Refrigerant Data Update

This article summarizes key physical, safety, and environmental data for refrigerants. It covers refrigerants that were widely used historically, that are in common use today, and selected candidates being considered for future use.

By **JAMES M. CALM, PE,**
Engineering Consultant,
Great Falls, Va.,
and **GLENN C. HOURAHAN, PE,**
Air Conditioning Contractors of America,
Arlington, Va.

The history of refrigerants, since the introduction of mechanical vapor-compression refrigeration in the 1830s, comprises four periods characterized by the dominant selection criteria beyond basic suitability. Figure 1 summarizes four distinct generations and identifies key refrigerant groups or criteria for them.

Most refrigerants in the first generation, a period of approximately 100 years, were solvents, fuels, or other volatile fluids familiar to early practitioners from other uses, essentially *whatever worked*. Broad commercialization of domestic refrigerators spurred a shift to a second generation. It differed with attention to improved *safety and durability*, leading to the advent of fluorochemical refrigerants. International response to protect the stratospheric ozone layer forced scheduled phaseouts of ozone-depleting refrigerants, among them chlorofluorocarbons (CFCs), such as R-12, and—in the future—also hydrochlorofluorocarbons (HCFCs), such as R-22. The measures also addressed similar chemicals for other applications, such as many widely used aerosol propellants, foam blowing agents, fire suppression agents (notably halons), and solvents. The third-generation shift to hydrofluorocarbon (HFC) and other refrigerants for *ozone protection* was perceived as a long-term solution, but growing awareness of climate change as

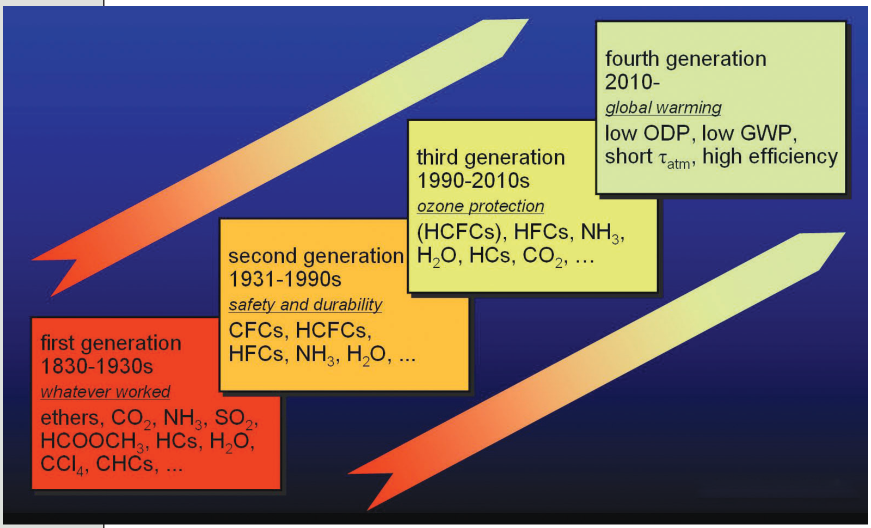

FIGURE 1. Refrigerant progression.

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James M. Calm is an internationally recognized engineering consultant specializing in heating, air-conditioning, and refrigeration systems. He is an ASHRAE Fellow; serves as lead author on refrigerants for the UNEP committee assessing technical options for refrigeration, air conditioning, and heat pumps; and has been directly involved in standards, codes, regulatory, and treaty actions impacting refrigerant use. As vice president of research and technology for the Air Conditioning Contractors of America (ACCA), Glenn C. Hourahan directs its technical, standards, and codes activities. He is actively involved in technical committees of a number of industry organizations. Between them, they have more than 60 years experience in design, construction, operation, and research of air-conditioning and refrigeration systems and authored more than 200 papers and articles.

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a more significant—or at least much more challenging—environmental issue now heralds a looming fourth generation to address *global warming*. This term is a bit misleading, as the impacts of climate change include warming in most regions but cooling in some (for example, in parts of Europe). It also includes sea level rise and attendant coastal land loss, changes in growing seasons and soil moisture retention (and, therefore, crop yields), and spread of diseases such as malaria now nearly localized to equatorial regions. In short, global climate change may impact virtually all aspects of life and raises significant international and intergenerational equity issues.

Interestingly, some of the fluids considered "natural refrigerants" (primarily ammonia, carbon dioxide, hydrocarbons, and water) in the first generation are being re-examined to replace "synthetic refrigerants" (primarily fluorochemicals) because of environmental concerns. Many of the claims and counterclaims for such fluids are more emotional or marketing-based than technical.

Most of the safety, durability, and performance issues that drove early refrigerant shifts remain concerns today, complicated by focus on low ozone depletion potential (ODP), low global warming potential (GWP), short atmospheric lifetime (τ_{atm}), and, perhaps most importantly, high efficiency. There are linkages that force trade-offs among these criteria, but none of them can be ignored.[1]

Manufacturers have commercialized more than 30 new refrigerants in the past decade, and they are examining additional candidates. Most new refrigerants are blends, because the options for suitable single-compound refrigerants are much more limited and generally already exploited. Users should expect a number of additional introductions as the phaseout approaches for R-22, now the most widely used refrigerant. A similar flurry of service fluid introductions occurred with the earlier phaseout of R-12 (then, the most widely used refrigerant) and R-502. Data refinement continues for both existing and new refrigerants with improvements in measurement methods, further studies, and new understanding, especially of environmental impacts.

REFRIGERANT DATA TABLES

This article provides two tables that update[2,3,4] and expand selected physical, safety, and environmental data for common refrigerants (retired and current) and leading candidates. The two tables contain the same data sorted differently. Table 1 is arranged by standard refrigerant designations, while Table 2 is sorted by refrigerant boiling points. Table 1 lends itself to finding information on a specific refrigerant. The sort order for Table 2 rearranges the refrigerants in coarse proximity of candidacy for similar applications, to facilitate comparisons.

The parameter descriptions that follow are in the same sequence as presented in Tables 1 and 2, going from the left to the right columns.

Identifiers

The *number* shown is the standard designation based on those assigned by or recommended for addition to ANSI/ASHRAE Standard 34-2004, *Designation and Safety Classification of Refrigerants*,[5] and addenda thereto for anticipated consistency with 34-2007 when published. These familiar designations are used almost universally, usually preceded by *R-*, *R*, the word *Refrigerant*, composition-designating prefixes (for example *CFC*, *HCFC*, *HFC*, or *HC*), or manufacturer trade names.

The *chemical formula* indicates the molecular makeup of the single-compound refrigerants, namely those consisting of only one chemical substance. The *blend composition* is shown for refrigerant blends, namely those consisting of two or more chemicals that are mixed to obtain desired characteristics. The composition consists of two parts. The first identifies the components, in order of increasing normal boiling points and separated by slashes. The second part, enclosed in parentheses, indicates the mass fractions (as percentages) of those components in the same order. The tables also indicate *common names* by which some refrigerants are frequently identified.

Physical properties

The *molecular mass* is a calculated value based on the atomic weights recognized by International Union of Pure and Applied Chemists (IUPAC).[6] It indicates the mass in grams of a mole of the refrigerant or, for blends, the mass-weighted average of a mole of the mixture.

The *normal boiling point* (NBP) is the temperature at which liquid refrigerant boils at standard atmospheric pressure, namely 101.325 kPa (14.6959 psia). The NBP and most dimensional units in the tables are shown in both metric (SI) and inch-pound (IP) units of measure. The temperature of the sublimation point is shown for refrigerants that sublimate, such as R-744 (carbon dioxide). The bubble point temperature—at which a bubble first appears and boiling begins—is shown as the NBP for blends. Unlike single-compound refrigerants that boil at a single temperature for a given pressure, the dissimilar volatilities of components cause mixture boiling to span a range between the bubble point and dew point temperatures. The dew point is so named because it is the condition at which condensation begins when the blend is cooled.

The *critical temperature* (T_c) is the temperature at the critical point of the refrigerant, namely where the properties of the liquid and vapor phases are identical. Unless actually determined, the T_c values shown for blends are the mass weighted averages of the component T_cs, sometimes referred to as the "pseudo-critical temperature."

The *critical pressure* (P_c) is the pressure at the critical point.

The NBP and critical properties suggest the application range for which an individual refrigerant might be suitable. Those with extremely low NBPs lend themselves to ultralow temperature refrigeration including cryogenic applications. Those with high NBPs generally are limited to high-temperature applications, such as chillers and industrial heat pumps. Both capacity and efficiency decline when condensing temperatures approach the T_c in a typical vapor-compression (reverse-Rankine) cycle, the one most commonly used. P_c will exceed the operating pressure except in transcritical cycles, which are uncommon except for R-744 (carbon dioxide). It is useful to compare relative operating pressures because practical cycles usually are designed to condense at 70 to 90 percent of the T_c (on an absolute basis) and, therefore, at corresponding fractions of the P_c.[1,7]

Safety data

The first safety column included in the tables tabulates the *occupational exposure limit* (OEL). It is an indication of chronic (long-term, repeat exposure) toxicity of the refrigerant for trained individuals likely to be exposed during their work. Common OELs include the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value-Time Weighted Average (TLV-TWA), the American Industrial Hygiene Association (AIHA) Workplace Environmental Exposure Level (WEEL) guide, the Deutsche Forschungsgemeinschaft (DFG) maximale Arbeitsplatz Konzentration (MAK, the maximum workplace concentration), the Japan Society of Occupational Health (JSOH) OEL, and the U.S. Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL). Some countries and manufacturers refer to them as the acceptable exposure limit (AEL), industrial exposure limit (IEL), workplace exposure standard, or with similar terms. These measures indicate recommended or adopted limits for workplace exposures for trained personnel for typical workdays and work weeks. OELs normally are expressed in ppm by volume (ppm v/v) on a time-weighted average (TWA) basis for a normal workday and workweek, unless preceded by a *C* to designate a "ceiling" limit.

The *lower flammability limit* (LFL) is the lowest concentration at which the refrigerant burns in air under prescribed test conditions. It is an indication of flammability.

The *heat of combustion* (HOC) is an indicator of how much energy the refrigerant releases when it burns in air, assuming complete reaction to the most stable products in their vapor state. Negative values indicate endothermic reactions (those that require heat to proceed), while positive values indicate exothermic reactions (those that liberate heat).

The ASHRAE *Standard 34 safety group* is an assigned classification that is based on data used to determine the TLV-TWA (or consistent measure), LFL, and HOC. It comprises a letter (A or B) that indicates relative toxicity followed by a number (1, 2, or 3) that indicates relative flammability. These classifications are widely used in mechanical and fire construction codes to determine requirements to promote safe use. Most of these code provisions are based on ASHRAE Standard 15, *Safety Standard for Refrigeration Systems*. Some of the classifications shown are followed by the lower case letter "r." It signifies that the committee responsible for ASHRAE 34 has recommended revision or addition of the classification shown, but final approval and/or publication is still pending. Similarly, a "d" indicates a deletion.

Blends were assigned dual classifications, such as A1/A2, in the past to indicate the safety groups both as formulated and for the worst case of fractionation. That practice changed to assignment of a single safety group reflecting the worst case of fractionation for specified leak and refill scenarios.

Environmental data

The *atmospheric lifetime* (τ_{atm}) is an indication of the average persistence of refrigerant released into the atmosphere until it decomposes, reacts with other chemicals, or is otherwise removed. While τ_{atm} factors into additional environmental parameters, it also is significant in its own right. It suggests the potential for atmospheric accumulation of released refrigerants (and other chemicals). Long atmospheric lifetime implies the potential for slow recovery from environmental problems, both those already known and additional concerns identified in the future.

The values shown for the refrigerant lives are composite atmospheric lifetimes. The lifetimes also can be shown separately for the tropospheric (lower atmosphere, where we live), stratospheric (next layer, where global depletion of ozone is a concern), and higher layers because the dominant atmospheric chemistry changes between layers.

The *ozone depletion potential* (ODP) is a normalized indicator, based on a value of one for R-11, of the ability of refrigerants (and other chemicals) to destroy stratospheric ozone molecules.

The values shown in Tables 1 and 2 are semi-empirical ODPs, calculated values that incorporate adjustments for observed atmospheric measurements.[8] The ODPs shown for blends are mass-weighted averages. The semi-empirical approach is conceptually more accurate than other measures, though it is still evolving with further and improved measurements and understanding.

Previous summaries[2,3,4] focused on modeled ODP values, then deemed the most indicative of environmental impacts based on consensus international assessments. There are several other ODP indices, including time-dependent and regulatory variations.

Time-dependent ODPs use chemicals other than R-11 as the reference. Normalizing values to short-lived compounds emphasizes near-term impacts, but discounts long-term effects. Time-dependent ODPs are not cited often, because release of ozone-depleting substances already has peaked, and recovery of the stratospheric ozone layer is under way.

The *global warming potential* (GWP) is a normalized indicator of the potency to warm the planet by action as a greenhouse gas. The values shown are relative to carbon dioxide (CO_2) for an integration period of 100 years, again based on

Text continued on Page 63

TABLE 1. Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP		T_c		P_c		OEL (PPMv)	LFL (%)	HOC		ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
			(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)			(MJ/kg)	(Btu/lb)				
11	CCl_3F	137.37	23.7	74.7	198.0	388.4	4.41	640	C1000	none	0.9	387	A1	45	1.000	4750
12B1	$CBrClF_2$, halon 1211	165.36	-4.0	24.8	154.0	309.2	4.10	595		none				16	7.100	1890
12	CCl_2F_2	120.91	-29.8	-21.6	112.0	233.6	4.14	600	1000	none	-0.8	-344	A1	100	1.000	10890
13B1	$CBrF_3$, halon 1301	148.91	-58.7	-73.7	67.1	152.8	3.97	576	1000	none			A1	65	16.000	7140
13	$CClF_3$	104.46	-81.5	-114.7	28.9	84.0	3.88	563	1000	none	-3.0	-1290	A1	640	1.000	14420
13I1	CF_3I, trifluoroiodomethane	195.91	-21.9	-7.4	123.3	253.9	3.95	573		none				~0.01	≤0.018	~1
14	CF_4, carbon tetrafluoride	88.00	-128.0	-198.4	-45.6	-50.1	3.75	544		none			A1	50000	0	7390
21	$CHCl_2F$	102.92	8.9	48.0	178.3	352.9	5.18	751	10	none			B1	1.7	0.010	151
22	$CHClF_2$	86.47	-40.8	-41.4	96.1	205.0	4.99	724	1000	none	2.2	946	A1	12.0	0.050	1810
23	CHF_3, fluoroform	70.01	-82.0	-115.6	26.1	79.0	4.83	701	1000	none	-12.5	-5374	A1	270	0	14760
30	CH_2Cl_2, methylene chloride	84.93	40.2	104.4	237.0	458.6	6.08	882	50	13			B2	0.38		10
31	CH_2ClF	68.48	-9.1	15.6	151.8	305.2	5.13	744	0.1					1.3	0.010	
32	CH_2F_2, methylene fluoride	52.02	-51.7	-61.1	78.1	172.6	5.78	838	1000	14.4	9.4	4041	A2	4.9	0	675
41	CH_3F, methyl fluoride	34.03	-78.3	-108.9	44.1	111.4	5.90	856						2.4	0	92
50	CH_4, methane	16.04	-161.5	-258.7	-82.6	-116.7	4.60	667	1000	4.8			A3	12.0	0	23
113	CCl_2FCClF_2	187.38	47.6	117.7	214.1	417.4	3.39	492	1000	none	0.1	43	A1	85	1.000	6130
114	$CClF_2CClF_2$	170.92	3.6	38.5	145.7	294.3	3.26	473	1000	none	-3.1	-1333	A1	300	1.000	10040
115	$CClF_2CF_3$	154.47	-38.9	-38.0	80.0	176.0	3.12	453	1000	none	-2.1	-903	A1	1700	0.440	7370
116	CF_3CF_3, perfluoroethane	138.01	-78.1	-108.6	19.9	67.8	3.05	442	1000	none			A1	10000	0	12200
123	$CHCl_2CF_3$	152.93	27.8	82.0	183.7	362.7	3.66	531	50	none	2.1	903	B1	1.3	0.020	77
124	$CHClFCF_3$	136.48	-12.0	10.4	122.3	252.1	3.62	525	1000	none	0.9	387	A1	5.8	0.020	609
125	CHF_2CF_3	120.02	-48.1	-54.6	66.0	150.8	3.62	525	1000	none	-1.5	-645	A1	29	0	3500
134a	CH_2FCF_3	102.03	-26.1	-15.0	101.1	214.0	4.06	589	1000	none	4.2	1806	A1	14.0	0	1430
E134	CHF_2-O-CHF_2	118.03	5.5	41.9	147.1	296.8	4.23	614		none				26	0	6320
141b	CH_3CCl_2F	116.95	32.0	89.6	204.4	399.9	4.21	611	500	5.8	8.6	3697		9.3	0.120	725
142b	CH_3CClF_2	100.50	-9.1	15.6	137.1	278.8	4.06	589	1000	6.0	9.8	4213	A2	17.9	0.070	2310
143a	CH_3CF_3	84.04	-47.2	-53.0	72.7	162.9	3.76	545	1000	7.0	10.4	4471	A2	52	0	4470
152a	CH_3CHF_2	66.05	-24.0	-11.2	113.3	235.9	4.52	656	1000	4.8	17.4	7481	A2	1.4	0	124
160	CH_3CH_2Cl, ethyl chloride	64.51	13.1	55.6	187.3	369.1	5.27	764	100	3.6	20.6	8856		0.11	0.020	
161	CH_3CH_2F, ethyl fluoride	48.06	-37.6	-35.7	102.2	216.0	5.09	738		3.8				0.21	0	12
170	CH_3CH_3, ethane	30.07	-88.6	-127.5	32.2	90.0	4.87	706	1000	3.1			A3	0.21	0	~20
E170	CH_3-O-CH_3, DME	46.07	-24.8	-12.6	127.2	261.0	5.34	775	1000	3.3	31.8	13672	A3	0.015	0	1
218	$CF_3CF_2CF_3$, perfluoropropane	188.02	-36.8	-34.2	71.9	161.4	2.64	383	1000	none			A1	2600	0	8830
227ea	CF_3CHFCF_3	170.03	-16.4	2.5	102.8	217.0	3.00	435	1000	none	3.3	1419	A1	42	0	3220
236fa	$CF_3CH_2CF_3$	152.04	-1.4	29.5	124.9	256.8	3.20	464	1000	none			A1	240	0	9810
245ca	$CH_2FCF_2CHF_2$	134.05	25.1	77.2	174.4	345.9	3.93	570		7.1	8.4	3611		6.2	0	693
245fa	$CHF_2CH_2CF_3$	134.05	15.1	59.2	154.0	309.2	3.65	529	300	none	6.1	2623	B1	7.6	0	1030
E245cb1	CH_3-O-CF_2-CF_3	150.05	5.9	42.6	133.7	272.7	2.89	419		flam				5.1	0	708
C270	-CH_2-CH_2-CH_2-, cyclopropane	42.08	-31.5	-24.7	125.2	257.4	5.58	809		2.4	49.7	21367		0.44	0.000	
290	$CH_3CH_2CH_3$, propane	44.10	-42.1	-43.8	96.7	206.1	4.25	616	2500	2.1	50.4	21668	A3	0.041	0	~20
C318	-CF_2-CF_2-CF_2-CF_2-	200.03	-6.0	21.2	115.2	239.4	2.78	403	1000	none			A1	3200	0	10250
E347mmy1	CF_3-CF(OCH_3)-CF_3	200.05	29.4	84.9	160.8	321.4	2.55	370						3.4	0	343

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TABLE 1 (continued). Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
400 >>	R-12/114 (50.0/50.0), R-400 (50/50)	141.63	-20.8	-5.4	129.1	264.4	3.94	571	1000	none			A1		1.000	10000
400 >>	R-12/114 (60.0/40.0), R-400 (60/40)	136.94	-23.2	-9.8	125.6	258.1	4.01	582	1000	none			A1		1.000	11000
401A	R-22/152a/124 (53.0/13.0/34.0), MP39	94.44	-32.9	-27.2	107.3	225.1	4.61	669	1000	none			A1		0.033	1200
401B	R-22/152a/124 (61.0/11.0/28.0), MP66	92.84	-34.5	-30.1	105.6	222.1	4.69	680	1000	none	-2.7	-1161	A1		0.036	1300
401C	R-22/152a/124 (33.0/15.0/52.0), MP52	101.03	-28.3	-18.9	111.7	233.1	4.37	634		none			A1		0.027	930
402A	R-125/290/22 (60.0/2.0/38.0), HP80	101.55	-48.9	-56.0	75.9	168.6	4.22	612	1000	none	-1.4	-602	A1		0.019	2800
402B	R-125/290/22 (38.0/2.0/60.0), HP81	94.71	-47.0	-52.6	82.9	181.2	4.52	656	1000	none	-1.6	-688	A1		0.030	2400
403A	R-290/22/218 (5.0/75.0/20.0), 69-S	91.99	-47.7	-53.9	87.0	188.6	4.70	682	1000	13.0			A1		0.038	3100
403B	R-290/22/218 (5.0/56.0/39.0), 69-L	103.26	-49.2	-56.6	79.6	175.3	4.33	628	1000	none			A1		0.028	4500
404A	R-125/143a/134a (44.0/52.0/4.0), HP62 and FX-70	97.60	-46.2	-51.2	72.0	161.6	3.72	540	1000	none	-6.6	-2837	A1		0	3900
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5), G2015	111.91	-32.6	-26.7	106.1	223.0	4.28	621	1000	none			d		0.026	5300
406A	R-22/600a/142b (55.0/4.0/41.0), Autofrost-X3	89.86	-32.5	-26.5	116.9	242.4	4.86	705	1000	8.2			A2		0.056	1900
407A	R-32/125/134a (20.0/40.0/40.0), Klea 60	90.11	-45.0	-49.0	81.8	179.2	4.47	648	1000	none	-3.6	-1548	A1		0	2100
407B	R-32/125/134a (10.0/70.0/20.0), Klea 61	102.94	-46.5	-51.7	74.3	165.7	4.07	590	1000	none	-1.8	-774	A1		0	2800
407C	R-32/125/134a (23.0/25.0/52.0), Klea 66 and Suva 9000	86.20	-43.6	-46.5	85.8	186.4	4.60	667	1000	none	-4.9	-2107	A1		0	1800
407D	R-32/125/134a (15.0/15.0/70.0)	90.96	-39.2	-38.6	91.2	196.2	4.45	645	1000	none	-4.3	-1849	A1		0	1600
407E	R-32/125/134a (25.0/15.0/60.0)	83.78	-42.7	-44.9	88.3	190.9	4.69	680	1000	none	-4.8	-2064	A1		0	1600
408A	R-125/143a/22 (7.0/46.0/47.0), FX-10	87.01	-44.6	-48.3	83.1	181.6	4.29	622	1000	none	5.7	2451	A1		0.024	3200
409A	R-22/124/142b (60.0/25.0/15.0), FX-56	97.43	-34.4	-29.9	109.3	228.7	4.70	682	1000	none	3.0	1290	A1		0.046	1600
409B	R-22/124/142b (65.0/25.0/10.0), FX-57	96.67	-35.6	-32.1	106.9	224.4	4.73	686		none			A1		0.045	1600
410A	R-32/125 (50.0/50.0), Suva 9100 and AZ-20	72.58	-51.4	-60.5	70.5	158.9	4.81	698	1000	none	-4.4	-1892	A1		0	2100
410B	R-32/125 (45.0/55.0)	75.57	-51.3	-60.3	69.7	157.5	4.71	683		none			A1		0	2200

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TABLE 1 (continued). Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
411A	R-1270/22/152a (1.5/87.5/11.0), G2018A	82.36	-39.5	-39.1	99.1	210.4	4.95	718	1000	5.5			A2		0.044	1600
411B	R-1270/22/152a (3.0/94.0/3.0), G2018B	83.07	-41.6	-42.9	96.0	204.8	4.95	718	1000	7.0	6.5	2794	A2		0.047	1700
----	R-1270/22/152a (3.0/95.5/1.5), G2018C	83.44	-41.8	-43.2	95.5	203.9	4.95	718		none					0.048	1700
412A	R-22/218/142b (70.0/5.0/25.0), Arcton TP5R	92.17	-38.0	-36.4	107.2	225.0	4.90	711	1000	8.7			A2		0.053	2300
413A	R-218/134a/600a (9.0/88.0/3.0), Isceon MO49	103.95	-33.4	-28.1	96.6	205.9	4.02	583		8.8			A2		0	2100
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5), GHG-X4	96.93	-33.0	-27.4	112.7	234.9	4.68	679	1000	none	3.6	1548	A1		0.043	1500
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5), Hot Shot	101.59	-32.9	-27.2	111.0	231.8	4.59	666		none			A1		0.039	1400
415A	R-22/152a (82.0/18.0)	81.91	-37.2	-35.0	102.0	215.6	4.96	719		5.6	2.7	1161	A2		0.041	1500
415B	R-22/152a (25.0/75.0), THR01b	70.19	-26.9	-16.4	111.4	232.5	4.65	674	1000	wff			A2		0.013	550
416A	R-134a/124/600 (59.0/39.5/1.5), FR-12	111.92	-24.0	-11.2	107.0	224.6	3.98	577		none	7.8	3353	A1		0.008	1100
417A	R-125/134a/600 (46.6/50.0/3.4), Isceon MO59 and NU-22	106.75	-39.1	-38.4	87.3	189.1	4.05	587	1000	none			A1		0	2300
418A	R-290/22/152a (1.5/96.0/2.5), THR03b	84.60	-41.7	-43.1	96.2	205.2	4.98	722		8.9	1.7	731	A2		0.048	1700
419A	R-125/134a/E170 (77.0/19.0/4.0), FX-90	109.34	-42.6	-44.7	79.3	174.7	3.71	538		none	10.0	4299	A2		0	3000
420A	R-134a/142b (88.0/12.0)	101.84	-24.9	-12.8	104.8	220.6	4.09	593	1000	none			A1		0.008	1500
----	R-134a/142b (80.6/19.4), RB-276	101.73	-24.2	-11.6	107.2	225.0	4.10	595		none					0.014	1600
421A	R-125/134a (58.0/42.0)	111.75	-40.7	-41.3	82.9	181.2	3.93	570	1000	none			A1		0	2600
421B	R-125/134a (85.0/15.0)	116.93	-45.6	-50.1	72.5	162.5	3.75	544	1000	none	-0.5	-215	A1		0	3200
422A	R-125/134a/600a (85.1/11.5/3.4), One Shot and Isceon MO79	113.60	-46.5	-51.7	71.8	161.2	3.75	544	1000	none			A1		0	3100
422B	R-125/134a/600a (55.0/42.0/3.0)	108.52	-41.3	-42.3	83.4	182.1	3.97	576	1000	none			A1		0	2500
422C	R-125/134a/600a (82.0/15.0/3.0)	113.40	-45.9	-50.6	73.2	163.8	3.78	548	1000	none	2.6	1118	A1		0	3100
422D	R-125/134a/600a (65.1/31.5/3.4), Isceon MO29	109.93	-43.2	-45.8	79.8	175.6	3.92	569	1000	none			A1		0	2700
423A	R-134a/227ea (52.5/47.5), Isceon 39TC	125.96	-24.1	-11.4	99.5	211.1	3.59	521	1000	none			A1		0	2300
424A	R-125/134a/600a/600/601a (50.5/47.0/0.9/1.0/0.6), RS-44	108.41	-39.7	-39.5	86.3	187.3	4.02	583	1000	none			A1		0	2400
425A	R-32/134a/227ea (18.5/69.5/12.0), THR03a	90.31	-38.1	-36.6	93.9	201.0	4.50	653	1000	none	5.1	2193	A1		0	1500

Continued on next page

TABLE 1 (continued). Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP		T_c		P_c		OEL (PPMv)	LFL (%)	HOC		ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
			(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)			(MJ/kg)	(Btu/lb)				
426A	R-125/134a/600/601a (5.1/93.0/1.3/0.6)	101.56	-28.5	-19.3	100.2	212.4	4.11	596	990	none	4.7	2021	A1 r		0	1500
427A	R-32/125/143a/134a (15.0/25.0/10.0/50.0), FX-100	90.44	-43.0	-45.4	85.1	185.2	4.37	634	1000	none			A1 r		0	2100
----	R-32/125/143a/134a, (2.0/41.0/50.0/7.0), FX-48B	95.82	-46.4	-51.5	72.7	162.9	3.80	551		none					0	3800
----	R-32/125/143a/134a (10.0/33.0/36.0/21.0), HX4	90.80	-46.5	-51.7	76.6	169.9	4.09	593		none					0	3100
428A	R-125/143a/290/600a (77.5/20.0/0.6/1.9), RS-52	107.53	-48.4	-55.1	68.9	156.0	3.72	540	1000	none			A1 r		0	3600
500	R-12/152a (73.8/26.2)	99.30	-33.6	-28.5	102.1	215.8	4.17	605	1000	none			A1		0.738	8100
501	R-22/12 (75.0/25.0)	93.10	-40.7	-41.3	95.9	204.6	4.76	690		none			A1		0.288	4100
502	R-22/115 (48.8/51.2)	111.63	-45.2	-49.4	80.2	176.4	3.92	569	1000	none			A1		0.250	4700
503	R-23/13 (40.1/59.9)	87.25	-87.8	-126.0	18.4	65.1	4.28	621	1000	none					0.599	15000
504	R-32/115 (48.2/51.8)	79.25	-57.7	-71.9	61.1	142.0	4.33	628		none					0.228	4100
505	R-12/31 (78.0/22.0)	103.48	-30.0	-22.0	117.8	244.0	4.73	686		none					0.782	8400
506	R-31/114 (55.1/44.9)	93.69	-12.3	9.9	142.2	288.0	5.16	748		none					0.455	4400
507A	R-125/143a (50.0/50.0), AZ-50	98.86	-46.7	-52.1	70.5	158.9	3.70	537	1000	none	-5.5	-2365	A1		0	4000
508A	R-23/116 (39.0/61.0), Klea 5R3	100.10	-87.6	-125.7	10.2	50.4	3.65	529	1000	none			A1		0	13000
508B	R-23/116 (46.0/54.0), Suva 95	95.39	-87.6	-125.7	11.2	52.2	3.77	547	1000	none			A1		0	13000
509A	R-22/218 (44.0/56.0), Arcton TP5R2	123.96	-49.7	-57.5	68.4	155.1	3.60	522	1000	none			A1		0.022	5700
----	R-23/32/134a (4.5/21.5/74.0), FX-220	83.14	-46.6	-51.9	90.8	195.4	4.78	693		none					0	1900
----	R-32/125/134a/600 (10.0/42.0/45.0/3.0)	96.64	-42.6	-44.7	85.5	185.9	4.36	632							0	2200
----	R-32/125/143a (10.0/45.0/45.0), FX-40	90.69	-49.0	-56.2	69.9	157.8	3.96	574		none					0	3700
----	R-32/125/161 (15.0/34.0/51.0), ZJU ZH1	61.24	-46.2	-51.2	91.1	196.0	5.21	756							0	1300
----	R-32/134a (30.0/70.0)	79.19	-41.7	-43.1	91.6	196.9	4.86	705	1000	wff					0	1200
----	R-32/600 (95.0/5.0)	52.30	-51.4	-60.5	81.4	178.5	5.98	867		flam					0	640
----	R-32/600a (90.0/10.0)	52.58	-53.1	-63.6	74.1	165.4	5.26	763		flam					0	610
----	R-125/134a/152a (35.0/40.0/25.0), GHG-X8	94.15	-34.9	-30.8	96.0	204.8	4.19	608	1000	wff					0	1800
----	R-125/134a/600/601a (50.0/47.0/2.7/0.3)	107.78	-39.6	-39.3	86.4	187.5	4.03	585							0	2400
----	R-125/152a/227ea (40.0/5.0/55.0), GHG-X7	136.53	-38.7	-37.7	87.0	188.6	3.56	516	1000	none					0	3200
----	R-125/290/134a/E170/227ea (55.4/0.6/34.0/2.5/7.5)	109.32	-41.4	-42.5	84.5	184.1	3.86	560							0	2700

Continued on next page

TABLE 1 (continued). Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
----	R-125/290/218 (86.0/5.0/9.0), Isceon 89	113.92	-53.4	-64.1	64.3	147.7	3.74	542		none					0	3800
----	R-152a/600a (70.0/30.0), C1	63.45	-27.7	-17.9	107.0	224.6	4.03	585		3.15					0	93
----	R-161/13I1 (80.0/20.0)	56.60	-37.7	-35.9	103.4	218.1	5.16	748							0.004	10
----	R-161/218/13I1 (65.4/18.2/16.4)	64.88	-37.8	-36.0	101.4	214.5	4.96	719							0.003	1600
----	R-170/290 (6.0/94.0), ER22/502	40.32	-51.5	-60.7	92.9	199.2	4.42	641		1.9					0	~20
----	R-218/134a/600 (32.7/62.8/4.5), CM1	115.36	-36.7	-34.1	89.8	193.6	3.85	558							0	3800
----	R-290/600a (50.0/50.0), propane/isobutane	50.15	-32.8	-27.0	118.2	244.8	4.24	615		2.0	49.8	21410			0	~20
----	R-600a/600 (50.0/50.0), isobutane/butane	58.12	-6.7	19.9	145.2	293.4	3.80	551		1.6					0	~20
----	R-601/602 (90.1/9.9), pentane/hexane	73.33	37.8	100.0	200.4	392.7	3.37	489		high					0	~20
----	R-601a/601 (37.0/63.0), isopentane/pentane	72.15	32.7	90.9	193.2	379.8	3.38	490		high					0	~20
----	R-717/E170 (60.0/40.0), "R723"	22.77	-39.3	-38.7	131.2	268.2	11.01	1597		6.0					0	<1
600	CH_3-CH_2-CH_2-CH_3, butane	58.12	-0.5	31.1	152.0	305.6	3.80	551	800	1.5	49.5	21281	A3	0.018	0	~20
600a	$CH(CH_3)_2$-CH_3, isobutane	58.12	-11.7	10.9	134.7	274.5	3.63	526	800	1.7	49.4	21238	A3	0.019	0	~20
601	CH_3-CH_2-CH_2-CH_2-CH_3, pentane	72.15	36.1	97.0	196.6	385.9	3.37	489	600	1.4				0.01	0	~20
601a	$(CH_3)_2CH$-CH_2-CH_3, isopentane	72.15	27.8	82.0	187.2	369.0	3.38	490	600	1.0	3531	1518^3	A3	0.01	0	~20
610	CH_3-CH_2-O-CH_2-CH_3, ethyl ether	74.12	34.6	94.3	214.0	417.2	6.00	870	400	1.9					0.000	
611	$HCOOCH_3$, methyl formate	60.05	31.7	89.1	214.0	417.2	5.99	869	100	4.5			B2	0.16	0.000	
630	$CH_3(NH_2)$, methylamine	31.06	-6.7	19.9	156.9	314.4	7.43	1078	5	4.9					0.000	
631	CH_3-$CH_2(NH_2)$, ethylamine	45.08	16.6	61.9	183.0	361.4	5.62	815	5	3.5					0.000	
702	H_2, normal hydrogen	2.02	-252.9	-423.2	-240.0	-400.0	1.32	191		4.0			A3		0.000	
704	He, helium	4.00	-268.9	-452.0	-268.0	-450.4	0.23	33		none			A1		0.000	
717	NH_3, ammonia	17.03	-33.3	-27.9	132.3	270.1	11.33	1643	25	15.0	22.5	9673	B2	0.01	0	<1
718	H_2O, water	18.02	100.0	212.0	373.9	705.0	22.06	3200		none			A1		0	<1
729	Air (78% N_2, 21% O_2, 1% Ar, +)	28.97	-194.2	-317.6	-140.4	-220.7	3.84	557		none					0	0
740	Ar, argon	39.95	-185.8	-302.4	-122.5	-188.5	4.86	705		none			A1		0.000	
744	CO_2, carbon dioxide	44.01	-78.4	-109.1	31.0	87.8	7.38	1070	5000	none			A1	>50	0	1
764	SO_2, sulfur dioxide	64.06	-10.0	14.0	157.5	315.5	7.88	1143	2	none			B1		0	300
784	Kr, krypton	83.80	-153.4	-244.1	-63.7	-82.7	5.53	802		none					0.000	
1130	CHCl=CHCl, dielene	96.94	47.8	118.0	243.3	469.9	5.48	795	200	5.6						
1150	CH_2=CH_2, ethylene	28.05	-103.8	-154.8	9.2	48.6	5.04	731	1000	2.7			A3	0.004	0.000	
1270	CH_3CH=CH_2, propylene	42.08	-47.7	-53.9	92.4	198.3	4.66	676	660	2.0			A3	0.001	0	~20

NBP = normal boiling point; T_c = critical temperature; P_c = critical pressure; OEL = occupational exposure limit in PPM by volume TWA, unless preceded by "C" for Ceiling, such as the ACGIH Threshold Limit Value (TLV-TWA), AIHA Workplace Environmental Exposure Level (WEEL), OSHA Permissible Exposure Limit (PEL), or a consistent limit (see text); LFL = lower flammability limit (% by volume in air), "flam" indicates flammable but the LFL is unknown and "wff" signifies that the worst case of fractionation may become flammable; HOC = heat of combustion; ODP = ozone depletion potential (semi-empirical); GWP = global warming potential (for 100-yr integration).

Suffixes to safety classifications indicate recommended changes that are not final yet ("d" for deletion and "r" for revision or addition) or classifications assigned as provisional ("p"); "d" alone indicates that a prior classification was deleted (withdrawn).

Data sources are identified in the Refrigerant Database; verify the data and associated limitations in those sources before use.

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TABLE 2. Physical, safety, and environmental data for refrigerants (sorted by normal boiling point).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP		T_c		P_c		OEL (PPMv)	LFL (%)	HOC		ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
			(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)			(MJ/kg)	(Btu/lb)				
704	He, helium	4.00	-268.9	-452.0	-268.0	-450.4	0.23	33		none			A1		0.000	
702	H_2, normal hydrogen	2.02	-252.9	-423.2	-240.0	-400.0	1.32	191		4.0			A3		0.000	
729	Air (78% N_2, 21% O_2, 1% Ar, +)	28.97	-194.2	-317.6	-140.4	-220.7	3.84	557		none					0	0
740	Ar, argon	39.95	-185.8	-302.4	-122.5	-188.5	4.86	705		none			A1		0.000	
50	CH_4, methane	16.04	-161.5	-258.7	-82.6	-116.7	4.60	667	1000	4.8			A3	12.0		23
784	Kr, krypton	83.80	-153.4	-244.1	-63.7	-82.7	5.53	802		none					0.000	
14	CF_4, carbon tetrafluoride	88.00	-128.0	-198.4	-45.6	-50.1	3.75	544		none			A1	50000	0	7390
1150	CH_2=CH_2, ethylene	28.05	-103.8	-154.8	9.2	48.6	5.04	731	1000	2.7			A3	0.004	0.000	
170	CH_3CH_3, ethane	30.07	-88.6	-127.5	32.2	90.0	4.87	706	1000	3.1			A3	0.21	0	~20
503	R-23/13 (40.1/59.9)	87.25	-87.8	-126.0	18.4	65.1	4.28	621	1000	none					0.599	15000
508A	R-23/116 (39.0/61.0), Klea 5R3	100.10	-87.6	-125.7	10.2	50.4	3.65	529	1000	none			A1		0	13000
508B	R-23/116 (46.0/54.0), Suva 95	95.39	-87.6	-125.7	11.2	52.2	3.77	547	1000	none			A1		0	13000
23	CHF_3, fluoroform	70.01	-82.0	-115.6	26.1	79.0	4.83	701	1000	none	-12.5	-5374	A1	270	0	14760
13	$CClF_3$	104.46	-81.5	-114.7	28.9	84.0	3.88	563	1000	none	-3.0	-1290	A1	640	1.000	14420
744	CO_2, carbon dioxide	44.01	-78.4	-109.1	31.0	87.8	7.38	1070	5000	none			A1	>50	0	1
41	CH_3F, methyl fluoride	34.03	-78.3	-108.9	44.1	111.4	5.90	856						2.4	0	92
116	CF_3CF_3, perfluoroethane	138.01	-78.1	-108.6	19.9	67.8	3.05	442	1000	none			A1	10000	0	12200
13B1	$CBrF_3$, halon 1301	148.91	-58.7	-73.7	67.1	152.8	3.97	576	1000	none			A1	65	16.000	7140
504	R-32/115 (48.2/51.8)	79.25	-57.7	-71.9	61.1	142.0	4.33	628		none					0.228	4100
----	R-125/290/218 (86.0/5.0/9.0), Isceon 89	113.92	-53.4	-64.1	64.3	147.7	3.74	542		none					0	3800
----	R-32/600a (90.0/10.0)	52.58	-53.1	-63.6	74.1	165.4	5.26	763		flam					0	610
32	CH_2F_2, methylene fluoride	52.02	-51.7	-61.1	78.1	172.6	5.78	838	1000	14.4	9.4	4041	A2	4.9	0	675
----	R-170/290 (6.0/94.0), ER22/502	40.32	-51.5	-60.7	92.9	199.2	4.42	641		1.9					0	~20
----	R-32/600 (95.0/5.0)	52.30	-51.4	-60.5	81.4	178.5	5.98	867		flam					0	640
410A	R-32/125 (50.0/50.0), Suva 9100 and AZ-20	72.58	-51.4	-60.5	70.5	158.9	4.81	698	1000	none	-4.4	-1892	A1		0	2100
410B	R-32/125 (45.0/55.0)	75.57	-51.3	-60.3	69.7	157.5	4.71	683		none			A1		0	2200
509A	R-22/218 (44.0/56.0), Arcton TP5R2	123.96	-49.7	-57.5	68.4	155.1	3.60	522	1000	none			A1		0.022	5700
403B	R-290/22/218 (5.0/56.0/39.0), 69-L	103.26	-49.2	-56.6	79.6	175.3	4.33	628	1000	none			A1		0.028	4500
----	R-32/125/143a (10.0/45.0/45.0), FX-40	90.69	-49.0	-56.2	69.9	157.8	3.96	574		none					0	3700
402A	R-125/290/22 (60.0/2.0/38.0), HP80	101.55	-48.9	-56.0	75.9	168.6	4.22	612	1000	none	-1.4	-602	A1		0.019	2800
428A	R-125/143a/290/600a (77.5/20.0/0.6/1.9), RS-52	107.53	-48.4	-55.1	68.9	156.0	3.72	540	1000	none			A1 r		0	3600
125	CHF_2CF_3	120.02	-48.1	-54.6	66.0	150.8	3.62	525	1000	none	-1.5	-645	A1	29	0	3500
1270	CH_3CH=CH_2, propylene	42.08	-47.7	-53.9	92.4	198.3	4.66	676	660	2.0			A3	0.001	0	~20

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TABLE 2 (continued). Physical, safety, and environmental data for refrigerants (sorted by normal boiling point).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
403A	R-290/22/218 (5.0/75.0/20.0), 69-S	91.99	-47.7	-53.9	87.0	188.6	4.70	682	1000	13.0			A1		0.038	3100
143a	CH_3CF_3	84.04	-47.2	-53.0	72.7	162.9	3.76	545	1000	7.0	10.4	4471	A2	52	0	4470
402B	R-125/290/22 (38.0/2.0/60.0), HP81	94.71	-47.0	-52.6	82.9	181.2	4.52	656	1000	none	-1.6	-688	A1		0.030	2400
507A	R-125/143a (50.0/50.0), AZ-50	98.86	-46.7	-52.1	70.5	158.9	3.70	537	1000	none	-5.5	-2365	A1		0	4000
----	R-23/32/134a (4.5/21.5/74.0), FX-220	83.14	-46.6	-51.9	90.8	195.4	4.78	693		none					0	1900
407B	R-32/125/134a (10.0/70.0/20.0), Klea 61	102.94	-46.5	-51.7	74.3	165.7	4.07	590	1000	none	-1.8	-774	A1		0	2800
422A	R-125/134a/600a (85.1/11.5/3.4), One Shot and Isceon MO79	113.60	-46.5	-51.7	71.8	161.2	3.75	544	1000	none			A1		0	3100
----	R-32/125/143a/134a (10.0/33.0/36.0/21.0), HX4	90.80	-46.5	-51.7	76.6	169.9	4.09	593		none					0	3100
----	R-32/125/143a/134a (2.0/41.0/50.0/7.0), FX-48B	95.82	-46.4	-51.5	72.7	162.9	3.80	551		none					0	3800
----	R-32/125/161 (15.0/34.0/51.0), ZJU ZH1	61.24	-46.2	-51.2	91.1	196.0	5.21	756							0	1300
404A	R-125/143a/134a (44.0/52.0/4.0), HP62 and FX-70	97.60	-46.2	-51.2	72.0	161.6	3.72	540	1000	none	-6.6	-2837	A1		0	3900
422C	R-125/134a/600a (82.0/15.0/3.0)	113.40	-45.9	-50.6	73.2	163.8	3.78	548	1000	none	2.6	1118	A1		0	3100
421B	R-125/134a (85.0/15.0)	116.93	-45.6	-50.1	72.5	162.5	3.75	544	1000	none	-0.5	-215	A1		0	3200
502	R-22/115 (48.8/51.2)	111.63	-45.2	-49.4	80.2	176.4	3.92	569	1000	none			A1		0.250	4700
407A	R-32/125/134a (20.0/40.0/40.0), Klea 60	90.11	-45.0	-49.0	81.8	179.2	4.47	648	1000	none	-3.6	-1548	A1		0	2100
408A	R-125/143a/22 (7.0/46.0/47.0), FX-10	87.01	-44.6	-48.3	83.1	181.6	4.29	622	1000	none	5.7	2451	A1		0.024	3200
407C	R-32/125/134a (23.0/25.0/52.0), Klea 66 and Suva 9000	86.20	-43.6	-46.5	85.8	186.4	4.60	667	1000	none	-4.9	-2107	A1		0	1800
422D	R-125/134a/600a (65.1/31.5/3.4), Isceon MO29	109.93	-43.2	-45.8	79.8	175.6	3.92	569	1000	none			A1		0	2700
427A	R-32/125/143a/134a (15.0/25.0/10.0/50.0), FX-100	90.44	-43.0	-45.4	85.1	185.2	4.37	634	1000	none			A1 r		0	2100
407E	R-32/125/134a (25.0/15.0/60.0)	83.78	-42.7	-44.9	88.3	190.9	4.69	680	1000	none	-4.8	-2064	A1		0	1600
----	R-32/125/134a/600 (10.0/42.0/45.0/3.0)	96.64	-42.6	-44.7	85.5	185.9	4.36	632							0	2200
419A	R-125/134a/E170 (77.0/19.0/4.0), FX-90	109.34	-42.6	-44.7	79.3	174.7	3.71	538		none	10.0	4299	A2		0	3000
290	$CH_3CH_2CH_3$, propane	44.10	-42.1	-43.8	96.7	206.1	4.25	616	2500	2.1	50.4	21668	A3	0.041	0	~20
----	R-1270/22/152a (3.0/95.5/1.5), G2018C	83.44	-41.8	-43.2	95.5	203.9	4.95	718		none					0.048	1700
----	R-32/134a (30.0/70.0)	79.19	-41.7	-43.1	91.6	196.9	4.86	705	1000	wff					0	1200

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TABLE 2 (continued). Physical, safety, and environmental data for refrigerants (sorted by normal boiling point).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
418A	R-290/22/152a (1.5/96.0/2.5), THR03b	84.60	-41.7	-43.1	96.2	205.2	4.98	722		8.9	1.7	731	A2		0.048	1700
411B	R-1270/22/152a (3.0/94.0/3.0), G2018B	83.07	-41.6	-42.9	96.0	204.8	4.95	718	1000	7.0	6.5	2794	A2		0.047	1700
----	R-125/290/134a/E170/227ea (55.4/0.6/34.0/2.5/7.5)	109.32	-41.4	-42.5	84.5	184.1	3.86	560							0	2700
422B	R-125/134a/600a (55.0/42.0/3.0)	108.52	-41.3	-42.3	83.4	182.1	3.97	576	1000	none			A1		0	2500
22	$CHClF_2$	86.47	-40.8	-41.4	96.1	205.0	4.99	724	1000	none	2.2	946	A1	12.0	0.050	1810
421A	R-125/134a (58.0/42.0)	111.75	-40.7	-41.3	82.9	181.2	3.93	570	1000	none			A1		0	2600
501	R-22/12 (75.0/25.0)	93.10	-40.7	-41.3	95.9	204.6	4.76	690		none			A1		0.288	4100
424A	R-125/134a/600a/600/601a (50.5/47.0/0.9/1.0/0.6), RS-44	108.41	-39.7	-39.5	86.3	187.3	4.02	583	1000	none			A1		0	2400
----	R-125/134a/600/601a (50.0/47.0/2.7/0.3)	107.78	-39.6	-39.3	86.4	187.5	4.03	585							0	2400
411A	R-1270/22/152a (1.5/87.5/11.0), G2018A	82.36	-39.5	-39.1	99.1	210.4	4.95	718	1000	5.5			A2		0.044	1600
----	R-717/E170 (60.0/40.0), "R723"	22.77	-39.3	-38.7	131.2	268.2	11.01	1597		6.0					0	<1
407D	R-32/125/134a (15.0/15.0/70.0)	90.96	-39.2	-38.6	91.2	196.2	4.45	645	1000	none	-4.3	-1849	A1		0	1600
417A	R-125/134a/600 (46.6/50.0/3.4), Isceon MO59 and NU-22	106.75	-39.1	-38.4	87.3	189.1	4.05	587	1000	none			A1		0	2300
115	$CClF_2CF_3$	154.47	-38.9	-38.0	80.0	176.0	3.12	453	1000	none	-2.1	-903	A1	1700	0.440	7370
----	R-125/152a/227ea (40.0/5.0/55.0), GHG-X7	136.53	-38.7	-37.7	87.0	188.6	3.56	516	1000	none					0	3200
425A	R-32/134a/227ea (18.5/69.5/12.0), THR03a	90.31	-38.1	-36.6	93.9	201.0	4.50	653	1000	none	5.1	2193	A1		0	1500
412A	R-22/218/142b (70.0/5.0/25.0), Arcton TP5R	92.17	-38.0	-36.4	107.2	225.0	4.90	711	1000	8.7			A2		0.053	2300
----	R-161/218/13I1 (65.4/18.2/16.4)	64.88	-37.8	-36.0	101.4	214.5	4.96	719							0.003	1600
----	R-161/13I1 (80.0/20.0)	56.60	-37.7	-35.9	103.4	218.1	5.16	748							0.004	10
161	CH_3CH_2F, ethyl fluoride	48.06	-37.6	-35.7	102.2	216.0	5.09	738		3.8				0.21	0	12
415A	R-22/152a (82.0/18.0)	81.91	-37.2	-35.0	102.0	215.6	4.96	719		5.6	2.7	1161	A2		0.041	1500
218	$CF_3CF_2CF_3$, perfluoropropane	188.02	-36.8	-34.2	71.9	161.4	2.64	383	1000	none			A1	2600	0	8830
----	R-218/134a/600 (32.7/62.8/4.5), CM1	115.36	-36.7	-34.1	89.8	193.6	3.85	558							0	3800
409B	R-22/124/142b (65.0/25.0/10.0), FX-57	96.67	-35.6	-32.1	106.9	224.4	4.73	686		none			A1		0.045	1600
----	R-125/134a/152a (35.0/40.0/25.0), GHG-X8	94.15	-34.9	-30.8	96.0	204.8	4.19	608	1000	wff					0	1800
401B	R-22/152a/124 (61.0/11.0/28.0), MP66	92.84	-34.5	-30.1	105.6	222.1	4.69	680	1000	none	-2.7	-1161	A1		0.036	1300
409A	R-22/124/142b (60.0/25.0/15.0), FX-56	97.43	-34.4	-29.9	109.3	228.7	4.70	682	1000	none	3.0	1290	A1		0.046	1600

Continued on next page

TABLE 2 (continued). Physical, safety, and environmental data for refrigerants (sorted by normal boiling point).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP		T_c		P_c		OEL (PPMv)	LFL (%)	HOC		ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
			(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)			(MJ/kg)	(Btu/lb)				
500	R-12/152a (73.8/26.2)	99.30	-33.6	-28.5	102.1	215.8	4.17	605	1000	none			A1		0.738	8100
413A	R-218/134a/600a (9.0/88.0/3.0), Isceon MO49	103.95	-33.4	-28.1	96.6	205.9	4.02	583		8.8			A2		0	2100
717	NH_3, ammonia	17.03	-33.3	-27.9	132.3	270.1	11.33	1643	25	15.0	22.5	9673	B2	0.01	0	<1
414A	R-22/124/600a/142b (51.0/28.5/4.0/16.5), GHG-X4	96.93	-33.0	-27.4	112.7	234.9	4.68	679	1000	none	3.6	1548	A1		0.043	1500
401A	R-22/152a/124 (53.0/13.0/34.0), MP39	94.44	-32.9	-27.2	107.3	225.1	4.61	669	1000	none			A1		0.033	1200
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5), Hot Shot	101.59	-32.9	-27.2	111.0	231.8	4.59	666		none			A1		0.039	1400
----	R-290/600a (50.0/50.0), propane/isobutane	50.15	-32.8	-27.0	118.2	244.8	4.24	615		2.0	49.8	21410			0	~20
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5), G2015	111.91	-32.6	-26.7	106.1	223.0	4.28	621	1000	none			d		0.026	5300
406A	R-22/600a/142b (55.0/4.0/41.0), Autofrost-X3	89.86	-32.5	-26.5	116.9	242.4	4.86	705	1000	8.2			A2		0.056	1900
C270	$-CH_2-CH_2-CH_2-$, cyclopropane	42.08	-31.5	-24.7	125.2	257.4	5.58	809		2.4	49.7	21367		0.44	0.000	
505	R-12/31 (78.0/22.0)	103.48	-30.0	-22.0	117.8	244.0	4.73	686		none					0.782	8400
12	CCl_2F_2	120.91	-29.8	-21.6	112.0	233.6	4.14	600	1000	none	-0.8	-344	A1	100	1.000	10890
426A	R-125/134a/600/601a (5.1/93.0/1.3/0.6)	101.56	-28.5	-19.3	100.2	212.4	4.11	596	990	none	4.7	2021	A1 r		0	1500
401C	R-22/152a/124 (33.0/15.0/52.0), MP52	101.03	-28.3	-18.9	111.7	233.1	4.37	634		none			A1		0.027	930
----	R-152a/600a (70.0/30.0), C1	63.45	-27.7	-17.9	107.0	224.6	4.03	585		3.15					0	93
415B	R-22/152a (25.0/75.0), THR01b	70.19	-26.9	-16.4	111.4	232.5	4.65	674	1000	wff			A2		0.013	550
134a	CH_2FCF_3	102.03	-26.1	-15.0	101.1	214.0	4.06	589	1000	none	4.2	1806	A1	14.0	0	1430
420A	R-134a/142b (88.0/12.0)	101.84	-24.9	-12.8	104.8	220.6	4.09	593	1000	none			A1		0.008	1500
E170	CH_3-O-CH_3, DME	46.07	-24.8	-12.6	127.2	261.0	5.34	775	1000	3.3	31.8	13672	A3	0.015	0	1
----	R-134a/142b (80.6/19.4), RB-276	101.73	-24.2	-11.6	107.2	225.0	4.10	595		none					0.014	1600
423A	R-134a/227ea (52.5/47.5), Isceon 39TC	125.96	-24.1	-11.4	99.5	211.1	3.59	521	1000	none			A1		0	2300
152a	CH_3CHF_2	66.05	-24.0	-11.2	113.3	235.9	4.52	656	1000	4.8	17.4	7481	A2	1.4	0	124
416A	R-134a/124/600 (59.0/39.5/1.5), FR-12	111.92	-24.0	-11.2	107.0	224.6	3.98	577		none	7.8	3353	A1		0.008	1100
400 >>	R-12/114 (60.0/40.0), R-400 (60/40)	136.94	-23.2	-9.8	125.6	258.1	4.01	582	1000	none			A1		1.000	11000
13I1	CF_3I, trifluoroiodomethane	195.91	-21.9	-7.4	123.3	253.9	3.95	573		none				~0.01	≤0.018	~1
400 >>	R-12/114 (50.0/50.0), R-400 (50/50)	141.63	-20.8	-5.4	129.1	264.4	3.94	571	1000	none			A1		1.000	10000
227ea	CF_3CHFCF_3	170.03	-16.4	2.5	102.8	217.0	3.00	435	1000	none	3.3	1419	A1	42	0	3220
506	R-31/114 (55.1/44.9)	93.69	-12.3	9.9	142.2	288.0	5.16	748		none					0.455	4400
124	$CHClFCF_3$	136.48	-12.0	10.4	122.3	252.1	3.62	525	1000	none	0.9	387	A1	5.8	0.020	609

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TABLE 2 (continued). Physical, safety, and environmental data for refrigerants (sorted by normal boiling point).

Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP		T_c		P_c		OEL (PPMv)	LFL (%)	HOC		ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
			(°C)	(°F)	(°C)	(°F)	(MPa)	(psia)			(MJ/kg)	(Btu/lb)				
600a	$CH(CH_3)_2$-CH_3, isobutane	58.12	-11.7	10.9	134.7	274.5	3.63	526	800	1.7	49.4	21238	A3	0.019	0	~20
764	SO_2, sulfur dioxide	64.06	-10.0	14.0	157.5	315.5	7.88	1143	2	none			B1		0	300
142b	CH_3CClF_2	100.50	-9.1	15.6	137.1	278.8	4.06	589	1000	6.0	9.8	4213	A2	17.9	0.070	2310
31	CH_2ClF	68.48	-9.1	15.6	151.8	305.2	5.13	744	0.1					1.3	0.010	
----	R-600a/600 (50.0/50.0), isobutane/butane	58.12	-6.7	19.9	145.2	293.4	3.80	551		1.6					0	~20
630	$CH_3(NH_2)$, methylamine	31.06	-6.7	19.9	156.9	314.4	7.43	1078	5	4.9					0.000	
C318	-CF_2-CF_2-CF_2-CF_2-	200.03	-6.0	21.2	115.2	239.4	2.78	403	1000	none			A1	3200	0	10250
12B1	$CBrClF_2$, halon 1211	165.36	-4.0	24.8	154.0	309.2	4.10	595		none				16	7.100	1890
236fa	$CF_3CH_2CF_3$	152.04	-1.4	29.5	124.9	256.8	3.20	464	1000	none			A1	240	0	9810
600	CH_3-CH_2-CH_2-CH_3, butane	58.12	-0.5	31.1	152.0	305.6	3.80	551	800	1.5	49.5	21281	A3	0.018	0	~20
114	$CClF_2CClF_2$	170.92	3.6	38.5	145.7	294.3	3.26	473	1000	none	-3.1	-1333	A1	300	1.000	10040
E134	CHF_2-O-CHF_2	118.03	5.5	41.9	147.1	296.8	4.23	614		none				26	0	6320
E245cb1	CH_3-O-CF_2-CF_3	150.05	5.9	42.6	133.7	272.7	2.89	419		flam				5.1	0	708
21	$CHCl_2F$	102.92	8.9	48.0	178.3	352.9	5.18	751	10	none			B1	1.7	0.010	151
160	CH_3CH_2Cl, ethyl chloride	64.51	13.1	55.6	187.3	369.1	5.27	764	100	3.6	20.6	8856		0.11	0.020	
245fa	$CHF_2CH_2CF_3$	134.05	15.1	59.2	154.0	309.2	3.65	529	300	none	6.1	2623	B1	7.6	0	1030
631	CH_3-$CH_2(NH_2)$, ethylamine	45.08	16.6	61.9	183.0	361.4	5.62	815	5	3.5					0.000	
11	CCl_3F	137.37	23.7	74.7	198.0	388.4	4.41	640	C1000	none	0.9	387	A1	45	1.000	4750
245ca	$CH_2FCF_2CHF_2$	134.05	25.1	77.2	174.4	345.9	3.93	570		7.1	8.4	3611		6.2	0	693
123	$CHCl_2CF_3$	152.93	27.8	82.0	183.7	362.7	3.66	531	50	none	2.1	903	B1	1.3	0.020	77
601a	$(CH_3)_2CH$-CH_2-CH_3, isopentane	72.15	27.8	82.0	187.2	369.0	3.38	490	600	1.0	3531	1518^3	A3	0.01	0	~20
E347mmy1	CF_3-$CF(OCH_3)$-CF_3	200.05	29.4	84.9	160.8	321.4	2.55	370						3.4	0	343
611	$HCOOCH_3$, methyl formate	60.05	31.7	89.1	214.0	417.2	5.99	869	100	4.5			B2	0.16	0.000	
141b	CH_3CCl_2F	116.95	32.0	89.6	204.4	399.9	4.21	611	500	5.8	8.6	3697		9.3	0.120	725
----	R-601a/601 (37.0/63.0), isopentane/pentane	72.15	32.7	90.9	193.2	379.8	3.38	490		high					0	~20
610	CH_3-CH_2-O-CH_2-CH_3, ethyl ether	74.12	34.6	94.3	214.0	417.2	6.00	870	400	1.9					0.000	
601	CH_3-CH_2-CH_2-CH_2-CH_3, pentane	72.15	36.1	97.0	196.6	385.9	3.37	489	600	1.4				0.01	0	~20
----	R-601/602 (90.1/9.9), pentane/hexane	73.33	37.8	100.0	200.4	392.7	3.37	489		high					0	~20
30	CH_2Cl_2, methylene chloride	84.93	40.2	104.4	237.0	458.6	6.08	882	50	13			B2	0.38		10
113	CCl_2FCClF_2	187.38	47.6	117.7	214.1	417.4	3.39	492	1000	none	0.1	43	A1	85	1.000	6130
1130	CHCl=CHCl, dielene	96.94	47.8	118.0	243.3	469.9	5.48	795	200	5.6						
718	H_2O, water	18.02	100.0	212.0	373.9	705.0	22.06	3200		none			A1		0	<1

NBP = normal boiling point; T_c = critical temperature; P_c = critical pressure; OEL = occupational exposure limit in PPM by volume TWA, unless preceded by "C" for Ceiling, such as the ACGIH Threshold Limit Value (TLV-TWA), AIHA Workplace Environmental Exposure Level (WEEL), OSHA Permissible Exposure Limit (PEL), or a consistent limit (see text); LFL = lower flammability limit (% by volume in air), "flam" indicates flammable but the LFL is unknown and "wff" signifies that the worst case of fractionation may become flammable; HOC = heat of combustion; ODP = ozone depletion potential (semi-empirical); GWP = global warming potential (for 100-yr integration).

Suffixes to safety classifications indicate recommended changes that are not final yet ("d" for deletion and "r" for revision or addition) or classifications assigned as provisional ("p"); "d" alone indicates that a prior classification was deleted (withdrawn).

Data sources are identified in the Refrigerant Database; verify the data and associated limitations in those sources before use.

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Continued from Page 52

consensus scientific assessments.[8,9,10] The GWPs shown for blends are calculated, mass-weighted averages.

GWP values can be calculated for any desired integration period, commonly referred to as the integration time horizon (ITH). Short ITH periods emphasize immediate effects, but overlook later impacts, while long ITH periods incorporate more of the later effects. The most common GWP values, including those cited herein, are for an ITH of 100 years.

These GWP values account only for the direct effect of refrigerants (or other substances) upon release as greenhouse gases. A variant dubbed an indirect GWP gauges the impacts of other atmospheric chemicals created or destroyed by released refrigerants. Examples include decomposition and catalyzed reaction products that act as greenhouse gases. Another example is ozone destruction by released refrigerants, hence removal of a potent greenhouse gas. Accordingly, indirect GWP values can be positive or negative numerically. A positive GWP indicates radiative forcing, or a global warming effect. A negative GWP signifies negative radiative forcing, or a global cooling effect. Summing direct and indirect GWPs yields net GWPs, which also could be positive or—for some ozone-depleting substances—negative. Indirect GWPs should not be confused with the "indirect effect" that accounts for action of energy-related emissions, as part of "total equivalent warming impact" (TEWI) and similar analyses.

Except for R-50 (methane), the GWP values shown in tables 1 and 2 are direct rather than net GWPs for consistency with international assessments, pending refinement of the indirect GWP data. The GWP values shown as "~20" for hydrocarbons reflect uncertainty in calculations, for which there is no scientific consensus at this time. The approximation shown is within the range of estimates. Further study, using three-dimensional (3D) models for a range of release scenarios, is needed to determine representative

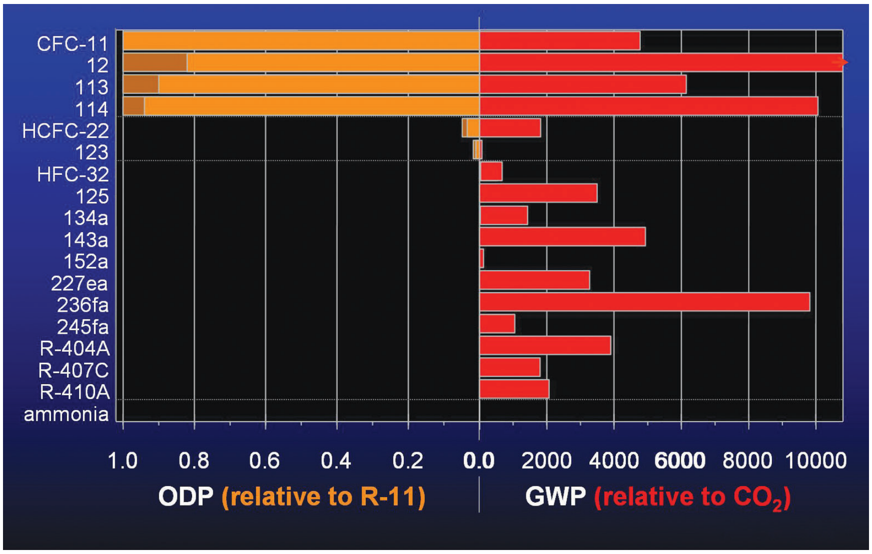

FIGURE 2. Ozone depletion potential (ODP) contrasted to global warming potential (GWP) for key refrigerants (brown and orange shading indicate semi-empirical and modeled ODPs, respectively). CFCs generally have high ODP and GWP. HCFCs generally have much lower ODP and GWP. HFCs offer near-zero ODP, but some have very high GWPs.

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GWPs for chemicals with very short atmospheric lifetimes, including the saturated and unsaturated hydrocarbons among others.

The atmospheric lifetime (τ_{atm}) impacts both the ODP and GWP, but those metrics also reflect separate chemical properties and other atmospheric data. The τ_{atm}, ODP, and GWP all should be as low as possible for selected refrigerants, and they should be considered along with performance, safety, and both chemical and thermal stability.[1]

Figure 2 depicts the ODPs and GWPs for common refrigerants. No inference should be drawn that a unit of ODP equals a unit of GWP; they are dissimilar metrics and there is no direct way to equate them. The intent of the figure is to enable quick identification of which refrigerants are high in both ODP and GWP, low in one or the other, or low in both.

References 8, 9, 10, and 11 provide further information on these indices.

ODP AND GWP DATA FOR REGULATORY AND REPORTING PURPOSES

The ODP and GWP data presented in tables 1 and 2 reflect the latest consensus determinations of potential impacts. However, the reduction requirements and allocations under the Montreal Protocol (and many national regulations pursuant to it) use older, adopted ODP values. The ODP values listed in the annexes to the Montreal Protocol, for example, have not been updated since 1987 for chlorofluorocarbons (CFCs) and 1992 for hydrochlorofluorocarbons (HCFCs).[9] A note in the Protocol indicates that the values "are estimates based on existing knowledge and will be reviewed and revised periodically," but that has not happened yet. Similarly, emission reporting pursuant to the Kyoto Protocol is based on data from an earlier assessment,[12] rather than more recent scientific findings.

Tables 3 and 4 contrast the regulatory (or reporting) ODP and GWP values to the latest data from international, scientific, consensus assessments. While the scientific data logically would precede the regulatory data, the order is shown as reversed because the scientific data were updated subsequently, while the regulatory values were not.

ENVIRONMENTAL DATA DIFFERENCES

The values for τ_{atm}, ODP, and GWP change as understanding of atmospheric science expands and the chemical kinetics involved become better understood. They also change when newer measurements are made. These factors have driven periodic reviews and consensus assessments by the scientific community.

The τ_{atm}, ODP, and GWP values shown in tables 1 and 2 reflect data from the latest international assessments.[8,9,10] The tables include additional data from selected scientific publications for refrigerants not addressed in these assessments. The data indicated for blends are calculated values based on the components and nominal formulations.

TABLE 3. Regulatory and consensus scientific ODP for BFC, CFC, and HCFC refrigerants.

Refrigerant	ODP		
	Regulatory[11]	Modeled[12]	Semi-empirical[8,9,10]
11	1.0	1.000	1.0
12	1.0	0.820	1.0
12B1	3.0	5.100	7.1
13	1.0	1.000	
13B1	10.0	12.000	16
21	0.04	0.010	
22	0.055	0.034	0.05
113	0.8	0.900	1.0
114	1.0	0.850	1.0
115	0.6	0.400	0.44
123	0.02	0.012	0.02
124	0.022	0.026	0.02
142b	0.065	0.043	0.07

TABLE 4. Regulatory and consensus scientific GWP for 100-year integration of HFC and PFC refrigerants.

Refrigerant	GWP	
	Regulatory[13]	Scientific[8,9,10]
14	6,500	7,390
23	11,700	14,760
32	650	675
116	9,200	12,200
125	2,800	3,500
134a	1,300	1,430
143a	3,800	4,470
152a	140	124
161		12*
218	7,000	8,830
227ea	2,900	3,220
236ea		1,370
236fa	6,300	9,810
245fa		1,030
C318	8,700	10,250
744	1	1

*R-161 GWP is from Reference 13

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