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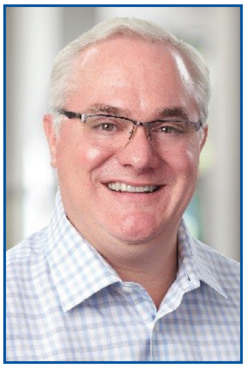

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A Conversation on Refrigerants

ASHRAE Journal conducted a roundtable with refrigerants experts to discuss the future of refrigerants.

What are potential alternatives for R-123, and what attributes make these good low global warming potential (GWP) alternatives for R-123?

Steve Kujak: Refrigerant technology has matured sufficiently in the last decade to offer a number of good replacements for R-123 and R-134a in large water-cooled centrifugal chiller products. All these options are new olefin (HFO) refrigerants. which are nonflammable (ASHRAE Standard 34-2019 Class 1) and which allows them to be readily adopted using existing product standards and building codes.

A near design-compatible option for R-123 designs is R-514A (ASHRAE Class B1). R-514A is an azeotropic blend of ultralow GWP (< 10) refrigerants R-1336mzz(Z) and R-1130(E), with nearly the same capacity and efficiency as R-123 and is in wide adoption at this time as a replacement for R-123.

Another option available is R-1233zd(E) for use in centrifugal chillers. R-1233zd(E) is a ASHRAE Class A1 refrigerant with about a 40% higher capacity than R-123 with similar efficiency, but requires a new chiller design.

A lesser-known emerging option is R-1224yd(Z) with a capacity about 60% higher than R-123 with similar efficiency. R-1224yd(Z) has similar capacity to R-245fa and would be considered a design-compatible replacement for HVAC&R equipment using R-245fa. Many organic Rankine cycle (ORC) are using R-245fa, and R-1224yd(Z) is under consideration as a replacement for these applications.

Philip Johnston: The new refrigerants currently available for low pressure water cooled centrifugal chillers are R-1233zd(E) and R-514A, with a third refrigerant, R-1224yd(Z) showing potential as an emerging solution.

R-1233zd(E) has key attributes we look for in a new refrigerant solution. It is classified as an "A1" (lower toxicity, with no flame propagation) by Standard 34-2019. It is a single working fluid, making it easier to reclaim and has high efficiency. It will also be used in other sectors beside large chillers (including foams and solvents), driving global demand and large-scale production. This suggests competitive pricing and widespread availability going forward. Working pressures are slightly higher than R-11 and R-123, meaning heat exchangers will be

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designed for working pressures above 15 psig (100 kPa) and carry ASME certification.

R-514A is a blend (75% R-1336mzzZ/25% R-1130E) designed to be close to R-123 in pressures and capacities. Like R-123 it is a higher toxicity fluid (ASHRAE "B1"), which may limit its market acceptance. It is primarily used in existing R-123 designs for new equipment applications.

Sarah Kim: In addition, I would like to add that R-1233zd(E) has a very low GWP of 1,[1] which makes it suitable as a long-term solution. With advancement in technology, it is expected that R-1233zd(E)-based low pressure solutions will replace some of the medium pressure smaller capacity chillers due to its superior efficiency and the nonflammable nature of the fluid per Standard 34-2019.

Are any of these more optimal solutions than others?

Johnston: R-1233zd(E) has been the refrigerant of choice for new equipment designs, with multiple manufacturers designing new chillers based on this fluid. The "A1" rating, high efficiency and single working fluid are key attributes driving this.

Kujak: All alternatives in this category are acceptable for use in large capacity water cooled chillers. They are all high efficiency and all easy to handle. Even though a number of these replacements are not design-compatible replacements for R-134a, manufacturers are announcing their use as primary options to replace existing R-134a products.

Can any of these alternatives be used to retrofit existing R-123 chillers?

Charles Allgood: Yes, R-514A was developed specifically as a replacement for R-123 in both existing R-123 chillers and new systems similar in design to traditional R-123 systems.

Kujak: Yes, R-514A is a near design-compatible option for R-123 designs, and engineered retrofits are available. Any refrigerant retrofit requires proper considerations to the impact on the application and the chiller performance. In the last transition, a large number of R-11 units were retrofitted to R-123. R-123 with a GWP of 77 is already considered a low GWP, so the cost of future R-123 will be unaffected by a GWP based refrigerant allocation restriction. Thirty years of experience with R-11 shows that R-123 will be available long into the future beyond the expected life of the equipment.

Johnston: With proper preparation, it would be possible to use R-514A in an existing R-123 chiller. For example, an oil flush and change is required, and impeller and/or gear changes may also be needed. It would be best to consult the chiller manufacturer about the possibilities and performance impacts.

What about using natural refrigerants in large water cooled chillers?

Kujak: Natural refrigerants like ammonia (R-717) are seeing incrementally more adoption in this area for comfort cooling, but its toxicity is limiting its use in large refrigerant charge systems. Hydrocarbons are not being adopted in this area because of significant safety concerns, and carbon dioxide (R-744) efficiency is too low and its pressure is too high to warrant any consideration.

Johnston: Due to their highly toxic and highly flammable properties, refrigerants such as R-717 or hydrocarbons are not preferred in these types of high charge size systems, especially when installed outside of industrial settings. Many of these large building chillers are in use in densely populated urban environments where the risks of using ammonia are too high, or simply not allowed by local regulations.

What are potential alternatives for R-134a and what attributes make these good low GWP alternatives for R-134a?

Allgood: R-513A is the leading nonflammable, low GWP replacement for R-134a in a wide variety of applications including low temperature ice rink chillers, low-temperature/medium temperature commercial refrigeration systems (stand-alone, cascade, distributed architectures) and comfort cooling chillers. Numerous OEMs have commercialized equipment based on R-513A. Its similarity to R-134a in terms of capacity, efficiency and pressures with ~50% reduction in GWP have also made it the preferred choice when retrofitting an existing R-134a system in the field.

Kujak: The HFC GWP regulations are a phasedown process rather than a phaseout process that was required during the ozone depletion regulation. As such, the regulation realizes that as refrigerant technology matures, interim moderate GWP refrigerants may be required as transitional fluids to enable the phasedown process and lessen the impact of the refrigerant transition.

R-513A is one of those candidates to replace R-134a. R-513A is an Standard 34-2019 A1 refrigerant with a GWP of 630, which is >50% lower in GWP than R-134a. R-513A has similar capacity, pressures and efficiency to R-134a, which makes it an ideal candidate for adoption to replace R-134a. R-513A is an azeotropic blend of ultralow GWP R-1234yf and R-134a. Products are available using this refrigerant, and since R-513A is near design compatible to R-134a, retrofitting is possible.

Johnston: R-513A, an HFO/HFC blend (56% R-1234yf/44%R-134a), was developed as an "A1" solution, adding enough R-134a to the R-1234yf to move into the nonflammable classification. This is viewed as an interim solution, as the GWP is higher than the GWP of R-1234yf and R-1234ze(E) (~1), and the efficiency is worse than R-134a. This means it may actually be a negative for the climate when compared to R-134a.

Since R-513A is considered an interim alternative, what will be the long-term solutions?

Allgood: Longer term products like pure HFO-1234yf with a GWP <1, or R-516A with a GWP <150 would provide similar performance to R-513A, with an A2L classification. Other products, like R-1234ze(E) and R-515B provide the industry additional options in this general performance category, but with higher boiling points and lower capacity, they may be more limited in use. The A2L solutions such as R-1234yf, R-1234ze and R-516A cannot be used as retrofit refrigerants and will only be applied in new systems designed for flammable refrigerants and in compliance with safety standards and codes.

Kujak: Obtaining lower GWP than R-513A requires the adoption of flammable refrigerants. Ultralow (<10 GWP) GWP R-1234yf and R-516A (<150 GWP), both Standard 34-2019 Class A2L, are both possible solutions. R-516A is an azeotropic blend of R-1234yf, R-134a and R-152a. Each has similar capacity to R-134a, but each is flammable, which will require different product design and application changes to allow their use. R-516A has been shown to be similar in capacity and efficiency to R-513A, so logistically it would be a preferred refrigerant to R-1234yf, which is lower in efficiency.

Other leading candidates are ultralow GWP R-1234ze(E) (ASHRAE Class A2L) and R-515B (<300 GWP ASHRAE Class A1), which is an azeotropic blend of R-1234ze(E) with R-227ea. R-1234ze(E) and R-515B are both 25% lower in capacity in comparison to R-134a, so they don't make ideal candidates as direct replacements for R-134a, but with a redesign can perform similarly to R-134a.

Johnston: R-515B (91% R 1234zeE/9% R 227ea), with a GWP less than 300, is a longer-term A1 blend option. This can operate in the new long-term R-1234ze(E) compressor designs, with better efficiency than R-513A. HFO-1234yf and HFO-1234ze(E) are viewed as long-term low GWP alternatives to R-134a. Both are single working fluids with properties similar to R-134a. R-1234yf offers similar capacity to R-134a, with about a 5% efficiency penalty. This makes it attractive for automotive air-conditioning applications, as the compressor size remains about the same. R-1234ze(E) offers similar efficiency to R-134a but with about a 25% loss in capacity when compared to R-134a. Because of the similar efficiency, R-1234ze(E) is the refrigerant of choice for HVAC applications, and compressor designs will have to be changed to recover the 25% capacity gap from R-134a drop-in designs. Both carry an ASHRAE "A2L" (lower toxicity, lower flammability) designation that will require changes to current building codes in many areas.

Kim: R-516A is an azeotropic blend with a very low GWP of 131.1 Refrigerants with <150 GWP are generally recognized as long-term solutions by various government entities in Europe (F-Gas), and California (CARB). As R-516A has zero glide, it is easier to handle, unlike zeotropic blends that can fractionate, and a whole system recovery would likely be needed in case of a system leak. Although R-516A should be used in new systems as an A2L fluid, R-516A is the lowest GWP fluid with matching capacity and efficiency to R-134a. Thus, R-516A would minimize the amount of design changes an OEM would encounter versus some of the other choices in this space.

Samuel Yana Motta: If regulations allow GWP <300, R-515B is a good long-term option. It helps minimize the cost of mitigation for flammable 2L refrigerants. If regulations require GWP <150, R-1234ze is the best long-term option.

Can any of these alternatives be used to retrofit existing R-134a chillers?

Allgood: R-513A is very similar to R-134a in terms of capacity, efficiency and pressures and, with ~50% reduction in GWP, have also made it the preferred choice when retrofitting an existing R-134a installation. As previously noted, the A2L solutions such as R-1234yf, R-1234ze and R-516A cannot be used as retrofit refrigerants and will only be applied in new systems designed for flammable refrigerants and in compliance with safety standards and codes.

Kujak: Retrofitting is possible with R-513A. However it requires an engineer retrofit with possible changes needed in lubricant, and consideration needs to be given to slight impacts on capacity and more importantly impacts on reduced efficiency. Retrofitting R-134a equipment with flammable refrigerants will not be allowed because of their flammability.

What about using natural refrigerants as a replacement for R-134a equipment?

Kujak: Natural refrigerants like ammonia (R-717) are seeing incrementally more adoption in this area for comfort cooling, but its toxicity is limiting its use. Hydrocarbons are not being adopted in this area because of significant safety concerns with flammability, and carbon dioxide (R-744) efficiency is too low and too high pressure to warrant any consideration.

What are potential alternatives for R-404A and what attributes make these good low GWP alternatives for R-404A?

Allgood: R-448A/R-449A are the leading nonflammable replacements for R-404A/R-507 in commercial refrigeration, particularly in the traditional supermarket parallel rack system designs, but also in cold storage and other industrial refrigeration applications—even those still relying on R-22. Due to their nonflammability (a requirement when retrofitting R-404A) and excellent performance match (equivalent capacity and improved EER) while reducing direct GWP by ~70% , they have been adopted by leading food retailers globally over the last decade to meet internal sustainability goals and regulatory requirements.

Ivan Rydkin: R-448A, R-449A and R-407H are emerging HFO/HFC or HFC blend solutions with GWP below 1,500. These are all class A1 refrigerants and are handled and optimized in the same way technicians are already used to. With R-407H, it's the same exact chemistry as R-407A and R-407C, which has been proven over the last 20 years. We expect that new installations and all R-404A retrofits can be completed with these gases and likely be in compliance with the overall phasedown through the 20+ year lifetimes of the systems. So, engineers specifying these gases today should be able to design for the long term.

Kujak: Unfortunately, fluorinated refrigerant technology options continue to be less ideal as R-404A replacements. In the last transition, R-404A was an ideal candidate to replace R-502 and R-22 since it had similar capacity and more importantly lower compressor discharge temperature and low temperature glide. Refrigerant temperature glide is an important attribute for a number of reasons, but the largest impact is on heat exchanger design and selection. Compressor discharge temperature is important to allow the adoption of the refrigerant without changes to compressor designs to provide discharge superheat cooling.

In the R-404A space, a number of interim GWP ASHRAE Class A1 candidates (GWPs from 1,200 to 1,500) have emerged as acceptable replacements for R-404A (GWP >3900). These candidates are blends of existing HFCs, like R-32, R-125, R-134a with R-1234yf and R-1234ze(E). R-448A, R-449A and R-452A (for transport refrigeration applications) are candidates that are being adopted globally. Unfortunately, these refrigerants are blends with elevated temperature glide, which doesn't allow them to be adopted in all R-404A applications, such as flooded evaporators. In addition, other lower HFC blends with similar attributes have been developed as well in the R-407 series of refrigerants, which are blends of R-32, R-125 and R-134a.

Can any of these alternatives be used to retrofit existing R-404A equipment?

Allgood: Conversion guidelines have been developed by refrigerant manufacturers and component OEMs have qualified their full lines for R-448A/R-449A service. The refrigerant conversions are relatively simple with key factors needing attention being expansion valve adjustments and discharge temperature mitigation.

Rydkin: Yes, they can with proper preparatory work. The changes may include simple system adjustments, TXVs, EXVs and updating the controller with new firmware, which is something the refrigeration industry companies and technicians are expert at, having gone from R-12 to R-502/R-22 to R-404A/R-507A and now to the next generation. For retrofits, R-448A, 449A and 407H can be drop-in for the last few R-22 systems (requiring an oil change), and they are "near" drop in for R-404A/R-507A systems (requiring TXV adjustment or replacement for low temp). For new systems, these alternatives provide an energy efficiency benefit up to 12% over R-404A and are used in the well-known equipment/compressors, so there are years of technical experience with these systems out in the industry.

Since many lower GWP alternatives are considered an interim alternative. What will be the long-term solutions?

Rydkin: We will see A2L refrigerants below GWP 150 such as the R-454 series, R-468A, R-455A as potential alternatives for some applications, with likely more on the horizon. We see all refrigerants as playing a role in the mix. This is a change from previous generations where the majority of cooling was centralized R-404A. In the future, a combination of solutions will likely be applied, with end users utilizing some portion of centralized CO2 systems, stand-alone A3 hydrocarbon systems and stand-alone and distributed A2L refrigeration systems.

Kujak: Going lower in GWP to a limit of <300 GWP, for example, requires the adoption of flammable refrigerants, either A2L (HFO/HFC blends) or A3 (hydrocarbons). In this area, HFO/HFC blends typically are similar to performance of the interim GWP candidates, but they are just as flammable.

Product safety standards are allowing higher charges of hydrocarbons, and both R-600a (isobutane) and R-290 (propane) are being used and sold today in the U.S. in small portable refrigeration and air-conditioning products. Hydrocarbons are higher efficiency than their fluorinated alternatives, but their high combustibility restricts their use to small, multi-circuit products.

What about using natural refrigerants as a replacement for R-404A applications?

Kujak: Ammonia is seeing some more innovation in this area by the appearance of smaller capacity package products such as air- or water-cooled chillers. In addition, carbon dioxide (R-744) is seeing wide adoption in cooler ambient climates where its lower efficiency impacts can be mitigated through advanced thermodynamic cycles. In addition, cascade systems (two refrigeration systems in series) are seeing more use in hotter climates, which takes into account the optimal attributes of a fluorinated refrigerant in the higher temperature operational conditions and R-744 used in the lower temperature operational conditions.

Product safety standards are allowing higher charges of hydrocarbons, and both R-600a (isobutane) and R-290 (propane) are being used and sold today in the U.S. in small portable refrigeration and air-conditioning products. Hydrocarbons are higher efficiency than their fluorinated alternatives, but their high combustibility restricts their use to small, multi-circuit products. Hydrocarbons are becoming mainstream in smaller charge (<0.33 lb [<150 g]) refrigeration systems like bottle coolers and small package cases.

As you notice from the discussion, increased product fragmentation is occurring and will continue in this HVAC&R market area with multiple refrigerants used to serve cooling needs from small capacity to large capacity.

Rydkin: We see these industrial gases being used very effectively today, and that shouldn't change in the future; for certain applications each of the three gases (ammonia, CO_2, and hydrocarbons), or a combination, may provide the best choice. A balance of efficiency, safety, and environmental impact combined with total cost of ownership will likely be the deciding factor. At the end of the day, a refrigerant and system solution for a gas station, a food delivery service, a mid-size supermarket or a full-size supermarket could be very different.

What are potential alternatives for R-410A? R-32 (HFC) and R-454B (HFO/HFC blend) are emerging solutions, and what attributes make these good lower GWP alternatives for R-410A? Are there others?

Kujak: Long-term low GWP replacements for R-410A (R-410A is 50/50 blend of R-32/R-125) is by far the most challenging technology area. There are two leading interim GWP candidates, pure R-32 (GWP 675) and R-32 blended with ultralow GWP R-1234yf to lower its GWP (GWP 460), which is called R-454B. Both are ASHRAE Class A2L and each has their beneficial attributes. R-454B is a lower GWP more design-compatible refrigerant for R-410A, while R-32 is a single refrigerant with higher capacity. R-32 adoption by OEMs requires a complete redesign of product platforms to optimize its use for both capacity, efficiency and more importantly high compressor discharge temperatures. R-454B is a close R-410A design-compatible refrigerant and only requires minor system design changes. R-454B also has the advantage of being lower GWP, which will likely allow its use longer into the regulatory future. Current regulatory actions are targeting a GWP of <750 for R-410A from 2024 to 2026.

An emerging nonflammable (ASHRAE class A1) <750 GWP candidate, R-466A, is under heavy consideration by a number of manufacturers. Being nonflammable it then could be easily adopted as a replacement for R-410A and reduce the complexity of using flammable refrigerants. R-466A is a blend of R-32, R-125 with an ultralow GWP nonflammable refrigerant R-13I1 or trifluoroiodomethane. R-13I1 is not a new refrigerant, but it was discounted in the last transition because of chemical stability and materials compatibility concerns. Compatibility additives and materials changes are likely required to allow its use.

R-466A would be an ideal interim solution until further until further innovation could lead to even lower GWP nonflammable alternatives. Myself and my colleagues have written a number of papers on the performance and potential compatibility needs for R-466A.

Johnston: Both R-32 and R-454B have lower GWP than R-410A. They are also both classified A2L (lower toxicity and lower flammability) by Standard 34-2019. There are several attributes of alternates for consideration, often viewed in “spider charts” to help visualize pros and cons. Some of these attributes include capacity, efficiency, safety, economy, chemical stability, chemical reactivity, availability, etc. Each application and each alternative should be reviewed holistically to consider all attributes.

R-32 has a GWP of 675, 68% lower than R-410A’s GWP. However, the GWP does not tell the whole story as it is not a measure of efficiency. While R-32 systems could reduce refrigerant charge in certain equipment up to 40%, which saves in direct emissions, 60% to 95% of climate impact over the product life cycle is from indirect emissions from power generation. Test data found that full- and part-load efficiency rating metrics can be improved by up to 12% with R-32 over R-410A, so equipment can be designed to consume less electricity over the equipment’s lifetime.

Some of the proposed blends like R-454B and R-452B have similar capacities to R-410A, but I think R-32 is preferable to other alternatives. That’s because R-1234yf, the common HFO component added to make these blends, has 40% of capacity and 95% of efficiency of R-410A. To use R-1234yf directly would require significant compressor changes in residential and light commercial equipment, and very large piping and heat exchangers—not good value. Because R-32 is a readily available commodity, it has the potential to make a service tech’s life easier. As a single component, R-32 can be charged in either liquid or gas phases and can be more easily reclaimed.

R-466A, an A1 nonflammable proprietary blend containing trifluoroiodomethane (CF3I) or R-13I1, has been announced as an R-410A alternative. It is a three-component blend (49%R-32/11.5% R-125/39.5% R-13I1) with a glide of 1.5 Δ°C. It takes the excellent performing lower GWP refrigerant R-32 and blends it with two other chemicals that have flame-retarding characteristics, impacting performance. Regarding R-13I1, the “I” is iodine and the C-I bond is weak, making it, in our opinion, questionable for stability and for compatibility with materials as a result of potential acid formation. This can lead to reliability, durability and performance problems over time. Increased glide limits its use in DX heat exchangers and can result in changes to blend concentrations as a result of leaks and recharging, impacting performance and safety classifications. A three component non-azeotropic blend with questionable stability certainly will be more difficult to manage through supply chain and reclamation that enables the reduction goals for GWP of HFCs.

Published information suggests R-466A has slightly lower performance than R-410A, and less than the performance of pure R-32. R-466A’s GWP of 733 GWP is within targeted thresholds <750. However, it requires more charge than R-410A by estimates of 10% to 25%, compared to R-32’s GWP of 675 with charge levels 25% to 40% less than R-410A. Any extra charge means more charge that could leak, so R-466A’s “effective” GWP is higher than R-32’s.

R-466A is an A1 class, but it as has a refrigerant concentration limit (RCL) of only 6.2 lb/Mcf (99 g/m^3) driven by its toxicity rather than flammability, and that compares to R-410A with a RCL of 26 lb/Mcf (420 g/m^3). With requiring 10% to 25% more charge compared to R-410A systems, charge limitations in real-world applications would still be an issue.

No major North American equipment or compressor manufacturers have announced or shared that they are developing equipment and component parts around this refrigerant. This suggests it is not presently viewed as a viable candidate. Further, R-466A is only produced in small quantities today, which potentially makes the blend expensive, which is concerning for the low-income sector and developing nations and inhibits broad-scale adoption.

Allgood: The two leading alternatives to R-410A in air conditioning are R-454B and R-32, which several OEMs have announced plans to use in new generations of systems. Both are classified by Standard 34-2019 as lower flammability (2L) refrigerants and based on the equipment standards that have been developed, they will only be used in new systems and cannot be used as retrofit gases. The finalization of safety standards and updating of building codes, along with training of the technician workforce, are key milestones in these new refrigerants becoming mainstream in North America.

R-454B and R-32 differ in several key technical aspects such as GWP: R-454B (466) vs R-32 (675). This difference can have implications in later years for long-term compliance with global HFC phasedown regulations. Differences in oil compatibility and discharge temperatures, along with overall system design compatibility when compared to R-410A system designs are also a consideration.

The technology barriers to designing a nonflammable R-410A solution are many, and they have to do with the performance characteristics desired versus the fluid properties available. When looking at fluid choice, flammability is one element of consideration, but it not the only consideration. As mentioned previously, refrigerant stability, materials of compatibility, overall environmental impact and total system cost are other factors included in fluid selection. OEMs evaluate all of these factors closely and make determinations based on the total picture and what will serve their customers and market best for the lifetime the equipment is expected to deliver.

Can any of these alternatives (R-32 and R-454B) be used to retrofit existing R-410A equipment?

Kujak: No! Under no circumstances should these flammable refrigerants (ASHRAE Class 2L, 2 or 3) be used to retrofit existing R-410A equipment. Serious safety situation could result. Much marketing of primarily R-32 and to a lesser extent R-454B and their potential benefits has led to inquiries to retrofit installed R-410A equipment.

On the other hand, R-466A potentially could be used as engineered retrofit for some R-410A products since R-466A is nonflammable (ASHRAE Class 1). This will be an interesting opportunity to watch and see how it develops for existing R-410A equipment.

Are these current alternatives (R-32 & R-454B) considered a long-term low GWP solution?

Johnston: Yes. Because of R-32's availability, low cost and excellent performance, it is already used in large quantities in R-410A and most alternative low GWP blends. Given R-410A's wide use today, we know R-410A, and therefore R-32, will be in the service chain for several years to come as high GWP HFCs are phased down gradually.

Kujak: No. Both R-32 (GWP 675) and R-454B (GWP 466) will be adopted to replace R-410A as interim GWP steps until phasedown regulations push them out of use. Much debate is occurring how long the adoption window will last, but it is estimated to be the 2030 to 2036 time frame before other lower GWP refrigerants will be needed to meet the regulations. Refrigerant research and innovation are underway on lower GWP alternatives to allow the transition from <750 GWP alternatives to more long-term sustainable GWP limits, with <300 GWP as a possible target.

What about using natural refrigerants as a replacement for R-410A applications?

Johnston: Natural refrigerants, for example R-290 (propane) with its A3 classification, are being used in small systems in very small charge quantities in residential refrigeration applications. As mentioned above, each refrigerant must be evaluated for each application in a variety of characteristics. The difficulty then for application of A3 refrigerants into larger capacity systems, which are the norm in residential and commercial buildings, is that due to the larger charge sizes necessary, the much lower (about 10 times) flammable concentration limits and much lower minimum ignition energy (MIE), it is much more difficult to apply such A3 refrigerants. For consideration of other natural refrigerants, characteristics such as toxicity (R-717) or pressure (R-744) either mean they can'tt be used in human comfort applications due to current building codes (R-717) or major system designs and efficiency can be problematic (R-744). Ammonia, hydrocarbons and CO_2 have not been widely pursued in this segment due to toxicity, safety and energy efficiency issues.

Kujak: Product standards are allowing higher charges of hydrocarbons, and both R-600a (isobutane) and R-290 (propane) are being used in small portable refrigeration and air-conditioning products. Hydrocarbons are higher efficiency than their fluorinated alternatives, but their high combustibility restricts their use to small, hermetically sealed multi-circuit products.

Carbon dioxide (R-744) is thermodynamically too low in efficiency to be given much consideration in this space other than in applications without efficiency restrictions. Ammonia (R-717) is not considered a possible alternative in applications requiring direct refrigerant expansion.

It is expected that product fragmentation will occur in the R-410A space with hydrocarbon being used in small hermetically sealed portable room air conditioner (RAC) products. Some large charge products will migrate to other available technological architecture, like chillers or other indirect refrigerant products.

References

1. Myhre, G, D. Shindell, F-M Bréon, Collins, W, et al. 2013. "Anthropogenic and natural radiative forcing." In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press. ■