FACT SHEET 12
Mobile air-conditioning

1. Description of market sector

This market sector includes mobile air-conditioning (MAC) systems used to cool the driver and passengers in land transport including cars, vans, lorries, buses, agricultural vehicles and trains.

Air-conditioning is also used on ships using similar technologies to those described in Fact Sheet 9 (larger air-to-air systems) and Fact Sheet 10 (water chillers). Ships are not discussed in this Fact Sheet.

Market sub-sectors

The sector has been split into two sub-sectors

a) MACs used in passenger cars and small vans

b) Larger MAC systems used in other vehicles, especially buses, coaches and trains.

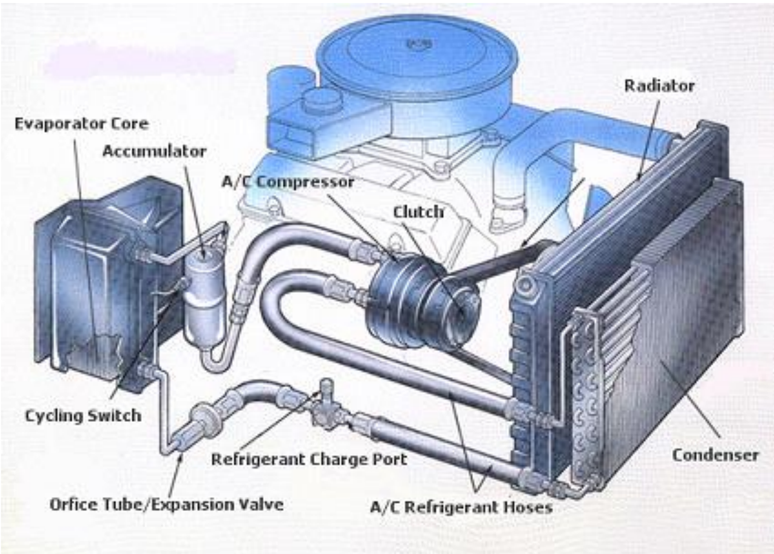
Typical system design

All systems use a direct expansion vapour compression cycle.

- **MACs in cars and small vans** usually use compressors that are belt driven from the main vehicle engine. The compressor and condenser are separately located in the engine compartment of the vehicle and the evaporator is usually located in a ventilation duct between the engine compartment and the passenger cabin. The main components are connected by flexible hoses. The system is assembled and charged on the main vehicle production line. Some recent MAC designs use electrically driven compressors – these are a new requirement to ensure the function when the main engine is off (e.g. in hybrid vehicles) and for fully electric vehicles.
- **Larger MACs used in buses and trains** are often located in a single unit containing all the system components. The unit is factory built and pre-charged with refrigerant. It is fitted by the vehicle body builder (e.g. roof mounted). The compressor is sometimes electrically driven with electricity from the main vehicle supply (e.g. from the track supply for an electric train or from a generator connected to the main engine). Some units have a dedicated diesel engine to supply electricity or to directly drive the compressor. On some bus and coach systems the compressor is located adjacent to the main vehicle engine and driven via a belt connection.

Alternative technologies

No alternative technologies are in common use. However, due to developments in car propulsion (e.g. hybrids; all-electric cars; stop-start) MAC designers are considering various new technologies including phase change storage of cold, use of secondary loops and reversible systems to provide vehicle heating via a heat pump.



Car MAC: system layout

Changes driven by ODS phase out

Prior to 1990, all MACs for cars and small vans used CFC-12. In non-Article 5 countries the majority of new cars started to use HFC-134a in the early 1990s. HFC-134a is the global standard refrigerant for small MAC systems. Larger MAC systems in non-Article 5 countries made significant use of HCFC-22 until around 2000. Current new systems use a number of refrigerants as shown in Table 1. In Article 5 countries HCFC-22 is still being used for some new systems.

Table 1: Mobile air-conditioning: summary of characteristics for HFC equipment

Market sub-sector:		Cars and small vans	Larger vehicles
Typical refrigerant charge		0.4 to 0.8 kg	2 to 20 kg
Typical cooling duty		3 to 5 kW	10 to 30 kW
HFC refrigerants widely used		HFC-134a (GWP 1430[1])	R-410A (GWP 2088) R-407C (GWP 1774) HFC-134a (GWP 1430)
Typical refrigeration circuit design		DX system with compressor belt driven by vehicle engine	Electrically or engine driven DX system
Manufacture / installation		Components fitted on car production line	Factory built unit, pre-charged with refrigerant
Typical location of equipment		In engine compartment and ventilation system	In separate enclosure (e.g. roof mounted)
Typical annual leakage rate		2% to 10%	5% to 15%
Main source of HFC emissions		Operating leakage	Operating leakage
Approx. split of annual refrigerant demand	New systems	70%	40%
	Maintenance	30%	60%

Roof mounted electrically driven bus MAC system

Roof mounted electrically driven train MAC system

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

2. Alternatives to currently used HFC refrigerants

Table 2: Lower GWP alternatives for mobile air-conditioning

Refrigerant	GWP	Flammability[2]	Comments
Cars and Small Vans			
HFO-1234yf	4	2L	Already in use in the EU as response to the EU MAC Directive and in US through GHG regulations.
R-744 (CO_2)	1	1	Under development by some car manufacturers
R-444A R-445A	93 120	2L 2L	Newly developed blends being considered by some manufacturers
Larger vehicles including buses and trains			
HFO-1234yf	4	2L	Has performance similar to HFC-134a and is suitable for systems where safety regulations allow use of a lower flammability refrigerant.
HFC-32 R-446A R-447A	675 460 582	2L 2L 2L	These three refrigerants have performance similar to R-410A and are suitable for systems where safety regulations allow use of a lower flammability refrigerant.
R-744 (CO_2)	1	1	Being considered by bus and train manufacturers. Some R-744 bus MACs already in use.
R-450A R-513A	601 631	1 1	New non-flammable blends with performance similar to HFC-134a

For cars and small vans there has been rapid development of low GWP alternatives, driven by regional legislation banning the use of HFC-134a (such as the European Union MAC Directive) or promoting the adoption of low GWP substances (such as GHG regulations in the United States). The main alternatives under consideration are HFO-1234yf and R-744. However, only HFO-1234yf is already in commercial use today. Many car manufacturers appear to favour HFO-1234yf as it only requires minor modifications to the system components. With a refrigerant charge of around 0.5 kg there has been extensive testing of this lower flammability refrigerant which has shown the refrigerant application to be safe. Some car manufacturers are considering a move to R-744. Hydrocarbons have been considered by some equipment suppliers, but most car manufacturers are not interested in using a refrigerant with higher flammability.

Finding a suitable alternative for larger systems on buses and trains is potentially more difficult as the refrigerant charge in each system is considerably higher than for cars. If a lower flammability refrigerant can be safely used there are a number of potential lower GWP alternatives to the current HFCs. If a non-flammable refrigerant is required, R-744 is a possible option, although efficiency in hot ambient conditions is a concern. R-450A and R-513A are non-flammable options with GWPs in the region of 600 and characteristics similar to HFC-134a; these may be suitable for some bus and train systems.

[2] 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

Cars and small vans: Extensive testing by car manufacturers has shown that HFO-1234yf (which has lower flammability) can be used safely, although some manufacturers disputed these findings. R-744 is a non-flammable option but to use R-744 safely designers need to ensure that high concentrations of R-744 cannot accumulate in the passenger compartment if the system leaks.

Larger MACs: For larger systems, the use of a low flammability refrigerant may be more restricted than in cars. If a lower flammability refrigerant can be shown to be safe there are a number of options including HFO-1234yf and also R-410A alternatives with GWPs in the 500 to 700 range. Where a non-flammable refrigerant is required the main options are R-744 or a blend with properties similar to HFC-134a and a GWP around 600.

Commercial availability

Cars and small vans: HFO-1234yf systems are becoming widely available and are used in numerous new car models. At the end of 2014 several million cars were on the road using HFO-1234yf. R-744 systems are not yet commercialised. OEMs and suppliers have conducted testing with R-445A for performance, material compatibility, flammability and risk assessment. However, these systems have not yet been commercialised.

Larger MACs: Developments are slow in this market and there are few lower GWP alternatives yet on the market. Some R-744 MAC systems are available. Further development work is required in this market sector.

Cost

Cars and small vans: HFO-1234yf is more expensive than HFC-134a (currently around 10 times the price). The price differential is expected to decrease with greater usage. The high cost of HFO-1234yf and its compatibility with HFC-134a might increase the risk of use of counterfeit refrigerants (i.e. charge with HFC-134a instead with HFO-1234yf). R-744 systems are expected to have higher costs than current HFC systems but these would also be expected to decrease if R-744 is widely adopted.

Larger MACs: The cost impact for large MAC systems is not yet clear.

Energy efficiency

Cars and small vans: HFO-1234yf systems may require minor improvements (e.g. use of an internal heat exchanger) to ensure energy efficiency comparable to HFC-134a. R-744 has higher efficiency at low/mild ambient temperature, but lower efficiency at high heat load in high ambient temperature.

Larger MACs: The energy efficiency impact for large MAC systems is not yet clear.

Applicability in high ambient

Cars and small vans: Using HFO-1234yf MACs with an internal heat exchanger at high ambient does not create any extra difficulties compared to using HFC-134a. R-744 is less well suited to high ambient temperature because of reduced energy efficiency.

Larger MACs: Lower pressure refrigerants such as HFO-1234yf, R-450A and R-513A are expected to perform reasonably at high ambient. R-744 is less well suited to high ambient temperature because of reduced energy efficiency.

Opportunities to retrofit existing equipment

It is not usually appropriate to retrofit MAC systems with a lower GWP alternative.

In some regions there has been retrofitting of car MACs with HCs. This is potentially dangerous and is not endorsed by the original car manufacturers.

Technician training

Lower flammability HFCs/ HFOs: Training will be essential for maintenance of MACs with lower flammability refrigerants. For HFO-1234yf, training is already being provided by car manufacturers and others.

R-744: Systems using R-744 operate at a higher pressure than HFC systems and technicians need a specific training to work on R-744 systems. Training is not yet available for R-744 MACs in cars as these systems are not yet in commercial use.

Minimising HFC emissions from existing equipment

Cars and small vans: The majority of emissions are from leakage during the life of a MAC (including up to 95% when the vehicle is not in use). Good maintenance procedures will reduce leakage, although there are limited opportunities to improve existing systems. Good design and selection of components by car manufacturers has already led to much lower levels of leakage than historic leak levels. For example, use of better quality flexible hoses, double captured O-rings and better compressor seals has a significant impact.

Larger MACs: As with cars, the majority of emissions are from leakage during the operating life of larger MAC systems. A regime of regular leak testing and use of good maintenance procedures can significantly reduce leak levels. These MACs contain a relatively large refrigerant charge, so HFC recovery during maintenance and at end-of-life is essential.