White Paper:

Revisiting Flammable Refrigerants

White Paper:
Revisiting Flammable Refrigerants

Introduction

Since the 1989 Montreal Protocol and its successor agreements, the world of refrigerants has been marked by change. In the search for more environmentally-preferable refrigerants, technology has moved from chlorofluorocarbons to a host of alternative substances. Many of these substances are serving as interim measures, until the phase-out of ozone-depleting and global-warming refrigerants meets the targets set by the U.S. Clean Air Act. The journey toward compliance has caused the HVAC equipment and appliance industries to revisit the potential use of substances that have good environmental and thermodynamic properties as refrigerants, but which are also, unfortunately, flammable.

This paper explores the ongoing efforts by those who are anticipating the more widespread use of flammable refrigerants in HVAC equipment and appliances, with the principle focus on the use of hydrocarbons as refrigerants. It is hoped that this paper will initiate a dialog among stakeholders, and increase the likelihood that the more widespread use of flammable refrigerants does not result in a decline in safety.

Anticipating the Increased Use of Flammable Refrigerants in the U.S.

It may be surprising to learn that the first commercial refrigerant was a flammable refrigerant. In 1850, an ethyl ether vapor compression system for ice making was developed. From that humble beginning of freezing a simple pail of water, a robust vapor compression refrigeration industry was developed.[1] Today, ice making alone is a nearly one billion-dollar industry in the U.S. Along the way, scientists, engineers and probably more than a few tinkerers[2] have experimented with numerous potential refrigerants.

Ammonia (R717) was an early choice for breweries and continues to be a popular refrigerant in industrial applications, including food processing, pharmaceutical and, even today, breweries.[3] Noxious but non-flammable sulphur dioxide (R764) became popular for small refrigerating systems, and was in widespread use in the U.S. into the 1940s.[4] Methyl chloride (R40) experienced brief popularity, but its flammability and potential toxicity ultimately made it unsuitable as a refrigerant. Propane (R290) was touted as

a replacement for ammonia refrigerant in the 1920s.[5] Isobutane (R600a) was first used as a refrigerant for small systems in the 1920s but, as with other flammable refrigerants (except ammonia), it quickly fell out of use when chloro-fluorocarbon (CFC) refrigerants were introduced for commercial use in 1931.[6]

CFCs had a 60 year run as the refrigerants of choice until they were identified in the late 1970s as ozone depleting substances. The phase-out of CFC refrigerants began a little over 10 years later.

A mature safety system had evolved over the decades, as various industries settled upon refrigerants which were generally non-toxic and non-flammable, which provided consistent performance, and which were relatively inexpensive.[7] Household refrigerators used the CFC R12. Larger commercial refrigerators used another CFC, R502, while air conditioners used R11 (CFC) and R22 (HCFC). Manufacturers ensured that their equipment was appropriately designed and constructed using well-established criteria and standards, chose the correct refrigerant for the application, and then sold the equipment for installation and use in accordance with equally well-established standards and codes.

However, beginning with the phase-out of CFCs, the choice of refrigerant has increasingly become a complicating factor in equipment design, construction, installation and use. In the U.S., the more widespread use of pure hydrocarbon refrigerants, flammable hydrocarbon refrigerant blends, or halo-hydrocarbon blends with flammable hydrocarbons has further complicated matters.

UL is involved in HVAC and appliance standards development worldwide. It has technical staff participating in leadership and expert roles on national and international committees.

Mr. Thomas Blewitt, PE is the Technical Advisor for the TC61 US TAG for household and similar electrical appliances. He is UL's Principal representative to the US National Electrical Code Panel 17 that covers appliances. He also is a member of IEC TC61 Maintenance Team for temperature limits for insulation and resistance to heat and fire.

Mr. Randall Haseman, PE is the Technical Advisor for the SC61C US TAG for household appliances for refrigeration.

Mr. Brian Rodgers is the Convener of the IEC61C Maintenance Team (MT 1) for motor compressors. He is also a member of ASHRAE Standing Standard Project Committee 15 that maintains ASHRAE 15, the Safety Standard for Refrigeration Systems.

Mr. Barry Karnes, PE is UL's Alternate representative to the US National Electrical Code Panel 11 that covers air conditioners.

Mr. Scott MacLeod is a member of ASHRAE Standing Standard Project Committee 34 that maintains ASHRAE 34, the Standard for Designation and Safety Classification of Refrigerants.

Mr. Robert Wozniak, PE is a member of the Technical Committee of the National Fuel Gas Code, NFPA 54/ANSI Z223.1 and the Accredited Standards Committee Z21/83 on Performance and Installation of Gas-Burning Appliances and Related Accessories.

The Challenges Posed by Flammable Refrigerants

Vapor compression refrigeration in appliances is a closed system that circulates a volume of refrigerant and lubricant under pressure. This system typically operates under variable environmental conditions, and often must be capable of adjustment to meet the end use application. From a traditional electrical equipment safety perspective (electric shock, fire and casualty hazards), appliance designers have sought to reliably contain the refrigerant. To accomplish this, they used tubing, vessels and other components with sufficient mechanical strength to handle the developed pressures under expected normal and abnormal operating conditions.

Because the typical HVAC and appliance refrigerant gas (excluding ammonia) was non-toxic in the volumes used and non-flammable, the potential for gas leakage or explosion was not considered to be a safety concern, except under fire conditions. In such cases, the refrigerant system was required to have a means for the controlled venting of refrigerant, before pressure build-up could cause an explosion hazard.

Aside from locations where large quantities of refrigerant might be found (e.g., large commercial / industrial facilities), there has been limited concern for the safety of refrigerant-containing appliances in all manner of occupancies.[8] This would include locations where a number of appliances are stored or used (e.g., warehouses, retail locations)'[9] or how the appliances are transported, serviced or disposed of. However, if a flammable refrigerant were to be used in these appliances, it cannot be assumed that safety is adequately assured.

Hydrocarbon refrigerants (HCs) present a risk of fire and explosion hazard if there is a refrigerant leak. The vapor within the closed refrigeration system is not flammable until oxygen is present at the location of the leak, or in the location(s) where the hydrocarbon gas travels after leaking from the system. If the gas and air mixture is within the upper and lower flammability limits (UFL and LFL respectively)[10] for the particular refrigerant, the mixture is flammable in the presence of an ignition source. Hot surfaces[11] and electrical arcs, such as those present at the contacts of electrical switching contacts (switches, temperature and humidity controls, etc.), are the principle potential ignition sources in HVAC and appliances.

The same concerns hold true for other flammable refrigerants, as well as for refrigerant blends containing flammable refrigerant components. The presence of a flammable gas and air mixture from a leaking refrigerant blend additionally depends upon the properties of the blended gasses, and whether they separate into individual component gasses (fractionate).[12]

Small quantities of flammable refrigerant discharged into an open area may disperse at a rate that ensures that the LFL is not achieved or is achieved for a very brief time period. However, for larger quantities of refrigerant, or in situations in which the leaked refrigerant is contained in a smaller volume space or in which the leaked refrigerant accumulates (e.g., heavier than air refrigerant), it is more likely that the LFL can be reached and sustained.

Supermarket refrigerated cases and building air conditioning systems typically have larger quantities of refrigerant. Because these systems are often assembled on-site, they are more often subject to leaks.[13] Indeed, leakage is assumed for field-assembled equipment. The Clean Air Act now requires refrigerant leaks to be repaired for systems containing over 50 pounds of refrigerant if the leakage is determined to be 35% or greater in a 12 month period for commercial refrigeration, and 15% for comfort cooling and other appliances.[14] Therefore, the use of a flammable refrigerant in such equipment would require improved containment features over those found in non-flammable refrigerant systems. It would also require mechanical ventilation and other mitigation procedures at the installation site to avoid the presence of a flammable gas and air mixture at potential ignition sources, either on the equipment or in the installation environment.

Smaller equipment such as household refrigerators can also leak. Improved containment over non-flammable refrigerant systems is also appropriate, but mechanical ventilation or other means to disperse the refrigerant may not be practical for such appliances. Equipment designers must then look to avoid placing potential ignition sources in locations (e.g., a storage compartment, hollow in a wall, etc.) that could yield a flammable gas and air mixture in the event of a leak. The designer, of course, can often do little about other possible ignition sources in the installed environment.

All equipment is serviced and, ultimately, disposed of. These activities also offer opportunity for leakage. The equipment design must minimize the risk of fire or explosion during servicing, and service personnel must have sufficient knowledge to safely do their job. Upon disposal, the refrigerant should be recovered, though relatively small propane or isobutane refrigerant charges could conceivably be released to the air in a controlled manner.[15] Parties involved in the disposal of HVAC equipment and appliances should also have sufficient knowledge to perform their job safely, and should be able to identify equipment with a flammable refrigerant charge. For their part, equipment designers must anticipate the need to evacuate the refrigerant from equipment upon disposal and to facilitate identification of locations on the equipment intended for this purpose.

Most appliances, room HVAC equipment and split systems are factory charged, and subsequently transported with the charge present, and may be transported multiple additional times throughout the product's useful life. Vehicle transport can jar or vibrate the parts containing refrigerant, increasing the risk of leakage. Designers must account for these concerns in the equipment design, as well as the equipment packaging.

If an individual appliance has a small refrigerant charge, but there are many such appliances at a given location (e.g., a warehouse or tractor-trailer), the aggregate amount of flammable refrigerant may be relatively large. Though it is unlikely under normal circumstance that all of the appliances might simultaneously leak, a warehouse fire or transportation accident could lead to the leakage of large volumes of flammable refrigerant.

While the risk conditions noted above can often be anticipated in the design process, it is much more difficult to anticipate the abuse of equipment in use, and to design appropriate safety features to mitigate that risk. For example, vending machines are checked for the risk of overturning in cases where the equipment is rocked back and forth to dislodge a vended product. But what type of rocking test would adequately assess the risk involving a vending machine with flammable refrigerant? It can also be a challenge to ensure that an installation site doesn't pose an unacceptable risk. For example, how can local building authorities anticipate and address the potential risk posed by having multiple appliances containing flammable refrigerant in a single-family residence or in a children's play area or classroom?

These and similar such concerns involve a number of potential stakeholders who individually and collectively have a key role in ensuring the safety of HVAC equipment and appliances containing flammable refrigerants. As the publisher of equipment safety standards for HVAC equipment and appliances, Underwriters Laboratories Inc. (UL) has identified stakeholder interests that it believes to be relevant to the total safety system, in which safety standards are an essential element. These areas of interest are depicted in Figure 1.

Stakeholder identification is just a first step in undertaking a unified and coordinated review of the potential impact of the wider use of flammable refrigerants in HVAC equipment and appliances. Gaps in codes and standards for installation and use, including the applicable equipment safety standards, need to be identified and addressed. Education and training for installers, service personnel, operators of storage and retail facilities, fire fighters and inspection professionals will also be important.

The remainder of this paper will explore the most important factors that are expected to result in flammable refrigerant HVAC equipment and appliances, the current state of safety standards, and some near-term activities to address gaps.

U.S. Federal Regulatory Environment

CFC and HCFC Phase Out

The phase-out of CFCs began in 1991, a change that drove equipment manufacturers to expand the use of hydrochlorofluorocarbons (HCFCs) where they could, and to use hydrofluorocarbons (HFCs) in applications as diverse as household refrigerators and automotive air conditioning. Manufacturers began to use hydrocarbons (HCs) as well around this time.

As noted earlier, isobutane (R600a) had long ago been used as a refrigerant. With the phase out of CFCs, isobutane was reintroduced as a refrigerant for household refrigerators and freezers in Japan[16] and Europe, and found widespread use and acceptance.[17] Though ANSI/UL 250, the U.S. safety standard for household refrigerators, anticipated as early as the 1990s the possible use of flammable refrigerants in the U.S., they were not introduced in U.S. appliances until 2008.

An interim solution, HCFCs are also ozone-depleting substances and were subject to a longer-term phase out than CFCs. In September 2007, the signatories of the Montreal Protocol agreed to a more aggressive phase-out of HCFCs. Table 1 describes the phase-out timetable under the U.S. Clean Air Act. The imminent HCFC phase-out, coupled with recent efforts to improve energy efficiency of certain appliances as well as experience outside of the U.S. market, has substantially renewed interest in the U.S. toward flammable refrigerants, isobutane and propane in particular, along with blends using these substances.

Finally, in September 2008, ice-cream maker *Ben and Jerry's* introduced a commercial ice cream case into the U.S. market, representing the first U.S.

Figure 1 — Stakeholder Interest Areas

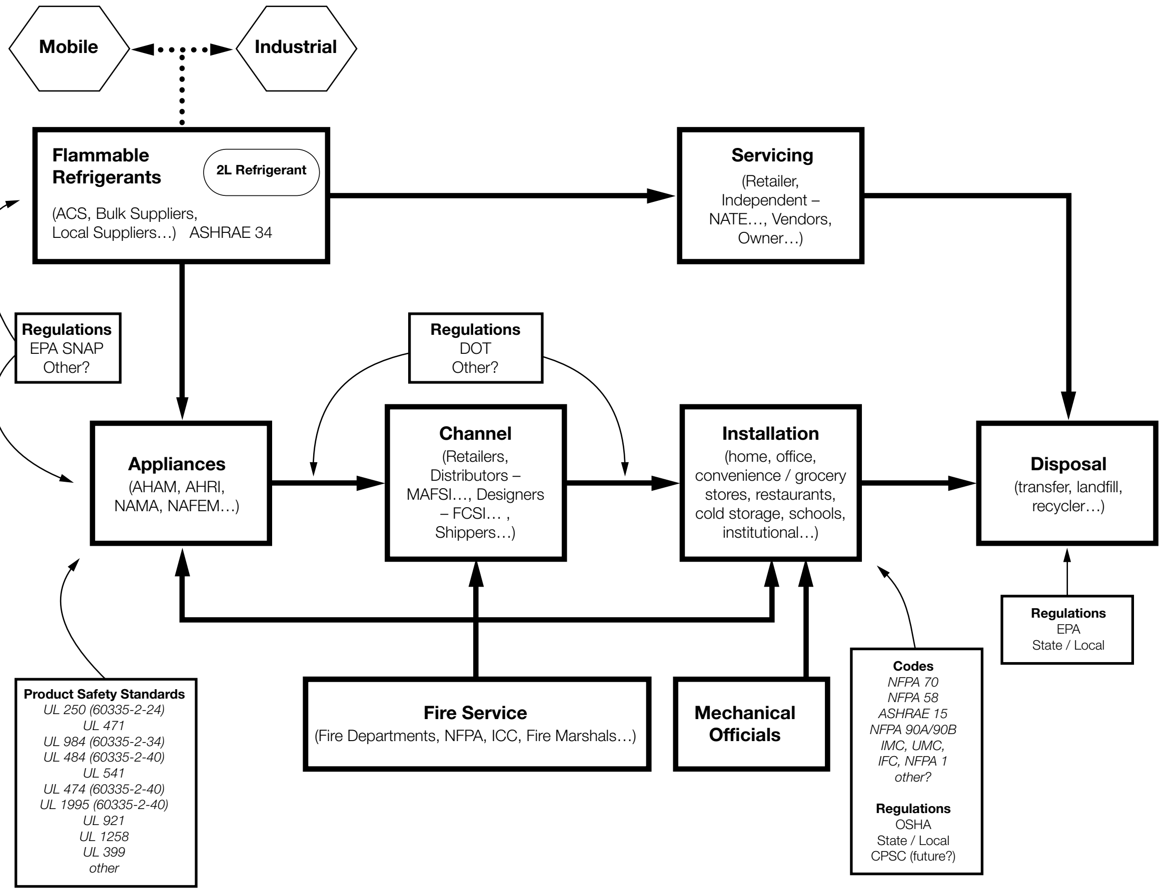


Table 1 — Phase-out of HCFC's in US

US Scheduled Phase-out of HCFCs[18]		
Year	**% Reduction Consumption and Production#**	**Implementation of HCFC Phase-out Per Clean Air Act**
2010	75.0%	No production or importing of HCFC 142b and HCFC 22, except for use in equipment manufactured before 2010.
2015	90.0%	No production or importing of any HCFCs, except for use in equipment manufactured before 2020.
2020	99.5%	No production or importing of HCFC 142b and HCFC 22.
2030	100.0%	No production or importing of any HCFCs.

Using prior cap as baseline

use of a hydrocarbon refrigerant in a conventional commercial food serving and display application in over 50 years. The self-contained freezer case, made by Unilever,[19] was of a cold wall construction that used propane refrigerant.

Notwithstanding the movement toward HC refrigerants, HFCs currently remain the predominant choice to replace HCFCs. However, under the European Climate Change Programme (ECCP), a 2006 regulation for all F-gases (fluorinated gases) "makes it mandatory to contain via the control of systems via leakage detection systems that are regularly checked, to recover and recycle, to monitor and archive, to label, to train and certificate servicing personnel, to restrict marketing of F-gases for emissive uses, etc."[20]

Automobile manufacturers selling in the European market must also contend with the EU's directive relating to emissions from air-conditioning systems in motor vehicles (2006/40/EC), also known as the MAC Directive.[21] The MAC Directive will eliminate the major mobile air conditioning market for the popular HFC 134a, and has led manufacturers to explore a "lower flammability" refrigerant (HFO 1234 yf), as well as CO_2 and other options.

Somewhat related is the move toward "natural refrigerants." Looking to avoid altogether the transition to HFCs, which have high global warming potential (GWP), a consortia of equipment manufacturers and retailers have included HC refrigerants in their plans to meet energy regulations.

Table 2 — Comparison of Refrigerant GWP and ODP[22]

Refrigerant	Global Warming Potential (GWP)	Ozone Depleting Potential (ODP)
R 134A	1430	0
R290	3.3	0
R600	3	0
R600A	3	0
R1234 YF	4	0
R717	0	0

See Table 2 for some examples of the GWP for flammable refrigerants.

Over time, these various initiatives can be expected to contribute to a reduction in use of HFCs as an alternative to HCFCs, and lead to increased use of HCs.

Energy Efficiency

In addition to being affected by the phase-out of ozone-depleting refrigerants, HVAC equipment and appliances employing refrigerants are subject to a variety of regulations in the U.S. Such equipment must meet the appropriate electrical, mechanical, fire and public health requirements of state and local jurisdictions. Increasingly, such equipment must also meet state and federal energy efficiency goals (e.g., Energy Policy and Conservation Act[23]) that can be expected to drive the search for new and more efficient technologies, including the types of refrigerant used.

As recently of September 2010, the U.S. Department of Energy has proposed standards for residential refrigerators and freezers that are expected to lower energy use by as much as twenty-five percent.[24] The energy efficiency appeal of flammable refrigerants in refrigeration equipment and air conditioners may also lead to its use in other appliances. For example, a storage tank water heater could potentially be more efficient if a reverse-cycle (heat pump) system with a relatively small flammable refrigerant charge were used instead of a large resistance-heating element to maintain the temperature of the water. A similar technology could be used in a clothes dryer to dehumidify clothing, instead of drying solely by resistance heat or heat of combustion.

U.S. EPA SNAP

It is only logical that the transition toward more environmentally preferable refrigerants and energy savings has renewed interest in HC refrigerants in appliances. And arguably the most significant regulation affecting the use of flammable refrigerants in appliances is the Clean Air Act, administered by the U.S. Environmental Protection Agency (EPA), under its Significant New Alternatives Policy (SNAP).

According to the EPA, the purpose of its SNAP program is "to allow a

Vapor Compression Refrigeration and Air Conditioning End-Uses#

- Chillers typically cool water, which is then circulated to provide comfort cooling throughout a building or other location. Chillers can be classified by compressor type, including centrifugal, reciprocating, scroll, screw and rotary.
- Cold storage warehouses are used to store meat, produce, dairy products and other perishable goods. The majority of cold storage warehouses in the United States use ammonia as the refrigerant in a vapor compression cycle, although some rely on other refrigerants.
- Retail Food Refrigeration includes all cold storage cases designed to chill food for commercial sale. In addition to grocery cases, the end-use includes convenience store reach-in cases and restaurant walk-in refrigerators.
- Vending machines are self-contained units that dispense goods that must be kept cold or frozen.
- Water coolers are self-contained units providing chilled water for drinking. They may or may not feature detachable containers of water.
- Commercial ice machines are used in commercial establishments to produce ice for consumer use, e.g., in hotels, restaurants, and convenience stores.
- Household refrigerators and freezers are intended primarily for residential use, although they may be used outside the home. Household freezers only offer storage space at freezing temperatures, unlike household refrigerators. Products with both a refrigerator and freezer in a single unit are most common.
- Residential dehumidifiers are primarily used to remove water vapor from ambient air for comfort or material preservation purposes. While air conditioning systems often combine cooling and de-humidification, this application serves only the latter purpose.
- Residential and light commercial air conditioning and heat pumps includes central air conditioners (unitary equipment), window air conditioners, and other products. Blended HFC 410A has supplanted HCFC-22, a class II substance, as the most common refrigerant for this application.

#Table content extracted from EPA web content: http://www.epa.gov/ozone/snap/refrigerants/index.html

safe, smooth transition away from ozone-depleting compounds by identifying substitutes that offer lower overall risks to human health and the environment."[25] SNAP specifically identifies the use of refrigerants used in HVAC equipment and appliances as a focus of the policy, including chillers, cold storage warehouses, retail food refrigeration, vending machines, water coolers, commercial ice machines, household refrigerators and freezers, residential dehumidifiers and residential and light commercial air conditioning and heat pumps.

EPA's SNAP has authorized HCs (propane, butane and blends) as alternative refrigerants for industrial process refrigeration only. For all other applications, such refrigerants are not yet authorized as substitutes for refrigerants employed today.[26] However, there are exemptions to this restriction for small volume producers of substitutes, and in cases where end-use equipment is being test-marketed or deployed for research and development.[27]

In response to the increased interest in HC refrigerants, the EPA issued a Notice of Proposed Rulemaking (NPRM) in the U.S. *Federal Register* in May 2010. The NPRM recommends that "isobutane, propane, HCR–188C[28] and HCR–188C1 be acceptable, subject to use conditions, as substitutes for R–12 and R–22 in household refrigerators, freezers, and combination refrigerator and freezers and commercial refrigeration (retail food refrigerators and freezers—stand-alone units only").[29]

The NRPM also references product safety standards ANSI/UL 250 and ANSI/UL 471,

Disposal#

"Refrigeration and air-conditioning equipment that is typically dismantled on-site before disposal (e.g., retail food refrigeration, central residential air conditioning, chillers, and industrial process refrigeration) has to have the refrigerant recovered in accordance with EPA's requirements for servicing prior to their disposal. However, equipment that typically enters the waste stream with the charge intact (e.g., motor vehicle air conditioners, household refrigerators and freezers, and room air conditioners) are subject to special safe disposal requirements.

Under these requirements, the final person in the disposal chain (e.g., a scrap metal recycler or landfill owner) is responsible for ensuring that refrigerant is recovered from equipment before the final disposal of the equipment. If the final person in the disposal chain accepts appliances that no longer hold a refrigerant charge, that person is responsible for maintaining a signed statement from whom the appliance/s is being accepted. The signed statement must include the name and address of the person who recovered the refrigerant, and the date that the refrigerant was recovered, or a copy of a contract stating that the refrigerant will be removed prior to delivery."

#Content taken from EPA web site fact sheet: http://www.epa.gov/ozone/title6/608/608fact.html

indicating that equipment must meet the requirements of these standards to use one of the specified flammable refrigerants. The proposal also specifies that hoses and piping be color coded to identify the presence of flammable refrigerants in these appliances, and that unique fittings and service ports be provided to avoid accidental connection of inappropriate service equipment while facilitating recovery of refrigerant during service or disposal of the appliances.

Finally, the NPRM proposes that technicians working with equipment using flammable refrigerants be "specifically trained in handling flammable refrigerants service or dispose of refrigerators and freezers containing these refrigerants" to minimize the risk of fire.[30]

U.S. DOT

The U.S. Department of Transportation (DOT) publishes requirements for "packaging"[31] which apply to cylinders that may contain liquefied petroleum gas (LP-Gas). These requirements describe the types and sizes, construction, testing, inspection and markings of these cylinders, often simply referred to as "DOT cylinders." The requirements are well established for the transport of LP-Gas cylinders for combustion equipment and, together with regulations from the U.S. Occupational Safety and Health Administration (OSHA) associated with workplace handling of LP-Gas, thoroughly cover transportation of flammable gas in cylinders.

HVAC equipment and appliances containing flammable refrigerant could be identified as hazardous material cargo due to the presence of flammable gas. 49 CFR Part 177.834 (Packages secured in a motor vehicle) states:

> "Any package containing any hazardous material, not permanently attached to a motor vehicle, must be secured against shifting, including relative motion between packages, within the vehicle on which it is being transported, under conditions normally incident to transportation. Packages having valves or other fittings must be loaded in a manner to minimize the likelihood of damage during transportation."

Fortunately, the Federal Motor Carrier Safety Administration (an agency of the DOT) reports that "crashes involving large trucks-those with a gross vehicle weight rating of more than 10,000 pounds-carrying hazardous materials (hazmat) are relatively rare."[32]

U.S. OSHA

OSHA publishes regulations intended to protect the safety or health of those employees working in federally-regulated workplaces. National consensus standards are frequently referenced for this purpose and, in accordance with 29 CFR 1910.7(c), ANSI/UL standards for refrigerators and freezers, heating and air conditioning equipment, associated components and appliances fulfill the requirements. Such products, once listed by a nationally recognized testing laboratory (NRTL) using the accepted standards, may be used in the workplace.

OSHA regulations addressing storage and handling of LP-Gases are documented in 29 CFR 1910.110. While these regulations do not anticipate LP-Gas refrigerants, they do cite compliance with DOT container requirements[33] and location of containers in buildings.

Of particular relevance for the servicing of HVAC equipment and appliances in-place is 1910.110 c) 5, which states that "when operational requirements make portable use of containers necessary and their location outside of buildings or structure is impracticable, containers and equipment are permitted to be used inside of buildings or structures...." There are also caveats to this allowance and they are comparable to the requirements of NFPA 58 (Liquefied Petroleum Gas Code).

Installation Requirements and Equipment Safety Standards Environment

Fulfilling government regulations is only part of the compliance landscape for HVAC equipment and appliance manufacturers. Equipment must also comply with safety standards in order to be installed in a workplace or (depending upon the local jurisdiction) in other occupancies. Retailers, insurers and other parties may also require evidence of compliance with safety standards.

In the U.S., UL is the principal standards developer addressing electrical appliance and HVAC equipment safety. UL standards are part of an overall safety system of coordinated standards and codes to facilitate safe installation and use of equipment. They complement the electrical installation requirements of the National Fire Protection Association (NFPA), notably the National Electrical Code® (NFPA 70), and mechanical refrigeration requirements of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Standards 15 and 34.

Installation codes for HVAC and refrigeration equipment are published by International Codes Council (ICC International Mechanical Code, Chapter 11) and the International Association of Plumbing and Mechanical Officials (IAPMO Uniform Mechanical Code, Chapter 11). Both mechanical codes reference ASHRAE 15 and 34, with additional requirements.

In addition, requirements for the storage, use and handling of refrigerants are published by ICC (International Fire Code, Section 606) and the NFPA (NFPA 1, Chapter 53). These model fire codes impose safety requirements for occupancy based on the volume and safety group of the refrigerant. As with any of the model codes (electrical, mechanical, fire, etc.), local jurisdictions can implement variations and additional requirements for equipment, and may elect to do so for HVAC equipment and appliances employing flammable refrigerants, especially in densely populated areas.

The remainder of this paper summarizes the current status of many of the standards and codes relevant to flammable refrigerants, as follows:

- ANSI/ASHRAE Standard 34, Designation and Safety Classification of Refrigerants
- ANSI/UL 2182, Standard for Safety for Refrigerants
- ANSI/NFPA 58, Liquefied Petroleum Gas Code
- ANSI/ASHRAE Standard 15, Safety Standard for Refrigeration Systems
- ANSI/UL 207, Standard for Safety for Refrigerant-Containing Components and Accessories, Nonelectrical
- ANSI/UL 250, Standard for Safety for Household Refrigerators and Freezers
- ANSI/UL 471, Standard for Safety for Commercial Refrigerators and Freezers
- ANSI/UL 1995, Standard for Safety for Heating and Cooling Equipment
- ANSI/UL 484, Standard for Safety for Heating and Cooling Equipment
- ANSI/UL 474, Standard for Safety for Heating and Cooling Equipment
- UL 984, Standard for Safety for Refrigerant Motor Compressors
- ANSI/UL 60335-2-34, Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Motor-Compressors

The first three standards listed above are applicable to refrigerants, while the remainder are applicable to equipment and components. These and other standards also address ammonia, but that refrigerant is outside the scope of this paper.

Refrigerant Standards

ANSI/ASHRAE Standard 34, Designation and Safety Classification of Refrigerants

According to the standard, "ASHRAE Standard 34-2010 is intended to establish a simple means of referring to common refrigerants instead of using the chemical name, formula, or trade name. It establishes a uniform system for assigning reference numbers, safety classifications, and refrigerant concentration limits to refrigerants."[34] Most notable in the context of this paper is the ASHRAE 34 designation of HC refrigerants as A3 – high flammability, lower toxicity (see Table 3 for illustration of classification scheme).

A significant inclusion in the latest edition (Clause 6.1.3) is the optional 2L subclass added to the existing Class 2 flammability classification, signifying Class 2 refrigerants with a burning velocity less than or equal to 10 cm/s. Class 2L refrigerants include R32 and the newer HFO 1234 yf, which is being promoted for use in motor vehicles.

The potential market for 2L refrigerants in HVAC equipment and appliances is currently unknown and further equipment standards development is needed. Otherwise, a 2L refrigerant will simply be handled as a Class 2 (e.g., A2) refrigerant. Proprietary studies done to date have suggested that equipment and installation requirements that result in ignition sources being kept a distance above the floor (or not directly below wall mounted equipment) may facilitate introduction of such refrigerants.

Table 3 — Refrigerant Safety Groups

Refrigerant Safety Groups (ASHRAE 34 and ISO 817)		
	Lower Toxicity	Higher Toxicity#
No Flame Propagation	A1	B1 (includes R123)
2L	A2L (includes HFO 1234 YF)	B2L (includes ammonia)
Lower Flammability	A2	B2
Higher Flammability	A3 (includes hydrocarbons)	B3

Except for ammonia, refrigerants classified as Bx are not permitted in appliances.

ANSI/UL 2182, Standard for Safety for Refrigerants

This standard contains test procedures and methods to evaluate refrigerants and to authoritatively mark containers according to the extent of the refrigerant's flammability. The refrigerants covered in this standard are those used as components of air-conditioning and refrigeration equipment.[35] The standard was created in 1994 as a supplement to ASHRAE 34, and is for intended for use in conjunction with end product appliance standards. It enables the characterization of flammable refrigerants (blends in particular) with respect to fractionalization, flammability and auto-ignition. The requirements do not yet address the additional characterization needed for Type 2L refrigerants.

ANSI/NFPA 58, Liquefied Petroleum Gas Code

This code applies to the storage, handling, transportation and use of LP-Gas. It indicates that "refrigeration cycle equipment and LP-Gas used as a refrigerant in a closed cycle" is outside the scope of the code.[36] However, the 2008 Handbook for NFPA 58 states that the scope exclusion for refrigerant cycle equipment does not include the storage of LP-Gas, which would include gas in cylinders such as may be used by service personnel. For small HVAC and appliances, the cylinders are likely to be DOT cylinders.[37]

It would seem likely that the well-established practice for handling LP-Gas cylinders used in barbeques and similar applications would be appropriate for the filling, transport and storage of cylinders used for servicing household and smaller commercial HVAC equipment and appliances. However, NFPA 58 does not specifically anticipate refrigerant recovery/recharge in clause 6.2.2, where it lists applications where containers may be brought into buildings, nor in clause 6.19 where specific uses are cited. Temporary use for training and demonstration purposes (clause 6.19.9) is limited to 20 lbs. of propane in a cylinder, although the cylinder may have a larger capacity.

Equipment Standards

ANSI/ASHRAE Standard 15, Safety Standard for Refrigeration Systems

ASHRAE Standard 15-2010 is directed toward the safety of persons and property on or near the premises where refrigeration facilities are located.[38] While the standard covers installations involving the full range of potential refrigerant charges in equipment, it defers to the listing of equipment complying with appliance safety standards for charges of less than 3 kg, with some restrictions. For example, institutional occupancies are permitted only up to 50% of the refrigerant concentration limit (RCL)[39] permitted for other occupancies.

Group A3 and B3 refrigerants are not permitted except where approved by the authority having jurisdiction. One exception to the restriction is "listed portable-unit systems containing no more than 0.331 lb. (150 g) of Group A3 refrigerant, provided that the equipment is installed in accordance with the listing and the manufacturer's installation instructions."[40] This requirement effectively means that self-contained, permanently installed (not "portable") commercial and large household refrigerators and freezers may employ A3 refrigerants only with permission. Typical household refrigerators, dehumidifiers and other cord and plug connected appliances meeting the charge restriction would be permitted.

ASHRAE 15 includes a general prohibition on the use of Group A2, A3, B1, B2 and B3 refrigerants for comfort cooling (Clause 7.5.2). There is an exception for sealed absorption (ammonia) systems and unit systems (e.g., window air conditioner), provided that the refrigerant quantity is no more than 3 kg or 10 kg for residential and commercial occupancies, respectively. [Note that ANSI/UL 484 is expected to restrict room air conditioners employing flammable refrigerants to A2 and A3 refrigerants.]

The ASHRAE committee responsible for Standard 15 (SSPC15) continuously maintains the standard and has formed an Ad Hoc group to address the new 2L refrigerant sub-class created by SSPC34 (committee responsible for ASHRAE 34).

ANSI/UL 207, Standard for Safety for Refrigerant-Containing Components and Accessories, Nonelectrical

These requirements cover non-electrical, refrigerant-containing components and accessories (e.g., accumulators, driers, evaporators, condensers, etc.), intended for field installation in accordance with ASHRAE 15 in refrigeration systems, air conditioning equipment, or both, charged with the refrigerants identified for use in the component or accessory. The requirements also apply to components and accessories intended for use by manufacturers in factory-assembled systems or units, in which case the component or accessory is also judged under the requirements for the individual system or unit.[41]

Primarily addressing strength of materials and mechanical assembly, the standard includes consideration of flammable refrigerants. ANSI/UL 207 Table 11 specifies the minimum design pressures for common refrigerants. Data for flammable refrigerants is excerpted from that table and reproduced here in Table 4.

ANSI/UL 250, Standard for Safety for Household Refrigerators and Freezers

This standard applies to self-contained household refrigerators and freezers for use in residential occupancies in accordance with the National Electrical Code®, ANSI/NFPA 70.[42] Supplement SA of the standard documents the requirements for refrigerators (freezers, etc.) having flammable refrigerants. It addresses concerns regarding the flammability of the refrigerant by limiting the amount of charge according to auto-ignition temperature or heat of combustion, and controlling for design and construction variables that can contribute to the risk of fire. See Table 5 for a summary of the requirements.

ANSI/UL 250 will be superseded in 2016 by ANSI/UL 60335-2-24, the *Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Refrigerating Appliances, Ice-Cream Appliances and Ice-Makers*.[43] With respect to flammable refrigerants, the IEC requirements are modified or replaced such that the requirements are effectively the same as the current ANSI/UL 250 standard.

The scope of ANSI/UL 60335-2-24 is not identical to that of ANSI/UL 250. ANSI/UL 60335-2-24 also includes ice makers and household ice cream makers, which are covered by ANSI/UL 563 (Ice Makers) and ANSI/UL 621 (Ice Cream Makers). Should such appliances use flammable refrigerants, ANSI/UL 60335-2-24 would be applicable for that aspect of their design.

ANSI/UL 471, Standard for Safety for Commercial Refrigerators and Freezers

These requirements cover unitary (self-contained) and remote commercial refrigerators and freezers intended for connection to circuits rated not greater than 600 volts AC. Commercial refrigerators and freezers include equipment such as display cases, reach-in

Table 4 — Minimum Design Pressures for Selected Flammable Refrigerants

Refrigerant	Group[a]	Name	Minimum design pressures pounds per square inch gauge (kPa)					
			Low side		High side			
					Water or evaporatively cooled		Air cooled	
R-30	B2	Methylene Chloride	15	(103)	15	(103)	15	(103)
R-40	B2	Methyl chloride	72	(496)	112	(772)	151	(1041)
R-170	A3	Ethane	616	(4247)	709	(4888)	709	(4888)
R-290	A3	Propane	129	(889)	188	(1296)	244	(1682)
R-600	A3	N-Butane	23	(159)	42	(290)	61	(421)
R-600A	A3	Isobutane	39	(269)	63	(434)	88	(607)
R-611	B2	Methyl Formate	15	(103)	15	(103)	15	(103)
R-717	B2	Ammonia	139	(958)	215	(1482)	293	(2020)
R-764	B1	Sulfur Dioxide	45	(310)	78	(538)	115	(793)
R-1150	A3	Ethylene	732	(5047)	732	(5047)	732	(5047)

[a] Classification in accordance with ASHRAE 34.

cabinets, meat cases, frozen food and merchandising cabinets, beverage coolers, beverage cooler-dispensers, food service carts, ice cream cabinets, soda fountain units, door panel assemblies and processing water coolers.[45]

Flammable refrigerant requirements of this standard (Supplement SB) are virtually identical to those of ANSI/UL 250, with the notable exception of a higher allowable refrigerant charge and the particulars of required markings and instructions. Clause SB3.3 of the standard limits flammable refrigerant charge as follows:

- 225 grams (8.0 oz) - ASHRAE 34 Class 2 "Lower Flammability" refrigerant. Has limits of flammability, and heat of combustion less than 19,000 kj/kg (8,174 Btu/lb.).
- 150 grams (5.3 oz) - ASHRAE 34 Class 3 "Higher Flammability" refrigerant. Has limits of flammability and heat of combustion greater than 19,000 kj/kg (8,174 Btu/lb.).

The current standard further indicates that, when the leaked amount of refrigerant during leak scenario testing of the refrigerating system does not exceed the 225 or 150 g value, a larger amount of charge would not be prohibited from being used.

ANSI/UL 1995, Standard for Safety for Heating and Cooling Equipment

The standard is applicable to stationary equipment for use in nonhazardous locations rated 7200 V or less, single- or 3- phase, and remote control assemblies for such equipment. Cooling equipment examples include heat pumps, air conditioners, liquid chillers, condensing units, heat pump water heaters and fan coil units.[46] Currently, the standard does not address the subject of flammable refrigerants, which should be construed to mean that flammable refrigerants (aside from ammonia[47]) are not permitted, an interpretation consistent with ASHRAE Standard 15.

There is an active, tri-national harmonization effort being conducted under the auspices of the Council for the Harmonization of Electrotechnical Standards of the Nations of the Americas (CANENA)[48] to update parts of ANSI/UL 1995 (and completely replace UL 484 and UL 474) with a standard based on IEC 60335-2-40, *Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Electrical Heat Pumps, Air Conditioners and Dehumidifiers*. Draft UL 60335-2-40 deals with the safety of electric heat pumps, including sanitary

Table 5 — Summary of Additional Requirements for Household Refrigerators and Freezers Employing Flammable Refrigerants

Charge	The charge size for refrigerators or freezers shall be as follows for the kind of refrigerant used: • No charge limit - Has no limits of flammability, has either an auto-ignition temperature less than or equal to 750°C (1382°F) or no auto-ignition temperature. • No charge limit - When the blend (does not fractionate). • 225 grams (8.0 oz.) - Has limits of flammability, and heat of combustion less than 19,000 kj/kg (8,174 Btu/lb). When the leaked amount of refrigerant during leak scenario testing of the refrigerating system, does not exceed 225 grams (8.0 oz.), a larger amount of charge is not prohibited from being used. • 50 grams (1.7 oz.) - Has limits of flammability and heat of combustion greater than 19,000 kj/kg (8,174 Btu/lb). When the leaked amount of refrigerant during leak scenario testing of the refrigerating system does not exceed 50 grams (1.7 oz.), a larger amount of charge is not prohibited from being used.
Construction	The requirements distinguish between protected and unprotected cooling systems, the difference largely based on the level of access the user has to refrigerant containing components via the refrigerated storage area. • No dead spaces anywhere within the appliance where flammable gas mixture can accumulate. • Refrigerant tubing must be protected or enclosed to avoid mechanical damage. • No quick-connect refrigeration fittings or packed-stem valves. • Refrigeration joints shall be brazed or welded and protected from mechanical damage. • Refrigeration circuit shall be protected from corrosion.
Leakage	For a protected cooling system, refrigerant leakage simulation at most critical point in system, which would be one of the joints in the refrigeration circuit. • 80% of the refrigerant charge, or quantity capable of being discharged in a prescribed way within 1 hr., is leaked in a controlled manner at a joint. • For an unprotected cooling system, refrigerant leakage simulation at prescribed location in food storage compartment • 80% of refrigerant charge is discharged within 10 min. • Where accumulation of refrigerant may occur outside the food storage area, leakage simulation at that location. • 80% of refrigerant charge is discharged at a constant rate over a period of 1 hr. • For each of the simulations, the refrigerant air mixture shall not exceed 75% of the lower flammable limit (LFL) for the flammable gas at any time and not exceed 50% of the LFL for a period exceeding 5 min.
Ignition	If exposed to the refrigerant during the leakage testing, electrical switching components are tested to determine whether they are capable of igniting the flammable refrigerant / air mixture. • Tested in accordance with ASTM E681-98 (Standard Test Method for concentration Limits of Flammability of Chemicals (Vapors and Gases)) at room ambient and again at 50oC
Temperature	Surface temperature of parts that may be exposed to a leaked refrigerant shall not exceed the ignition temperature of the refrigerant reduced by 100 °C. • R290 (Propane) – ignition temperature: 470 oC, LFL 2.1% • R600 (n-Butane) – ignition temperature 365 oC, LFL 1.5% • R600A (Isobutane) – ignition temperature 460 oC, LFL 1.8%
Scratch	Accessible surfaces of protected cooling system components are scratched in a prescribed way as preconditioning of the Strength Test applicable to all refrigerant pressure containing systems. [Typical strength test pressures are comparable to those of CFC's]
Markings and Instructions	Permanent markings on the appliance are required: • *"DANGER - Risk Of Fire or Explosion. Flammable Refrigerant Used. Do Not Use Mechanical Devices To Defrost Refrigerator. Do Not Puncture Refrigerant Tubing".* • *"DANGER - Risk Of Fire Or Explosion. Flammable Refrigerant Used. To Be Repaired Only By Trained Service Personnel. Do Not Puncture Refrigerant Tubing".* • *"CAUTION - Risk Of Fire Or Explosion. Flammable Refrigerant Used. Consult Repair Manual/Owner's Guide Before Attempting To Service This Product. All Safety Precautions Must be Followed".* • *"CAUTION - Risk Of Fire Or Explosion. Dispose Of Property In Accordance With Federal Or Local Regulations. Flammable Refrigerant Used".* • *"CAUTION - Risk Of Fire Or Explosion Due To Puncture Of Refrigerant Tubing; Follow Handling Instructions Carefully. Flammable Refrigerant Used".* The refrigeration system processing tubes shall be color-coded to indicate the refrigerant used.44 Cautionary statements shall be repeated in the instructions and packaging. They shall emphasize that servicing shall be done by factory authorized service personnel.

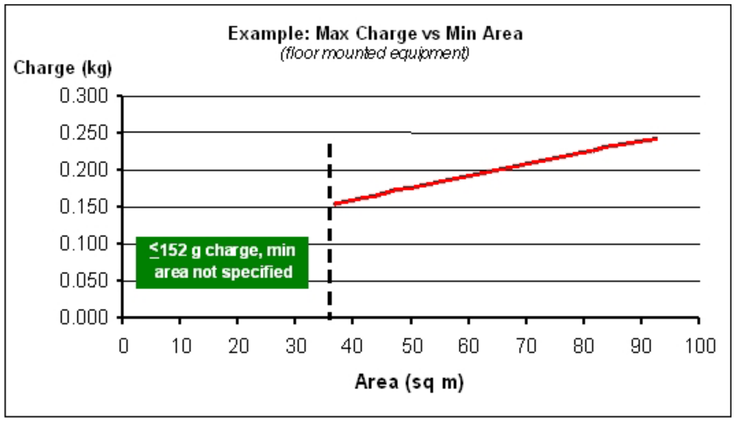
hot water heat pumps, air-conditioners, and dehumidifiers incorporating motor-compressors and hydronic room fan coils.

Though the IEC standard also addresses electric heat pumps, air conditioners and dehumidifiers containing flammable refrigerant, the Standards Technical Panel developing the draft standard has not itself addressed flammable refrigerants in its work. For this reason, the draft UL standard has a U.S. national deviation that would currently preclude use of flammable refrigerants.

IEC 60335-2-40 uses the ASHRAE 34 refrigerant classification system (also used in ISO equivalent standard, ISO 817). For mechanical strength of the refrigeration system, the standard refers to ISO 5149 requirements.[49] Many of the construction requirements for equipment employing flammable refrigerants are similar to those described for ANSI/UL 250, with the addition of specific construction requirements for equipment charged at the installation site, and of requirements addressing transport, storage and service operations. The most significant difference between the standards involves how charge limits are determined.

Rather than a fixed charge limit, IEC 60335-2-40 correlates refrigerant charge, volume of the space (room) for equipment installed indoors, and installation height (floor, wall, window, ceiling). Smaller amounts (e.g., ffi152 g propane) of flammable refrigerant in products such as portable dehumidifiers are addressed in a manner similar to that of a refrigerator (minimum room size not specified, mechanical ventilation not required).

Figure 2



For more than these amounts (e.g. 152 < g ffi 988 propane), the equipment must be marked with a minimum room size, calculated in accordance with Annex GG of the standard (see Figure 2 for example results). This requirement will typically affect portable air conditioners. Larger amounts (up to 4.94 kg) of refrigerant will require mechanical ventilation operated by a leak detector/sensor. These amounts are limited to fixed equipment only.

Equipment having very large amounts of refrigerant is not covered by IEC 60335-2-40, which states that national standards shall apply (e.g., ASHRAE 15).

ANSI/UL 484, Standard for Safety for Heating and Cooling Equipment

These requirements cover room air conditioners rated not more than 600 Vac. Room air conditioners include packaged terminals (PTACs), special purpose and recreational vehicle type air conditioners. Flammable refrigerant requirements have recently achieved consensus in the UL 484 Standards Technical Panel and will be published shortly. These requirements are similar to the requirements described above for IEC 60335-2-40, in that the maximum charge is correlated to the size of the room in which the air conditioner is intended to be installed. However, they do not include an allowance for larger amounts of flammable refrigerant when there is mechanical ventilation.

ANSI/UL 474, Standard for Safety for Heating and Cooling Equipment

This standard details requirements for movable, household, self-contained dehumidifiers employing hermetic refrigerant motor-compressors, and intended for connection to single-phase, alternating-current circuits rated not more than 20 A, 125 V or 15 A, 208 or 230 V. The situation relative to flammable refrigerants is identical to that of ANSI/UL 484.

UL 984, Standard for Safety for Refrigerant Motor Compressors

This is the legacy standard applicable to hermetic refrigerant motor-compressors rated 7200 V or less, for use in air-conditioning and refrigerating equipment that comply with the standards applicable to such equipment.[50] It distinguishes between refrigerants primarily by their thermodynamic properties, and by the strength of materials necessary to contain the refrigerants under normal and abnormal conditions. Specific reference to flammable refrigerants is not made in the standard; instead, it defers to ASHRAE 15.

The basic requirements are the same for all types of refrigerants, except that leakage around gaskets and seals is not permitted during Strength Testing of compressors intended for refrigerants other than A1 (or A1/A1 blends). The flammable refrigerant, lubrication and the compressor motor electrical insulating system must also be compatible. The standard prescribes a test to establish compatibility, though there are alternative means to do so.

Going forward, UL 984 will only cover motor-compressors that are outside the scope of ANSI/UL 60335-2-34.

ANSI/UL 60335-2-34, Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Motor-Compressors

In late 2009, revisions to the previously published UL 60335-2-34 were completed so that the standard could be declared as harmonized with UL 984. Designation as an American National Standard (ANS) was then transferred from UL 984 to UL 60335-2-34.

ANSI/UL60335-2-34 is based on IEC 60335-2-34 whose scope "deals with the safety of sealed (hermetic and semi-hermetic type) motor-compressors, their protection and control systems, if any, which are intended for use in equipment for household and similar purposes and which conform with the standards applicable to such equipment. It apples to motor-compressors tested separately, under the most severe conditions which may be expected to occur in normal use, their rated voltage being not more than 250 V for single-phase motor-compressors and 480 V for other motor-compressors."[51]

There is no difference between ANSI/UL 60335-2-34 and UL 984 with regard to how refrigerants are handled.

Other Appliance Standards

Other standards potentially affected by the introduction of flammable refrigerants are ANSI/UL 412, *Standard for Safety for Refrigeration Unit Coolers*, ANSI/UL 399, *Standard for Safety for Drinking Water Coolers*,[52] and ANSI/UL 541, *Standard for Safety for Refrigerated Vending Machines*.

"Reverse-cycle" heating, long the staple of heat pumps, is also making an appearance in products such as clothes dryers and water heaters. With their experience in the use of HC refrigerants in household refrigerators and freezers, European manufacturers have expanded the application to these newer energy saving technologies (e.g., clothes dryers[53]).

The water heater application is currently covered by ANSI/UL 1995 for conventional refrigerants. There is no current mechanism within that standard to address a flammable refrigerant. Similarly, clothes dryer requirements (ANSI/UL 2158, *Standard for Electric Clothes Dryers*) do not anticipate the heat pump technology (conventional or flammable refrigerants). For this reason, there is an effort underway at UL to re-purpose an existing *Standard for Refrigerating Units*, ANSI/UL 427, to be a general source for refrigeration circuits employed in appliances where the relevant appliance standard does not already include such requirements.

Conclusion

In the 1990s the U.S. market was not ready for the introduction of flammable refrigerants in many HVAC and appliance applications when CFC phase-out began to take effect. However much experience with equipment using HC refrigerants has been gained around the world in the intervening years. As the drive toward more environmentally-friendly refrigerants and greater energy efficiency continues, it's time to revisit the use of flammable refrigerants in the U.S. Anticipating that these refrigerants can very quickly attain more widespread use, it is important that the stakeholders of the U.S. safety system take a holistic look at the potential impact of such use, and take the necessary steps to ensure the continued safety track record of HVAC equipment and appliances. UL believes that raising awareness and facilitating dialogue among stakeholders is an important first step in this direction.

For information about the "Revisiting Flammable Refrigerants in HVAC Equipment and Appliances" white paper, please contact Thomas Blewitt, Director of Primary Designated Engineers, Underwriters Laboratories at Thomas.V.Blewitt@us.ul.com.

References

[1] CFC's: Time of Transition, ASHRAE, 1989, p 4.

[2] Individuals experimenting with refrigerants outside of university and corporate laboratories are not just a thing of times past. Hawaii News Now (hawaiinewsnow.com) reported in a June 20, 2008 article by Howard Dashefsky that auto mechanic Richard Maruya of Kaneohe, HI developed the hydrocarbon refrigerants HCR 188 and HCR 188c in his garage using off-the-shelf materials. These refrigerants are currently out for public review for recognition under the EPA SNAP Program.

[3] Ammonia Refrigeration Products and Services, "What is Ammonia Refrigeration," by Renewable Energy institute, http://am-moniarefrigeration.net/.

[4] CFCs: Time of Transition, ASHRAE, 1989, p 9.

[5] Ibid, p 11.

[6] Ibid.

[7] For example, R12 was so inexpensive that it was commonly used as an aerosol propellant in consumer products such as hairspray.

[8] This observation is based on the appliance being used and installed as intended by the manufacturer and does not take into account environmental concerns or abuse (e.g. refrigerant "huffing").

[9] This observation doesn't take into account the potential exposure to byproducts of combustion that may be present in a building fire.

[10] From UL 250 Table SA5.1 Refrigerant lower flammability limit (LFL): 2.1% for propane (R290), 1.5% for n-butane (R600), 1.8% for isobutane (R600a).

[11] From UL 250 Table SA5.1 Refrigerant ignition temperature: 470oC for propane, 365 oC for n-butane and 460 oC for isobutane.

[12] This is a simplification of what can be a complex circumstance. Other factors, including compressor motor lubricants, the nature of the leak and ambient environment, among others, can affect the risk that a flammable gas and air mixture is present.

[13] Historically, "the average (commercial) refrigeration system loses its complete refrigerant charge three times in 10 years," according to "The True Cost of Refrigeration Leaks," Esslinger, S., "CFC's in Transition," ASHRAE, 1989, p 235.

[14] US EPA Ozone Layer Protection - Regulatory Programs, "Leak Repair," http://www.epa.gov/ozone/title6/608/leak.html

[15] Propane (R290) and isobutane (R600a) are "natural refrigerants" considered to have no ozone depletion potential (ODP) and low global warming potential (GWP).

[16] "In 2002, Japan, a major producer of domestic refrigerators/freezers, introduced its first hydrocarbon (HC) refrigerators onto the market. HC refrigerants, especially R-600a, have since dominated the Japanese domestic refrigeration market and are continuing to grow in market share." Quoted from "Transitioning to Low GWP Alternatives in Domestic Refrigeration," U.S. Environmental Protection Agency, EPA-430-F-10-042, October 2010 (http://www.epa.gov/ozone/downloads/EPA_HFC_DomRef.pdf).

[17] "Practical Application of Refrigerant R600a Isobutane in Domestic Refrigerator Systems," Danfoss, November 2000.

[18] Simplification of a table appearing on EPA web site: US EPA Ozone Layer Protection - Regulatory Programs, "Comparison of the Montreal Protocol and United States Phaseout Schedules," http://www.epa.gov/Ozone/title6/phaseout/hcfc.html. Referenced cap is average of a) 1989 HCFC production + 2.8% of 1989 CFC production and b) 1989 HCFC consumption + 2.8% of 1989 CFC consumption.

[19] Unilever is the world's largest producer of ice cream (Breyers and Ben and Jerry's brands in US). Since 2004, the company has been replacing commercial freezers that display their products with units using hydrocarbon (HC) refrigerants, around 430,000 units to date (11/2010) according to their website (unilever.com).

[20] "Natural Refrigerants Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs," Proklima International, published by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, July 2008, p 31.

[21] The Directive covers the use of refrigerants with global warming potential (GWP) over 150 in Mobile Air Conditioning for passenger cars only. The intent is to restrict direct emissions from such systems. The Directive will be implemented beginning in 2011 with a target of full implementation by 2017.

[22] "Transitioning to Low GWP Alternatives in Commercial Refrigeration" EPA-430-F-10-043 October 2010 (http://www.epa.gov/ozone/downloads/EPA_HFC_ComRef.pdf) and "Transitioning to Low GWP Alternatives in MVACs," EPA-430-F-10-041, October 2010 (http://www.epa.gov/ozone/downloads/EPA_HFC_MVAC.pdf).

[23] "Minimum standards of energy efficiency for many major appliances were established by the U.S. Congress in Part B of Title III of the Energy Policy and Conservation Act (EPCA), ... the National Energy Conservation Policy Act, ... the National Appliance Energy Conservation Act, ... the National Appliance Energy Conservation Amendments of 1988, ... and by the Energy Policy Act of 1992, ... and by the Energy Policy of 2005...." US DOE, Building Technologies Program, "Appliances & Commercial Equipment Standards, Laws and Regulations," http://www1.eere.energy.gov/buildings/appliance_standards/laws_regs.html.

[24] US DOE Press Release: "DOE Proposes Higher Efficiency Standards for Refrigerators," September 28, 2010, http://www.energy.gov/news/9582.htm.

[25] US EPA Ozone Layer Protection - Alternatives / SNAP, "Significant New Alternatives Policy (SNAP) Program," http://www.epa.gov/ozone/snap/index.html.

[26] US EPA Air and Radiation Stratospheric Protection Division 6205J, "Substitute Refrigerants Under SNAP as of June 16, 2010," http://www.epa.gov/ozone/snap/refrigerants/reflist.pdf.

[27] U.S. EPA Guidance document for the Significant New Alternatives Policy (SNAP), Program Information Notice EPA-1265-07 June 30, 2011 (sic), p. 16.

[28] The "refrigerant is a blend of propane, isobutane, ethane, and pentane gases, with variations that include hexane, methane, and heptane." Appliance Design, "Cooling Technologies: Alternative Refrigerants Attract Attention," Larry Adams, March 31, 2009 (http://www.appliancedesign.com/Articles/Article_Rotation/BNP_GUID_9-5-2006_A_10000000000000558309).

[29] Federal Register / Vol. 75, No. 89 / Monday, May 10, 2010 / Proposed Rules p. 25799

[30] Ibid, p 25809

[31] US Code of Federal Regulations, 49CFR178 "Specifications for Packagings."

[32] US DOT Federal Motor Carrier Safety Administration Office of Information Management, "Crashes Involving Trucks Carrying Hazardous Materials," by Ralph Craft, PhD, Publication #: FMCSA-RI-04-024, May 2004 http://www.fmcsa.dot.gov/facts-research/research-technology/analysis/fmcsa-ri-04-024.htm.

[33] Other containers may also be employed where appropriate (e.g. those complying with the Rules for Construction of Unfired Pressure Vessels, Section VIII, Division 1, ASME Boiler and Pressure Vessel Code).

[34] ANSI/ASHRAE Standard 34, Designation and Safety Classification of Refrigerants, Scope.

[35] Standard for Safety of Refrigerants, ANSI/UL 2182, Scope.

[36] ANSI/NFPA 58-2011, Liquefied Petroleum Gas Code Clause 1.3.2.

[37] DOT cylinder specifications are provided in 49CFR178, "Specifications for Packaging."

[38] ANSI/ASHRAE Standard 15-2010, Safety Standard for Refrigeration Systems, Scope.

[39] Refrigerant concentration limit (RCL) is the measure of complete discharge of each independent refrigeration circuit into a volume of space.

[40] ANSI/ASHRAE Standard 15-2010, Safety Standard for Refrigeration Systems, Clause 7.5.3 Higher Flammability Refrigerants, Exception c.

[41] Standard for Safety for Refrigerant-Containing Components and Accessories, Nonelectrical, ANSI/UL 207, Scope.

[42] Standard for Household Refrigerators and Freezers, ANSI/UL 250, Scope.

[43] Tri-national (US, Canada, Mexico) standard based on the eponymous IEC 60335-2-24.

[44] The U.S. EPA is proposing that equipment must have distinguishing color-coded hoses and piping to indicate use of a flammable refrigerant. They indicate that one unspecified color would be sufficient for both household refrigerator and freezers and retail food refrigeration (stand-alone units). (Federal Register / Vol. 75, No. 89 / Monday, May 10, 2010 / Proposed Rules p. 25808).

[45] Standard for Commercial Refrigerators and Freezers, ANSI/UL 471, Scope.

[46] Standard for Safety for Heating and Cooling Equipment, ANSI/UL 1995, Scope.

[47] "In general, ammonia can be used in unlimited quantities in direct systems for industrial occupancies; however it must be used in indirect (secondary) systems for commercial and public occupancies, while its general use in small absorption equipment is unrestricted." "Ammonia as a Refrigerant," Position Document Approved by ASHRAE Board of Directors January 17, 2002, Reaffirmed by ASHRAE Board of Directors January 26, 2006, http://www.ashrae.org/docLib/200622793710_347.pdf.

[48] According to the CANENA website (http://www.canena.org/about/about.aspx#canena), "CANENA provides a forum for harmonization discussions and; upon agreement, the draft harmonized standards are then processed by the respective standards developer in each country, in accordance with that SDO's procedures."

[49] ISO 5149, Mechanical refrigerating systems used for cooling and heating — Safety requirements.

[50] Standard for Hermetic Refrigerant Motor Compressors, ANSI/UL 984, Scope.

[51] Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Motor-Compressors, ANSI/UL 60335-2-34, Scope.

[52] Rockwell Industries Ltd of India claims to be able to produce water coolers using hydrocarbon refrigerant (http://www.rockwell.co.in/aboutus.html).

[53] Patent application filed by Agent BSH Home Appliances, Intellectual Property Department: HOUSEHOLD APPLIANCE CONTAINING A HEAT TRANSFER FLUID, Publication date: 08/26/2010, Patent publication number: 2010-0212178. The patent is described to be "for a household appliance includes a drying chamber, a process air loop and a heat pump. The heat pump includes a heat transfer loop containing a heat transfer fluid, an evaporator heat exchanger, a liquefier heat exchanger, a compressor, and a nozzle. The heat transfer fluid has a critical temperature above 60° C., a nominal heat of vaporization at boiling point of at least 220 kJ/kg, a GWP index of less than 150 and a lower flammability level of at least 0.1 kg/m3. Preferably, the household appliance is a dryer for drying wet laundry." (Description obtained from http://www.faqs.org/patents/app/20100212178 where the refrigerant was further described to be R152a).