Merging the Transition to Next Generation HVAC Refrigerant Technology with Effective Climate Policy

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ABSTRACT

As the world's governments begin to focus on transitioning the HVAC industry away from high global warming potential (GWP) hydrofluorocarbons (HFCs), the industry is being pressed to identify the best alternatives. Included in this debate how to handle the transition from the ozone depleting hydrochlorocarbon (HCFC) R22, which is also a high GWP refrigerant. Climate policies can benefit the environment and the consumer, but adherence to the science of refrigerants and stationary air conditioning (HVAC) technology is crucial to ensuring a sustainable, safe and beneficial transition. The primary focus of this paper is to highlight the challenges and opportunities with maximizing the direct environmental benefits of lower GWP refrigerants, some of which are slightly flammable, while considering energy efficiency and associated emissions.

This paper will review the latest next generation refrigerant technology developments for HVAC applications, cover the timing of updating safety codes and standards to accommodate the new refrigerants, and the issue of maximum efficiency technology in HVAC applications. This paper will help attendees understand the key safety and technology trade-offs inherent in any refrigerant choice for HVAC equipment, provide examples of best practices for transitioning to lower GWP refrigerants and identify technological opportunities along the way.

Introduction

Previous climate policies designed to improve HVAC climate performance were relatively simple and straight forward. The Montreal Protocol was originally adopted globally in 1989 to eliminate the use of ozone depleting substances (ODSs) by limiting production and consumption over time. The highest ozone depletion potential (ODP) CFCs were phased out first in 1996, followed by the lower ODP refrigerants (HCFCs like R22, and R123) which are still transitioning out today (Chemours 2016).

Today, the substitutes for HCFCs are high GWP HFCs. Although HFCs contribute less than 2% of total greenhouse gases (GHGs) today, they could comprise as much as 20% of all GHGs by 2050 (Velders, 2009). Transitioning to lower GWP solutions in the near term could reduce the GHG impact of HFCs dramatically as shown in Figure 1.

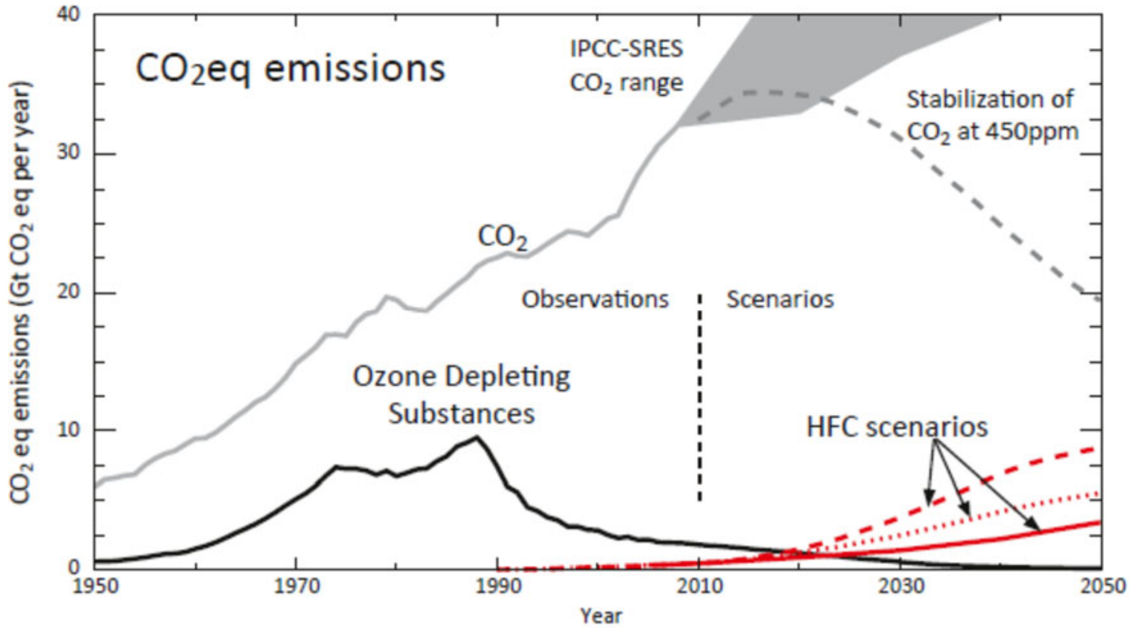

Figure 1: Trends in Co2 eq emissions of CFCs, HCFCs, and HFCs since 1950 and projected to 2050. The HFC emissions scenarios are from Velders et al. (2009) and Gschrey et al. (2011). The low-GWP HFC line represents the equivalent HFC emissions for a scenario where the current mix of emissions (with an average lifetime of HFCs of 15 years and an average GWP of 1600) was replaced by a mix of low GWP HFCs (with an average lifetime of less than 2 months or GWPs less than 20). (UNEP 2011)

Transitioning away from ozone depleting refrigerants was challenging, but substitutes were developed quickly and did not require design or service changes with regard to safety, primarily due to the fact that the replacement HFCs and HCFCs were non-flammable. Many HFC substitutes are being developed in the form of blends that reduce GWP and flammability and maximize thermodynamic efficiency. Because HFCs are included in these blends in order to balance key performance and safety attributes of the substitutes, the notion of a HFC phase down is being promoted, rather than a phase out. Good examples of this are two proposed R-410A replacements, R-32, and R-452B. R-32 is an HFC, and with a GWP of 675, is about 1/3 the GWP of R-410A. R-452B is a blend that contains R-125, R-1234yf, and R-32, and has a similar GWP of 675, as indicated in figure 2. HFCs will be a critical element to developing the lower GWP solutions to the refrigerants we use today, so phase down solutions should allow for their use as long as the overall greenhouse gas contribution is reduced.

Balancing Flammability, Performance and Toxicity in Next Generation HVAC Products:

For the past several decades, the HVAC industry, for the most part, has been able to utilize both non-toxic, and non-flammable refrigerant solutions. As we drive to achieve the best balance in environmental performance, there is increasing pressure to evaluate the use and benefits of slightly flammable solutions. The use of slightly flammable refrigerants now give the industry an additional host of potential solutions with which to develop next generation solutions.

An example is the use of R410A for unitary applications. R410A is a 50/50 blend of R32 and R125. This particular blend was developed to be able to utilize the favorable efficiency of slightly flammable refrigerant (R32), with the very low flammability of R125. Unfortunately, due to the poor energy performance of R125, the resulting blend, R410A, was not nearly as efficient as R22 which it replaced (Fig 2).

Now that we are able to evaluate slightly flammable refrigerant solutions, more efficient blends are now able to be developed that are superior in efficiency to R410A, that also have significant reductions in global warming potential.

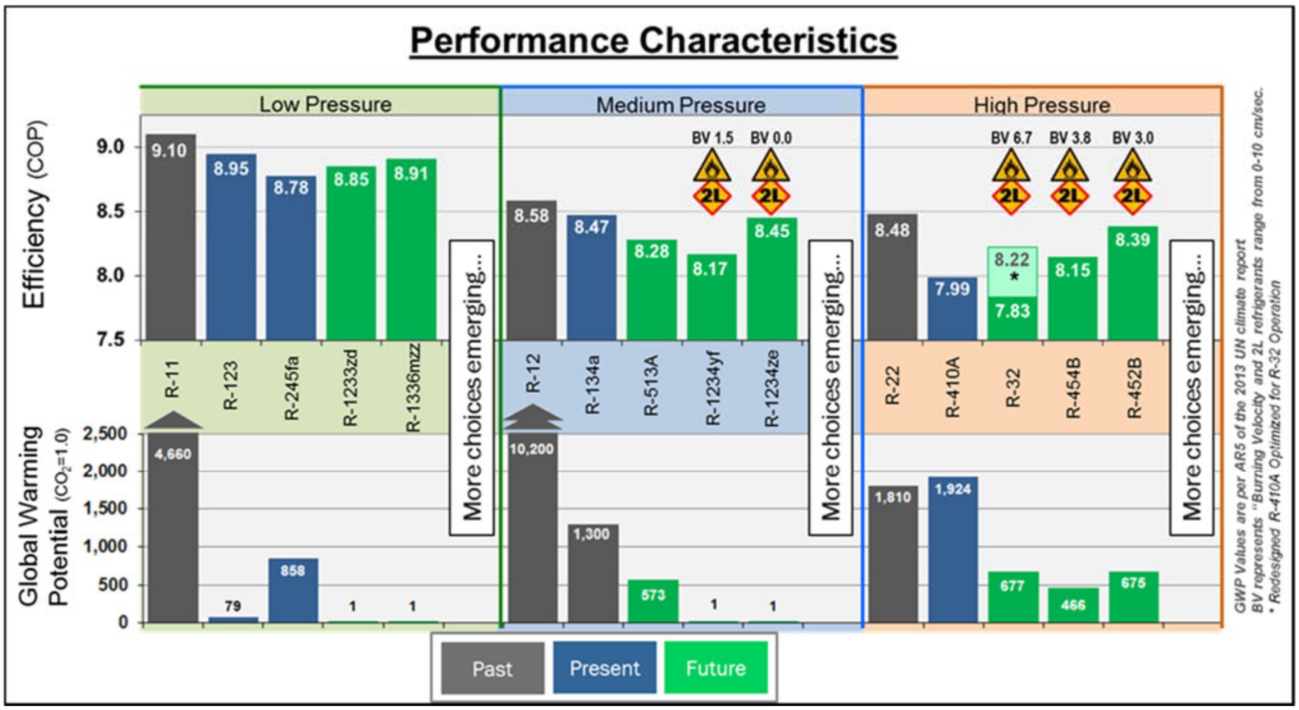

Figure 2: Efficiency, GWP and safety characteristics of next generation refrigerants (Refrigerant Performance Data)

Concerns of toxicity with the new generation of refrigerants do not appear to be a problem. In general, most fluorocarbons are relatively low in toxicity when compared to other chemicals in general use in most buildings. As we move to next generation refrigerant solutions, the toxicity levels of the new refrigerants tend to be similar or lower than what is already being used in the marketplace.

As the industry moves towards a better understanding of how to deal with slightly flammable refrigerant solutions, there is an opportunity to take advantage of certain high performance chemicals that were previously considered "off limits" due to flammability, and will enable superior environmental solutions.

Effective Policies Will Facilitate a Smooth Transition:

The HVAC industry has been through refrigerant transitions in the past, beginning with the phase out of CFCs in the early 1990's, to the current phase out of HCFCs. For the most part, these transitions have transpired with very little market disruption. By taking a careful look at previous transitions, we should be able to ensure that the next transition happens smoothly, and at an even more rapid pace.

There were several factors from the Montreal Protocol that ensured a successful transition out of ozone depleting substances. Many of those factors are currently being employed to reduce HFCs in the developing countries, and included in proposals at the Montreal Protocol that advocate a global HFC phase down. (UNEP, Ozone Secretariat). Some of those policies are:

- Setting overall HFCs phasedowns for countries, but allowing the individual nations decide specifically how they will achieve these overall HFC reductions. (US EPA, 2014)
- Allowing additional time for developing countries to reduce HFCs, allowing for the developed countries to participate in the early commercialization of new technology.
- Setting very specific transition goals by individual countries that will allow adequate time for industries to develop appropriate technology (US EPA, 2016).
- Facilitating the development of sustainable and lowest cost technology roadmaps in developing countries provides the necessary certainty that the industry needs to act.
- Not being specific about the next generation technology to allow for creativity and development of new and better solutions.

With the current path being developed by the Montreal Protocol to phase down the global use of HFCs, past lessons have been learned and applied to ensure a successful future transition. Together, next generation technology and effective policies will ensure the most environmentally responsible solutions that will be the most acceptable to consumers around the world.

Opportunities and Limits of HFOs

Next generation refrigerants include newly developed unsaturated fluorocarbons known generally as hydrofluoroolefins, but are commonly referred to as HCFOs and HFOs. Going forward in this paper this group of refrigerants will be referred to as HFOs. HFCs and HFOs can act and perform similarly in HVAC applications, but a very short atmospheric life (less than 1 year) makes the impact to the climate by HFOs negligible (Fig 2).

HFOs can be reliable and efficient substitutes for HFCs in HVAC applications, but some need to be blended with HFCs to meet the performance requirements. Four primary HFOs are available in the market today; R1233zd, R1336mzz, R1234yf and R1234ze. Figure 3 provides a summary of various refrigerants. Operating pressures range from high pressure refrigerants similar to R410A, medium pressure refrigerants similar to R134a, and low pressure refrigerants similar to R123. In general, medium and low pressure refrigerants are used in screw and centrifugal chiller applications, whereas unitary and residential applications use higher pressure refrigerants.

One way to ease transition and thus increase the adoption rate of lower GWP solutions is to offer refrigerant solutions that have similar operating pressure to the refrigerants used today. For example, R452B is an HFC/HFO blend that requires a slightly lower operating pressure than R410A which allows for easy use in systems designed for R410A.

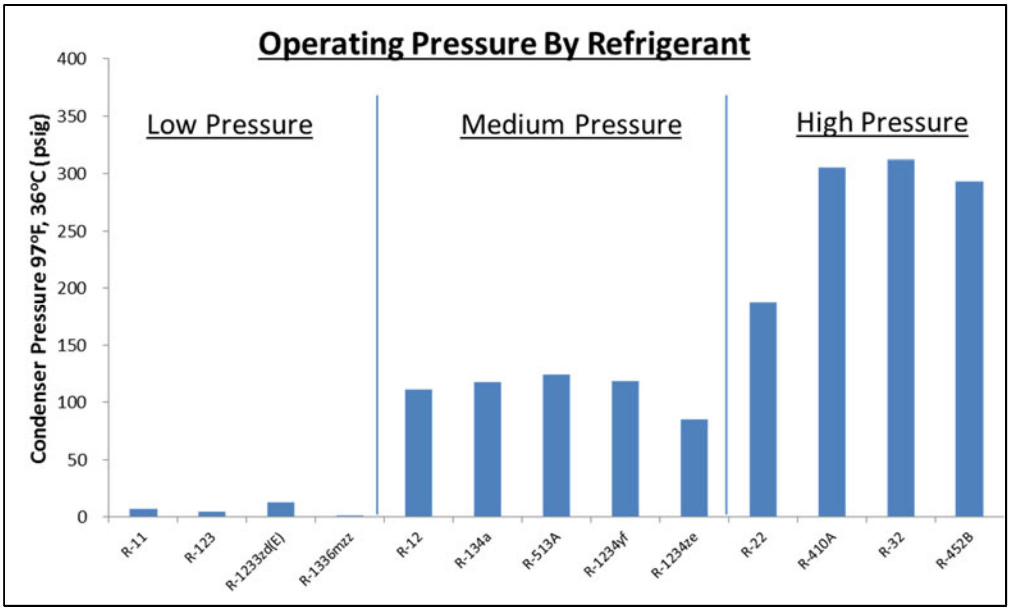

Figure 3: Summary of refrigerant operating pressure versus type (Refrigerant Performance Data)

Figure 2 gives a summary of past refrigerants and next generation HFO and HFO/HFC blends for each pressure category. Next generation options are indicated in green. Also indicated on the slide is the comparative energy efficiency versus current and past generation options. Some of the next generation refrigerants are labeled as “2L” flammable refrigerants. This designation indicated that it falls under the ASHRAE definition of a “slightly flammable” refrigerant. Slightly flammable refrigerants are significantly less flammable than the hydrocarbon counterparts such as propane. The flammability is also rated with the refrigerants BV (Burning velocity). The lower the burning velocity results in lower resulting flammability of the compound.

As shown in Figure 2, refrigerants with lower operating pressures tend to show increased energy efficiency, but are larger and less compact, and are primarily used in chiller applications. Refrigerants with higher operating pressure result in smaller and more compact equipment which is necessary for unitary and residential applications. As fluorocarbons get higher in pressure, they tend to become more flammable. Non-flammable solutions exist for low pressure applications, slightly flammable solutions exist for medium pressure solutions, and flammability gets a little higher for the high pressure solutions.

The quickest opportunity for introducing next generation equipment into the marketplace is in the low and medium pressure applications, like screw and centrifugal chillers with nonflammable substitutes. These solutions are R1233zd, R1336mzz and R513A, which are nonflammable and have similar operating pressures and efficiency to R123 and R134a. (Schultz, Kujak and Majurin 2015)

Merging Optimum Technologies with Effective Climate Policies

There is a strong desire among the climate leaders of the world to move away from HFCs quickly. A quick move is both technically feasible, and environmentally responsible for some HVAC applications. However, other applications will require additional time to address flammability and the resulting safety issues. Safety standards and building codes are on track to be updated in the coming years and will allow for the use of slightly flammable refrigerants in many HVAC applications.

Equipment manufacturers are consistently updating HVAC products to meet the latest energy efficiency standards, or to incorporate the latest design technologies. If specific refrigerant phase out dates are set, then manufacturers can easily incorporate refrigerant updates concurrent with regularly planned product updates. The CFC to HFC transition experience tells us that a specific phase out date set at the appropriate amount of time in the future will result in an orderly and effective transition.

The industry can move rapidly in applications where nonflammable, design compatible refrigerants and can be used in the following areas.

Cost Impact of Next Generation Refrigerants

Whenever the HVAC industry is charged with transitioning to newer technology, there always the concern that cost will dramatically increase. The history of refrigerant change outs has proven that this concern is often exaggerated. For example, when the industry transitioned from the CFCs R11 and R12 in the early 1990s, the new products and refrigerants were very expensive at first. Over a very short period of time, prices dropped down to levels lower than the technology that preceded it. The end result was that the industry adopted the new refrigerant two years ahead of the mandated 1996 phase out date.

It is expected that the same trend will continue with next generation HFOs. The developed countries will initially see higher pricing for early adopters, but by the time the changes are mandated, and the developing countries are required to transition, the cost impact will likely be negligible. This is especially true with technologies that can incorporate “design compatible” solutions that will not require major equipment redesigns.

Base equipment costs with next generation solutions are not expected to increase significantly as compared to what is used today. The primary cost add will be from the additional cost of the refrigerant. Depending on the equipment type, refrigerant cost comprises approximately 5-15% of the overall cost of HVAC equipment. There is also technology being employed, such as mico-channel heat exchangers in air cooled equipment that can significantly reduce refrigerant charge. The higher the cost of the refrigerant, the more effort goes towards reducing refrigerant charge of the equipment, which, in turn, reduces the cost impact of new refrigerants.

Currently Available - Nonflammable and Low Flammable Solutions

- Low pressure centrifugal chillers using R1233zd, sizes ranging from 700 tons to 4200 tons
- Low pressure centrifugal chillers using R1336mzz, with sizes ranging from 150 tons to 3900 tons.
- Screw chillers and centrifugal chillers using R513A (100 tons to 400 tons), and screw and centrifugal chillers in the EU using R1234ze (less restrictions in some countries to use a nearly non-flammable refrigerant). Tonnage range for these chillers is approximately 100-350 tons, with larger capacities available if multiple compressors are employed.
- Small capacity and thus small refrigerant charge sealed systems using R452B, R32 and hydrocarbons. The options are currently limited to small charge chillers and mini splits due to the work still underway on treatment of slightly flammable refrigerants.

As of February 2016, there are next generation solutions available in the marketplace in a variety of products and from a variety of manufacturers. Some of those products include:

- Centrifugal chillers using R1233zd, R513A and R1234ze , R1336mzz
- Screw chillers using R513A and R1234ze
- Small air cooled scroll chillers using R452B
- Small split systems using R32

Available Soon - 2L Flammable Solutions for Outdoor Chiller Applications

- Outdoor centrifugal and screw chillers globally using R1234ze
- Outdoor scroll chillers using R452B or R32

Available after 2021 - 2L Flammable Solutions for All Applications

- Indoor mechanical equipment room applied centrifugal and screw chillers
- Unitary (scroll and reciprocating compressors) applications using R452B, and R32
- Residential applications using R452B, and R32

Design compatible or “drop in” solutions should be prioritized where available because they require the least amount of design changes. For example, R513A may appear to be a less ideal substitute for R134a (GWP= 1300) because of its GWP of 572. R513A has a near identical pressure and capacity profile as R134A. However, R513A is a nonflammable candidate to replace R134a which results in a nearly 60% reduction in GWP. R513A also has a near identical pressure profile as R134A, which makes an ideal “drop in” candidate that can facilitate rapid, cost effective transition. Future lower GWP solutions, like R1234ze, are slightly flammable and require equipment redesigns which require investment and time to develop as optimize solutions. The HVAC industry typically opposes a “dual transition” strategy, but because one of the transitions is virtually without investment and barriers, moving to R513A is considered insignificant. Although a minor efficiency reduction results with the use of R513A in existing R134a systems, the equipment can be adjusted to easily meet the most strict energy efficiency regulations at full and part load efficiency.

R452B is a similar design compatible solution for R410A products with an additional benefit of approximately 5% increase in energy efficiency (Fig. 2). No redesign is required with the use of R452B, and the significant efficiency improvement provides an incentive to transition the unitary and residential equipment very rapidly once safety standards and building codes are updated (Kujak and Schultz 2015).

Summary

Balancing the availability of next generation technology with effective climate policy can help the environment, while also minimizing the financial impact the users of HVAC equipment.

The keys points that must be recognized are:

- Technology is available today for some applications, such as chillers and smaller unitary applications.
- Regulatory pressure will be required to facilitate the move to lower GWP solutions in these areas due to the initial higher cost of the refrigerant and equipment.
- The additional cost of the new refrigerant and the technology is expected to moderate over time as regulations are put in place
- The CFC to HFC transition teaches us that a specific phase out date set at the appropriate amount of time in the future will result in an orderly and effective transition.
- In some cases, such as a transition away from R410A where design compatible solutions like R452B are available with a significant improvement in efficiency, there is an opportunity for very fast adoption once the hurdles of safety standards and building codes are put in place to handle 2L flammable refrigerants.
- Design compatible nonflammable solutions, like R513A to replace R134a, offer an immediate opportunity for transition with little to no market cost needed to make the transition.

In developing countries the transition from R22 to R410A is in process or has not taken place. No optimal next generation low GWP refrigerants have been identified to replace R22. Developing countries that are currently using R22 should give very careful consideration to both the issue of design compatibility and flammability. These countries are very concerned about being first with a new refrigerant due to both flammability and cost concerns. There is also a high level of concern about converting the industry to an HFC solution that will quickly become obsolete. Solutions like R452B to replace R410A will allow for developing countries to invest in R-410A technology in the short term, with the knowledge that they will be able to easily convert to a design compatible solution once the concerns about cost and safety are resolved by the earlier transition by developed countries.

Conclusions:

Technology exists today, and new products are becoming rapidly available that can significantly contribute to a global phase down of HFCs needed to meet proposals currently in discussion at the Montreal Protocol. A total ban on HFCs is not planned, but dramatic reductions can be achieved that are safe and efficient.

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