Appendix B

California Facilities and Greenhouse Gas Emissions Inventory – High-Global Warming Potential Stationary Source Refrigerant Management Program

Research Division

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1. Background

The proposed Refrigerant Management Program regulation for the management of refrigerants used in stationary refrigeration equipment was developed by the California Air Resources Board (ARB) staff to reduce the emissions of high global warming potential (GWP) greenhouse gases (GHG) used in commercial and industrial refrigeration equipment. This regulation was developed as an early action measure as part of implementing Assembly Bill 32, the Global Warming Solutions Act of 2006 (AB 32). This program aims to minimize emissions of high-GWP refrigerants from stationary refrigeration equipment through facility registration, leak detection and monitoring, leak repair, system retrofit and retirement, required service practices, and record-keeping and reporting.

This appendix outlines analysis conducted to determine statewide emissions estimates of high-GWP GHG from stationary refrigeration and air-conditioning (R/AC) equipment. This analysis was used in the development of the proposed Refrigerant Management Program regulation.

High-GWP refrigerants include chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC), and hydrofluorocarbons (HFC). CFC and HCFC are also classes of ozone depleting substances (ODS). HFC are non-ozone depleting substitutes. Both ODS and HFC have very high global warming potentials, ranging between 500 and 10,000 times more potent than carbon dioxide (CO_2).

ODS production is controlled under the Montreal Protocol as a result of concerns about stratospheric ozone depletion, but emissions are not strictly controlled. The underlying assumption of the Montreal Protocol is that all the gases produced will eventually be emitted. However, for some end uses there can be a considerable time lag between gas production and emission.

High-GWP GHG can generally be categorized as Kyoto gases or Non-Kyoto gases. Kyoto gases are those that pertain to the Kyoto Protocol including CO_2, HFC, methane, nitrous oxide, perfluorocarbons, and sulfur hexafluoride. Non-Kyoto gases include the ODS Montreal Protocol gases, and several miscellaneous gases not covered under either treaty.

<u>Existing Regulations:</u> ODS emissions from R/AC equipment are regulated at the federal level through regulations promulgated under the Clean Air Act and Amendments (CAAA) Section 608, (Stratospheric Ozone Protection, Stationary Sources), which establish maximum allowable leak rates and mandatory leak repair requirements for R/AC equipment that contains 50 lbs or more ODS refrigerant. The same regulations establish requirements prohibiting venting of ODS and HFC refrigerants.

In California, the South Coast Air Quality Management District (SCAQMD) regulates R/AC equipment under Rule 1415 (Reduction of Refrigerant Emissions from Stationary Refrigeration and Air Conditioning Systems).

Rule 1415 is consistent with regulations related to Section 608 of the CAAA as it applies to the minimum refrigerant charge size of 50 lbs per system, and applies to ODS. Rule 1415 is more stringent in allowable leak rates than Section 608, because Rule 1415 requires that leaks be repaired within 14 days after they are discovered (or should have been discovered), while Section 608 regulations allow annual leak rates up to 35% for refrigeration systems, and up to 15% for air-conditioning (AC) systems before repair is required.

Refrigeration and AC Equipment Identified as Potentially Significant Contributors to GHG Emissions: Stationary R/AC equipment was selected as a source of GHG emissions that could potentially be reduced, because R/AC equipment contains high-GWP greenhouse gases, a known contributor to overall GHG emissions.

Based on the 2002-2004 average emissions in the California GHG inventory, high-GWP sector emissions represented about 3 percent all California GHG emissions (source: ARB Climate Change Scoping Plan, Dec 2008, page 13). However, high-GWP sector emissions are one of the fastest growing sources of GHG emissions, and future Kyoto gas emissions from stationary R/AC equipment are expected to at least double by 2020 (sources: Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004, California Energy Commission, December 2006; and Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990 – 2006, U.S. EPA, April 15, 2008).

To get an initial rough estimate of GHG emissions from stationary R/AC equipment in California, ARB staff used the United States Environmental Protection Agency (U.S. EPA) Vintaging Model national estimates for years 2010 – 2030 provided to ARB in October 2008. The U.S. EPA Vintaging Model was developed to estimate nationwide patterns of GHG emissions of HFCs, perfluorocarbons (PFCs), CFCs, and HCFCs from all major emission sources, including refrigerant usage.

National estimates were scaled down to California's 12.5% proportion of the U.S. population. Year 2010 was used as a baseline year; with year 2020 used as the initial target goal date for AB 32 measures. When estimating emissions through 2020, it was assumed that California's proportion of the U.S population remains at a constant 12.5 percent.

The following Table 1 shows initial emissions estimates from stationary R/AC equipment in California for baseline year 2010, as scaled down from national estimates using the U.S. EPA Vintaging Model.

Table 1. Stationary R/AC Equipment Annual Emissions Baseline Year 2010					
Stationary Source	**Number of Facilities [1]**	**Annual Emissions ($MMTCO_2E$)**	**Annual Emissions (Million lbs)**	**Percent of Stationary Refrigerant Emissions**	**Emissions Rate in lbs/facility/year**
Large Commercial Refrigeration ≥ 50 lbs	26,000	9.4	10.8	37%	415
Small Commercial Refrigeration < 50 lbs	70,000	1.1	1.4	4%	20
Large Commercial AC ≥ 50 lbs	23,000	2.3	1.8	9%	80
Small Commercial AC < 50 lbs	500,000	5.2	5.7	21%	11
Residential AC and Refrigeration	10 million	7.3	7.3	29%	< 1
Total	10.6 million	25.3	27.0	100%	3

Source: U.S. EPA Vintaging Model estimates and technical data sheets, provided to ARB October 2008, and adapted through additional ARB analysis to determine facility numbers and R/AC source categories, as described in this appendix.

The following is a description of the five basic R/AC sectors shown in Table 1:

- Large commercial refrigeration (equipment contains 50 lbs or more refrigerant charge) includes refrigerated equipment found in supermarkets, large grocery stores, and other retail food establishments. The refrigeration equipment generally consists of refrigerant condensing units that commonly contain 50 to 200 lbs of refrigerant, and large centralized refrigeration systems that commonly contain more than 200 lbs of refrigerant, with a central compressor rack and condensing unit system linked to multiple display cases through extensive piping. Large commercial refrigeration also includes industrial process refrigeration, which consists of complex, often custom-designed refrigeration equipment used in manufacturing and industrial applications including the chemical, petrochemical, pharmaceutical, oil and gas, and metallurgical industries. Industrial process refrigeration systems are generally quite large, with an average refrigerant charge size of greater than 2,000 lbs.
- Small commercial refrigeration (equipment contains less than 50 lbs refrigerant charge) includes stand-alone display cases, small walk-in cold rooms, and other small refrigeration equipment used primarily in convenience stores, small grocery stores, pharmacies, and restaurants.

[1] Initial facility number estimates for commercial refrigeration and large commercial AC ranged from 10,000 to 100,000 for each sector. Facility numbers shown in this table reflect best estimates after additional analysis as described in this appendix.

- Large commercial AC (equipment contains 50 lbs or more refrigerant charge) includes centrifugal chillers and positive displacement (packaged) chillers used for comfort cooling in non-residential commercial buildings. Centrifugal chillers have a large refrigerant charge size, usually greater than 1,000 lbs of refrigerant, and packaged chillers generally have a refrigerant charge size between 500 and 600 lbs, on average.
- Small commercial AC (equipment contains less than 50 lbs refrigerant charge) includes unitary AC systems used for commercial building comfort cooling. The AC systems generally contain 20 lbs or less refrigerant charge.
- Residential AC and refrigeration include packaged AC units and refrigerator-freezers used in households. Packaged AC units generally contain 10 lbs or less of refrigerant charge, and refrigerator-freezers generally contain less than 1 lb. of refrigerant charge.

The 2010 estimated GHG emissions are predominantly from ODS (75% of total emissions), with the remaining 25% from HFC. By 2020, total GHG emissions only increase slightly, from 25 to 28 $MMTCO_2E$, but the HFC portion of emissions increases three-fold, from 25% to 75% of the total.

<u>Minimum refrigerant charge size threshold for emissions analysis:</u>
To focus emission estimates on R/AC equipment that create the most emissions, a decision was made at the beginning of the process to set a minimum refrigerant charge size threshold for further detailed analysis. As shown in Table 1, all stationary R/AC equipment emissions were initially estimated, regardless of refrigerant charge size.

Generally, it is understood that the more refrigerant a R/AC system contains, the greater the potential refrigerant loss. However, a cursory look at the data also show that R/AC systems with small refrigerant charges account for significant emissions, as can be seen in Table 1, which shows that residential AC and refrigeration account for 29% of total stationary R/AC equipment emissions, despite almost all residential systems containing less than 10 lbs of refrigerant. Additionally, small AC systems used commercially on average contain less than 20 lbs of refrigerant, but contribute 21% of all stationary R/AC emissions.

Cumulative emissions from R/AC equipment with less than 50 lbs of refrigerant are significant, but their emissions on a per facility basis tend to be low (compared to facilities with R/AC equipment that contains more than 50 lbs of refrigerant). For example, the significant emissions from residential AC and refrigeration are due to millions of households each potentially emitting small amounts of refrigerant. Similarly, the significant emissions from small AC systems are due primarily to the large number of facilities (approximately 500,000) with small AC systems.

In analysis, ARB staff chose to ensure consistency with the existing regulatory framework used in the CAAA Section 608 regulations and SCAQMD Rule 1415 to directly address emissions from R/AC systems with a minimum threshold of 50 lbs refrigerant charge and to indirectly address emissions from other appliances through technician required services practices. Because SCAQMD and federal regulations are based on R/AC equipment with a refrigerant charge of 50 lbs or greater of ODS as the regulatory threshold, a different threshold set by ARB statewide would create confusion.

California-Specific Data: The U.S. EPA Vintaging Model data was used as a starting point to identify the largest sources of GHG emissions from stationary R/AC equipment. Although the U.S. EPA Vintaging Model is an excellent data source, ARB staff also sought additional data from sources that would enable California-specific emission estimates. The emission estimates shown in this appendix are based upon California-specific data sources, which are described in detail in section 3.B., "Data Sources".

Outcome of Emissions Analysis: As part of its assessment of the feasibility of potential regulations, the ARB must consider cost-effectiveness. Development of such an estimate requires a characterization of the baseline emissions as well as the potential emission reductions from the proposal. It also requires identification of compliance costs, and estimates of the number and types of businesses using applicable R/AC systems. This appendix describes the methodology used to determine:

- Types and numbers of businesses with R/AC equipment;
- Types and numbers of R/AC equipment;
- Baseline refrigerant GHG emissions from a current business-as-usual (BAU) scenario; and
- Emission reductions as a result of rule implementation.

The results of the analysis summarized in this appendix are used as the basis to calculate costs of the proposed rule, which are presented in Appendix C.

2. Summary of Results

The numbers of facilities with R/AC equipment were estimated, along with potential GHG emission reductions from these facilities.

Number of Facilities with Refrigeration or AC Equipment
Numbers of facilities with stationary R/AC equipment containing 50 lbs or more high-global warming potential refrigerant were estimated.

R/AC equipment sizes were broken into the following six groups to allow for more precise analysis of the number of facilities using applicable R/AC systems, emissions, and potential emission reductions:

Refrigeration Equipment Refrigerant Charge Size Categories:

- Small Commercial Refrigeration Systems: 50 lbs or greater, but less than 200 lbs (50-<200 lbs);
- Medium Commercial Refrigeration Systems: 200 lbs or greater, but less than 2,000 lbs (200-<2,000 lbs); and
- Large Commercial Refrigeration Systems: 2,000 lbs or greater (≥2,000 lbs).

AC Equipment Refrigerant Charge Size Categories:

- Small Commercial AC Systems: 50 lbs or greater, but less than 200 lbs (50-<200 lbs);
- Medium Commercial AC Systems: 200 lbs or greater, but less than 2,000 lbs (200-<2,000 lbs); and
- Large Commercial AC Systems: 2,000 lbs or greater (≥2,000 lbs).

The following Table 2 shows the number of facilities with R/AC equipment in each refrigerant charge size category described above.

Table 2. Number of Facilities with R/AC Equipment ≥ 50 lbs; Baseline Year 2010

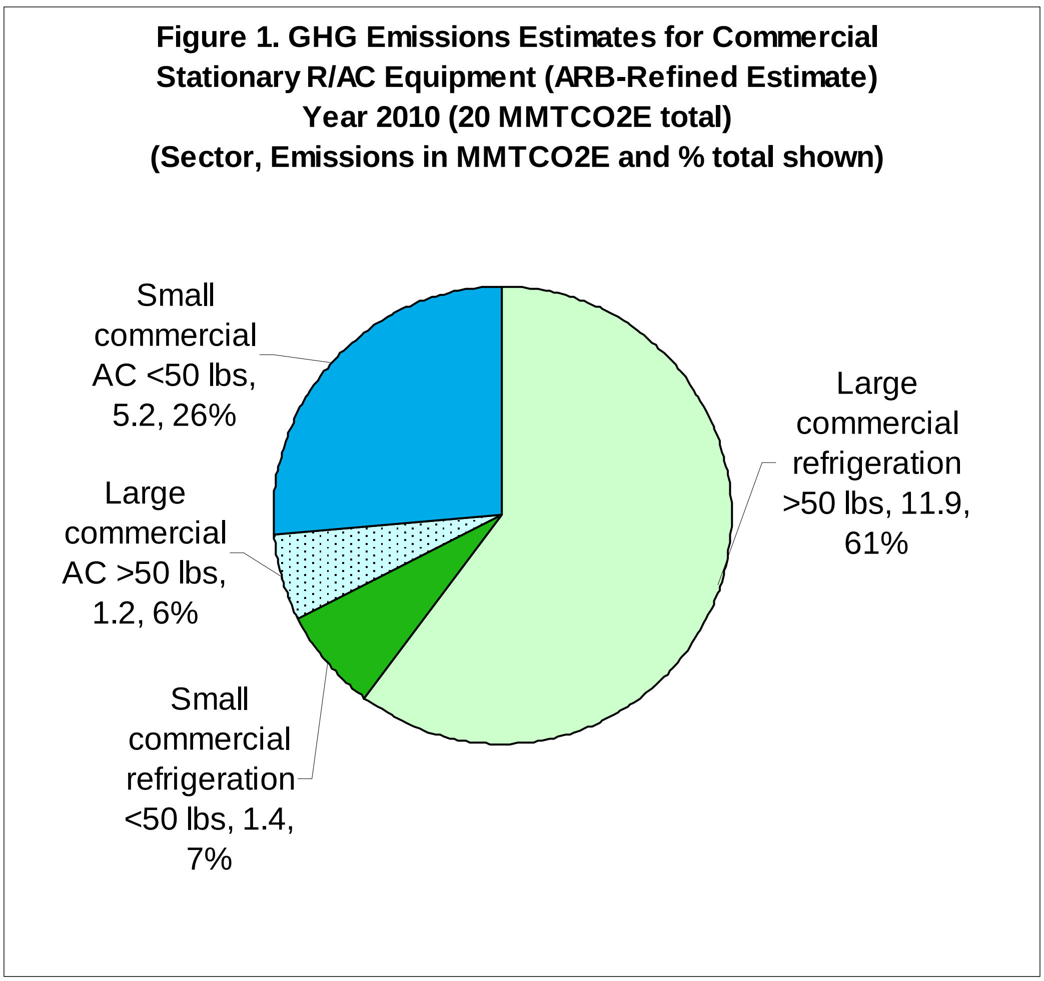
Facility Category (number of facilities containing the following equipment types) [2]	**Lower Range**	**Best Estimate**	**Upper Range**
Small Commercial Refrigeration Systems	10,000	15,500	22,000
Medium Commercial Refrigeration Systems	1,000	8,500	19,000
Large Commercial Refrigeration Systems	2,000	2,000	13,000
Sub-total Facilities with Commercial Refrigeration Equip ≥ 50 lbs	13,000	26,000	54,000
Small Commercial AC Systems	14,000	14,300	52,000
Medium Commercial AC Systems	700	6,100	11,100
Large Commercial AC Systems	800	2,700	4,900
Sub-total Facilities with AC Equip ≥ 50 lbs	15,500	23,100	68,000
Totals	**28,500**	**49,100**	**122,000**

[2] The number of facilities shown in this table represents facilities containing one or more pieces of R/AC equipment within a given refrigerant charge size category. The best estimate is the most likely number of facilities ≥ 50 lbs. Note that the best estimate is not the average or mid-point between the lower range and upper range, but instead was determined using the most reliable data sources.

Emissions and Emission Reductions

The following Figure 1 shows finalized emissions estimates for baseline year 2010 to allow a quick visual comparison of the relative emissions from each commercial R/AC sector. (Refrigerant emissions from residential sources are not analyzed further in this emissions analysis.) These refined emissions estimates do not match exactly with the U.S. EPA Vintaging Model results shown in Table 1 due to the use of California-specific data which yielded slightly different state-wide emission factors, and therefore, slightly different results.

Because the California-specific data was based upon empirical data and a comprehensive bottom-up approach, it is believed to be more accurate than national estimates scaled down to California's population. The two primary changes resulting in using California-specific data was that the large commercial refrigeration sector initial emissions estimates increased from 9.4 to 11.9 $MMTCO_2E$, while the large commercial AC sector initial emissions estimates decreased from 2.3 to 1.2 $MMTCO_2E$. (Table 3 shows the emissions breakdown for each R/AC equipment refrigerant charge size category.)



Data source: U.S. EPA Vintaging Model Estimates refined by ARB using California-specific data and emission factors, as described in this emissions methodology appendix.

Refrigeration Equipment:
Baseline 2010 emissions from stationary refrigeration equipment with refrigerant charges of 50 lbs or greater are about 7.4 $MMTCO_2E$ from HFC and 4.5 $MMTCO_2E$ from ODS (11.9 $MMTCO_2E$ total).

By 2020, BAU emissions from stationary refrigeration equipment with refrigerant charges of 50 lbs or greater are anticipated to increase 33% to 15.8 $MMTCO_2E$. HFC emissions are anticipated to almost double by 2020 to 14.3 $MMTCO_2E$ while ODS emissions are anticipated to decrease to 1.5 $MMTCO_2E$. (Montreal Protocol agreements limiting production of ODS including CFC and HCFC are responsible for a transition towards non-ODS replacements such as HFC.)

AC Equipment:
Baseline 2010 emissions from stationary AC equipment with refrigerant charges of 50 lbs or greater are about 0.2 $MMTCO_2E$ from HFC and 1.0 $MMTCO_2E$ from ODS (1.2 $MMTCO_2E$ total).

By 2020, BAU emissions from stationary AC equipment with refrigerant charges of 50 lbs or greater are anticipated to increase 17% to 1.4 $MMTCO_2E$. HFC emissions are anticipated to increase by 2020 to 1.0 $MMTCO_2E$ while ODS emissions will decrease to 0.4 $MMTCO_2E$.

Total Reductions:
Potential emission reductions from facilities with applicable R/AC equipment include HFC emission reductions of approximately 7.2 $MMTCO_2E$ by 2020, with another 0.9 $MMTCO_2E$ additional emission reductions from ODS (above the expected transitional decreases), for a total of 8.1 $MMTCO_2E$ GHG emission reductions. Additional potential emission reductions from AC equipment are 0.5 $MMTCO_2E$ (0.4 from HFC and 0.1 from ODS); for total projected emissions reductions of 8.6 $MMTCO_2E$.

The potential emission reductions are equal to the difference in the statewide emissions estimated using the average BAU leak rates (Table 3, 2020 BAU), and the statewide emissions estimated using the lower achievable leak rates obtainable using best management practices (Table 2, 2020 Post-Rule).

In aggregate, the proposed rule is expected to result in GHG emission reductions of approximately 50 percent, compared to BAU.

The following Table 3 shows emissions and potential reductions from commercial stationary R/AC equipment containing 50 lbs or more refrigerant charge. Emissions are broken out by basic type of equipment (refrigeration or AC), and refrigerant charge size (small, medium, or large).

Table 3. Potential emissions and emission reductions associated with the proposed regulation in 2010 and 2020. All emissions expressed in $MMTCO_2E$.				
	Emissions			**Emission Reductions**
R/AC Equipment Charge Size Category	**2010 BAU**	**2020 BAU**	**2020 Post-Rule**	**2020 Total GHG Reduction**
Small Commercial Refrigeration Systems	1.2	1.4	0.5	0.9 (0.8 HFC + 0.1 ODS)
Medium Commercial Refrigeration Systems	5.7	7.9	4.6	3.3 (3.0 HFC + 0.3 ODS)
Large Commercial Refrigeration Systems	5.0	6.5	2.6	3.9 (3.3 HFC + 0.6 ODS)
Refrigeration Subtotals	11.9	15.8	7.7	8.1 (7.2 HFC + 0.9 ODS)
Small Commercial AC Systems	0.6	0.7	0.3	0.4 (0.3 HFC + 0.1 ODS)
Medium Commercial AC Systems	0.3	0.3	0.2	0.1 (0.1 HFC + 0.0 ODS)
Large Commercial AC Systems	0.3	0.4	0.4	0 see footnote 3
AC Subtotals	**1.2**	**1.4**	**0.9**	**0.5 (0.4 HFC + 0.1 ODS)**
Total Emissions and Reductions	**13.1**	**17.2**	**8.6**	**8.6 [7.5 HFC + 1.1 ODS]**

Note: Sub-totals and totals may not sum exactly due to rounding.

The emissions and potential reductions estimates provide a single data mid-point within a range of plus or minus 22% that reflects the standard error of all refrigerant system leak rates, as determined through refrigerant usage and leak data reported by facilities to the South Coast AQMD under Rule 1415.

Reasonable ranges are as follows:

- 2010 BAU Emissions: 11.6 - 14.6 $MMTCO_2E$
- 2020 BAU Emissions: 15.2 - 19.4 $MMTCO_2E$
- 2020 Post-Rule Emissions: 8.5 - 8.7 $MMTCO_2E$
- Total Potential Emission Reductions: 6.7 - 10.5 $MMTCO_2E$

[3] Emission reductions for large commercial air-conditioning equipment (centrifugal chillers) are probable, but not well-defined using the methodology of comparing current business-as-usual leak rates to lower achievable leak rates, because the empirical data showed that for large centrifugal chillers, the lower achievable leak rate was already being met. Therefore, in this analysis, estimated reductions for large air-conditioning equipment are indicated as zero not because reductions cannot be achieved, but because they are not quantifiable given the constraints of current methodologies to identify further reductions from large chillers that, as reported, already achieve a low annual leak rate of 1%, which is less than the expected lower achievable leak rate of 2-4% per year.

3. Methods

This section describes the methodology used to estimate the number of facilities with R/AC equipment containing ≥ 50 lbs of refrigerant charge, current baseline emissions from those facilities, future emissions under a business-as-usual scenario, and potential emission reductions.

The Methods section is divided into the following sub-sections:

- 3.A. Emissions Calculation Formula and Emission Factors
- 3.B. Data Sources Used
- 3.C. Steps Taken to Determine Number of Facilities, Emissions, and Reductions
- 3.D. Detailed Description of Steps Used in Emissions Analysis
- 3.E. Potential Biases and Uncertainties in Data

3.A. Emissions Calculation Formula and Emission Factors

The calculation formula used to estimate GHG emissions is:

Emissions (MMTCO$_2$E) =
*Number of facilities * number of R/AC equipment units (systems) per facility * average refrigerant charge (lbs)/system * average percent of systems leaking during a given year * average percent of refrigerant charge lost from leaking systems * 4.54 x 10^{-10} MMT per lb * GWP of refrigerant*

Where:

- Number of facilities includes all facilities estimated to have R/AC equipment. In addition to the number of facilities, the types of businesses using applicable R/AC systems were also analyzed.
- The number of R/AC equipment units per facility factor is an average of the number of R/AC equipment units within a facility. The factor was developed by dividing the total number R/AC equipment units by the total number of facilities containing those systems.
- The average refrigerant charge per system is the average number of pounds of refrigerant for a given R/AC equipment category.
- The average percent of R/AC equipment units leaking during a given year is the total number of leaking R/AC equipment units divided by the number of all R/AC equipment units. This factor was calculated for each distinct combination of R/AC equipment type and refrigerant charge size (large centralized systems, medium centralized systems, large cold storage, medium cold storage, large process cooling, small refrigerant condensing

units, large centrifugal chiller, medium centrifugal chiller, medium packaged chiller, and small unitary AC).

- The average percent of refrigerant charge lost from leaking systems is the amount of refrigerant lost from leaking systems divided by the total refrigerant charge capacity of those systems that leak. (When the average percent of systems leaking during a given year is multiplied by the average percent of refrigerant charge lost from those leaking systems, the result is the annual average leak rate across all systems within the category. When this annual average leak rate is multiplied by the total quantity of refrigerant charge, the product is the annual amount of refrigerant lost in pounds, resulting from leaks.)
- Pounds of refrigerant loss (emissions) are converted to million metric tons (MMT) as a precursor to expressing emissions in the accepted "common denominator" of $MMTCO_2E$.

  4.54×10^{-10} MMT per lb is the conversion factor to convert pounds of refrigerant to million metric tons of refrigerant, which is derived from the following formula:

  *x lbs (input) * 0.454 kg/lb *.001 metric ton (MT)/kg * 0.000001 MMT/MT = MMT*
- The global warming potential of the refrigerant compared to CO_2 over a 100-year time horizon (GWP) is used to convert emissions in MMT to $MMTCO_2E$.

  For consistency with the method used to calculate California's GHG baseline emissions for AB 32, the Intergovernmental Panel on Climate Change (IPCC) Second Annual Report (IPCC SAR) was used as the source of GWP values. Where GWP values had not been published for specific refrigerants in the IPCC SAR, the values from the IPCC Third Annual Report (IPCC TAR) were used. Multiplying the quantity of refrigerant in MMT by the GWP yields emissions in terms of $MMTCO_2E$.

  In order to use the proper GWP for projected BAU emissions in 2010 and 2020, it was necessary to also use the U.S. EPA Vintaging Model's estimated ratio of R/AC equipment units that use HFC refrigerants compared to the systems that use ODS refrigerants (and the comparative share of all HFC and ODS refrigerant use by both pounds and $MMTCO_2E$). After individual GWPs were assigned to specific equipment, a weighted-average GWP was used for each category of R/AC equipment (centralized systems, cold storage systems, process cooling, chillers, refrigerant condensing units, and unitary AC units.)

The following example calculation shows how baseline 2010 GHG emissions were calculated from facilities within the small refrigeration equipment category, containing refrigerant condensing units that use 50 to 200 lbs of refrigerant. The source of data and rationale for the methodology used is further explained in subsequent sections after the example calculation.

Example Emissions Calculation:

Given:
15,500 facilities with refrigerant condensing units in 2010.
Each facility contains on average 5 condensing units.
15,500 facilities * 5 condensing units/facility = 77,500 units (systems).

Each system contains on average 122 lbs of refrigerant.

During an average given year, 22% of the systems leak.
Those systems that leak lose 65% of their refrigerant charge.
Therefore, the average annual leak rate across all systems is:
22% leaking systems * 65% of refrigerant charge leaked (from those leaking systems) = 14.5% of all refrigerant leaked each year, on average, from all systems.

The total refrigerant contained in the condensing units is:
122 lbs/system * 77,500 systems = 9,455,000 lbs.

At an annual leak rate of 14.5%, total pounds emitted are:
14.5% loss * 9,455,000 lbs = 1,370,975 lbs leaked per year.

To convert pounds to MMT, multiply by conversion factor 4.54×10^{-10} MMT per lb = 1,370,975 lbs * 4.54×10^{-10} MMT = 0.00062 MMT.

Converting MMT to $MMTCO_2E$, multiply by the GWP of the refrigerant in the equipment (average GWP of refrigerant in condensing units is 2,043):

0.00062 MMT * 2,043 = 1.27 $MMTCO_2E$ emissions per year.

The above calculation process was repeated for each of the distinct categories of R/AC equipment, which are described in methodology section 3.D., "Detailed Description of Steps Used in Emissions Analysis".

3.B. Data Sources Used

Multiple data sources were used in this analysis to determine facility numbers, emissions, and potential emission reduction estimates. The data sources are briefly described below. Additional details on how the data sources were used to develop emission factors are included in subsequent sections of this appendix.

For each data source, the emission factors it provided or helped to develop are included at the beginning of each data source section, followed by a description of the data source. Several data sources were used only to guide the analysis in the proper direction by informing staff on typical R/AC equipment uses, while other data sources were used as a secondary cross-check of more complete or precise data sources.

California Commercial End-Use Survey (CEUS): Emission factors derived from this data source include: number of facilities; number of R/AC equipment units (systems per facility); and average refrigerant charge per system (as a cross-reference).

Administered by the California Energy Commission, the CEUS survey collects a wide variety of data on the energy use of commercial buildings in California. The CEUS data included many data fields pertaining to commercial refrigeration and cooling systems. The following is a partial list of fields used to estimate statewide refrigerant emissions:

- Numbers of facilities in California by broad business-type categories.
- Number of facilities with specific types of R/AC equipment (single-zone direct expansion [DX] units, multiple-zone DX units, remote refrigerant condensing units, chillers, and HVAC systems [single-zone and multiple-zone]) and for specific retail food equipment (walk-in coolers/freezers, and multiple types of display cases).
- The total number of R/AC equipment units and the average number of units per type of business.
- Tons of cooling capacity by type of R/AC equipment (converted to pounds refrigerant charge for the emissions analysis).

CEUS data for year 2007 was a sampling of commercial buildings in California from 85 percent of the state's population and regions. The survey data was presented to ARB after it had been extrapolated to represent the entire survey region and population. ARB staff further extrapolated these estimates to 100 percent coverage of the state by multiplying all data results (building numbers, R/AC equipment units) by 1.18, (or 100%/85%) to scale up to a 100 percent representation of state data.

Note that the CEUS survey did not contain any information on the specific type of refrigerant used or annual refrigerant usage (losses). As a result, it was not used to establish specific emission factors such as average leak rates of systems. Instead the South Coast Air Quality Management District Rule 1415 data was used to establish most emission factors specific to refrigerant use.

South Coast Air Quality Management District (SCAQMD) Rule 1415 dataset: Emission factors derived from this data source include: number of facilities, number of R/AC equipment units (systems) per facility, average refrigerant charge per system, average percent of systems leaking during a given year, and average percent of refrigerant charge lost from leaking systems. Rule 1415 data was also used identify the types of businesses using the specific types of R/AC equipment, and to identify the refrigerants used in specific R/AC equipment groups.

As part of the SCAQMD Rule 1415 (Reduction of Refrigerant Emissions from Stationary Refrigeration and Air Conditioning Systems), all facilities using R/AC equipment with an ODS refrigerant charge 50 lbs or greater are required to submit a biennial report on the refrigerant charge of each piece of equipment and the amount of refrigerant used each year. The amount of refrigerant used each year is the amount added to existing systems, and is assumed to represent leaked refrigerant emissions. Only facilities with R/AC equipment utilizing ODS refrigerants are required to report under Rule 1415, although some systems using HFC refrigerant are included in reports.

In addition to refrigerant use patterns the biennial reports also include facility descriptions, standard industrial classification (SIC) codes, and types of R/AC equipment used.

The Rule 1415 biennial reports were selected as the primary source of data for emission factors because they were the most comprehensive collection of data available specific to actual refrigerant usage and losses, which gave it the distinction of being the best source of empirical data for refrigerant emissions in California. The Rule 1415 data were available for six years (reporting years 2000 through 2005) and consisted of approximately 16,000 records.

ARMINES - Inventory of Direct and Indirect GHG Emissions from Stationary Air conditioning and Refrigeration Sources, with Special Emphasis on Retail Food Refrigeration and Unitary Air Conditioning. Final Report, March 2009 (ARMINES 2009 report): ARMINES survey data was used as the primary source of information for numbers of facilities within the following business type categories: retail food, pharmacies, and hotels/motels. The ARMINES report was also used as a cross-reference for average refrigerant charge per system, average annual leak rates from R/AC equipment, and types of refrigerants used in food-related refrigeration.

The final report provided by ARMINES (principal investigator, Denis Clodic) as a part of a contract with ARB provides comprehensive inventories that are California-specific on the numbers and types of retail food facilities (supermarkets, grocery stores, convenience stores, mini-markets, restaurants, etc.), as well as the numbers and types of refrigeration equipment used by these facilities.

Data was obtained using surveys and facility visits in California. Additional reported data included inventories on numbers and types of commercial refrigeration systems used in cold storage, industrial process cooling, and air cooling in businesses. The ARMINES report was also used to establish or confirm various emission factors, including cooling capacities of refrigeration systems, types of refrigerants used in centralized systems, and typical refrigerant charge sizes.

The ARMINES report also made extensive use of the Building Services Research and Information Association (BSRIA) 2005 marketing study, which was used as a primary source of information to estimate the installed base of chillers in California.

U.S. EPA Vintaging Model. The U.S. EPA Vintaging Model emission estimates were used at the beginning of the analysis to determine current and future emissions from stationary R/AC equipment in California. Refrigerant distribution data was used to build a profile of typical refrigerants used for specific R/AC equipment groups. Technical summary sheets of R/AC equipment were used to cross-check several emission factors from other sources, including: number of R/AC systems per facility, average refrigerant charge per system, and annual refrigerant leak rates for distinct R/AC equipment groups.

The U.S. EPA Vintaging Model was developed to estimate nationwide patterns of GHG emissions of HFCs, perfluorocarbons (PFCs), CFCs, and HCFCs from all major emission sources, including refrigerant usage. Three U.S. EPA Vintaging Model data sources were used:

1) National GHG emission estimates projected for years 2010 through 2030 from the U.S. EPA's Vintaging Model for R/AC equipment were provided to ARB in October 2008. National estimates were scaled down to California based on population size.

2) Refrigerant distribution by R/AC equipment type, for baseline year 2010, and for year 2020. As part of the input variables added to the U.S. EPA Vintaging Model, refrigerant usage trends are estimated for each major R/AC equipment group. For each R/AC group, the specific refrigerants used and their share of the distribution are listed. For example, in 2010, it is estimated that for large and medium centralized systems, 42% of the systems will use R-22; 40% will use R-404A; and 18% will use R-507. Refrigerant distribution is shown in Table 5.

3) U.S. EPA Vintaging Model, EPA ODS Tracking System, and Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) Comparison for Common Refrigerants (U.S. EPA 2007). Consists of U.S. EPA Vintaging Model technical summaries of R/AC system numbers, average annual leak rates of R/AC equipment, refrigerant emissions, average refrigerant charge size, types of refrigerant used, and trends in R/AC equipment and refrigerant uses. Used to supplement, refine, and act as a cross-check for Rule 1415 data. Summaries are provided for the following R/AC categories:

- ODS and ODS Substitutes in U.S. Commercial Refrigeration End Uses (includes centralized systems).
- ODS and ODS Substitutes in the U.S. Cold Storage End Uses.
- ODS and ODS Substitutes in the U.S. Industrial Process Refrigeration (IPR) End Uses.
- ODS and ODS Substitutes in the Centrifugal Chiller End Uses.
- ODS and ODS Substitutes in the Positive Displacement Chiller End Uses.
- ODS and ODS Substitutes in the Commercial Unitary AC End Uses.

US Census Bureau NAICS code website: Used as a secondary source to cross-check facility types and numbers.

The US Census Bureau published an online guide to mapping SIC codes to 2002 North America Industry Classification System (NAICS) codes on their website: http://www.census.gov/epcd/www/naics.html. This resource was used to help translate, or map the SIC codes provided in the Rule 1415 data to the currently used NAICS codes. NAICS codes are the “common denominator” used to describe facilities, and these had to be determined to extrapolate the number of facilities within the Rule 1415 dataset to a statewide number of facilities.

US Census Bureau censtats database: This resource was used to estimate the statewide number of facilities for individual NAICS codes. The US Census Bureau publishes statewide facility number estimates for individual NAICS codes in California on their website: http://censtats.census.gov/cbpnaic/cbpnaic.shtml.

Energy Information Administration 2003 Commercial Buildings Energy Consumption Survey (CBECS): The CBECS report provided characterizations of commercial heating, ventilation, and air-conditioning (HVAC) equipment use for broad facility categories, including office buildings and office complexes. CBECS data provided a cross-check for numbers and types of facilities with R/AC equipment ≥ 50 lbs.

The national Commercial Buildings Energy Consumption Survey was conducted to collect information on the number of commercial buildings nationwide and to characterize energy related building characteristics. As a part of this survey a data table is available that outlines the estimated number of buildings within several broad building activity types (e.g., office buildings and office complexes) that utilize comfort cooling equipment including packaged air-conditioning units, central chillers, and district chilled water. A “NAICS code crosswalk” including a list of three digit NAICS codes which are representative of the types of facilities characterized by each of the principal building activities is also provided. The NAICS codes provided a breakdown of office building categories by the types of HVAC equipment used, which allowed estimates of the proportion of office buildings within the refrigerant charge size categories of small, medium, and large.

Intergovernmental Panel on Climate Change Second Assessment Report (IPCC SAR), and Third Assessment Report (IPCC TAR): Used as the source for refrigerant global warming potential (GWP) used in emission estimates. Initially developed to address potential strategies to reduce or avoid climate change worldwide, the IPCC second and third assessment reports include estimates of the global warming potentials for common refrigerants.

2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC GHG Guidelines): IPCC developed guidelines in 2006 for estimating national GHG inventories. Volume 3 (Industrial Processes and Product Use), Chapter 7 (Emissions of Fluorinated Substitutes for Ozone-Depleting Substances) includes a range of estimates of refrigerant charge (kilograms of refrigerant), lifetime of equipment (years), annualized refrigerant emissions, and recovery efficiency for several types of R/AC equipment.

Relevant types of R/AC equipment reported include: stand-alone commercial refrigeration, medium and large commercial refrigeration, industrial refrigeration (including food processing and cold storage), chillers, and commercial air conditioning. The IPCC guidelines contain information on the proper methodology to follow when estimating refrigerant GHG emissions. These methodologies helped inform and direct the ARB methodology used to estimate GHG emissions in California from stationary R/AC equipment.

IPCC/TEAP (Intergovernmental Panel on Climate Change [IPCC] and Technology and Economic Assessment Panel [TEAP]) Special Report on Safeguarding the Ozone Layer and the Global Climate Systems, 2005 (IPCC Special Report). Used as the primary source of information for estimated minimum achievable leak rates using best management practices for R/AC equipment.

The minimum feasible and achievable leak rates are used to estimate potential emission reductions. The Special Report provides the scientific context required for consideration of alternatives to ODS, potential methodologies for assessing options, and technical issues related to GHG emission reduction opportunities for several ODS emission sectors, including refrigeration and air conditioning.

The Special Report was used as a basic source of technical information on commercial refrigeration and air conditioning; providing an overview of relevant technologies, emission patterns and trends, ranges of annual leak rates for R/AC equipment, and consideration of improving containment, recovery, and recycling of refrigerants.

United Nations Environment Programme 1998 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, October 1998; Annex III-Refrigerant Data (UNEP 1998): The information contained within this report was used to compare international estimates of average refrigerant leak rates for R/AC equipment (as a "reasonable" baseline) with the average refrigerant leak rates reported under Rule 1415. A comprehensive report with detailed summaries on all major types of R/AC equipment used commercially, it describes GHG emissions from R/AC equipment, trends in refrigerant usage (transition of ODS to HFC and other refrigerants), and numbers and types of R/AC equipment.

United Nations Environment Programme 2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, January 2007 (UNEP 2007): This update to the 1998 report includes additional information on refrigerant leak rates under BAU scenarios and minimum achievable leak rates using best management practices for R/AC equipment. Used in conjunction with the IPCC Special Report to assign reasonable lower feasible and achievable leak rates for existing R/AC equipment.

3.C. Steps Taken to Determine Number of Facilities; Emissions and Potential Emission Reductions

The following steps were used determine the statewide number of facilities, emissions, and potential emission reductions from R/AC equipment with ≥ 50 lbs of high-GWP refrigerant (the steps will be described in further detail in the next section of this appendix):

1. R/AC equipment divided into basic three refrigerant charge size categories (small, medium, large)
2. Emission profiles made more specific by adding distinct R/AC equipment types to the existing refrigerant charge size categories of small, medium, and large. Identified distinct equipment groups, based on equipment type or function (including centralized system, cold storage, process cooling, refrigerant condensing units, chiller, and unitary AC).
3. Emission factors developed for each size and type of R/AC equipment
4. Number of facilities with R/AC equipment
5. Annual emissions estimated for baseline year 2010
6. Potential emissions estimated for year 2020 under business-as-usual scenario (no rule implementation)
7. Feasible lower average leak rates achievable after rule implementation is estimated
8. Emission reductions estimated for year 2020 (BAU emissions less post-rule emissions)

3.D. Detailed Description of Steps Used in Emissions Analysis

The following sub-section describes the methodology used in the steps taken to ultimately estimate number of facilities with R/AC equipment, emissions, and potential emission reductions.

Step 1. R/AC equipment divided into basic three refrigerant charge size categories (small, medium, large)

After the minimum refrigerant charge size threshold of 50 lbs per system was established, staff determined that a "one size fits all" approach to the rule would not result in the highest emission reductions for the lowest cost. The emission profiles of the R/AC equipment differ based on refrigerant charge size, and based on reported data, the different categories of R/AC equipment tend to be within defined refrigerant charge sizes. ARB staff analyzed more than 16,000 refrigerant leak data records reported under SCAQMD Rule 1415. Refrigerant loss (both in total pounds and by leak rate) was compared to refrigerant charge size. Natural break points recognized in the data showed three distinct groups of equipment, as determined by charge size, each with its own emissions profile. Based on the analysis, staff developed the following three basic refrigerant charge size groupings:

Small Equipment ≥ 50 lbs, < 200 lbs
As previously described, 50 lbs was the minimum refrigerant charge size threshold established. Small R/AC equipment using less than 200 lbs of refrigerant are characterized by relatively lower leak rates with less potential for large overall emissions compared to larger systems. An upper limit of 200 lbs was set based on its inclusion of all refrigerant condensing units and all unitary AC (with moderate leak rates), while excluding all centralized refrigeration systems, which tend to have higher leak rates. Small R/AC equipment comprises 60 percent of the number of facilities using applicable R/AC systems, and accounts for 15 percent of emissions from stationary commercial R/AC equipment.

Medium Equipment (≥ 200 lbs, < 2,000 lbs)
The 200-lb. threshold was primarily set to focus on emissions profiles representing moderate to extensive leak rates from a large number of systems. This category includes 90 percent of the centralized refrigeration equipment, 50 percent of cold storage equipment, 25 percent of centrifugal chillers, and all the packaged chillers. Medium R/AC equipment comprises 30 percent of the number of facilities using applicable R/AC systems, and accounts for 45 percent of emissions from stationary commercial R/AC equipment.

Large Equipment (≥ 2,000 lbs)
The 2,000-lb. lbs threshold was based upon emissions data from the Rule 1415

dataset, which shows that very large R/AC equipment using 2,000 lbs or more of refrigerant have relatively high leak rates. The combination of large refrigerant charge size and high leak rates combine to form the potential for the greatest emissions. The large category includes all process cooling equipment, 50 percent of cold storage equipment, 10 percent of the largest centralized refrigeration systems, and 75 percent of centrifugal chillers. Although large R/AC equipment only comprises 10 percent of the number of facilities using applicable R/AC systems, it accounts for 40 percent of emissions from stationary commercial R/AC equipment.

Step 2. Emission profiles made more specific by adding distinct R/AC equipment types to the existing refrigerant charge size categories

Initial emission estimates were made for three groups of R/AC equipment: small, medium, and large. The data generally indicated that as R/AC equipment become larger, they have higher leak rates. However, stakeholder comments led to additional analysis of all Rule 1415 data that clearly showed AC systems under the medium and large categories are chillers which leak significantly less than refrigeration equipment of the same refrigerant charge size.

To produce a meaningful analysis of equipment leak data to address stakeholder comments staff re-analyzed all equipment emissions by categorizing equipment into the following R/AC equipment types.

Refrigeration Systems

- Process Cooling (also called industrial cooling, industrial process cooling, and industrial refrigeration)
- Cold Storage
- Centralized Systems (also called DX [Direct Expansion] systems or parallel rack systems)
- Condensing Units (also called refrigerant condensing units or remote condensing units)

Air-conditioning (AC) Systems

- Centrifugal Chillers
- Packaged Chillers (also called positive displacement chillers, which include sub-types of chillers: reciprocating, screw, and scroll)
- Unitary AC (includes Split AC Systems [ducted and non-ducted]; Roof-top Units; and Packaged AC Systems)

The following summarizes typical uses of R/AC Systems:

- Process cooling, while technically a function and not a system, is the term commonly used to describe customized, built systems used in food and drink processing (brewing, distilling, dairy, and soft drink industries), and for industrial refrigeration in the chemical, petrochemical, and pharmaceutical industries. Process cooling systems fall into the large refrigerant charge size category based on very large refrigerant charges (3,500 lbs on average).

- Cold storage is also more technically a function, and not a system, but is the generally accepted term for custom built refrigeration systems used to cool large storage areas at temperatures between –20º and +50º F, primarily for food storage. Cold storage systems generally fall into the large and medium-size refrigerant charge size categories.
- Centralized systems are commonly used in supermarkets and grocery stores to cool food in display cases and walk-in-coolers. Centralized systems may contain multiple compressor racks in a central location, where the refrigerant circulates from the central location to the retail floor space. Centralized systems tend to be leaky because of the many feet of refrigerant piping and number of connections necessary for these systems. Centralized systems fall into the large and medium-size refrigerant charge size categories.
- Condensing units are similar to centralized refrigeration systems, but are smaller, consisting of only one compressor rack that may cool a single walk-in-cooler or one or two display cases. Generally used in retail food businesses such as convenience stores, and medium-sized to smaller-sized grocery stores. Condensing units are in the small refrigerant charge size category.
- Chillers, also known as water chillers, cool water or heat transfer fluids for air conditioning in retail and commercial buildings. The two primary types of chillers are centrifugal chillers and packaged chillers, which differ primarily by the mechanical system used. Packaged chillers tend to be smaller and more leak-tight than centrifugal chillers. Centrifugal chillers are in the large or medium-size refrigerant charge size categories. Packaged chillers are in the medium-size refrigerant charge size category only.
- Unitary AC systems are self-contained cooling units used for air conditioning in buildings. The typical unitary AC system contains less than 100 lbs of refrigerant. Unitary AC systems are in the small refrigerant charge size category.

Emission estimates were refined by categorizing systems by both refrigerant charge size and R/AC equipment type based on ten distinct combinations, or categories of R/AC equipment type and refrigerant charge size categories.

With three basic refrigerant charge size categories, and seven R/AC equipment types identified, theoretically, there could be 21 distinct combinations of refrigerant charge size and equipment type, but several combinations do not exist in reported data (such as large unitary AC systems, or small process cooling systems).

The ten R/AC equipment categories defined by the R/AC equipment types and refrigerant charge size combinations existing in the Rule 1415 dataset are:

- Centralized refrigeration system - large
- Centralized refrigeration system - medium
- Cold storage - large
- Cold storage - medium
- Process cooling - large
- Refrigerant condensing units - small
- Centrifugal chiller - large
- Centrifugal chiller - medium
- Chiller - packaged - medium
- Unitary AC - small

Each combination pairing of refrigerant charge size category and equipment type creates a distinct R/AC equipment category that defines the basis for all analysis. By estimating emissions from each distinct R/AC equipment type and refrigerant charge size combination, it allowed for a more precise analysis of emissions risks by R/AC equipment categories and total BAU emissions and potential reductions.

Step 3. Emission factors developed for each size and type of R/AC equipment

Emission factors were developed for each R/AC equipment category primarily from empirical data as reported under SCAQMD Rule 1415. As previously stated, GHG emissions in $MMTCO_2E$ were calculated using the following equation:

Emissions in $MMTCO_2E$ =

*Number of facilities * number of R/AC equipment units (systems) per facility * average refrigerant charge (lbs)/system * average percent of systems leaking during a given year * average percent of refrigerant charge lost from leaking systems * 4.54×10^{-10} MMT per lb * GWP of refrigerant*

The following Table 4 shows the emission factors for each distinct R/AC equipment category. The emission factors are also described in greater detail in this appendix sub-section.

(Table 4 shown on following page to preserve table continuity.)

Table 4. Emission Factors by R/AC Equipment Category						
R/AC Equipment Type and Charge Size Category	**Facility Number (2010)**	**Facility Number (2020)**	**Charge (lbs) / System[4]**	**% of Systems Leaking**	**% of Charge Leaked - leaking systems only**	**Avg. Annual Leak Rate - all systems[5]**
Small Refrigeration Systems (≥ 50 lbs, < 200 lbs)						
refrigerant condensing units	15,500	17,123	122	22%	65%	14%
Medium Refrigeration Systems (≥ 200 lbs, < 2,000 lbs)						
centralized refrigeration system	7,500	8,285	704	36%	43%	15%
cold storage	900	994	565	45%	80%	36%
Large Refrigeration Systems (≥ 2,000 lbs)						
centralized refrigeration system	900	994	2,486	77%	28%	21%
cold storage	800	884	7,546	77%	36%	27%
process cooling	340	376	3,640	22%	31%	7%
Small AC Systems (≥ 50 lbs, < 200 lbs)						
unitary AC systems	14,300	15,800	100	19%	60%	11%
Medium AC Systems (≥ 200 lbs, < 2,000 lbs)						
centrifugal chiller	800	900	1,007	6%	23%	1%
packaged chiller	5,300	5,900	526	18%	37%	7%
Large AC Systems (≥ 2,000 lbs)						
centrifugal chiller	2,700	3,000	3,978	15%	16%	2%

A. Number of Facilities:

Estimating the number of facilities with R/AC equipment ≥ 50 lbs of refrigerant charge required a detailed analysis that is covered in the next sub-section (Step 4) of this appendix.

[4] On average, there are approximately 2 refrigeration systems per facility with a large system, and 5 refrigeration systems per facility with medium or small systems. For AC equipment, there are approximately 1.8 chillers per facility with large or medium centrifugal or packaged chillers, and 5.5 unitary AC systems per facility with small AC systems.

[5] The average annual leak rate (all systems) is used to represent an average amount of refrigerant charge leaked per year across all systems, and is calculated by multiplying the percent of leaking systems by the percent of refrigerant charge leaked from those leaking systems. For example, if an equipment type had 40 percent of all systems leaking in a given year, and those systems on average leaked about 30 percent of their refrigerant charge, the resulting annual leak rate averaged across all systems would be 12 percent (40% * 30% = 12%).

B. Number and types of refrigeration or air conditioning equipment units (systems) per facility:

SCAQMD Rule 1415 empirical data was used as the basis to extrapolate numbers and types of R/AC equipment units per facility to statewide averages. For each reporting facility, the numbers and types of R/AC equipment (by equipment type and by refrigerant charge size) were summed for each category; and divided by the number of facilities containing the equipment category.

The following equation was used for each of the ten distinct R/AC equipment categories:

Average number of pieces of R/AC equipment per facility =
Number of R/AC systems/number of facilities containing that type of R/AC system

R/AC equipment units per facility were also independently calculated using CEUS survey data using the same method. CEUS data showed about 20 percent fewer systems per facility than the Rule 1415 data. Results between CEUS data and Rule 1415 were averaged to arrive at a mean number of R/AC equipment units per facility.

C. Average refrigerant charge size (pounds of refrigerant) per system:

Using methodology similar to that used to determine the average number of R/AC equipment units (systems) per facility, the Rule 1415 data reported refrigerant charge sizes for each piece of equipment were summed and divided by the total pieces of that equipment type:

Average refrigerant charge size per system =
Total pounds refrigerant charge (by R/AC equipment category)/total number of R/AC systems (by R/AC equipment category)

CEUS data was used to independently estimate average refrigerant charge size per system. The CEUS data level of precision for this factor is lower than the Rule 1415 average, because an additional conversion was necessary for CEUS data. Specifically, the CEUS data did not report the actual refrigerant charge size of systems in pounds, but was reported in terms of tons of cooling capacity for the system, which had to be converted to an equivalent refrigerant charge size in pounds. Conversion factors of 3.5 lbs refrigerant per ton of cooling capacity for AC systems and 5 lbs refrigerant per ton of cooling capacity for refrigeration systems were used.

Estimates of average refrigerant charge size from CEUS data were within ten percent of Rule 1415 estimates, but only Rule 1415 data was used because it was more precise. As an additional cross-check, average refrigerant charge sizes were compared to U.S. EPA Vintaging Model technical assessments, which indicated a wide range of average refrigerant charge sizes. Rule 1415 data fell well within U.S. EPA Vintaging Model refrigerant charge size parameters.

D. Types of refrigerants (and their global warming potentials) used:

Rule 1415 data was initially used to determine the types of refrigerants used for baseline emissions year 2010. However, an inherent bias was recognized within Rule 1415 data – only ODS-containing systems were required to report; therefore, HFC-containing systems would be virtually absent. Because Rule 1415 only requires ODS refrigerant reporting, use of this data set without adjustment would have under-estimated statewide emissions of HFCs.

The likely under-estimation of HFC emissions was corrected by using U.S. EPA Vintaging Model estimates of the current distribution of the number and types of R/AC equipment, including the type of refrigerant (ODS or HFC) used in the equipment. These current estimates formed the basis of the baseline 2010 refrigerant distribution assumptions.

For a given R/AC equipment category, the Vintaging Model refrigerant distribution was assigned to normalize Rule 1415 refrigerant data to actual refrigerant usage. For example, if 100% of the process cooling systems reported in Rule 1415 that an ODS refrigerant was used, but Vintaging Model data indicated that nationally, 40% of process cooling use HFC refrigerants, then 40% of the process cooling systems in Rule 1415 were randomly chosen and assigned HFC refrigerant to reflect the national distribution. Random assignment was used to prevent any systematic bias against associating high or low leakage systems with any particular type of refrigerant.

Note that in about five percent of the Rule 1415 reports, the refrigerant reported was indecipherable or inconclusive, such as “refrigerant R”, or “Freon”. Where the refrigerant used could not be ascertained, it was automatically selected for random assignment of normal refrigerant distribution for that type of system.

U.S. EPA Vintaging Model data was used to estimate refrigerant distribution according to R/AC equipment type in 2020. The U.S. EPA Vintaging Model projects that the proportion of R/AC equipment using ODS refrigerants will decline from 2010 to 2020 and use of HFC refrigerants will increase as ODS refrigerants are phased out. Projections are based on the number of R/AC equipment units currently in place, the average lifetime of equipment, ODS phase-out schedules, and the most probable non-ODS refrigerant replacements.

Aggregated industry data is used to estimate current R/AC equipment and their lifetimes. Projecting the likely non-ODS refrigerant substitutes is based upon current usage trends, assuming that refrigerant transitions occur linearly from the start date until the date of full usage. The U.S. EPA’s Vintaging Model often uses several sets of assumptions to better approximate non-linear transitions, such as the transition of AC equipment from HCFC-22 to HFC blends.

The following Table 5 shows projected refrigerant distribution in 2010 and 2020, based on U.S. EPA Vintaging Model analysis.

Table 5. Refrigerant Distribution by R/AC Equipment Type, 2010 and 2020

R/AC Equipment type	Refrigerant	GWP	% Equipment 2010	% Equipment 2020	HFC or ODS
Centralized Systems	HCFC-22	1500	42.2%	3.0%	ODS
	R-404A	3260	39.7%	65.2%	HFC
	R-507	3300	18.1%	31.8%	HFC
Cold Storage	CFC-12	8100	2.0%	0.0%	ODS
	HCFC-22	1500	56.6%	28.1%	ODS
	R-404A	3260	26.2%	54.2%	HFC
	R-502	4500	6.6%	0.0%	ODS
	R-507	3300	8.6%	17.7%	HFC
Process Cooling	CFC-11	3800	1.0%	0.0%	ODS
	CFC-12	8100	15.6%	0.0%	ODS
	HCFC-22	1500	22.0%	11.0%	ODS
	HCFC-123	90	23.3%	29.4%	ODS
	HFC-134a	1300	33.3%	44.5%	HFC
	R-401A	970	0.4%	0.3%	HFC
	R-404A	3260	2.7%	8.8%	HFC
	R-410A	1725	0.9%	3.4%	HFC
	R-507	3300	0.8%	2.6%	HFC
Refrigerant Condensing Units	CFC-12	8100	2.2%	0.0%	ODS
	HCFC-22	1500	30.4%	7.3%	ODS
	HFC-134a	1300	40.4%	44.5%	HFC
	R-404A	3260	19.0%	33.3%	HFC
	R-507	3300	8.0%	14.9%	HFC
Chillers	CFC-11	3800	2.6%	0.0%	ODS
	CFC-12	8100	0.9%	0.0%	ODS
	HCFC-22	1500	73.8%	32.3%	ODS
	HCFC-123	90	6.8%	8.2%	ODS
	CFC-114	9300	0.1%	0.0%	ODS
	HFC-134a	1300	14.1%	32.3%	HFC
	HFC-236fa	6300	0.4%	0.1%	HFC
	R-407C	1526	1.0%	18.2%	HFC
	R-410A	1725	0.1%	8.9%	HFC
	R-500	6010	0.2%	0.0%	ODS
Unitary AC	HCFC-22	1500	78.4%	15.0%	ODS
	HFC-134a	1300	0.1%	0.7%	HFC
	R-407C	1526	0.3%	1.5%	HFC
	R-410A	1725	21.2%	82.8%	HFC

No break-out by equipment refrigerant charge size was available for HFC-ODS distribution ratios, but assessment of the U.S. EPA Vintaging Model data indicates that the distribution of refrigerants used by R/AC equipment is generally consistent across all refrigerant charge sizes for a given equipment type.

Global warming potentials (GWPs) were assigned according to the values for the 100-year time horizon as reported in the IPCC Second Annual Report (IPCC SAR). For some refrigerant GWP values not shown in the SAR, the IPCC Third Annual Report (IPCC TAR) values were used.

E. Average percent of systems leaking (during a given year):

Rule 1415 data was the best source of data for this factor, as other data tended to report annualized leak rates assuming that all equipment leaked a certain amount each year.

The factor is calculated from:

*Number of systems reporting a leak/total number of systems * 100%*

F. Average percent of refrigerant charge lost from leaking systems:

Rule 1415 data was used to calculate the average percent of refrigerant charge lost from leaking systems using the following equation:

Average percent of refrigerant charge lost from leaking systems =
*Pounds refrigerant lost (added) to equipment annually/total refrigerant charge (lbs) of leaking equipment * 100%*

The average percent of refrigerant charge lost from leaking systems can also be described as the annual leak rate for leaking systems. For example, if a system charge holds 100 lbs of refrigerant, and it leaked 20 lbs in a year, the annual leak rate for that system is 20%.

All refrigerant losses were summed for each specific R/AC equipment category and divided by the summed total of all refrigerant charge within the equipment category. Leak rates were also computed for individual systems, summed, and averaged to give a result for all systems. The results were consistent with the overall weighted average loss for all leaking systems.

Given the percent of systems leaking in a given year, and the average leak rate of refrigerant leaked from leaking systems, the average annual leak rate for all systems can be calculated:

Average annual leak rate (all systems) =

*Average percent systems leaking (during a given year) * average percent of refrigerant charge lost from leaking systems.*

Emissions projections under a BAU scenario for 2020 assume that current leak rates remain constant through 2020; although more leak-tight systems may be developed in the future. A discussion of improvements in equipment leak-tightness and how they would affect projected emissions and reductions is presented in more detail in section 3.E, "Potential Biases and Uncertainties in Data".

G. Final Result: Amount of refrigerant leaked from leaking systems (in pounds and in MMTCO$_2$E):

The emission factors are used to estimate the desired result of emissions from R/AC equipment containing 50 lbs or more refrigerant charge. Emissions are first calculated in pounds, and then converted to MMTCO$_2$E:

*Amount of refrigerant leaked (in pounds) from all leaking systems = Average percent of leaking systems * the average leak rate of those leaking systems * total pounds of refrigerant charge of all systems within the R/AC equipment category.*

To convert emissions from pounds to MMTCO$_2$E:

Leak amount in MMTCO$_2$E =
*Pounds refrigerant leaked * conversion factor of 4.54×10^{-10} MMT per lb * GWP of refrigerant.*

Step 4. Number of Facilities with R/AC Equipment

ARB staff used several different sources of data to determine the number of facilities with R/AC equipment. Initially, SCAQMD Rule 1415 reported data was used to determine the types and numbers of facilities containing R/AC equipment with 50 lbs or more refrigerant.

For each R/AC equipment unit with 50 lbs or more ozone-depleting refrigerant, Rule 1415 reports require a description of the R/AC equipment, type of refrigerant used, and refrigerant charge size in pounds. Rule 1415 reports also include a business description and the SIC code for each reporting facility.

Reported SIC codes were mapped to NAICS codes and used, in conjunction with data provided by the US Census Bureau censtats database, to extrapolate the regional Rule 1415 data into a statewide estimate of the number of facilities in California in 2006. The data collected from Rule 1415 reports were treated as a valid sample of facilities statewide.

After initial facility estimates were made, ARB staff obtained additional data sources which resulted in a more precise estimate of the number of facilities with R/AC equipment. Specifically, staff realized that based on available data, better facility estimates could be made by looking at the number of facilities containing specific types of R/AC equipment rather than using the more general data available from Rule 1415 reports. Staff determined that no single data source was the best source of information for determining the number of facilities containing a given type of R/AC equipment. Therefore, each distinct type of R/AC equipment required a different data source or combination of sources.

To determine the total facilities inventory, it was necessary to break out the number of facilities containing one or more of the following types of R/AC equipment (with 50 lbs or more refrigerant):

- Centralized refrigeration systems
- Refrigerant condensing units
- Cold storage
- Process cooling
- Chillers (centrifugal and packaged)
- Unitary AC

The number of facilities was estimated for each distinct R/AC equipment category; as no single methodology was sufficient for all the different types of facilities and their R/AC equipment. To prevent double-counting, a facility was counted only once for its largest R/AC system. For example, if a facility contained a large centralized system and a small refrigerant condensing unit, it was counted once as a facility with a large refrigeration system.

<u>Refrigerant condensing units</u>

By definition in this emissions analysis, a refrigerant condensing unit contains less than 200 lbs of refrigerant, and is essentially a smaller version of a centralized system. Conversely, centralized systems are defined as direct expansion systems with 200 lbs or more refrigerant.

SCAQMD Rule 1415 data was used to determine the number of facilities with refrigerant condensing units. The SIC code for each reporting facility was mapped to a NAICS code. Based on an assessment of the facility type represented for each NAICS code (US Census Bureau website) it was determined whether systems used by facilities with each NAICS code represented refrigeration or AC systems. For example, the NAICS code 52210 represents facilities in the commercial banking sector. Based on this business description it was assumed that all R/AC equipment reported under this code were used for comfort cooling (AC systems) and not refrigeration. Similarly, the NAICS code 424420 represents facilities that are “packaged frozen food merchant wholesalers”. Based on this business description it was assumed that

R/AC equipment reported under this code were used for refrigeration and were included in the inventory of facilities using refrigerant condensing units.

Reports from 2000 – 2005 served as the primary contributor to the Rule 1415 dataset (total 16,000 systems). However, after many of the analyses were conducted, more recent reports from 2006 – 2007 became available and were used to cross check and verify the analyses conducted with the older dataset. One important difference between the older reports and the newer reports is the inclusion of more precise descriptions of each R/AC system reported which classify the systems function as refrigeration, freezing, or air conditioning.

Reports from the 1415 dataset were not sufficiently specific to enable accurate mapping to a NAICS code for retail food facilities. Additionally, it was unclear whether pharmacies reporting to the SCAQMD used refrigeration or AC systems with more than 50 lbs refrigerant. The inventory of commercial refrigeration equipment in California provided in the ARMINES report was used to cross check the number of retail food and pharmacy facilities. The ARMINES report inventory indicated that, on average, the only retail food facilities with refrigerant condensing units with more than 50 lbs refrigerant were minimarkets, convenience stores, grocery stores, and supermarkets. Because supermarkets also used centralized systems with more than 200 lbs refrigerant they were counted in the inventory of facilities which use medium and large centralized systems.

<u>Centralized refrigeration systems</u>

The number of facilities with centralized refrigeration systems was derived from analyses of the SCAQMD Rule 1415 dataset and the ARMINES report in the same way that the number of facilities with refrigerant condensing units was derived. All facility types which reported using systems with between 200 - 2,000 lbs of refrigerant in the Rule 1415 dataset were considered.

As before, the SIC code for each reporting facility in the Rule 1415 dataset was mapped to a NAICS code. Of all the facility types which reported using R/AC equipment with 200 – 2,000 lbs of refrigerant, the facility types most likely to represent refrigeration systems (and not AC systems), were isolated in the same way as is described for refrigerant condensing units.

For those facilities representing medium and large refrigeration systems there were two possible system types that could be assigned, centralized systems or cold storage. All facility types that did not match the criteria for cold storage were assumed to represent centralized systems.

As with the refrigerant condensing units, these analyses of Rule 1415 data and equipment assignments were cross checked and verified by looking at the most recent Rule 1415 reports which include improved equipment descriptions and specific designations of the purpose of the systems reports (refrigeration, freezing, or AC).

Cold storage and Process cooling

SCAQMD Rule 1415 data was used to determine the number of facilities with cold storage or process cooling systems. As described previously for refrigerant condensing units and centralized systems the SIC code for each reporting facility was mapped to a NAICS code. Facility descriptions for individual NAICS codes are generally too specific to be useful for broad characterizations of affected business types in California. As a result, similar NAICS codes were grouped into aggregated business type categories.

The following Table 6 shows some of the NAICS codes associated with aggregated business types likely to use cold storage or process cooling refrigeration equipment.

Table 6. Facilities with Cold Storage or Process Cooling Equipment - List of mapped NAICS codes and Aggregated Facility Category

Aggregated Facility Category	Cold Storage	Process Cooling	Mapped NAICS codes		
Agricultural service	✓		115000		
Beer and ale	✓		312120	424810	
Dairy	✓		311510	311511	311513
Food processing			311000	311111	311812
Fresh fruit and vegetable wholesale	✓		424410	424480	424490
			493110		
Frozen food wholesale	✓		424420		
Fruit and vegetable processing			311400	311421	
Ice manufacturing	✓	✓	312113		
Manufacturing (non-food)		✓	325000	325120	325412
			325414	336400	325320
Meat processing	✓		311600	311611	311612
			311710		
Petroleum		✓	221110	324000	324110
Refrigerated warehousing/storage	✓		493120		

After NAICS codes were aggregated into similar facility categories, the number of facilities within each aggregated category was estimated using the U.S. Census Bureau censtats website.

The censtats website includes all facilities within a NAICS code. This inventory yields an artificially high estimate because facilities with systems containing less than 50 lbs of high GWP refrigerant are included. In order to include only those facilities with R/AC equipment using 50 lbs or greater of refrigerant it was necessary to use additional data sources.

Facility numbers were adjusted accordingly to remove those with very small R/AC equipment units (< 50 lbs) by using data in the CEUS dataset, U.S. EPA Vintaging Model technical data sheets, and the ARMINES report.

Additionally, ARB staff contacted stakeholders including equipment manufacturers, produce and vegetable growers, and other industry stakeholders to verify ARMINES research indicating that at least 80% of cold storage and food processing facilities in California use ammonia or CO_2 as their refrigerant, and thus would not be subject to the proposed rule. Stakeholders were able to verify this assumption, and based on this information, facility number estimates were reduced by 80% at all refrigerant charge sizes for cold storage and food processing categories (including agricultural service, beer and ale, dairy, food processing, fresh fruit and vegetable wholesale, fruit and vegetable processing, meat processing, and refrigerated warehousing/storage).

Chillers (centrifugal and packaged)

The number of facilities that have chillers in California was estimated primarily from CEUS inventory data, with ARMINES report data also used extensively as a cross-check. Because the refrigerant charge size of chillers was not always precise using CEUS data, the ARMINES report data was used to determine the number of chillers that fell into the medium and large categories, the distribution of refrigerant charge sizes, and technology type (centrifugal or packaged chiller).

Chiller data was compared to the inventory provided in the ARMINES Stationary Air Conditioning and Refrigeration Inventory Final Report, March 2009 (Table 1.11, U.S. Installed Base of Chillers from 1990 to 2004). The Building Services Research and Information Association (BSRIA) 2005 marketing study was used as the primary source of information, with national chiller sales and the installed base scaled to California's population

Additionally, chiller inventories from the CEUS and ARMINES reports were compared to estimates from the U.S. EPA Vintaging model technical datasheets scaled down to California based on population size.

Unitary AC

The number of facilities with unitary AC systems (between 50 and 200 lbs refrigerant) was estimated from CEUS data, and these estimates were cross-checked with data from the CBECS report, the U.S. EPA Vintaging Model technical data sheets, and the ARMINES report. Initial attempts to use Rule 1415 data to estimate facilities with unitary AC systems resulted in extremely high facility estimates that could not be confirmed using more precise data provided through CEUS, CBECS, and ARMINES.

The number of facilities with single and multi-zone HVAC systems was reported in CEUS, along with the tons of cooling capacity. Cooling capacity was converted to pounds refrigerant to exclude facilities using AC systems with less than 50 lbs of refrigerant.

Because CEUS data is specific to California commercial facilities, it is considered more accurate than scaled-down results from national estimates obtained from the CBECS, ARMINES, and U.S. EPA Vintaging Model technical data sheets.

The following conversion factors and assumptions were obtained from SCAQMD Rule 1415 data and the CEUS report:

- Rooftop AC systems in California contain, on average, 11 lbs of refrigerant, with very few (10%) containing more than 50 lbs refrigerant.
- Half of the rooftop AC systems in California are in commercial facilities, and the other half are residential.
- Each facility with unitary AC systems (50 lbs or greater) contain on average, 5.5 systems per facility.

The ARMINES data also included estimates for all AC systems in California. Analysis of data contained within the ARMINES report was in close agreement with CEUS estimates. Estimates obtained from analyses of the CBECS report resulted in facility numbers 30 percent higher than estimates based on CEUS. Although CBECS and ARMINES estimates varied, the CEUS data was used as the best facility number estimate; because the uncertainty level was much lower.

Using the methodology above, staff also estimated that approximately 500,000 facilities in California contain unitary AC equipment with less than 50 lbs of refrigerant.

Emissions and Reductions Summary for Steps 5 - 8:
The following Table 7 shows R/AC equipment emission estimates for baseline year 2010, projected emissions for 2020 under a business-as-usual scenario, and projected reduced emissions for 2020 after implementation of the proposed regulation.

Total GHG emission reductions in 2020 are the difference between 2020 emissions under business-as-usual, and after rule implementation. Methodology and results are further described in following sub-sections steps 5 through 8.

Table 7. Summary of Emissions by R/AC Equipment Charge Size. All emissions shown in MMTCO2E.				
	Emissions			Potential Emission Reductions
R/AC Equipment Type and Charge Category	**2010 BAU**	**2020 BAU**	**2020 Post-Rule**	**2020 Total GHG Reduction[6]**
Small Refrigeration Systems (≥ 50 lbs, < 200 lbs)				
refrigerant condensing units (one type of small refrigeration system, same as subtotal)	1.3	1.4	0.5	0.9 (0.8 HFC + 0.1 ODS)
Medium Refrigeration Systems (≥ 200 lbs, < 2,000 lbs)				
centralized refrigeration system	4.6	6.6	4.3	2.3 (2.2 HFC + 0.1 ODS)
cold storage	1.0	1.3	0.3	1.0 (0.8 HFC + 0.2 ODS)
Subtotal: Medium Refrigeration Systems	5.7	7.9	4.6	3.3 (3.0 HFC + 0.3 ODS)
Large Refrigeration Systems (≥ 2,000 lbs)				
centralized refrigeration system	1.1	1.5	0.7	0.8 (0.8 HFC + 0 ODS)
cold storage	3.7	4.8	1.7	3.1 (2.5 HFC + 0.6 ODS)
process cooling	0.2	0.2	0.2	0 see footnote 6
Subtotal: Large Refrigeration Systems	5.0	6.5	2.6	3.9 (3.3 HFC + 0.6 ODS)
Refrigeration System Subtotals	**11.9**	**15.8**	**7.7**	**8.1 (7.2 HFC + 0.9 ODS)**

[6] Note on Process Cooling and Centrifugal Chiller Emission Reductions: Data from the U.S. EPA Vintaging Model, IPCC Third Annual Report, and ARMINES indicate that large process cooling units tend to leak about 10% of their refrigerant each year. It is not known why the process cooling systems under Rule 1415 have a lower leak rate (7% annually) than other estimates. Similarly, centrifugal chiller leak rate data from Rule 1415 reports show very low leak rates (1% annually for medium centrifugal chillers, and 2% annually for large centrifugal chillers) that are lower than the commonly cited 2-4% annual leak rate.

Emission reductions for process cooling and centrifugal chillers are probable, but not well-defined using the methodology of comparing current business-as-usual leak rates to lower achievable leak rates, because the empirical data showed that for these R/AC equipment types, the lower achievable leak rate was already being met. Therefore, in this analysis, estimated reductions for process cooling and centrifugal chillers are indicated as zero not because reductions cannot be achieved, but because they are not quantifiable given the constraints of current methodologies to identify further reductions from equipment that, as reported, already achieve leak levels that are lower than expected achievable leak rates. CARB staff chose to under-estimate emission reductions by not assigning an arbitrarily lower achievable leak rate.

Table 7. Summary of Emissions by R/AC Equipment Charge Size. All emissions shown in MMTCO2E.				
	Emissions			Potential Emission Reductions
R/AC Equipment Type and Charge Category	**2010 BAU**	**2020 BAU**	**2020 Post-Rule**	**2020 Total GHG Reduction[6]**
Small AC Systems (≥ 50 lbs, < 200 lbs)				
unitary AC systems (one type of small AC system, same as subtotal)	0.6	0.7	0.3	0.4 (0.3 HFC + 0.1 ODS)
Medium AC Systems (≥ 200 lbs, < 2,000 lbs)				
centrifugal chiller	0.02	0.02	0.02	0 see footnote 6 (previous page)
packaged chiller	0.28	0.28	0.18	0.1 (0.1 HFC + 0.0 ODS)
Subtotal: Medium AC Systems	0.3	0.3	0.2	0.1 (0.1 HFC + 0.0 ODS)
Large AC Systems (≥ 2,000 lbs)				
centrifugal chiller (one type of large AC system, same as subtotal)	0.3	0.4	0.4	0 see footnote 6 (previous page)
AC System Subtotals	**1.2**	**1.4**	**0.9**	**0.5 (0.4 HFC + 0.1 ODS)**
Totals All R/AC Systems	**13.1**	**17.2**	**8.6**	**8.6 (7.5 HFC + 1.1 ODS)**

Step 5. Annual emissions estimated for baseline year 2010

Using the emission factors previously described, the baseline emissions in year 2010 were estimated for each size and type of system, as shown in Table 7.

Step 6. Potential emissions estimated for year 2020 under business-as-usual scenario (without rule implementation)

Year 2020 potential emissions were estimated under a business-as-usual scenario and are shown in Table 7. The following assumptions were included in the 2020 BAU emissions estimate:

- Number of facilities will grow by one percent per year.

- Refrigerant usage will gradually transition away from CFCs and HCFCs towards HFCs, as previously shown in Table 5 (Refrigerant Distribution by Equipment Type, 2010 and 2020).
- No other changes in emission factors will occur, i.e., the following remain unchanged:
  - Number of systems/facility
  - Average refrigerant charge (pounds) per system
  - Average percent of systems leaking during a given year
  - Average percent of refrigerant charge lost from leaking systems

Step 7. Feasible lower average leak rates achievable after rule implementation

It is not possible to prevent all refrigerant leaks in refrigeration and AC systems. Normal aging of equipment, such as weakened fittings and gaskets lead to leaks and are a part of R/AC equipment usage in the real world. However, it is possible to find and repair leaks more quickly when best practices in refrigerant management and system maintenance are utilized.

A primary assumption used to estimate emission reductions is that the proposed rule would not necessarily reduce the actual number, or percent of leaking R/AC systems during a given year. Rather, the rule defines inspection and maintenance best management practices and use of these practices would cause leaks to be detected and repaired more quickly and completely, thus reducing overall refrigerant emissions.

In order to calculate emission reductions from BAU to post-rule implementation, it was necessary to first estimate how much the annual leak rate could be reduced, then to quantify those emissions.

Two key sources were used as the basis of lower achievable leak rates:
1) the United Nations Environment Programme (UNEP) *2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee*; and 2) the Intergovernmental Panel on Climate Change [IPCC] and Technology and Economic Assessment Panel [TEAP] *Special Report on Safeguarding the Ozone Layer and the Global Climate Systems, 2005*. U.S. EPA Vintaging Model technical sheets on specific R/AC equipment types normal leak rates were also used as supplementary references.

The two key references indicate that using best management practices on old or new refrigeration equipment can reduce the average annual leak rates to 10 percent or less for large equipment, and 5 percent or less for small equipment.

Available references were often ambiguous on what was meant by “large” or “small” equipment. Initially, staff assumed large to be equipment with 2,000 lbs or more refrigerant, and small equipment contained less than 200 lbs refrigerant. However, additional analysis showed that the term “large” was frequently used to include any equipment with about 100 kilograms (220 lbs) or more refrigerant, and “small” equipment generally included all systems with less than less than 100 kilograms.

Therefore, the achievable lower annual leak rates for the purpose of estimating emission reductions was set to 10 percent for systems with 200 lbs or more refrigerant (medium and large equipment category), and 5 percent for systems with less than 200 lbs refrigerant (small equipment category).

Achievable lower leak rates for AC systems were also researched. AC systems are generally more leak tight than refrigeration systems of the same refrigerant charge size, especially chillers, which often operate under negative pressure, so that if a leak occurs, the system will take in air, instead of refrigerant leaking out.

The IPCC Special Report and U.S. EPA Vintaging Model estimate that centrifugal chillers should be able to leak as little as 2 to 4% annually, and medium-sized packaged chillers can achieve leak rates of 3.5% or less per year. Small unitary AC systems can achieve leak rates as low as 5% or less annually.

The following Table 8 shows average annual leak rates calculated from Rule 1415 data on actual usage (refrigerant losses) over six consecutive years (2000 through 2005) for the identified R/AC equipment categories. Table 8 also shows the lower achievable annual leak rates using best management practices, based on industry studies reported in the IPCC/TEAP Special Report and the UNEP Report as previously described.

Table 8. Refrigeration Equipment Leak Rates, BAU Compared to Post-rule

R/AC Equipment Type and Charge Category	Rule 1415 Data - Avg. Annual Leak Rate	Lower Achievable Avg. Annual Leak Rate w/ Best Mgmt. Practices	Reduction of Leak Emissions (relative %)
Refrigeration Systems			
centralized system (large)	21%	10%	53%
centralized system (medium)	15%	10%	33%
cold storage (large)	27%	10%	64%
cold storage (medium)	36%	10%	72%
process cooling (large)	7%	7%	0% see footnote 7

[7] Note on Process Cooling and Centrifugal Chiller Emission Reductions: Data from the U.S. EPA Vintaging Model, IPCC Third Annual Report, and ARMINES indicate that large process cooling units tend to leak about 10% of their refrigerant each year. It is not known why the process cooling systems under Rule 1415 have a lower leak rate (7% annually) than other estimates. Similarly, centrifugal chiller leak rate data from Rule 1415 reports show very low leak rates (1% annually for medium centrifugal chillers, and 2% annually for large centrifugal chillers) that are lower than the commonly cited 2-4% annual leak rate.

Table 8. Refrigeration Equipment Leak Rates, BAU Compared to Post-rule			
R/AC Equipment Type and Charge Category	**Rule 1415 Data - Avg. Annual Leak Rate**	**Lower Achievable Avg. Annual Leak Rate w/ Best Mgmt. Practices**	**Reduction of Leak Emissions (relative %)**
refrigerant condensing units (small)	14%	5%	65%
Sub-total refrigeration systems, (weighted average)	**19%**	**9%**	**51%**
AC Systems			
centrifugal chiller (large)	2%	2%	0% see footnote 7
centrifugal chiller (medium)	1%	1%	0% see footnote 7
packaged chiller (medium)	7%	3.5%	50%
unitary AC (small)	11%	5%	56%
Sub-total AC systems, (weighted average)	**5%**	**3%**	**40%**
Totals (weighted average)	**16%**	**8%**	**50%**

Step 8. Emission reductions estimated for year 2020 (BAU emissions less post-rule emissions):

Emission reductions for year 2020 are estimated by taking the difference between BAU emissions and achievable lower emissions as a result of rule implementation. Results are shown in Table 7.

3.E. Potential Biases and Uncertainties in Data

Potential biases inherent in the Rule 1415 baseline dataset and resulting emission factors include the assumptions made for current and future leak rates, which would decrease or increase estimates of emissions and potential reductions as a result of rule implementation.

<u>1). Current Leak Rates:</u>
The Rule 1415 reports were the most complete data set for leak rates of actual R/AC equipment used in California. However, SCAQMD estimated that less than twenty percent of regulated facilities submit required reports, which results in an under-reporting of data that could potentially bias data from a representative sample of all regulated facilities.

Footnote 7 (cont.) Emission reductions for process cooling and centrifugal chillers are probable, but not well-defined using the methodology of comparing current business-as-usual leak rates to lower achievable leak rates, because the empirical data showed that for these R/AC equipment types, the lower achievable leak rate was already being met. Therefore, in this analysis, estimated reductions for process cooling and centrifugal chillers are indicated as zero not because reductions cannot be achieved, but because they are not quantifiable given the constraints of current methodologies to identify further reductions from equipment that, as reported, already achieve leak levels that are lower than expected achievable leak rates. CARB staff chose to under-estimate emission reductions by not assigning an arbitrarily lower achievable leak rate.

Bias could be introduced in two ways: 1) lower leak rates than representative of the general R/AC equipment population because the facilities that report tend to be the ones that already have best management practices (and therefore low leak rates); or 2) higher leak rates than representative, because facilities that report do so because they have been identified by local environmental enforcement agencies for serious or minor violations of environmental regulations, and have been told to report for Rule 1415 and other environmental regulations. ARB staff believes it is likely that both scenarios exist, nullifying the positive and negative biases and rendering them neutral, leaving a valid non-biased sample from under-reporting of facilities.

2). Future Leak Rates:

Estimates of future fugitive emissions are difficult to predict or quantify, as they assume changes in R/AC equipment and refrigerant usage patterns that may not have occurred yet. Specifically, two alternate scenarios were considered in leak rate assumptions that change estimated BAU emissions and reductions in 2020 from those used in this analysis:

a) Achievable lower leak rate by 2020 for medium sized refrigeration equipment is decreased from 10% to 7.5% (increases estimated emission reductions). Although achievable lower leak rates for large and small sized refrigeration systems were described and supported by several studies, medium-sized equipment was not addressed directly.

ARB staff chose a 10% achievable lower leak rate for medium sized equipment, which is the same as for large equipment. Smaller equipment is assigned an achievable lower leak rate of 5%. Therefore, ARB staff considered assigning a 7.5% achievable lower leak rate for medium systems because it is the midpoint between achievable lower leak rates of 5% for small equipment and 10% for large equipment. However, such an assumption could not be fully justified because the studies available could be interpreted to show that what ARB considers medium equipment (200 – 2,000 lbs refrigerant), encompasses what the studies included as large equipment (220 lbs or more refrigerant). If we assume that medium-sized equipment could achieve a 7.5% leak rate, the projected emission reductions for 2020 are increased from 8.6 $MMTCO_2E$ to 9.8 $MMTCO_2E$ (15 percent greater emission reductions).

b) Newer equipment becomes increasingly leak-tight (decreases estimated emission reductions). Due to a combination of best management practices and better equipment design, average annual leak rates for R/AC equipment have decreased significantly since the late 1980s (due in part to the adoption of the Montreal Protocol in 1987, and the Section 608 requirements in the Clean Air Act Amendments of 1990).

ARB staff estimated 2020 BAU emissions with the assumption that current leak rates for BAU would be constant through 2020, with no reduced leak rates due to better equipment design. However, ICF International environmental consulting company has conducted research indicating that the past trends of more leak-tight equipment should continue through 2020 and beyond, with leak rates at least 10 percent less for new equipment compared to existing equipment.

The reduced leak rates would be expected to apply more towards factory-manufactured equipment, and less to “built” systems, which are custom-built on site, and have leak characteristics different for each system. ARB staff did not use this projection for estimated future emissions under BAU scenarios, because business-as-usual by definition implies that significant changes will not take place. However, ARB staff acknowledges that continued improvements in R/AC equipment design will most likely take place, thus helping to reduce refrigerant emissions, in conjunction with best management practices.

For comparison to BAU emissions in 2020 as calculated, ARB staff calculated 2020 emissions if new equipment installed between 2010 and 2020 leaked 10 percent less than existing equipment; the expected emissions in 2020 under the new BAU assumptions would decrease from 17.2 to 15.5 $MMTCO_2E$. Similarly, total expected emission reductions from the rule would decrease from 8.6 to 7.0 $MMTCO_2E$ (20 percent fewer reductions).

4. Summary and Conclusions

<u>Summary:</u>
Statewide estimates of the number of facilities using refrigeration or air-conditioning (R/AC) equipment containing 50 lbs or more of refrigerant were calculated and refined using several data sources. Emissions inventory estimates were calculated using R/AC equipment use patterns and annual leak rate data provided in the SCAQMD Rule 1415 dataset. Estimates of the distribution of R/AC equipment using specific HFC and ODS refrigerants were obtained from the U.S. EPA Vintaging Model estimates and applied to the Rule 1415 dataset. Refrigerant use distributions were adjusted to reduce a known bias in the rule 1415 data set generated by a requirement to report refrigerant use patterns for only R/AC equipment utilizing ODS refrigerants.

Finally, the reductions in emissions that could be associated with implementation of the proposed regulation and full compliance were estimated. Approximately 50 percent of CO_2E emissions could be reduced from stationary refrigeration or air-conditioning equipment (subject to the proposed rule) as a result of reduced leak rates from improved inspection and maintenance practices required by the regulation.

Conclusions:
Requiring the use of refrigerant best management practices outlined in the Refrigerant Management Program proposed regulation would result in significant GHG emission reductions. The primary emission reductions are a result of the leak detection and monitoring and leak repair components of the proposed rule. The reporting and record-keeping components ensure that the emission reductions are real, verifiable, and enforceable.

HFC emissions inventory estimates for the total annual CO_2 equivalent emissions from leaks associated with stationary refrigeration equipment (containing 50 lbs or more refrigerant) in California in 2010 are 7.4 $MMTCO_2E$, and are projected to increase to 14.3 $MMTCO_2E$ by 2020 under the BAU scenario. HFC emissions double between 2010 and 2020 as a result of the continued transition away from ozone-depleting refrigerants to HFC refrigerants. As a result of transitioning away from ODS refrigerants, emissions of ODS from refrigeration equipment are anticipated to decrease from 4.5 $MMTCO_2E$ in 2010 to 1.5 $MMTCO_2E$ in 2020. (Total GHG emissions of HFC and ODS combined increase about 33%, from 11.9 $MMTCO_2E$ in 2010 to 15.8 $MMTCO_2E$ in 2020.)

HFC emissions from AC equipment are projected to increase from 0.2 $MMTCO_2E$ in 2010 to 1.0 $MMTCO_2E$ in 2020. ODS emissions are anticipated to decrease from 1.0 $MMTCO_2E$ in 2010 to 0.4 $MMTCO_2E$ in 2020. The net increase in GHG emissions from AC equipment is 0.2 $MMTCO_2E$ (1.2 to 1.4 $MMTCO_2E$).

Analyses conducted by ARB staff estimate that approximately 50% of the CO_2E emissions from stationary R/AC equipment could be eliminated relative to BAU as a result of implementing inspection and maintenance best practices such as the leak detection and monitoring and leak repair practices.

Potential annual emission reductions of 7.2 $MMTCO_2E$ HFCs, with an additional 0.9 $MMTCO_2E$ ODS (8.1 $MMTCO_2E$ total) from refrigeration equipment by the year 2020 are projected as a result of the rule. Additional minor reductions from AC equipment are also anticipated as a result of required service practices, but are not quantified in this analysis.

Addendum A – Additional Methodology Details

Initial facility number estimates made by ARB for the proposed rule relied upon the SCAQMD Rule 1415 reported data for all facilities. As more precise data sources became available, the Rule 1415 data was used as the primary data source only to estimate the number of facilities with small refrigerant condensing units, cold storage systems, or process cooling systems (as previously described in this appendix). Although in most cases, the initial methodology was rejected in favor of better methodologies as more precise data became available, the initial methodology used is included below for completeness, because it was used to help identify types of businesses and refrigeration equipment likely to be subject to the rule. After the types of businesses and equipment were initially identified, further refinements could be made to more precisely estimate number of facilities, types and number of R/AC equipment, and emission factors of the equipment and facilities.

SCAQMD Rule 1415 reports include useful data on the types of businesses, R/AC equipment, refrigerant usage, and other data that were used by ARB to develop initial estimates on the magnitude of GHG emissions from stationary R/AC equipment.

All data obtained from SCAQMD Rule 1415 databases were initially scanned for errors and reasonable attempts to fill the data gaps were made, whenever possible.

Section 1. Initial Identification of Types of Businesses, Using SIC Codes.

Rule 1415 reports included a field for the business SIC code, which was used to map to a current NAICS code. NAICS codes were generally too specific and contained too few facilities for meaningful emissions analysis, so similar NAICS coded facilities were aggregated into similar business types.

Occasionally, the Rule 1415 report left the SIC code field blank. If a report did include a specific business description identical to descriptions provided by other facilities reporting an SIC code, then in these cases the facility with a missing SIC code was assigned the same SIC code as the other facilities with identical business descriptions.

Additionally, if a facility provided a business description that was sufficiently specific, a three digit SIC code was assigned to the respective facility based on NAICS code business descriptions. If a facility did not report an SIC code and the description provided was too vague to allow confident assignment of a three digit SIC code the data was not incorporated in further analyses.

The US Census Bureau NAICS code website was used to obtain a better understanding of the types of facilities included within each NAICS or SIC code throughout this process. In many cases the reported SIC code was mapped to a NAICS code based on the suggested mapping scheme provided by the US Census Bureau. In cases where two-digit SIC codes were reported, direct mapping to a NAICS code was not possible. In these cases the specific business description reported by each facility and the reported SIC code were used as guides to map a three- to four-digit NAICS code.

In general, the business description was relied upon more heavily than the reported SIC code because it was assumed that the employee reporting to the SCAQMD was better able to accurately describe their business than assign an appropriate SIC code from the list provided. Additionally, if SIC codes or business descriptions reported were vague, mapping to fewer NAICS digits was used to avoid over-specifying facility categories.

<u>*Assumptions/sources of bias:*</u> Several assumptions are implicit in the methods used to map SIC codes/business descriptions to NAICS codes described. It is necessary to assume that the employees completing and submitting the reporting forms to the SCAQMD accurately selected SIC codes to represent their primary business activity and that the business descriptions provided are also accurate. It is possible that the employee reporting included a business description that they felt reflected the goals of the SCAQMD instead of the actual business conducted there (for example: a real estate office building with a chiller, including a business description as “building cooling” instead of “real estate”). It is also necessary to assume that, during the SIC to NAICS code mapping process, accurate assessments of facility types included within each NAICS or SIC code were made based on information obtained from the US Census Bureau NAICS code website.

Finally, it is necessary to assume that data within the SCAQMD Rule 1415 dataset is accurate. Data was initially obtained as hard copies and converted to an electronic format using optical character recognition software. It is possible that errors were made during the process of converting data from hard copies to electronic format. However, any errors made during data transcription would have been compensated for by cross-checking the data for reasonableness and how well it reflected actual R/AC equipment numbers and refrigerant usage patterns, as compared to data from CBECS survey, CEUS survey, ARMINES research, and the U.S. EPA Vintaging Model.

Section 2. Initial Estimates of Facility Numbers and R/AC Equipment Numbers Using Rule 1415 Data

After NAICS code mapping was conducted and all NAICS codes were assigned, the numbers of facilities were determined. Facilities were designated further into categories by type of R/AC equipment and refrigerant charge size category.

R/AC Equipment Size Ranges: Datasets were first generated by sorting SCAQMD data by equipment refrigerant charge size. All R/AC equipment with at least 50 lbs of refrigerant was placed into one of the three basic refrigerant charge categories (large R/AC equipment 2,000 lbs or greater; medium R/AC equipment 200 lbs to 2,000 lbs; and small R/AC equipment 50 lbs to 200 lbs). R/AC equipment was also identified by its specific equipment type or function (centralized system, cold storage, chiller, etc.)

Initial Statewide Extrapolation: The next step to calculate numbers of facilities impacted by the proposed regulation was to determine the number of facilities statewide in each of the NAICS codes represented in the Rule 1415 dataset. Statewide facility number estimates for each NAICS code represented in each refrigerant charge size range were obtained from the US Census Bureau censtats database. The sum of these statewide facility number estimates provided the preliminary statewide estimates for the number of facilities potentially subject to the proposed rule.

To simplify data presentation, individual NAICS codes were assigned to aggregated categories representing broad facility types in California. After statewide facility number estimates for all represented NAICS codes were determined within each R/AC equipment size category, the estimates were summed to yield a cumulative facility number within each aggregated category.

The following Table 9 shows the NAICS codes that were assigned to aggregated categories of business types. Many aggregated categories consist of multiple NAICS codes because the codes are for very specific types of businesses, where the aggregated categories represent very broad business types, such as office buildings.

Table 9. Aggregated Facility Categories and Corresponding Mapped NAICS Codes

Aggregated category	Mapped NAICS codes				
Agricultural service	115000				
Airport	488110				
Amusement/recreation parks	713990	713950	713110	711211	711110
	711219				
Beer and ale	424810	312120			
Bottled gas dealers	454312				
Cemeteries/crematories	812220				
Dairy	311513	311511	311510		
Department stores	452111				
Education - Junior colleges	611210				
Education - tech and trade schools	611519				
Education - universities	611300				
Elementary and secondary schools	611110				
Food processing	311812	311111	311000		

Table 9. Aggregated Facility Categories and Corresponding Mapped NAICS Codes					
Aggregated category	**Mapped NAICS codes**				
Fresh fruit and vegetable wholesale	493110	424490	424480	424410	
Frozen food wholesale	424420				
Fruit and vegetable processing	311421	311400			
Hotels/motels	721110				
Ice manufacturing	312113				
Libraries	519120				
Manufacturing (non-food)	313000	322120	322200	322210	323110
	334516	334613	335313	335911	334513
	336300	336322	336400	336410	336411
	336414	336419	339000	339110	325000
	325120	325211	325300	325320	325411
	325412	325414	325510	325520	325991
	326113	326140	326160	326192	327213
	327310	331000	331111	331316	331512
	332811	332813	333319	334220	334410
	334413	334414			
	313000	322120	322200	322210	323110
Meat processing	311710	311612	311611	311600	
Medical care	623110	622310	622110	621512	
Misc warehousing/storage	493190				
Museums	712130	712110			
Office buildings	813990	813930	813910	425000	561439
	551112	551100	541860	541511	541330
	541110	541000	531312	531110	524298
	522390	522110	518210	518111	
Petroleum	324110	324000	221110		
Pharmacies	446110				
Publishing	511130	511120	511110	323117	
Refrigerated warehousing/storage	493120				
Religious organizations	813110	813000			
Research and development	541710				
Retail (food)	445299	445200	445110	445000	
Retail (non-food)	454390	453998	452000	448310	442110
	441110				
Service industry	811490	811198	561720		
Telecommunications	517110				
TV/movie production	515120	512191	512110		
Utilities	221320	221310	221210	221119	221000
	211111				
Wholesale - (non-food)	424690	424100	423410	423110	

Section 3. Assumptions Used to Assign R/AC Equipment Type

Rule 1415 reports were used as the primary source of data to identify the types and numbers of R/AC equipment with ≥ 50 lbs of refrigerant charge, and therefore, potentially subject to the proposed rule.

Where equipment type was not conclusive from Rule 1415 data (for example, “cooling unit”), an equipment type was assigned based on comparing the equipment’s refrigerant type and refrigerant charge size to other R/AC equipment used in the same type of business, and assigning it to the most likely R/AC equipment category. The following Table 10 shows the likely equipment type assigned to unclear R/AC equipment descriptions.

Table 10. Equipment type designations assigned for unclear reported data

Aggregated Facility Category	Equipment ≥ 50 lbs, < 200 lbs (small)	Equipment ≥ 200 lbs, < 2,000 lbs (medium)	Equipment ≥ 2,000 lbs (large)
agricultural service	unitary AC or refrigerant condensing unit	cold storage	N/A
airport	unitary AC	chiller	N/A
amusement/recreation parks	unitary AC	chiller	centrifugal chiller
beer and ale	unitary AC or refrigerant condensing unit	cold storage	N/A
bottled gas dealers	unitary AC	chiller	N/A
cemeteries/crematories	unitary AC or refrigerant condensing unit	chiller	N/A
dairy	unitary AC or refrigerant condensing unit	cold storage	cold storage
department stores	unitary AC	chiller	centrifugal chiller
education - K - 12	unitary AC	chiller	centrifugal chiller
education - Junior college	unitary AC	chiller	N/A
education - tech and trade schools	unitary AC	N/A	N/A
education - universities	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
food processing	unitary AC or refrigerant condensing unit	cold storage	cold storage
fresh fruit and vegetable wholesale	unitary AC or refrigerant condensing unit	cold storage	cold storage
frozen food wholesale	unitary AC or refrigerant condensing unit	cold storage	cold storage

Table 10. Equipment type designations assigned for unclear reported data			
Aggregated Facility Category	**Equipment ≥ 50 lbs, < 200 lbs (small)**	**Equipment ≥ 200 lbs, < 2,000 lbs (medium)**	**Equipment ≥ 2,000 lbs (large)**
fruit and vegetable processing	unitary AC or refrigerant condensing unit	cold storage	N/A
hotels/motels	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
ice manufacturing	unitary AC or refrigerant condensing unit	N/A	N/A
libraries	unitary AC	chiller	N/A
manufacturing (non-food)	unitary AC or refrigerant condensing unit	chiller or cold storage	chiller, cold storage or process cooling
meat processing	unitary AC or refrigerant condensing unit	cold storage	cold storage
medical care	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
misc warehousing/storage	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
museums	unitary AC	chiller	N/A
office buildings	unitary AC	chiller	centrifugal chiller
petroleum	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
pharmacies	unitary AC or refrigerant condensing unit	chiller	N/A
publishing	unitary AC	chiller	centrifugal chiller
refrigerated warehousing/storage	unitary AC or refrigerant condensing unit	cold storage	cold storage
religious organizations	unitary AC	chiller	N/A
research and development	unitary AC or refrigerant condensing unit	chiller	N/A
retail (food)	unitary AC or refrigerant condensing unit	refrig: centralized system	refrig: centralized system
retail (non-food)	unitary AC	chiller	centrifugal chiller
semiconductor	unitary AC	chiller	process cooling
service industry	unitary AC	chiller	centrifugal chiller
telecommunications	unitary AC	chiller	N/A
television/movie production	unitary AC	chiller	centrifugal chiller

Table 10. Equipment type designations assigned for unclear reported data			
Aggregated Facility Category	**Equipment ≥ 50 lbs, < 200 lbs (small)**	**Equipment ≥ 200 lbs, < 2,000 lbs (medium)**	**Equipment ≥ 2,000 lbs (large)**
utilities	unitary AC or refrigerant condensing unit	chiller	centrifugal chiller
wholesale - (non-food)	unitary AC	chiller	centrifugal chiller