDI usage were developed for HFCs (90 percent HFC-134a and 10 percent HFC-227ea). After developing the F-gas distribution profile for MDI aerosol propellants, the emission results were back-calculated into pounds of emissions from specific propellant.

To convert a known quantity of $MMTCO_2e$ into pounds of F-gas emissions, the following formula was used:

Equation 5. Conversion of $MMTCO_2e$ into pounds of F-gas

*Lbs. = $MMTCO_2e$ (known) / [[(decimal portion constituent 1) *GWP1 * 4.53592 x 10^{-10} MMT/lb. conversion factor] + [(decimal portion constituent 2) *GWP2 * 4.53592 x 10^{-10} MMT/lb. conversion factor] + (repeat for all constituents)]]*

Note: The conversion factor is derived from: 0.454 kg/lb. *1 MT/1000 kg * 1 Million MT/1000000 MT = 4.53592 x 10^{-10} MMT/lb.

Because the baseline year for MDI emission estimates were for year 2010, previous emission year total pounds emissions had to be back-cast based on annual growth factors of MDI usage of 1.5 to 3 percent/year (IPCC/TEAP, 2005). Speciation of propellants was also back-cast and can be forecast. Final phase-out of CFCs used in MDI manufacturing, sales, and dispensing in the U.S. was complete by December 31, 2013 (FDA, 2010). Starting in 2014, the annual GHG emissions from this source will be from (relatively) lower-GWP HFC propellants and the annual emissions are expected to decrease by 50 percent from 2010 emissions (US EPA, 2008). The U.S. EPA Vintaging Model emissions estimates were used as the source of data for all years through 2020, which estimated that HFC emissions would increase by 1.5 percent annually.

The following section of the MDI emissions methodology describes further analysis that were used to further refine F-gas emissions from MDIs, or used as a reference.

Usage estimated by Montreal Protocol "Essential Use" Nominations for MDI: The U.S. EPA Vintaging Model estimates were further refined after reviewing the United Nations Environment Programme (UNEP) Technology and Economic Assessment Panel (TEAP) progress reports for years 1999 through 2012 (UNEP, 1999-2012). National usage amounts were scaled to California's share on the national population.

Similarly, using IPCC/TEAP global estimates and UNEP global estimates, the scaled-down California estimates are 0.37 and 0.26 million pounds of emissions per year. With scaled F-gas emissions from MDIs in 2010 in California increasing to 0.68 million pounds (A.D. Little data), 0.73 million pounds (IPCC/TEAP data), and 0.51 million pounds (UNEP data).

For the global usage scaled to California, the average unit size of 23.9 grams/unit was selected from medical literature (Brock et al., 2002). Dry-powder inhalers (DPIs) contain no propellant and their usage has been increasing globally (UNEP, 2011). Although dry powder inhalers have been commonly used in Europe for more than a decade, their acceptance in the United States has been slow (Atkins 2005).

For this MDI category methodology, it is assumed that beginning in 2014, the only F-gases used will be HFC-134a (90 percent of F-gases) and HFC-227ea (10 percent of F-gases). An annual growth rate of 1.5 percent is used from the Vintaging Model. The growth rate in HFCs could be reduced by increased usage of dry-powder inhalers or by some non-HFC propellant to be determined.

U.S. EPA Vintaging model updates will be used for future estimates if no stand-alone methodology for California MDI usage is developed.

II. Consumer product aerosol propellants

For all non-MDI aerosol propellant emissions, four separate data sources were analyzed: 1) ARB survey data, 2) U.S. EPA Vintaging Model estimates, 3) National Aerosol Association (NAA) estimates, and 4) Alliance for Responsible Atmospheric Policy (ARAP) estimates. The ARB survey data were used as the data source because it best reflected actual aerosol propellant usage in California.

For aerosol propellant emissions, we assume 100% emissivity and that all emissions occur in the same year as aerosol can production.

A 2006 ARB industry survey of consumer product emissions was used to estimate aerosol propellant F-gas emissions (CARB, 2011c), and supplemental data were used from ARB staff research in Consumer Products Regulatory Amendments (CARB, 2008c; CARB, 2009e; CARB, 2010b). The 2006 survey was back-cast to 2000 and forecast to 2050 based on population growth for consumer product aerosols. An exception was made for the assumed growth rate of duster (pressurized gas) spray, which was assumed to increase at the equivalent growth rate of personal computer at 8.5 percent annually between 2000 and 2008, due to the prevalent use of duster spray as a keyboard cleaner (EIA, 2009; IDC, 2012). From 2008 through 2050, the duster growth rate is assumed to more closely correlate to population growth. Approximately 5 million pounds of emissions in 2014 were estimated based on a forecast of the 2006 survey.

ARB staff research and regulations were used to establish the rate of transition for replacing HFC-134a with HFC-152 for duster use to estimate likely distribution. The ARB industry survey was also augmented by additional speciation and background data from UNEP and IPCC research (UNEP, 2002a; IPCC/TEAP 2005), and compared to consumer aerosol propellant usage data sources that include the U.S. EPA Vintaging Model, Earth911, the National Aerosol Association, and the Alliance for Responsible Atmospheric Policy (U.S. EPA, 2008; Earth911, 2011; NAA, 2005; ARAP, 2007).

For emissions beyond baseline years, we assume that the ARB regulations for high-GWP consumer products will have full compliance, as HFC-134a aerosol propellant is replaced by HFC-152a or other lower-GWP propellants in specific applications (e.g., duster spray) (CARB, 2008c).

III. Fire suppressants

Fire protection emissions data are from the ARB-funded project titled "Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers, and Ozone Depleting Substances" and conducted by the Institute for Research Technology and Assistance (IRTA) (IRTA, 2011).

Fire suppressants account for 0.0.22 percent of HFC emissions in 2013. High-GWP fire suppressant emissions occur from large total flooding systems, smaller streaming (extinguisher) emissions, and emissions that occur at the time of Halon recycling. The high-GWP fire suppressant compounds used are Halon 1211, Halon 1301 (both ODSs), and the ODS replacements HFC-125 and HFC-227. A negligible amount of PFC blends were also used in the early 2000s.

Emissions are estimated for baseline year 2010 and projected through 2020 in the IRTA report. Back-casting to 1990 estimates were based on data from the IRTA report that included the number and types of fire suppressant systems in the early 1990s in California. As noted in the IRTA report, fire suppressant systems are very leak tight, with very few accidental releases. Purposeful release of fire suppressants averages just two percent of the suppressant amount per year. Recycling fire suppressants for re-use emits another one percent per year of the recycled amount.

The high-GWP fire suppressant emissions have been decreasing since 1990, and are expected to continue to decrease through 2050. Lower-GWP suppressant replacements to Halons and HFCs such as Inergen and F-K-1-5-12 continue to increase their share of total flooding and streaming fire suppressant systems. In 2011, just 51,000 lbs. of high-GWP fire suppressants were emitted, which had a GHG impact of 0.09 $MMTCO_2e$, or 0.2 percent of all F-gas emissions. Methodology

IV. Insulating foam

F-gas emissions from insulating foam are from the ARB-funded research on insulating foam banks and emissions inventory conducted by Caleb Management Services, Ltd. The findings of the three-year project are in their Final Report, "Developing a California Inventory for Ozone Depleting

Substances (ODS) and Hydrofluorocarbon (HFC) Foam Banks and Emissions from Foams" (Caleb, 2010). The Final Report also describes the emissions estimates methodology in detail.

A comprehensive inventory of foam in California was developed by Caleb through industry surveys and analysis of foam usage. Foam emission categories were identified and grouped into the following five foam GHG emission sources: 1) building insulation, 2) residential appliances (refrigerator-freezers and water heaters), 3) commercial refrigeration equipment, 4) transport refrigerated units (TRUs), and 5) marine buoyancy. Building insulation was further divided into the following insulation types: extruded polystyrene (XPS), polyiso, polyurethane panel, and polyurethane spray. Additionally, there were three distinct sub-types of buildings: commercial, single-family, and multiple-family buildings. Appliance inventory and foam types used were developed from data supplied by the Association of Home Appliance Manufacturers (AHAM, 2010). Residential appliances were divided into water heaters, refrigerator-freezers, and freezer-only.

As described in the Caleb report, commercial refrigeration equipment and transport refrigerated unit (TRU) foam emissions were developed by applying industry standard insulating foam profiles to the California inventory of commercial refrigeration equipment and TRU equipment. Transport refrigerated units includes refrigerated trailers and trucks, rail refrigerated units, and refrigerated shipping containers. In all, 19 separate foam categories were researched to estimate emissions from each type of foam and application combination.

The remaining foam application are in the marine categories buoyancy, including leisure boats, canoes, and buoyancy flotation aids. Industry surveys were used to develop foam profiles for this category. Surfboards and windsurfers were investigated as a possible source of GHG emissions, but these foam applications have used water-based foam expansion agents since the 1980's and are not a GHG emissions source. Additionally, polystyrene (often called Styrofoam® after its trademarked name from Dow Chemical) used for cups, plates, and packaging has not been a source of F-gas emissions since the late 1970s and is no longer a source of F-gas emissions (Caleb, 2010; Kremer, 2003).

The foam emissions category is relatively complex which cannot be covered with a simple formula. Caleb (2010) developed emission profiles from the five emissive parts (processes) of the foam lifecycle: 1) at time of manufacturing, 2) during application (relevant to spray foams), 3) during lifetime of equipment, 4) at time of building decommissioning or equipment end-of-life shredding/recycling, and 5) after disposal and landfilling. Emission profiles were developed for each category (building, residential appliances, commercial refrigeration equipment, transport refrigeration, and marine buoyancy) and each type of foam within the category (spray foam, polyurethane block foam, extruded polystyrene foam, etc.). Profiles were further refined by assigning foam expansion agent distribution according to year of foam manufacture. The basic emissions formula for each of the emissive processes is shown below:

Equation 6. Emissions from foam

$$\text{Emissions (lbs.)} = \text{volume of foam } [m^3] * \text{density of foam } [kg/m^3] * \text{\% of foam expansion agent by weight} * \text{\% of foam expansion agent loss/emitted} * 2.20462\ kg/lb.$$

Foam GHG emissions were estimated from 1975 through 2020. To cross-check back-casting emissions estimates from baseline year 2008, internal ARB analysis also refined historical foam expansion agent profiles with foam usage information contained in IPCC reports (IPCC/TEAP 2005), and UNEP reports (UNEP, 2002b; UNEP, 2006a; UNEP, 2010b; UNEP, 2010c).

For residential appliance foam insulation emissions and speciation forecasting, additional ARB-funded research conducted by ICF International was used to cross-check assumptions (ICF, 2011). Additional research on landfilled foam GHG emissions was conducted by the Global Waste Research Institute, associated with California Polytechnic State University, San Luis Obispo. Researchers concluded that ODS and HFC emissions were 90 percent less than previously assumed, due to the high capture rate and destruction of fluorinated gases recovered and combusted by methane recovery systems in landfills (CARB, 2012c).

V. Solvents

F-gas emissions estimates from industry solvents are from the ARB-sponsored research conducted by the Institute for Research and Technical Assistance (IRTA), (IRTA, 2011). A survey of solvent-using industries in California was, along with a review of applicable air permits to determine emissions of specific F-gases from the solvent category. If no specific usage data could be obtained from the permit holder, it was assumed they had used the entire amount they were permitted to use during the year.

Emission estimates from the IRTA research were made during research years 2008-2010, and were used for 2007, 2008 and 2010 emission years. The 2000 through 2006 solvent F-gas emissions estimates were not within the time-frame of the IRTA research. To form a backwards trend analysis for solvent emissions prior to 2007, historical usage and speciation trends were informed by five research reports that included solvent usage trends (ICF, 2004; IPCC/TEAP, 2005; UNEP, 1998; UNEP, 2006b; and UNEP, 2002c).

Due to stringent VOC limitations in solvent usage in California, particularly for the South Coast Air Quality Management District, many industries have converted to low-VOC and water-based cleaners for industrial applications. There has been a concurrent decrease in the amount of HCFC and HFC solvent usage as well, with California using only 10 to 50 percent as much HCFC and HFC solvent, per capita, as average national usage (IRTA, 2011; US EPA, 2008). The U.S. EPA estimates that solvents account for only 1 percent of all emissions from ODS replacements (U.S. EPA, 2012a). We estimate that for 2013, solvents comprised only 0.6 percent of all HFC emissions, as well as all F-gas emissions. We assume that because HFC solvents continue to be manufactured, they are not stock-piled, and are 100 percent emissive in the year they are purchased and used.

VI. Medical sterilants

The F-gas emissions from medical sterilants were estimated using the same methodology as described for metered-dose inhalers, with U.S. EPA Vintaging Model national estimates scaled to California's population for CO_2e emissions. Pounds of emissions were then back-calculated from the $MMTCO_2$e.

Traditionally, CFCs and HCFC s were used in medical sterilants. For the ODS substitutes to medical sterilants, all sterilants approved by the U.S. EPA Significant New Alternatives Program (SNAP) are low-GWP, with none containing HFCs (U.S. EPA, 2011). Although one of the alternatives, trifluoromethyl iodide (CF_3I), contains fluorines, it has a GWP of 1 (IPCC, 2001). Therefore, sterilants will no longer be a source of high-GWP F-gas emissions beginning 2015.

VII. Semiconductor manufacturing

Perfluorocarbons (PFCs) are the primary high-global warming potential compounds used in the manufacture of semiconductors. PFC emission estimates from semiconductor manufacturing are not within the primary emission boundaries of this particular methodology, but are briefly described here for reference. PFC emissions in California have previously been estimated by the ARB Greenhouse Gas Inventory (CARB, 2015).

The ARB Greenhouse Gas Inventory (CARB, 2015), estimates that a small amount of HFC-23 is used in the manufacture of semi-conductors in California, about 11,000 pounds/year statewide. The emissions of HFC-23 from this sector were taken directly from the ARB inventory, with no additional changes in methodology or emission estimates.

Nitrogen trifluoride (NF_3) is also used in semiconductor manufacturing and the manufacture of plasma screen televisions. Approximately 18,000 pounds are used per year statewide, as reported by the ARB Greenhouse Gas Inventory (CARB, 2015).

Due to ARB regulations, PFC emissions are expected to be reduced in the future, with only 44 percent of 2008 baseline emissions being emitted by 2015. HFC-23 emissions are expected to increase by 0.5 percent annually from 2010 onward, much slower than BAU estimated rates due to ARB regulations (CARB, 2009a). NF_3 emissions should conceivably increase even with industry GHG reduction requirements, because substituting NF_3 for PFC-116 (C_2F_6) is an approved alternative chemistry for reduction of GHGs in chemical vapor deposition (CVD) chamber cleaning. Additionally, the semiconductor GHG emission regulations do not cover NF_3 used in plasma televisions. Due to increasing NF_3 use in semiconductor manufacturing and in plasma televisions, NF_3 emissions were estimated to increase 11 percent annually between 1978 and 2008 (Weiss, et al., 2008). We conservatively estimate continued NF_3 emissions increases at one-fourth the previous growth rate, for an annual emissions increase of 2.75 percent annually through 2020.

END-USE CATEGORY SPECIATION METHODOLOGY

In addition to the previously discussed methodology used to determine high-global warming potential (GWP) emissions, the following methodology describes how emissions were segregated into end use categories used by the ARB greenhouse gas (GHG) annual inventory. High-GWP emissions were reported using the follow matrix template:

I. Refrigeration and AC

Refrigerant emissions were categorized into the appropriate sectors of commercial, industrial, transportation, and residential. For most refrigerant sources, the appropriate sector had already been determined by definition, for example, industrial process refrigeration by definition belongs in the industrial sector. Many of the refrigeration and AC sub-categories are used in both commercial and industrial applications. For these sub-categories, the Armines Center for Energy and Processes report (Armines 2009) was used to determine the relative proportions of emissions from either commercial or industrial.

All refrigerant emissions are assumed to take place at the location of the refrigeration and AC equipment, with the following exceptions where a portion of the emissions take place at the time of equipment recycling and disposal (and attributed to the industrial sector): residential refrigerator-freezers, residential and commercial window AC units, and mobile vehicle AC (light duty vehicles, heavy duty vehicles, bus, and off-road vehicles) (ICF, 2011; Wimberger, 2010; Zhan, 2012b).

The following ODS replacements are emitted from the refrigeration and AC category: HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, and HFC-236fa.

The following table shows the 21 refrigeration/AC sub-categories analyzed and the relative proportions of their emissions from the commercial, industrial, residential, and transportation sectors.

Table 6. Refrigeration and AC sub-categories

Refrigeration/AC sub-category	Commercial portion	Industrial portion	Residential portion	Transportation portion
Centralized system large (2000 or more lbs.)	0.77	0.23		
Centralized system medium (200-1999 lbs.)	0.77	0.23		
Chiller - centrifugal large (2000 or more lbs.)	0.77	0.23		
Chiller - centrifugal medium (200-1999 lbs.)	0.77	0.23		
Chiller - packaged medium (200-1999 lbs.)	0.77	0.23		
Cold storage large (2000 or more lbs.)	1.00			
Cold storage medium (200-1999 lbs.)	1.00			
Marine vessels (ships)				1.00
Mobile Vehicle AC (MVAC) Light Duty (LD)		0.15		0.85
MVAC Bus		0.15		0.85
MVAC Heavy Duty (HD) (non-bus)		0.15		0.85
MVAC Off-road		0.15		0.85
Process cooling large (2000 or more lbs.)		1.00		
Refrigerated condensing units small (50-199 lbs.)	1.00			
Refrigerated condensing units very small (less than 50 lbs.)	1.00			
Refrigerated shipping containers				1.00
Residential A/C		0.06	0.94	
Residential appliance (refrigerator-freezer)		0.90	0.10	
Transport refrigerated units (TRUs)				1.00
Unitary A/C small (50-199 lbs.)	1.00			
Unitary A/C very small (less than 50 lbs.)	0.99	0.01		

Residential A/C and Unitary A/C in the "very small" category (less than 50 lbs.) are similar in that they both consist of small centralized AC units plus small window AC units. Emissions from central units are assumed to take place at their location. Due to the hermetically sealed structure of small window AC units, only 10 percent of their emissions are estimated to occur where they are used (residential or business), with the remainder of emissions inadvertently occurring at the time of recycling or disposal (industrial) (ICF, 2011). The emission factors seen in the table are different between unitary AC less than 50 pounds and residential AC due to the relatively lower number of commercial window AC unit emissions compared to the number of commercial central AC units (18 percent of very small commercial AC units are window units, compared to 34 percent for residential).

II. Aerosol propellants

Metered dose inhaler (MDI) data are derived from U.S. EPA and United Nations emission and usage estimates, which were then scaled to California's population (U.S. EPA, 2008; UNEP, 1999-2012). All aerosol propellants used in metered dose inhalers are assigned to the residential sector, as they are used for personal health in the treatment for symptoms of asthma and chronic obstructive pulmonary disease (COPD).

Non-MDI aerosol propellants were separated into the four economic sectors (commercial, industrial, residential, or transportation) by applying the ARB 2006 aerosol survey results which shows the pounds of aerosol used in California in 2006 by 26 specific categories of aerosol products (CARB, 2011b).

For each product category, the pounds of propellant were broken out into one of the three HFC propellants used; HFC 43-10mee, HFC-134a, or HFC-152a. Each of the product categories was then placed into its best fit of economic sector. For example, all personal care products were deemed residential use, tire inflator products were assigned to the transportation sector, and degreasers for manufacture were placed into the industrial sector. The product categories and their relative apportionment by emissions sector are listed below.

Table 7. Types of aerosol propellants

Code and Type of Aerosol Product Surveyed by ARB, 2006	Commercial portion	Industrial portion	Residential portion	Transportation portion
20101 - Double phase aerosol air freshener	0.04		0.96	
20327 - General purpose degreaser sold exclusively to establishments which manufacture or construct goods (labeled not for retail sale)		1.00		
21010 - Silicone-based multi-purpose lubricant		1.00		
21015 - Lubricants sold exclusively to establishments which manufacture or construct goods (labeled not for retail sale)		1.00		
21018 - Special purpose lubricant: gear, chain and wire lubricant		1.00		
21019 - Special purpose lubricant: mold release (aerosol)		1.00		
21021 - Other special purpose lubricants		1.00		
21022 - Defense spray (e.g. pepper spray)			1.00	
21405 - Furniture maintenance product (aerosol)			1.00	
21501 - Hobby gun compressed gas			1.00	
21509 - Aerosol party/festive spray (e.g. foam string); see also 80127			1.00	
21510 - Aerosol air horn			1.00	
30508 - Deodorant body spray			1.00	
30606 - Hair shine (aerosol)			1.00	
40403 - Crawling bug insecticide (aerosol)	0.04		0.96	
40408 - Flying bug insecticide (aerosol)	0.04		0.96	
40414 - Insect repellent (aerosol)	0.04		0.96	
70101 - Automotive wax/polish/sealant/glaze (all other forms)				1.00

Code and Type of Aerosol Product Surveyed by ARB, 2006	Commercial portion	Industrial portion	Residential portion	Transportation portion
70117 - Other products with HFC-134a refrigerants (24 Oz. sizes and smaller only)	0.25	0.25	0.5	
80113 - Tackifying sprays		1.00		
80115 - Mold release coatings		1.00		
80120 - Conformal coatings (silicone/acrylic/etc.)		1.00		
80121 - Electrical coatings		1.00		
80124 - Anti-rust coatings	0.15	0.75	0.10	
80127 - Aerosol party/festive coating products (e.g. foam string/snow coating/glitter coating)			1.00	
99999 - Not a Surveyed Category (Carpet & Spot Cleaners)	0.04		0.96	
Tire Inflator				1.00
Pressurized Gas Duster	0.35		0.66	

Several of the products can be used in both households and places of business (commercial sector). For these products, such as insecticides and carpet cleaners, a best estimate breakout of 96% was used in residential, and 4% are used in commercial business. The estimate is based on the following information and assumptions: Approximately 1 million businesses are operating in California (CEUS, 2006), with approximately 12.5 million households (U.S. Census, 2010). Therefore, businesses represent 8 percent of buildings (business facilities plus households) in California. It is assumed that the use of residential-type products in the business is half the rate of residential homes, which would decrease the 8 percent share to 4 percent.

Aerosol dusters for computers were an exception to the apportionment applied for a product typically used in both households and businesses. Based on the relative numbers of personal computers used for home and business, it was estimated that 66 percent of duster use is for households, and 34 percent for business (EIA, 2009; IDC, 2012).

The following were assumed to be used for industrial purposes because of their use in construction or manufacturing: tackifyng sprays, mold release coatings, conformal coatings, and electrical coatings. Anti-rust coatings were apportioned into the commercial, industrial, and residential sectors due to their use in a variety of applications.

III. Insulating foam

The foams emissions category was broken out by 18 separate categories of foam, each with its own emissions characteristics and detailed emissions spreadsheet. Foam emission calculations are complicated by their dual nature of emissions history; they emit by steady off-gassing at the initial source of foam usage, and then emit again at the foam end-of-life, whether it be appliance recycling or building renovation and demolition. For example, residential refrigerator-freezers should clearly be considered a residential source of emissions. However, only 14 percent of the foam emissions occur during the residential use phase of the appliance, with the remaining emissions occurring at the time of appliance recycling and landfilling, both of which are industrial sector emissions. Similarly, for many types of building foam insulation, the majority of emissions occur after the foam has been removed from the building and landfilled. The Caleb study was augmented by additional foam off-gassing loss data (UNEP, 2010b) to determine the emissions occurring at the initial location of the foam compared to the emissions occurring at its end-of-life.

The following table shows the types of foam inventoried, and the relative amount of emissions by sector.

Table 8. Types of foam across sectors

Foam sub-category	Commercial portion	Industrial portion	Residential portion	Transportation portion
Appliances (refrigerator-freezer)		0.86	0.14	
Appliances (water heater)		0.86	0.14	
Buoyancy foam for boats		0.80		0.20
Cold storage and foam buoys	0.35	0.65		
Commercial building extruded polystyrene	0.62	0.38		
Commercial building polyisocyanurate	0.35	0.65		
Commercial building polyurethane panel	0.35	0.65		
Commercial building spray foam	0.35	0.65		
Commercial refrigeration and vending	0.35	0.65		
Multi-family extruded polystyrene		0.38	0.62	
Multi-family polyisocyanurate		0.65	0.35	
Multi-family polyurethane panel		0.65	0.35	
Multi-family spray foam		0.65	0.35	
Single-family extruded polystyrene		0.38	0.62	
Single-family polyisocyanurate		0.65	0.35	
Single-family polyurethane panel		0.65	0.35	
Single-family spray foam		0.65	0.35	
Transport refrigerated units		0.65		0.35

IV. Solvents

Solvent emissions from semiconductor manufacturing are not included in this section of the inventory, which are included in the separate semiconductor section.

Solvent data for non-semiconductor uses were taken from the ARB-funded research inventory project number 07-313, titled “Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers, and Ozone Depleting Substances” and conducted by the Institute for Research Technology and Assistance (IRTA) (IRTA, 2011). Fluorinated solvent usage was inventoried in California for baseline year 2010, with projections through 2020. All fluorinated solvent use inventoried was for industrial applications.

ODS substitutes used as solvents consist of HFC-125, HFC-227ea, HFC-236fa, and negligible amounts of PFCs.

V. Fire protection

Fire protection data were taken from the same 2011 IRTA report used for solvents. Fire suppressant chemicals were inventoried for the state and their uses by sector were described in the report. Based upon a careful analysis of the IRTA inventory, a best estimate was made that assigned 80 percent of the fire protection to the commercial sector, with the remaining 20 percent assigned to the industrial sector. Note that although there is a minimal amount of older Halon fire suppressants used in the aviation (transportation) sector, Halon is an ozone-depleting substance that is still being recycled and reused, and their replacements are typically not-in-kind non-fluorinated substitutes, such as Inergen, which consists of nitrogen, argon, and carbon dioxide.

ODS substitutes used for fire protection consist of HFC-43-10mee, HFC-245fa, HFC-365mfc, and perfluorocarbon/perfluoropolyethers (PFC/PFPEs).

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APPENDIX I

U.S. EPA regulatory changes to high-GWP ODS Substitutes in July 2015

(through the U.S. EPA Significant New Alternatives Policy (SNAP) Program changes July 22, 2015)

AEROSOLS – PROPELLANTS **Substitutes**	**Decision**	**Uses that Are Acceptable, Subject to Use Conditions**
HFC-125	Unacceptable as of January 1, 2016.	None.
HFC-134a	Unacceptable as of July 20, 2016 except for uses listed as acceptable, subject to use conditions.	From July 20, 2016 to January 1, 2018: acceptable, subject to use conditions for the following specific uses: products for which new formulations require federal governmental review, and ☐ products for smoke detector functionality testing. As of July 20, 2016: acceptable, subject to use conditions for a number of additional uses specified in the rule.
HFC-227ea and blends of HFC-227ea and HFC-134a	Unacceptable as of July 20, 2016 except for uses listed as acceptable, subject to use conditions.	As of July 20, 2016: acceptable for FDA-approved MDIs for medical purposes.

FOAMS End-use	**Substitutes**	**Decision***
Rigid Polyurethane and Polyisocyanurate Laminated Boardstock	HFC-134a, HFC-245fa, HFC-365mfc and blends thereof	Acceptable subject to narrowed use limits for military or space- and aeronautics-related applications* and unacceptable for all other uses as of January 1, 2017. Unacceptable for all uses as of January 1, 2022.
Flexible Polyurethane	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof	
Integral Skin Polyurethane	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof; Formacel TI, and Formacel Z-6	
Polystyrene Extruded Sheet	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof; Formacel TI, and Formacel Z-6	
Phenolic Insulation Board and Bunstock	HFC-143a, HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof	
Rigid Polyurethane Slabstock and Other	HFC-134a, HFC-245fa, HFC-365mfc and blends thereof; Formacel TI, and Formacel Z-6	Acceptable subject to narrowed use limits for military or space- and aeronautics-related applications* and unacceptable for all other uses as of January 1, 2019. Unacceptable for all uses as of January 1, 2022.

End-use	Substitutes	Decision*
Rigid Polyurethane Appliance Foam	HFC-134a, HFC-245fa, HFC-365mfc and blends thereof; Formacel TI, and Formacel Z-6	Acceptable subject to narrowed use limits for military or space- and aeronautics-related applications* and unacceptable for all other uses as of January 1, 2020. Unacceptable for all uses as of January 1, 2022.
Rigid Polyurethane Commercial Refrigeration and Sandwich Panels	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof; Formacel TI, and Formacel Z-6	
Polyolefin	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof; Formacel TI, Formacel Z-6	
Rigid Polyurethane Marine Flotation Foam	HFC-134a, HFC-245fa, HFC-365mfc and blends thereof; Formacel TI, and Formacel Z-6	
Polystyrene Extruded Boardstock and Billet (XPS)	HFC-134a, HFC-245fa, HFC-365mfc, and blends thereof; Formacel TI, Formacel B, and Formacel Z-6	Acceptable subject to narrowed use limits for military or space- and aeronautics-related applications* and unacceptable for all other uses as of January 1, 2021. Unacceptable for all uses as of January 1, 2022.

MOTOR VEHICLE AIR CONDITIONING - NEW LIGHT-DUTY SYSTEMS Substitutes	Decision
HFC-134a	• Unacceptable as of Model Year (MY) 2021, except where allowed under a narrowed use limit through MY 2025. • Acceptable, subject to narrowed use limits, for vehicles exported to countries with insufficient servicing infrastructure to support other alternatives, for MY 2021 through MY 2025. • Unacceptable for all newly manufactured vehicles as of MY 2026.
R-406A, R-414A (HCFC Blend Xi, GHG-X4), R-414B (HCFC Blend Omicron), HCFC Blend Delta (Free Zone), Freeze 12, GHG-X5, HCFC Blend Lambda (GHG-HP), R-416A (FRIGC FR-12, HCFC Blend Beta), SP34E, R-426A (RS-24, new formulation)	Unacceptable as of MY 2017.

RETAIL FOOD REFRIGERATION End-use	Substitutes	Decision
Supermarket Systems (Retrofit)	R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of July 20, 2016
Supermarket Systems (New)	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of January 1, 2017
Remote Condensing Units (Retrofit)	R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of July 20, 2016
Remote Condensing Units (New)	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of January 1, 2018
Stand-Alone Units (Retrofit)	R-404A, R-507A	Unacceptable as of July 20, 2016
End-use	Substitutes	Decision

RETAIL FOOD REFRIGERATION End-use	**Substitutes**	**Decision**
Stand-Alone Medium-Temperature Units1 with a compressor capacity below 2,200 Btu/hour and not containing a flooded evaporator (New)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	Unacceptable as of January 1, 2019
Stand-Alone Medium-Temperature Units with a compressor capacity equal to or greater than 2,200 Btu/hour and Stand-Alone Medium-Temperature Units containing a flooded evaporator (New)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03.	Unacceptable as of January 1, 2020
Stand-Alone Low-Temperature Units2 (New)	HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)	Unacceptable as of January 1, 2020

VENDING MACHINES End-use	**Substitutes**	**Decision**
Retrofit	R-404A, R-507A	Unacceptable as of July 20, 2016
New	FOR12A, FOR12B, HFC-134a, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-426A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), SP34E	Unacceptable as of January 1, 2019