FACT SHEET 4
Commercial Refrigeration

1. Description of market sector

This market sector includes commercial refrigeration systems and appliances used for storage and display of products in food and drink retail (supermarkets, convenience stores, shops etc.) and in food service (restaurants, hotels etc.).

Market sub-sectors

This sector uses three distinct types of equipment. These are:

a) **Stand-alone factory sealed equipment**: small systems using technology with similarities to domestic refrigerators

b) **Condensing units**: “split systems” with a cooling evaporator in the refrigerated space (e.g. a retail display) connected to a remotely located compressor and condenser.

c) **Centralised systems**: large distributed systems with a number of cooling evaporators connected to a remotely located compressor pack and external condenser.

Each sub-sector has different characteristics, especially in terms of the amount of refrigerant used (in each system). The options for alternative refrigerants vary considerably between these sub-sectors.

Operating temperature

Commercial refrigeration systems operate at two distinct temperature levels:

- Medium temperature (MT) for chilled products held at between 0°C and +8°C
- Low temperature (LT) for frozen products held at between -18°C and -25°C

Typical system design

Almost all commercial refrigeration systems use direct expansion (DX) vapour compression refrigeration cycles. Most current HFC systems use single stage compression. Each system is dedicated to a particular temperature level (MT or LT). Stand-alone systems serve one cooling load (e.g. a single food display case). Condensing units and centralised systems can serve a number of food display cases and cold storage rooms.

Alternative technologies

There is no use of technologies other than vapour compression. An alternative to the widely used DX system for centralised systems is an “indirect system” which uses a chiller to cool a secondary refrigerant (e.g. glycol, brine or pumped CO_2) which is circulated to provide cooling. They require much less primary refrigerant than a DX system. Multi-stage compression can be used to improve efficiency.

Changes driven by ODS phase out

Prior to 1990 most MT systems used CFC-12 and most LT systems used R-502. In non-Article 5 countries, HCFC-22 was used in new systems for about 10 years from the late 1980s, although most have now been replaced. From around 1997 R-404A[1] became a widely used refrigerant for both LT and MT systems. There is also some use of HFC-134a in MT systems. In Article 5 countries the use of HCFC-22 remains dominant and use of R-404A is becoming more widespread in new equipment.

[1] R-507A is also used for commercial refrigeration systems although less widely than R-404A. Comments about R-404A in this Fact Sheet also apply to R-507A.

Table 1: Commercial refrigeration: summary of characteristics for HFC equipment

Market sub-sector:		Stand-alone	Condensing Unit	Centralised
Typical refrigerant charge		0.1 to 0.5 kg	1 to 10 kg	20 to 200 kg
Typical cooling duty		0.1 to 1 kW	2 to 20 kW	40 to 200 kW
HFC refrigerants widely used		R-404A (GWP 3922[2]) HFC-134a (GWP 1430)		
Refrigeration circuit design		Factory sealed direct expansion	Distributed direct expansion	
Manufacture / installation		Factory built	Site installed refrigerant pipework	
Typical location of equipment		Class A (access by persons not acquainted with safety precautions)		
Typical annual leakage rate		< 1%	5% to 20%	10% to 30%
Main source of HFC emissions		Losses at end-of-life	Operating leakage	Operating leakage
Approximate split of annual refrigerant demand	New systems	90%	50%	30%
	Maintenance	10%	50%	70%

Stand-alone hermetically sealed systems

[2] All GWP values are based on the IPCC 4th Assessment Report

Small condensing unit:
1 compressor and condenser connected to 1 or 2 display cabinets in retail shop

Centralised system:
Rack of 7 compressors connected to numerous display cabinets in supermarket and connected to an externally located condenser

Factory built stand-alone systems have a small refrigerant charge and low leakage rates.

The larger condensing units and central systems require long runs of site installed refrigerant pipework. This leads to considerably larger refrigerant charge and the potential for much higher leakage rates. For centralised systems, the use of refrigerant to top up leaks dominates the total HFC consumption.

R-404A is the dominant HFC refrigerant used in all 3 sub-sectors of the commercial refrigeration market, for both MT and LT systems. It has a very high GWP (3922). In many countries R-404A represents more than 90% of the GWP-weighted HFC consumption in the commercial sector.

2. Alternatives to currently used HFC refrigerants

Low GWP alternatives are summarised in Table 2.

Stand-alone systems

There is wide-spread use of hydrocarbons (HCs) in this market sub-sector. Over three million ice cream freezers using HC-290 are already in use and range of other types of stand-alone system are available using HCs including retail display cases, water coolers and ice making machines. R-744 has been used successfully in bottle coolers. HFO-1234yf and HFO-1234ze are possible alternatives when HCs are restricted by regional safety codes, as they have lower flammability. Non-flammable HFC/HFO blends with properties similar to HFC-134a are available with GWPs around 600.

Table 2: Lower GWP alternatives for commercial refrigeration

Refrigerant	GWP	Flammability[3]	Comments
Alternatives to avoid use of R-404A (in new equipment and for retrofit of existing)			
R-407A	2107	1	There has been significant use of these blends in Europe as R-404A alternatives (both for new systems and for retrofit). Can have higher efficiency than R-404A systems.
R-407F	1825	1	
R-448A	1387	1	Newly developed blends with properties similar to R-407A and R-407F, but lower GWP. Currently there is limited commercial experience.
R-449A	1397	1	
Alternatives, new equipment only			
HC-600a HC-290 HC-1270	3 3 2	3 3 3	HCs are suitable for stand-alone equipment (e.g. in ice cream freezers and bottle coolers) and already in widespread use in both Article 5 and non-Article 5 countries. HCs can be considered for very small condensing units subject to safety regulations. HCs are used in some large supermarkets in stand-alone units rejecting heat into a water circuit. HCs can be used as primary refrigerant for chillers in indirect systems and cascade R-744 systems.
R-744 (CO_2)	1	1	Stand-alone: used in bottle coolers and other equipment Condensing units: some use, but capital cost is a barrier for small condensing units. Centralised: widespread use of R-744 in both transcritical and cascade configurations
R-717 (ammonia)	0	2L	Used in indirect systems, but energy efficiency can be low
HFO-1234yf HFO-1234ze	4 7	2L 2L	Not currently used, but being considered for stand-alone systems and MT condensing units.
R-450A R-513A R-451A R-451B	601 631 140 150	1 1 2L 2L	Newly developed blends with thermophysical properties similar to HFC-134a. Being considered for MT systems.
Blends awaiting ASHRAE number	150 to 300	2L	Development blends with properties similar to HFC-404A. Being considered for LT and MT condensing units.
R-446A R-447A	460 582	2L 2L	Newly developed blends with properties similar to HFC-410A. Being considered for condensing units.
HFC-32	675	2L	Being considered for condensing units.

[3] Flammability classes based on ISO 817 and ISO 5149
3 = higher flammability; 2 = flammable; 2L = lower flammability; 1 = no flame propagation

Condensing units

A difficult sub-sector because the refrigerant charge is relatively high and flammability is an important issue. Various non-flammable R-404A alternatives are available with GWPs in the 1400 to 2100 range. These can be used in new equipment and some can be retrofitted into existing systems. Non-flammable HFC-134a alternatives are available with GWP around 600. R-744 is an option, although getting high efficiency and low capital cost is proving a challenge for condensing units. Various lower flammability (2L) refrigerants are under development and may be safe to use in many condensing unit applications, subject to safety regulations.

Centralised systems – new equipment

For new systems, R-744 is now in widespread use, especially in Europe. In mild climates transcritical R-744 booster systems are a popular configuration[4]. In hot climates it has been considered more energy efficient to use a cascade system[5], although the latest innovations for transcritical systems (e.g. parallel compression and ejectors) are allowing efficient use of booster systems in relatively hot climates. There are various other alternatives that can also be considered for new centralised systems. For example, some use has been made of stand-alone HC units, cooled by a water circuit.

Centralised systems – exisiting

Various options are available to retrofit R-404A in exisiting systems. There are several of non-flammable alternatives with GWPs in the 1400 to 2100 range. Case studies have shown that there can be energy efficiency improvements of 5% to 10% following retrofit, especially for MT systems.

3. Discussion of key issues

Safety and practicality

Stand-alone: Use of HCs is a safe option in many stand-alone applications as the refrigerant charge is small. In some countries, including the United States, safety codes limit the charge size for HCs. A recent announcement by the US EPA's SNAP programme, lists as acceptable additional HCs for stand-alone commercial refrigeration. Where higher flammability refrigerants are unacceptable various other refrigerants listed in Table 2 can be considered, including those with flammability categories 1 and 2L. HFOs have lower flammability (2L), so safety issues still need to be addressed. Standards such as IEC 60335-2-89 do not currently distinguish between flammability categories, which is a barrier to use of lower flammability refrigerants.

Condensing units: A potentially difficult market sub-sector from a safety perspective. Systems are usually too large for use of HCs. R-744 is a possibility, but cost and efficiency may be a challenge in these small systems. Another option is use of lower flammability alternatives such as HFC-32, pure HFOs and HFO/HFC blends. Safety standards may need updating for use of lower flammability refrigerants in condensing units.

Centralised: Widespread use of R-744 in some regions shows that this refrigerant can be used safely and cost effectively in centralised systems. Significant improvements in system designs and

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[4] R-744 has a very low critical temperature (only 31ºC compared to over 70ºC for most refrigerants). This has a significant impact on the way R-744 systems operate. Transcritical booster systems use direct expansion R-744 for both LT and MT cooling, with heat rejected into the atmosphere from an R-744 condenser / gas cooler. When the ambient temperature is below approximately 20ºC, the system operates in a conventional sub-critical mode. In hot weather the system operates with heat rejection above the critical temperature.

[5] Cascade systems are designed to avoid operation above the critical temperature of R-744. They use direct expansion R-744 for the LT cooling and a pumped R-744 secondary system for MT cooling. Heat is rejected via a "cascade refrigeration chiller" which uses a different refrigerant. The chiller is usually located in a special machinery room or on a roof-top, so it can use a range of possible refrigerants including HC-290, R-717, HFO-1234ze or HFO-1234yf. Use of a cascade arrangement keeps the R-744 well below its critical temperature under all ambient temperature conditions – this gives improved efficiency in hot climates.

specialised components during the last 5 years can make the latest systems highly effective. Prevention of leakage is an important design issue as R-744 has very high operating pressures.

Commercial availability

Stand-alone: There is reasonable availability of HC equipment in most regions. A much wider range of HC, R-744, HFC / HFO blends, and HFO stand-alone equipment is likely to become available during the next 5 years.

Condensing units: There is little commercial experience of using either R-744 or lower flammability refrigerants in this sub-sector. Significant work is required on development of components and of safety standards before widespread use is likely.

Centralised: There is good availability of R-744 equipment in several regions such as the EU. There is also good availability of central systems based on water cooled stand-alone units.

Cost

Stand-alone: Capital cost of HCs units is close to HFC units, although there are some investment costs at factories making stand-alone equipment for safe handling of flammable refrigerants. R-744 and HFO-1234yf equipment are likely to be more expensive due to higher cost of components (for R-744) or refrigerant (for HFOs).

Condensing units: If low flammability refrigerants are acceptable then there will be little difference in hardware cost, but some of the lower GWP refrigerants may be more costly than R-404A. Small R-744 systems are currently considerably more expensive than HFC systems.

Centralised: R-744 systems are currently more expensive than R-404A – 10% to 20% extra is typical. However, the cost increment is falling as usage becomes more widespread. Some of the latest equipment is within 5% or less of current HFC system cost.

Energy efficiency

Stand-alone: HC systems have better efficiency than current HFC designs. There is little data available for HFOs and HFO/HFC blends, but equal or better efficiency than R-404A may be possible.

Condensing units: Information is not yet available on efficiency of HFC-32, HFOs and HFO/HFC blends in condensing units. The expectation is for better efficiency than current R-404A designs

Centralised: R-744 systems can have better efficiency than current R-404A designs. In cold and mild climates transcritical R-744 systems show good efficiency. In hot climates it may be necessary to use cascade systems to get good efficiency, although use of innovations such as parallel compression and ejectors enables efficient use of transcritical systems in hotter climates than previously thought possible.

Applicability in high ambient

Stand-alone: There are no extra difficulties designing HC or HFO stand-alone systems for operation in high ambient temperatures (compared to using R-404A or HFC-134a). R-744 is more difficult to use with good efficiency in small equipment at high ambient temperature and may not be suitable for all stand-alone equipment applications.

Condensing units: Little data is yet available on performance of new HFO/HFC blends. For MT systems, blends with properties similar to HFC-134a may be the best option at high ambient temperature as they have a low discharge pressure. For LT systems, blends with properties similar to R-404A may be more suitable. Higher pressure refrigerants such as HFC-32 and new blends with properties similar to R-410A may be more difficult to use at high ambient because of high discharge temperatures, although liquid and vapour injection can mitigate this problem at some added cost.

Centralised: Transcritical R-744 systems have lower energy efficiency and reduced capacity at high ambient temperatures, although this can be mitigated with some new innovations (such as parallel compression and ejectors). R-744 used in hot countries can be based on a cascade design, which uses R-744 in sub-critical conditions, with heat rejected into a separate high temperature cooling circuit (which could use a range of refrigerants including HCs, ammonia or HFO-1234ze). Cascade designs are already used in some existing installed systems and have been shown to be efficient and cost effective.

Opportunities to retrofit existing equipment

There are good opportunities to retrofit **centralised** R-404A systems with various refrigerants with much lower GWPs as shown in Table 2. Retrofit of centralised commercial systems can lead to significant early reductions in HFC consumption.

There are also possibilities to retrofit **condensing units** (although it is usually less cost effective than for centralised systems). Retrofit is not appropriate for **stand-alone** systems.

Technician training

HCs: Technicians doing maintenance need training that addresses handling of higher flammability refrigerants. There are well established training courses available in regions already using HCs. Training related to stand-alone units is widespread. Training for use of higher flammability refrigerants in larger systems (e.g. chillers for cascade systems) is less common.

Lower flammability HFCs/ HFOs: Training will also be essential for maintenance of systems with lower flammability refrigerants. These are not yet in widespread use for commercial refrigeration, so little training is currently available.

R-744: Systems using R-744 operate at much higher pressure than HFC systems and may be based on unfamiliar system design. Technicians need significant extra training to work on R-744 systems. There are well established training courses available in regions already using R-744.

For all new refrigerants, training is also required for system design engineers.

Minimising HFC emissions from existing equipment

Stand-alone: The majority of HFC emissions from stand-alone systems occur at end-of-life (operational leak rates are very low and mostly occur through accidental damage). End-of-life recovery procedures must be established to minimise these potential emissions.

Condensing units and centralised systems: Most emissions occur through leakage during the operating life of this equipment. Applying best practice in design, installation and maintenance practices can lead to significant leakage reductions. Case studies have shown that for **existing installed systems** it is possible to reduce average leakage from over 20% per year to under 10%. Best practice design has been shown to reduce average leakage from **newly designed and installed systems** to well below 5% per year. There is a useful financial benefit for minimising leakage as it helps ensure that maximum energy efficiency can be maintained. During plant maintenance it is important to ensure that refrigerant is not vented to atmosphere. At end-of-life it is possible to recover well over 95% of refrigerant from old systems if good recovery procedures are used.

It is interesting to note that many low GWP alternatives require much better design to achieve low leakage. R-744 systems operate at very high pressure, so leak prevention is crucial. Preventing leaks of flammable refrigerants is also crucial if safety risk is to be minimised. New HFO/HFC blends will be more expensive, creating a driver to minimise leakage. If the same good design practices are applied to conventional HFC systems, leakage levels could be considerably reduced. Good refrigerant conservation practices should be encouraged.