CO_2: The Inconvenient Truth

There are now better technologies than CO_2 for retail refrigeration systems

Opteon™

Introduction

Several articles have been published over the last 12-18 months **raising doubts about the green credentials of R-744** as a refrigerant due to its inherent poor energy efficiency.

This raises the obvious questions of why did the industry choose a relatively high total emissions technology and are there other technologies which need to be considered before a definitive opinion can be made about which low GWP option provides the lowest environmental impact and best value for money.

From a climate change emissions perspective, it's obvious that any significant leakage of the high GWP R-404A (3922) easily outweighs any energy efficiency benefits seen over using R-744. Of course, the issue when choosing R-744 technology is that the equipment is more complex, more expensive and less energy efficient. **This contributes to a higher 10-year Life Cycle Cost, but the EU F-Gas Regulations primary focus is low GWP not cost, so R-744 appeared to be a good choice...**

BUT IS IT REALLY?

What options were initially available?

The use of R-744 as a refrigerant is of course nothing new. During the development of vapor compression refrigeration systems in the late 19th century diethyl ether, ammonia and carbon dioxide (R-744) were all commonly considered as refrigerant fluids. As vapor compression technology developed, the flammability of diethyl ether and the poor energy efficiency of R-744 proved to be more difficult to overcome than the low flammability and toxicity of ammonia leading to a decline in the popularity of R-744.

Fast forward to the late 20th century when agreements such as the Kyoto Protocol (1997) raised awareness of the spectre of global climate change and the gases that are contributing toward it. With a GWP of 1, R-744 seemed to be a perfect candidate and many research projects were launched to tackle the previously mentioned energy efficiency deficiencies.

Following the phase-out of CFCs in the early 1990s, R-404A became the dominant refrigerant choice for retail refrigeration, often in systems with poor maintenance regimes and very high (>15%) annual leakage rates (ALR). From a climate change emissions perspective these very high leakage rates combined with the high GWP of R-404A (3922) easily out-weighed any energy efficiency benefits over using R-744 (Figure 1). This led to the transcritical R-744 Flash Gas Bypass (FGB) or booster system becoming the most common low GWP technology chosen today by retail stores for new equipment.

The fly in the ointment when choosing R-744 technology is of course that the equipment is more complex and expensive and the poor energy efficiency leads to a higher 10-year Life Cycle Cost (10-year LCC, Figure 2), but the regulations primary focus is low GWP not cost, so R-744 appeared to be a good choice.

After 2021 the EU F-Gas Regulation will ban the use of refrigerants with a GWP >=150 in multi-compressor retail systems >=40kW capacity. Ultimately by 2030, under the EU F-Gas phasedown where an approximate 400 GWP average must be achieved. For these reasons, although the use of moderately low GWP refrigerants such as Opteon™ XP40 reduces the 10-year LCC and the total emissions by 36-47% compared to R-404A, at a 10% ALR it still has higher total emissions than an equivalent transcritical R-744 FGB system, even in hot climates (Figure 1), and is therefore not a practical long-term choice for new equipment under the EU F-Gas Regulation.

Figure 1

Comparison of 10-year Total Emissions ($TeqCO_2$) using R-404A (10% ALR), Opteon™ XP40 (10% ALR) and Transcritical R-744 FGB systems for a standard supermarket (~2000m² sales area, 160 kW medium temperature/30 kW low temperature) in different climates

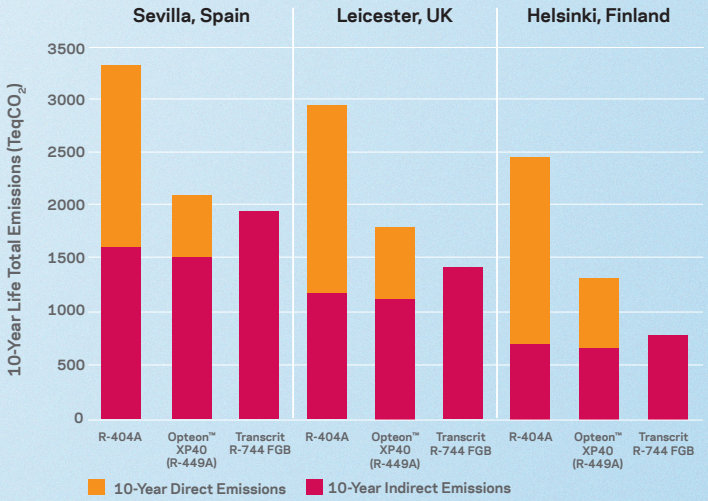
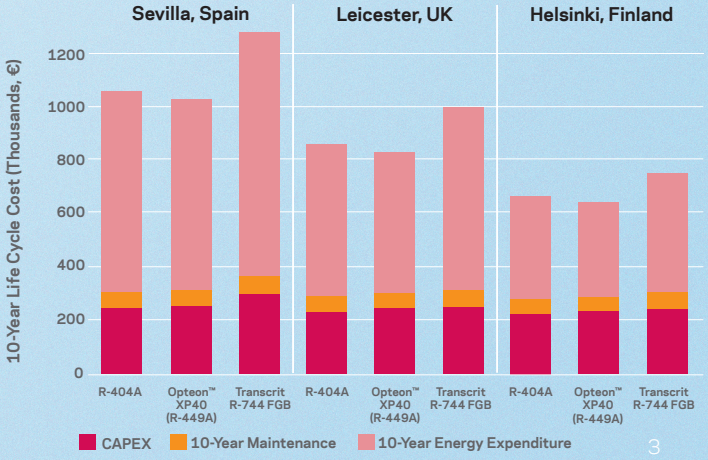


Figure 2

Comparison of 10-year Life Cycle Cost using Transcritical R-744 FGB System, R-404A and Opteon™ XP40 systems for a standard supermarket (2000m² sales area, 160 kW medium temperature/30 kW low temperature) in different climates



Is there a better option than R-744?

As well as reducing total climate change emissions, retailers have expressed a wish list of criteria to which their choice of refrigeration technology should comply:

- **Match Cooling Performance**
- **Match Or Exceed Energy Performance**
- **Match System Uptime (minimise risk to trade)**
- **Match Or Improve Total Cost Of Ownership AND**
- **Ideally Match Ease Of Installation And Maintenance**

Although R-744 achieves the primary objective of lowering the total emissions, apart from matching cooling performance, the use of R-744 does not necessarily meet the other desired criteria.

Clearly there is room for improvement in the technology choice.

Very low GWP A2L refrigerant blends such as Opteon™ XL20 and Opteon™ XL40 have been commercially available since 2016, but the focus of many retailers to retrofit existing equipment away from R-404A ahead of the EU F-Gas 2020 service ban, has meant opportunities to explore the benefits of these options have, until now, been limited.

Within the refrigeration sector, the first commercial application of the very low GWP Opteon™ XL range was made in October 2017 when a low temperature cold store at Park Cake Bakeries in Oldham (UK) was installed using Opteon™ XL40. Raising the profile of this alternative technology led to interest from retailers for use in supermarket refrigeration. Equipment and components for the Opteon™ XL products are now available, as evidenced by the installations made by the large retailer ASDA and Central England Co-op in the UK, meaning the use of the very low GWP Opteon™ XL range is now a valid choice for retailers to consider.

A study performed by Wave Refrigeration considered the use of the very low GWP Opteon™ XL products based on the published practical experience gained working with ASDA.

The very low GWP of Opteon™ XL20 and Opteon™ XL40 combined with the improved leakage rates achieved by responsible retailers (<5%), greatly reduces the contribution of direct refrigerant emissions which, when combined with the improved energy performance when using Opteon™ XL refrigerants, results in the total emissions in a standard sized supermarket (~2000m^2 retail area) being lower than the total emissions for an equivalent Transcritical R-744 FGB system (Figure 3) in the locations considered (Helsinki 6-8% lower, Leicester 15-17% lower & Sevilla 18-20% lower).

As there is now an alternative low emissions technology that can match or reduce the total emissions to atmosphere from a transcritical R-744 FGB system, the cost element now becomes a relevant and important consideration.

Use of the Opteon™ XL refrigerant systems provide the lowest CAPEX and maintenance costs, but by far the most significant cost saving over a 10-year period is from the lower energy consumption (Figure 4) leading to significantly lower 10-year Life Cycle Costs (Helsinki 8-9% lower, Leicester 14% lower & Sevilla 17-18% lower).

The results of this analysis leave no doubt that the use of the Opteon™ XL refrigerants meet all criteria expected by retailers, delivering lower total emissions at a lower cost than Transcritical R-744 FGB technology.

Figure 3
Comparison of Total Emissions (TeqCO$_2$) for R-404A, Opteon™ XP40, Opteon™ XL40, Opteon™ XL20, R-744 FGB System and the optimal R-744 technology for a standard supermarket in different climates using 5% ALR

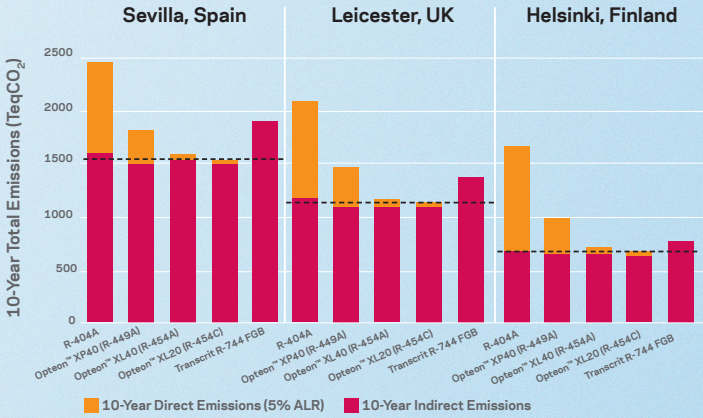
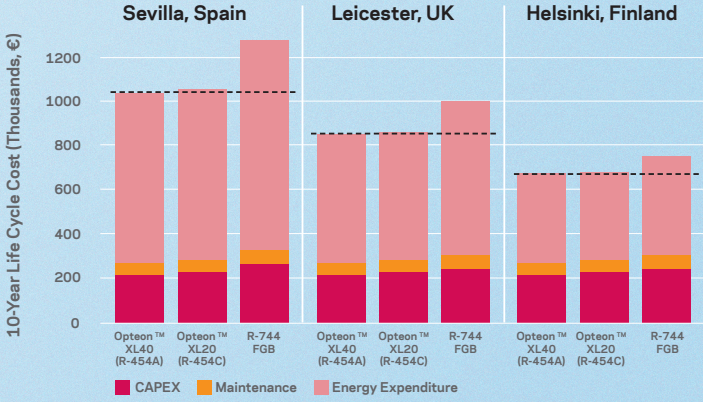


Figure 4
Comparison of 10-Year Life Cycle Cost for Opteon™ XL40, Opteon™ XL20 and R-744 FGB System for a standard supermarket in different locations



Are there other R-744 technologies that need to be considered?

Whilst the Transcritical R-744 FGB technology is often used, it is not the only R-744 architecture that has been developed. The knowledge that R-744 systems have an inherently poor energy efficiency in warmer climates has led to a geographical barrier, which has become known as the CO_2 Equator, where the use of R-744 FGB systems can become excessively costly.

This has led to over a decade of developments to try to improve the system energy efficiency, particularly in locations south of the R-744 FGB CO_2 equator boundary. To improve the performance of R-744 systems several architecture changes are employed:

1. **Transcritical R-744 FGB + Internal Heat Exchanger (IHX)**
2. **Parallel Compression**
3. **Parallel Compression + Ejector Technology**

For the standard size supermarket, across all the locations considered in this study, the R-744 option with the lowest energy consumption was the Ejector technology, but the difference in energy consumption between the R-744 FGB system and the R-744 Ejector systems significantly decreased as the climatic conditions became cooler meaning the additional CAPEX for this technology may be difficult to justify for the level of benefit achieved.

Since the climatic conditions and indirect emissions from power generation have a significant impact on the total emissions resulting from using the various technologies, a method often used to determine the most cost-efficient technology to reduce the environmental footprint of a system, is to calculate the cost of abatement per Tonne of CO_2 equivalent emissions ($TeqCO_2$) over a 10-year period.

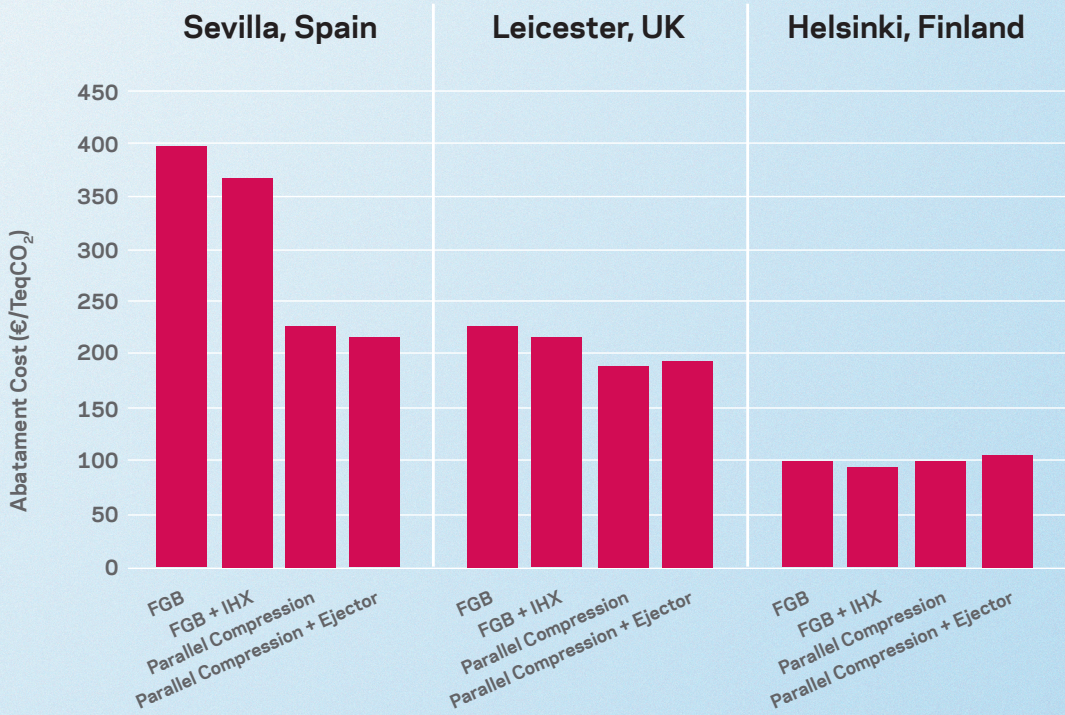
The relative emissions abatement cost can be calculated by dividing the difference in the 10-year LCC of the alternate technology (compared to R-404A) by the difference in the 10-year Total emissions of the alternate technology (compared to R-404A, 5% ALR) to give a €/$TeqCO_2$ abatement cost.

This approach does not show which technologies provide the largest reductions but does give a true vision of which technologies offer the best value for money to achieve a given level of emission reductions (or carbon footprint reduction), which in this case is at least equivalent to the R-744 FGB technology.

This approach reveals the optimum R-744 technology for each location is different i.e. the R-744 Ejector technology for Sevilla, Parallel Compression for Leicester and FGB + IHX for Helsinki (Figure 5).

Figure 5

Abatement costs of the various R-744 technologies to determine the optimal technology for each location



$$\text{Relative } CO_2 \text{ Emissions Abatement Cost} = \frac{(LCC_{Alt} - LCC_{R\text{-}404A})}{(Emissions_{R\text{-}404A} - Emissions_{Alt})}$$

At the hot climate Sevilla, Spain condition, the improvement in performance over a standard R-744 FGB system using the Ejector technology in a standard supermarket is significant (10-year LCC 5% lower and the 10-year total emissions 9% lower), but this still pales into insignificance when compared to utilisation of the Opteon™ XL refrigerant technologies which deliver 17-18% lower 10-year LCC (Figure 6) and 18-20% lower emissions (Figure 7) compared to a standard R-744 FGB system.

At the moderate climate condition of Leicester, UK, the performance improvement over R-744 FGB using the optimum Parallel Compression technology is even less significant (10-year LCC 2% lower and the 10-year total emissions 4% lower), whereas the use of Opteon™ XL refrigerant technologies still delivers a very significant reduction (10-year LCC 14% lower and the 10-year total emissions (15-17% lower) compared to a standard R-744 FGB system.

The trend continues at the cool, low energy cost, low energy emissions location of Helsinki, Finland, with just a 1% or less improvement over the standard R-744 FGB using the optimum R-744 FGB + IHX technology. In comparison, the Opteon™ XL Refrigerant technologies deliver 6-8% lower emissions at 8-9% lower 10-year LCC than the standard R-744 FGB system.

Figure 6

10-Year Life Cycle Cost Comparison of R-744 FGB & the optimum R-744 technology with Opteon™ XL refrigerant technologies for a standard supermarket architecture in different locations

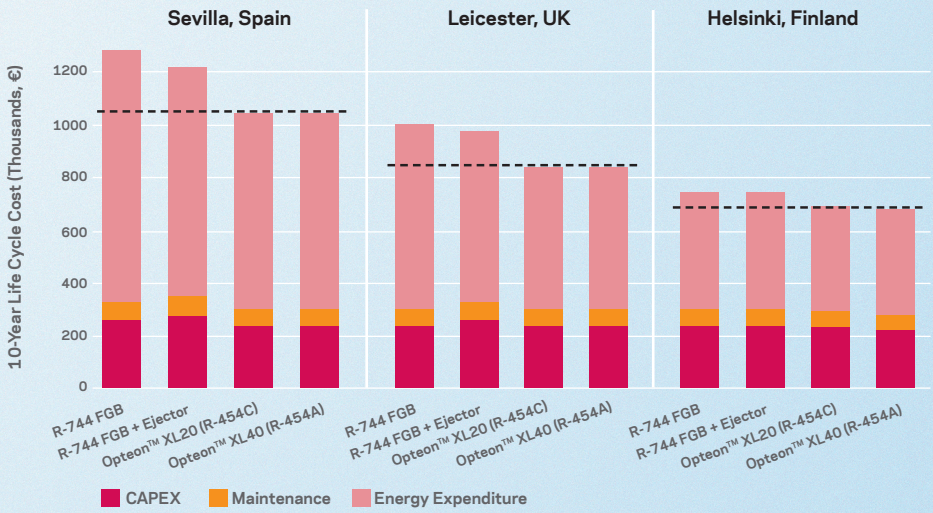
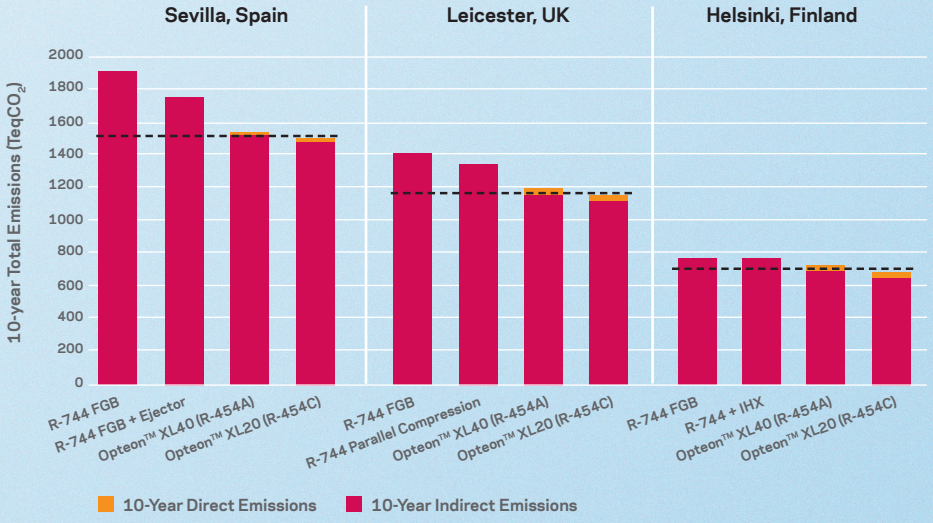


Figure 7

10-Year Total Emissions Comparison of R-744 FGB & the optimum R-744 technology with Opteon™ XL refrigerant technologies for a standard supermarket architecture in different locations (5% ALR)

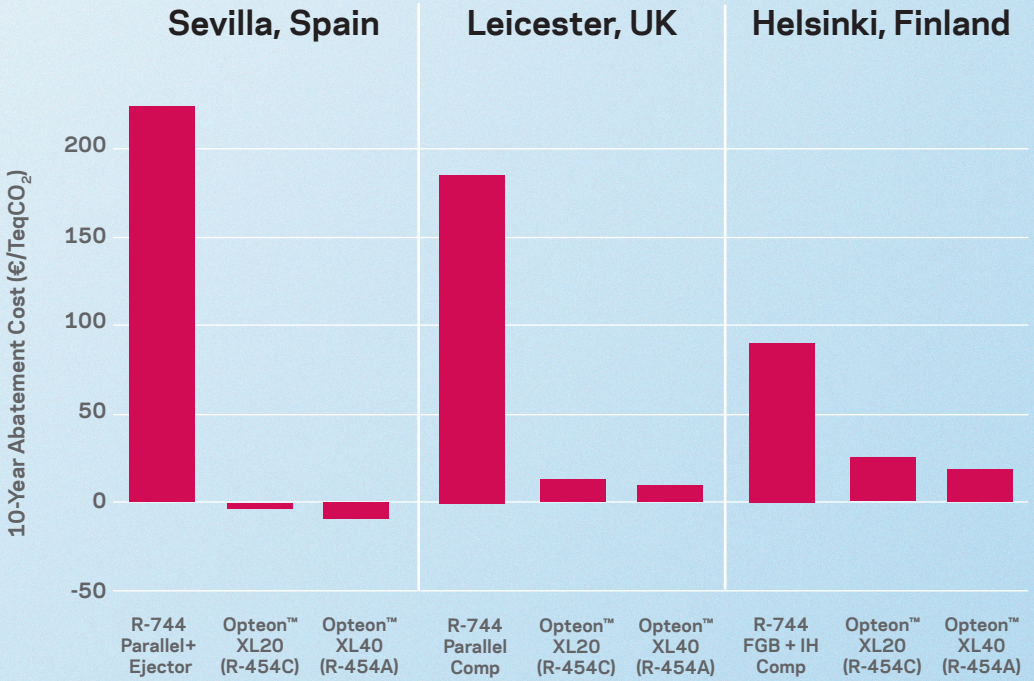


Using these enhanced R-744 technologies reduces the cost of abatement compared to using the standard R-744 FGB technology but in all locations, the abatement costs are >70% lower when using an Opteon™ XL Refrigerant technology (Figure 8).

In the hot climate conditions of Sevilla, the use of Opteon™ XL refrigerants not only reduce emissions, but deliver the required emissions reduction at a lower 10-year cost than if the system was still operating with R-404A, with no emissions reduction i.e. a negative cost of abatement (-3 to -10 € per $TeqCO_2$).

This compares very favourably to the optimum R-744 technologies, for example, in Sevilla using the optimal R-744 ejector technology the abatement cost is €218 per $TeqCO_2$. In the moderate Leicester climate, the abatement costs compared to R-744 + parallel compression use are 92-96% lower when using Opteon™ XL refrigerants and even in the cool, low carbon and low-cost power generation location of Helsinki, the abatement cost is 73-83% lower when using the Opteon™ XL refrigerants compared to using a transcritical R-744 FGB + IHX system.

Figure 8
10-Year $TeqCO_2$ abatement costs (compared to R-404A 5% ALR) in a Standard Supermarket architecture using the optimum R-744 technology in various locations compared to Opteon™ XL refrigerant technology (5% ALR)



Inconvenient or not, the truth is...

With a very low direct GWP, R-744 initially appeared to be a good choice to replace the high emissions R-404A technology but the inherent low energy efficiency and complexity of R-744 systems has left many question marks as to whether this technology is indeed the best choice.

The introduction of very low GWP Opteon™ XL20 and Opteon™ XL40 has been proven to be a viable alternative to R-404A and R-744 in both standard and small supermarket refrigeration applications. The practical experience from installations have shown improved energy performance compared with R-404A whilst maintaining similar equipment costs, system simplicity and reliability and all this has been achieved with the lowest 10-year total emissions of all the low GWP alternatives commonly used.

In terms of TeqCO_2 abatement costs, it has been demonstrated that the use of Opteon™ XL refrigerants is by far the most cost-effective technology for reducing the environmental footprint of an installation. Results vary greatly depending on location and store size, ranging from >70% lower abatement cost (compared to the optimum R-744 technology) in the cool, low cost and low carbon emissions power generation location of Helsinki to >100% lower abatement cost (compared to the optimum R-744 technology) for a standard supermarket in the hot climate of Sevilla.

So, if you are looking for a very low GWP R-404 alternative technology that:

- **Match Cooling Performance**
- **Match Or Exceed Energy Performance**
- **Match System Uptime (minimise risk to trade)**
- **Match Or Improve Total Cost Of Ownership AND**
- **Ideally Match Ease Of Installation And Maintenance**

Opteon™ XL refrigerants, why would you choose anything else?

Chemours™

The information set forth herein is furnished free of charge and based on technical data that Chemours believes to be reliable. Chemours makes no warranties, express or implied, and assumes no liability in connection with any use of this information. Nothing herein is to be taken as a license to operate under or a recommendation to infringe any patents or patent applications. ©2020 The Chemours Company FC, LLC. Opteon™ and any associated logos are trademarks or copyrights of The Chemours Company FC, LLC. Chemours™ and the Chemours Logo are trademarks of The Chemours Company.