FACT SHEET 6
Transport Refrigeration

1. Description of market sector

This market sector includes refrigeration systems used in various modes of transport. Most transport refrigeration systems are used for the carriage of frozen or chilled food and beverage products.

Market sub-sectors

Transport refrigeration can be split into the following three sub-sectors:

a) Road vehicles (vans, trucks, trailers)
b) Intermodal containers (reefer containers)
c) Ships (included refrigerated cargo vessels, fishing vessels and passenger liners)

Operating temperatures

Food and beverage products are transported at two temperature levels[1]:

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

An important feature of most transport refrigeration systems is the ability to operate at either of these temperature levels. Stationary systems are usually dedicated to just one temperature level, whereas transport systems regularly switch between MT and LT. It is also a common requirement for road transport to provide simultaneous cooling at both temperature levels to separate compartments.

Transport systems encounter large variation of ambient temperature conditions, depending on routes undertaken. Intermodal containers could have to operate in ambient varying from -30°C to +50°C.

Typical system design

The majority of transport refrigeration systems use direct expansion (DX) vapour compression refrigeration cycles. There is a wide range of designs:

- Small vehicles (e.g. vans for shopping deliveries) have a compressor powered by the vehicle engine, via a belt drive; cooling can only be provided when the vehicle engine is running.
- Larger road vehicles have a dedicated diesel engine powering the refrigeration system, typically via a mechanical connection, allowing operation when the vehicle main engine is off.
- Some road vehicles use electrically driven compressors – with electricity generated either by the main vehicle engine or a dedicated diesel engine.
- Intermodal containers have electrically driven compressors. When a container is on board a ship it is connected to the ship's electricity supply. When a container is on a road trailer it is connected to the main diesel engine generator or uses a dedicated diesel generator.
- Ship refrigeration systems are much larger than those for road vehicles or containers and can use a wide variety of different designs. Some of the discussion in Fact Sheet 5 on Industrial Refrigeration is applicable to ship based systems.

[1] Non-food products may be transported at much lower temperatures (e.g. liquefied natural gas). Some food products are transported at higher temperatures e.g. bananas at up to +15ºC

Alternative technologies

There is limited use of cooling using eutectic plates. The plates contain a phase change material that is usually frozen in a stationary refrigeration facility. Cooling is provided to the contents of a vehicle as the material melts during a journey (a similar principle to an ice pack used for domestic cold boxes). It is also possible to provide cooling via an on board supply of liquid nitrogen or CO_2, although this is usually an expensive option in terms of energy costs.

Changes driven by ODS phase out: Prior to 1990 the majority of road transport systems and containers used R-502 or CFC-12. From around 1997, R-404A[2] or HFC-134a have been used in non-Article 5 countries and more recently in Article 5 countries. HCFC-22 is still widely used in ships, especially those owned by Article 5 countries.

Table 1: Transport refrigeration: summary of characteristics for HFC systems

Market sub-sector:		Road vehicles	Containers	Ships
Typical refrigerant charge		1 to 8 kg	4 to 8 kg	20 to 1000 kg
Typical cooling duty		3 to 10 kW	5 to 15 kW	40 to 2000 kW
HFC refrigerants widely used		R-404A (GWP[3] 3922) HFC-134a (GWP 1430)		
Refrigeration circuit design		Diesel or electrically driven compressor, DX	Electrically driven compressor, DX	Various
Manufacture / installation		Small: site installed Larger: factory built	Factory built	Site installed
Typical location of equipment		Varied operation locations affect safety issues		
Typical annual leakage rate		8% to 20%	3% to 12%	5% to 30%
Main source of HFC emissions		Operating leakage	Operating leakage	Operating leakage
Approx. split of annual refrigerant demand	New systems	40%	50%	20%
	Maintenance	60%	50%	80%

Small refrigerated truck, compressor located by main vehicle engine

[2] R-507A can also used for transport systems although much less widely than R-404A. Comments made about R-404A in this Fact Sheet also apply to R-507A.

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

Refrigerated trailer with dedicated diesel engine and cooling system

Intermodal container with dedicated cooling system

Flake ice making system for a fishing trawler

Small road vehicles usually have a refrigeration compressor located in the main engine compartment – refrigerant pipework is installed by the vehicle body builder to connect the compressor to the evaporator mounted inside the cooled space and the condenser mounted at roof level.

Larger road vehicles usually have a factory built pre-charged refrigeration unit mounted at the front of a refrigerated trailer. These units have a small diesel engine and a factory built refrigeration circuit – installation work does not involve any refrigerant pipework.

Intermodal containers also have dedicated refrigeration units that are factory built and pre-charged.

Ships require a range of different cooling systems, depending on function e.g. there are specialised vessels for bulk products (e.g. liquefied natural gas) and for preserving fish in fishing vessels. Passenger liners require large cooling systems both for food preservation and for air-conditioning.

2. Alternatives to current HFC refrigerants

Table 2: Lower GWP alternatives for road transport and containers

Refrigerant	GWP	Flammability[4]	Comments
R-744 (CO_2)	1	1	Transcritical R-744 is being developed for large road vehicles and for intermodal containers. Use of R-744 requires major changes to the design of transport refrigeration systems and the development of many new components. Some systems were trialled in 2014 and it can be expected that R-744 may be widely available for transport applications by 2020.
R-407A	2107	1	There has been some limited use of these blends in road vehicles as R-404A alternatives. High compressor discharge temperature must be addressed in high ambient e.g. using liquid injection.
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 very little commercial experience or availability in transport sector, but they may be suitable as R-404A alternatives in new systems. High compressor discharge temperature must be addressed in high ambient e.g. using liquid injection.
R-449A	1397	1	
R-452A	2141	1	A new blend targeted at the transport sector; an R-404A alternative with low discharge temperature at high ambient.
R-450A R-513A	601 631	1 1	Newly developed blends with properties similar to HFC-134a. May be suitable for new road vehicles and containers that are currently designed to use HFC-134a.
HFC-32	675	2L	Recent developments are showing high efficiencies and acceptable risks for operation with certain flammable refrigerants including HCs and HFC-32. Use of flammable refrigerants require special safety measures and new designs.
HC-290 HC-1270	3 2	3 3	

Table 2 shows alternatives that are applicable to road transport and containers. There are trials with HFC-32 and hydrocarbons; flammable refrigerants require correct safety measures, engineering design efforts, quality controls, proper maintenance, education and training. Other lower flammability refrigerants with GWPs in the 150 to 700 range are also being considered.

Ships can use a wider variety of alternatives, which are not shown in Table 2. Many of the options discussed in Fact Sheet 5 (industrial refrigeration) are applicable. R-717 and R-744 are both used e.g. in fishing vessels. The HFOs suited to large industrial chillers (e.g. HFO-1234ze) may be applicable in passenger ships.

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

3. Discussion of key issues

Safety and practicality

Road transport and containers: Flammability is a very important consideration. Most vehicles travel through various countries and need to comply with international UN or IMO-CSC codes for transport of dangerous goods requirements with regard to refrigerants. These give no restrictions for use of less than 12 kg of flammable refrigerants. However, it may be also necessary to comply with a range of national safety legislation which may be more restrictive.

Use of a non-flammable refrigerant simplifies this issue. As shown in Table 2, many of the options being considered are non-flammable. If R-744 can be used this provides the lowest possible GWP. R-744 was listed by U.S. EPA in 2014, as acceptable for refrigerated transport applications. Non-flammable fluorocarbon alternatives to R-404A have a GWP in the range 1400 to 2100.

The availability of spare parts and maintenance skills is an important consideration as road vehicles could require servicing in a remote location. This could have a strong influence on the selection of alternatives and enhances the argument for a globally consistent approach.

Transport systems may require certification to ensure effective preservation of foodstuffs. The ATP is a UN treaty that affects temperature controlled vehicles. It applies in more than 50 countries and sets performance standards for vehicle bodywork and refrigeration units. Compliance with ATP is essential for new refrigerants being introduced.

Ships: Use of R-717 (ammonia) is a possibility on non-passenger ships, as the crew can be trained to address safety issues. It is already used in a range of vessels, including fishing trawlers. R-717 may not be appropriate for passenger ships.

Commercial availability

Road transport: It is likely that R-404A alternatives will become widely used in new equipment in some regions within the next 5 years. The rate of development for R-744 depends on the results of current trials.

Intermodal Containers: R-744 systems have been tested and are available on the market. Various lower GWP fluorocarbon alternatives to R-404A are also becoming available. One intermodal container manufacturer has announced the possible introduction of a refrigeration system with HCs in 2018-19 subject to the constraints of future legislation.

Ships: Availability of alternatives for ships may follow developments for industrial refrigeration applications. R-717 systems are already widely available. R-744 requires significant development of systems and components. HFO chillers may become widely available within 5 years.

Cost

Road transport and containers: Fluorocarbon alternatives such as R-452A will have a similar cost to R-404A systems. The refrigerant may be more expensive, but this should not increase the total system price by more than a few percent. Costs for R-744 in transport systems are not yet known. Costs are not yet known for intermodal containers using HFC-32 or HCs.

Ships: R-717 could be 10% to 30% more expensive to install than HCFC-22, but life cycle costs could be lower through improved efficiency. HFO-1234ze chillers will only be slightly more expensive than HFC-134a systems, because of a higher refrigerant price.

Energy efficiency

Road transport and containers: The energy efficiency of fluorocarbon alternatives is expected to be higher than exisiting R-404A systems. The efficiency of R-744 systems will depend on ambient temperature. In a mild climate (e.g. less than around 20^{o}C) the efficiency has the potential to be higher than R-404A systems. In hotter conditions the efficiency will fall. For many highly populated regions the average ambient for typical road transport operation is low enough for R-744 to have an efficiency advantage. HCs and HFC-32 are expected to have similar efficiencies to HFC-134a.

Ships: R-717 and cascade R-744 systems have the potential for higher efficiency than R-404A. Efficiency of HFO-1234ze chillers expected to be equal to HFC-134a systems.

Applicability in high ambient

Road transport and containers: In high ambient some fluorocarbons may not be ideal because of the impact of high discharge temperatures. R-452A is an option for high ambient conditions. R-744 is likely to have lower efficiency in high ambient.

Ships: There are no extra challenges for new equipment being designed for high ambient. Most ships already require systems that can operate at high ambient and the use of water cooled condensers reduces the condensing temperatures to acceptable levels.

Opportunities to retrofit existing equipment

Road transport and containers: Retrofit of R-404A transport systems is not likely to be widespread. It is technically possible to convert to lower GWP refrigerants but the ATP Regulations could add significantly to conversion cost as vehicles may need recertification. In most cases the move to a lower GWP refrigerant will occur when old equipment is being replaced.

Ships: There is potential to retrofit R-404A systems on ships with a lower GWP fluorocarbon, although there is currently little experience of this being done.

Technician training

R-744: Systems using R-744 operate at a higher pressure than HFC systems and may be based on unfamiliar system design. Technicians need extra training to work on R-744 systems. If R-744 technology is adopted the transport sector will need to ensure the availability of trained technicians across the regions supplied by R-744 equipment.

R-717: There is already use of R-717 in parts of the shipping industry (e.g. fishing vessels) and there is some availability of trained technicians. If use of R-717 increases then extra training based on established courses will be required.

Other flammable refrigerants: If flammable refrigerants (e.g. HCs or HFC-32) are to be used for road transport or containers, new training initiatives will be required.

Minimising HFC emissions from existing equipment

Most emissions occur through leakage during the operating life of transport equipment. Applying best practice in design and maintenance practices can lead to significant leakage reduction. During system maintenance it is important to ensure refrigerant is not vented to atmosphere. At end-of-life over 95% of refrigerant from old systems can be recovered if adequate procedures are used.