Flammability and New Refrigerant Options

BY STEVE KUJAK, MEMBER ASHRAE

Increasing concerns about the impact of refrigerants on the environment and on climate change are driving new regulatory policies to restrict and lower the global warming potential (GWP) impact of fluorocarbon refrigerants used in the HVAC&R industry. In response, the industry is developing and examining a new class of lower GWP refrigerants. As this transition moves forward, many questions exist about changing refrigerants options and requirements to use them safely. This article highlights some important considerations, particularly flammability, that engineers, designers, and building owners should keep in mind regarding next-generation refrigerants.

Not all next-generation refrigerants are flammable. Numerous ultralow GWP refrigerants (defined in this article as having a GWP of less than 10) are nonflammable.

And, some flammable next-generation refrigerants are blended with nonflammable refrigerants, much like many of the refrigerant blends we use today. For example, the blend R-410A mixes a flammable refrigerant (R-32, ASHRAE Class 2L) with a nonflammable refrigerant (R-125, ASHRAE Class 1).

ASHRAE Standard 34-2016, *Designation and Classification of Refrigerants,* defines flammability in three separate classes:

- Class 1 (No Flame Propagation);
- Class 2 (Lower Flammability); and
- Class 3 (Higher Flammability).

ASHRAE has established a new 2L subclassification for refrigerant flammability to address new next-generation refrigerants that have lower flammability characteristics, which this article will discuss further.

Therefore, throughout this discussion it's important to keep in mind that flammability is a continuum and not a set of absolutes as determined by Standard 34.

What Should You Know About Flammability?

Safety—including the issues of flammability and toxicity—is a key consideration when evaluating next-generation refrigerants.

The HVAC&R industry has been asked to consider lower GWP refrigerants with both Class 2 (lower flammability refrigerants) and Class 3 (higher flammability refrigerants).

At a high level, the industry will likely select refrigerants that both meet regulations and are nonflammable or that have the lowest level of flammability possible. The lower the flammability, the lower the risk.

Refrigerant flammability is classified by Standard 34-2016 or the newly published ISO Standard 817-2014, *Refrigerants—Designation and Safety Classification*. Both

Steve Kujak is director next generation refrigerant research at Trane, La Crosse, Wis. He is chair of TC 3.1, Refrigerants and Secondary Coolants, and a member of SSPC 34, *Designation and Classification of Refrigerants.*

What is Driving the Refrigerant Transition?

With growing concerns about the impact on the environment and climate change, pressure has been mounting for years to reduce the use of high-GWP refrigerants across many applications and industries. In response, all 197 member countries, including the U.S. and Canada, agreed last year to amend the Montreal Protocol to phase down hydrofluorocarbons (HFCs).

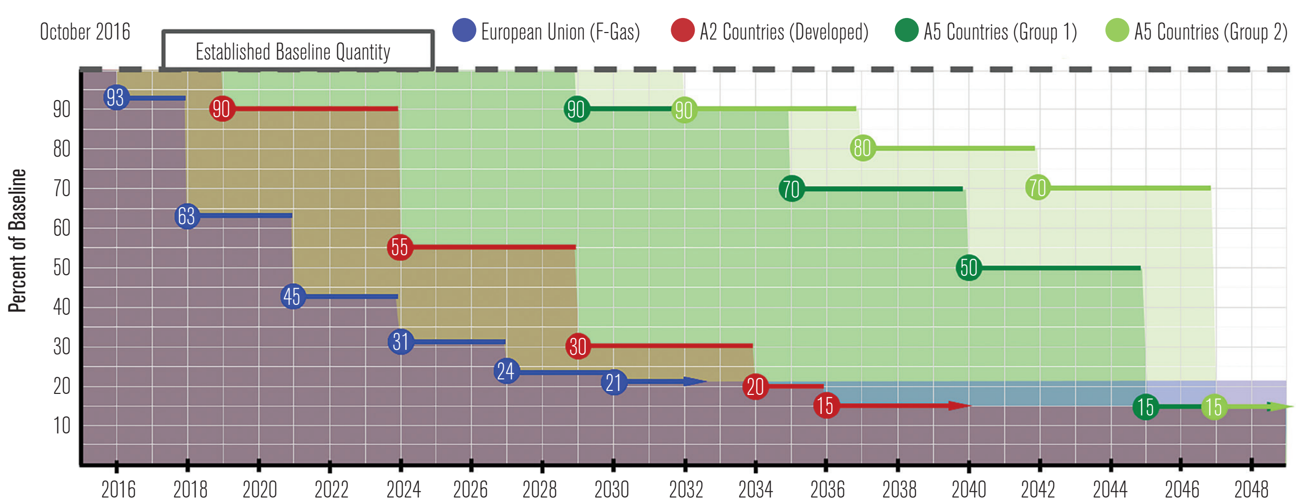
On Oct. 16, 2016, the Kigali Amendment to the Montreal Protocol was passed, paving the way for the global phasedown of HFCs. *Figure 1* shows the phasedown schedule agreed to by the parties. It also shows the European Union F-gas law, providing a perspective on how existing regional laws influenced the phasedown schedule.

Ahead of the Kigali Agreement, the U.S. Environmental Protection Agency (EPA) issued two rules regarding the change of listing status of certain HFCs in the U.S. The first rule[1] establishes phaseout dates for HFCs in retail food refrigeration, aerosols, propellants, and motor vehicles. The EPA used its regulatory authority through the Significant New Alternative Policy (SNAP) by designating particular SNAP-listed HFC refrigerants as "unacceptable" and SNAP delisting these refrigerants for new retail food refrigeration in 2017, aerosols and propellants in 2018, and motor vehicles in 2021. The second EPA rule[2] establishes the phaseout date for HFCs in chillers. Specifically, R-134a, R-410A and R-407C are banned from use in new chillers (air-cooled and water-cooled, scroll, screw, and centrifugal) beginning Jan. 1, 2024.

In a separate rule,[3] the EPA also made several other changes to management requirements for refrigerants in Section 608 of the Clean Air Act, effective Jan. 1, 2019, to include the following:

- Extending the requirements previously in place for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) to include all replacement substances, including HFCs and the new hydrofluoroolefin (HFO) options. Hydrocarbons in small, self-contained systems are given an exception for venting.
- Reduced leak trigger rates, which in turn requires enhanced leak tightness requirements. This may push or incentivize the industry to move to technologies that are more hermetic with fewer joints and seals, for better long-term refrigerant containment.
- New requirements for mandatory leak inspections on equipment and increased record keeping requirements.

FIGURE 1 The HFC phasedown schedule agreed to by the parties of the Kigali Amendment to the Montreal Protocol.[4,5]



Group 1: Kigali Amendment Article 5 parties not part of Group 2
Group 2: Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates

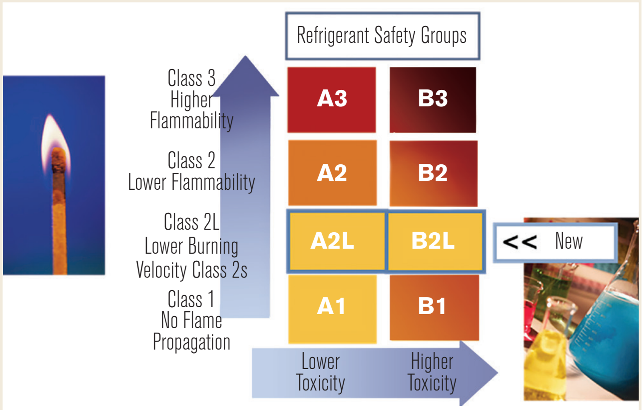


FIGURE 2 Classes of refrigerant flammability.

standards use similar methodologies, but there are some small differences between them.

As shown in *Figure 2*, Standard 34-2016 divides flammability into three defined classes with an additional subclassification:

- Class 3: higher flammability;
- Class 2: lower flammability;
- Class 2L: lower burning velocity (BV) Class 2s with burning velocities less than or equal to 10 cm/s (3.9 in./s); and
- Class 1: no flame propagation.

The 2L subclassification may become a separate class within Standard 34 to match a similar recent change to ISO Standard 817-2014, which made 2L a separate class. This article will not discuss the detail around how Standard 34 determined the toxicity classes.

Historically, most refrigerants used in HVAC&R products were Class 1, or nonflammable.

Ammonia, which is a Class 2L material, has been used in large industrial refrigeration systems for over 100 years. The safety of these systems is heavily controlled as the result of ammonia's toxicity rather than its flammability. These systems often are a low exposure risk since they are used in applications with low occupancies.

There is limited industry experience with ammonia's flammability risks because these controls on toxicity limit the ability for ammonia to form flammable mixtures. In the end, flammable events have occurred with ammonia installations, which give some insight into system risks with very large Class 2L refrigerant charge.

Hydrocarbons, which are Class 3 materials, have recently been used more in systems like small domestic refrigerators or freezers with very small refrigerant charge sizes.

Refrigerant Selection— A Balancing Act

While the HVAC&R industry evaluates next-generation refrigerant alternatives, the challenge is to balance environmental benefits with safety, sustainability, and design requirements. It's likely that trade-offs between GWP, flammability, and efficiency will need to be made in selecting refrigerants.

When considering refrigerant alternatives for the future, policy makers, the public, and manufacturers must select refrigerants with the best balance of the following:

- Environmental performance (direct environmental impact such as inconsequential ozone depleting and reduced GWP);
- Safety for consumers (flammability and toxicity);
- Energy efficiency (indirect environmental impacts such as reduced CO_2 emissions, especially at high ambient operations;
- Intellectual property considerations;
- Transition costs (impact on industry and consumers); and
- Product sustainability (long operational life, reliability, maximizing recyclable content, and repurposing components)

Flammability safety in these systems is controlled by restricting the charge size to a low enough level to dramatically reduce the risk of propagating a flammable mixture beyond the equipment and limiting a potential flammable event's severity. The use of Class 3 refrigerants has not expanded much beyond these applications because of the severe safety implications of using large refrigerant charge sizes with these materials.

Some manufacturers offer larger charge hydrocarbon systems, but these products have not become mainstream and likely will not because of the extensive safety procedures needed compared to an alternate system that might be using an equivalent GWP refrigerant with reduced safety restrictions.

While some nonflammable, ultralow GWP refrigerants exist, these are lower-pressure refrigerants, and they are typically used only in centrifugal chiller applications. These refrigerants cannot cover the whole range of HVAC&R product needs.

Advertisement formerly in this space.

Advertisement formerly in this space.

The HVAC&R industry is actively investigating the safety of flammable refrigerants. The industry is determining the risks of flammable refrigerants by understanding the probability of potential occurrences and severity of events in various application situations, including servicing and handling.

Understanding Class 2L Refrigerants

The boundaries between Class 2 and Class 3 refrigerants are defined as a lower flammability limit (LFL) of greater than 100 g/m^3 (6.2 lb/1,000 ft^3) and heat of combustions (HOC) of less than 19 000 kJ/kg (8,169 Btu/lb).

Illustrated in *Figure 3*, the new 2L subclass designation divides Class 2 by limiting the burning velocity to less than 10 cm/s (3.9 in./s). The 2L class was added to express the lower flammability properties of many of the new unsaturated HFCs (sometimes referred to as HFOs) and other refrigerants with similar flammability properties, such as R-32 and ammonia.

The 2L classification is being investigated by the HVAC&R industry to see if larger refrigerant charge sizes can be safely used beyond those currently specified for hydrocarbons (Class 3) and R-152a (Class 2).

Debate exists in both the ASHRAE and ISO Standards about how to define the boundary between Class 1 (nonflammable) and Class 2, which is determined per the ASTM E681 test method. There's also debate about what the limits for a 2L flammable refrigerant should be, since not all 2L refrigerants have the same flammability characteristics.

Research is under way at the request of product and application standards committees, and more research is being proposed to investigate these limits and to understand testing methods and variability. Because the LFL does not allow for differentiation among the use of 2L refrigerants, many in the industry support using other factors such as minimum ignition energy (MIE) to help differentiate. MIE would allow greater charge sizes to be used for refrigerants with lower 2L burning velocities or for refrigerants that approach the nonflammable limit.

As demonstrated in *Figure 4*, the higher the MIE, the less likely the chemical is to ignite near an ignition source (for example, a light switch, pilot light, or other ignition sources, or open flames, such as a candle). Likewise, the lower the BV, the less likely it is to propagate across a room or through a system. Hence, the higher the MIE and the lower the BV, the safer a refrigerant becomes for HVAC&R application.

Advertisement formerly in this space.

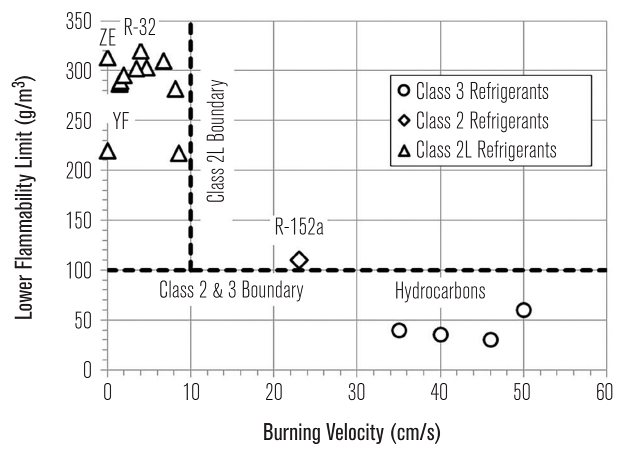


FIGURE 3 Classes of refrigerant flammability comparing the lower flammability limits (LFLs) and burning velocity (BV) for various refrigerants.[6]

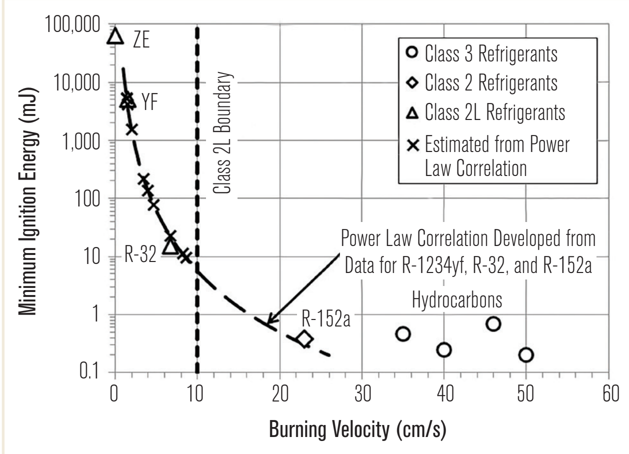


FIGURE 4 Classes of refrigerant flammability, comparing the minimum ignition energy (MIE) and burning velocity (BV) for various refrigerants.[6]

Challenges with Using Flammable Refrigerants

Because of the challenges associated with flammable refrigerants, the HVAC&R industry launched several risk assessment projects. Flammability risk can be defined by considering and controlling three factors (also illustrated in *Figure 5*):

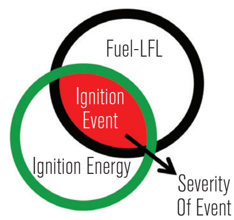
1. Likelihood of a flammable event from a refrigerant leak that reaches the LFL. This can be controlled numerous ways: through the use of leak sensing in combination of either air circulation or air ventilation to mix or dilute air/refrigerant mixture as it forms, restricting the refrigerant charge, controlling the

room area and volume, placing the unit outside or in a controlled equipment room, reducing leaks and joints, and eliminating opportunities to service the unit.

2. Presence of an ignition source that is greater than the MIE needed to start combustion of the refrigerant. This can be managed by restricting or enclosing product ignition sources and removing sources or control in the room.

3. Impact of the severity of a potential event, which includes the probability of complete combustion, the pressure rise, and the potential to create a secondary fire in the presence of combustible materials, which is a function of time and temperature. This can be controlled by designing the application to handle pressure rise (through venting, for example) and by placing the unit outside.

Flammability Safety Controlling and Designing for Key Factors



Fuel—Refrigerant Concentration (LFL)

- Refrigerants with higher LFLs are safer as higher refrigerant concentrations are required to obtain a flammable mixture

Ignition Sources and Energy (MIE)

- Restrict or enclose
- Refrigerants with higher MIEs are safer because it requires a stronger ignition source to be present to start the combustion process

Severity of Event

- Design application to handle the pressure rise (venting)
- Design refrigerant to minimize potential secondary issues
- Refrigerants with lower burning velocities can reduce the flame propagation of an event

FIGURE 5 Flammability risk can be defined by considering and controlling three factors: refrigerant concentration, ignition sources and severity of event.

Impacts of Refrigerant Flammability

Several groups—the Air-Conditioning, Heating and Refrigeration Technology Institute (AHRTI), ASHRAE, and the U.S. Department of Energy (DOE)—are currently working together to research the various impacts of refrigerant flammability.

AHRTI is investigating how refrigerant release height, charge size, leak rate, temperature, humidity, room size, and obstacles, to name a few, affect the severity of events in whole-room tests by application type.

The U.S. DOE, through Oak Ridge National Laboratory, is studying the methodology of today's charge limits for all flammable-classed refrigerants and if they can be increased, which would allow flammable refrigerants to be used in more applications.

For example, with limited controls in place, hydrocarbon charge limits today max out at approximately 150 g (5.3 ounce). With maximum controls, charge limits can be 3,000 g to 5,000 g (6 lb to 11 lb) for hydrocarbons, but these limits are not practical with all the safety controls required.

Today's 150 g (5.3 ounce) refrigerant charge limits restrict hydrocarbon application in direct expansion air conditioning units to portable window-type units for residential applications and to small portable refrigeration devices like bottle coolers. In the end, product standards (UL, IEC, etc.) have found that refrigerant charge size is the most reliable controllable mitigation factor, since ignition sources are nearly impossible to control in occupied spaces and the minimum room areas are hard to enforce. Also, products could be placed in small spaces, such as hotel room refrigerators being placed in sealed cabinets.

Though product standards are not final, there is a lean toward actions that detect and mitigate to increase refrigerant charge sizes—such as requiring refrigerant leak detection and turning on the product's fan to mix or close valves on the unit to prevent further progression of the leak—as other proactive ways to lower the risk of potential events.

A Changing Landscape

New refrigerant technology is developing rapidly. Some refrigerants are starting to emerge as potential next-generation solutions. Many of these choices are lower-pressure, nonflammable solutions with vapor pressures similar to R-123 with ultralow GWP that are ideal for chiller applications with larger refrigerant charge sizes, or they are nonflammable refrigerant blends, with vapor pressures similar to R-134a and moderate GWP of less than 750.

The industry continues to study the use of flammable refrigerant options. It's important to keep in mind that flammability is a continuum with no specific natural flammable limits, and that not every refrigerant has the same flammability risks.

As standards and codes continue to change, there are many factors to consider as the industry works to find the best balance between minimizing environmental impacts, maintaining safety, and managing product costs.

The HVAC&R industry will likely have to adjust product refrigerant charge sizes in most direct refrigerant expansion applications to meet the standards. Some direct refrigerant expansion applications where refrigerant charge sizes are quite large, such as large splits, VRF systems, and large distributed commercial refrigeration systems, may not be available in their current form in the future because of flammability requirements.

Optimization of GWP, flammability, and performance is possible for next-generation refrigerant options, with the proper research to develop flammability design tools. This work is being conducted on a path forward to enable transition to low-GWP refrigerants for the industry. In the end, using nonflammable, low-GWP refrigerants that meet the regulatory requirements in high efficiency products is the easiest way to quickly meet environmental goals.

References

1. EPA. 2015. "Protection of Stratospheric ozone: change of listing status for certain substitutes under the Significant New Alternatives Policy Program; Final Rule" *Federal Register* 80(138):42870–42959. U.S. Environmental Protection Agency.

2. EPA. 2016. "Protection of Stratospheric Ozone: new listings of substitutes; changes of listing status; and reinterpretation of unacceptability for closed cell foam products under the Significant New Alternatives Policy Program; and revision of Clean Air Act Section 608 Venting Prohibition for Propane; Final Rule." *Federal Register* 81(231):86778–86895. U.S. Environmental Protection Agency.

3. EPA. 2016. "Protection of stratospheric ozone: update to the refrigerant management requirements under the Clean Air Act; Final Rule." *Federal Register* 81(223):82272–82395. U.S. Environmental Protection Agency.

4. European Parliament. 2014. "Regulation No. 517/2014 on Fluorinated Greenhouse Gases and Repealing Regulation (EC) No 842/2006."

5. UN. 2016. "Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer," Decisions XXVIII/1 and XXVIII/2. United Nations.

6. Metghalchi, H. 2014. "Developing Alternative Approaches to Predicting the Laminar Burning Speed of Refrigerants Using the Minimum Ignition Energy." ASHRAE Research Project RP-1854, Final Report. ■