



TRANSITIONING TO LOW-GWP ALTERNATIVES IN TRANSPORT REFRIGERATION

Background

This fact sheet provides current information on low-Global Warming Potential (GWP) refrigerant and foam blowing agent alternatives used in transport refrigeration equipment, relevant to the *Montreal Protocol on Substances that Deplete the Ozone Layer*. The transport refrigeration sector primarily moves perishable goods (i.e., food), and to a lesser extent pharmaceutical products, at temperatures between -30° C and 16° C, by various modes of transportation, including road, rail, ships, and intermodal containers. The text box (right) describes these modes of transportation in more detail. The transport refrigeration sector has special requirements in terms of equipment reliability and durability to guarantee product quality and personnel safety.

The expected lifetime for road vehicles, railcars, and intermodal containers is between 10 and 15 years, and between 20 and 25 years for equipment aboard ships. Refrigerant charge size varies based on mode of transport, typically between 4.5 and 7.5 kg for road vehicles, railcars, and intermodal containers and 100 to 500 kg for conventional equipment aboard ships. In addition to refrigerant, transport refrigeration equipment also contains insulating foam. Commonly used foam types include polyurethane (PU) injected pipe-in-pipe foam, PU rigid panels (continuous and discontinuous), block, and extruded polystyrene (XPS) board foam. The typical foam density in intermodal containers is high, ranging from 40 to 45 kg/m³, to maintain temperatures over long distances and time periods. Hold sizes on refrigerated ships are often 25-35% smaller than equivalent-sized non-refrigerated cargo ships, due to the thickness of the PU foam insulation required for the refrigerated systems.

Because demand for HFCs in refrigeration and air conditioning equipment is increasing, particularly in developing countries, HFC emissions could rise to as much as 19% of projected global CO₂ emissions by 2050 if left unchecked. In 2010, the transport refrigeration sector accounted for about 9% of global HFC consumption in the refrigeration/AC sector—approximately 80 million metric tons of carbon dioxide equivalent (MMTCO₂eq.)—or approximately 7% of HFC consumption across all sectors. Developing countries' use of HFCs in the transport refrigeration end-use accounted for approximately 3% of

Modes of Transportation in the Transport Refrigeration Sector

Intermodal Containers—refrigerated containers allow uninterrupted storage during transport on different mobile platforms, including railways, road trucks, and ships.

Rail—refrigerated railcars, mainly used for long distances, account for only a small share of total refrigerated transport, gradually being replaced by intermodal containers.

Road—refrigerated vans, trucks, or trailer-mounted systems are the most common mode of refrigerated transport, with an estimated 4 million vehicles in operation worldwide in 2009 (of which 30% were trailers, 30% large trucks, and 40% small trucks/vans).

Ships—refrigerated ships and marine branches, including merchant, naval, fishing and cruise-shipping, are commonly used to transport perishable goods.

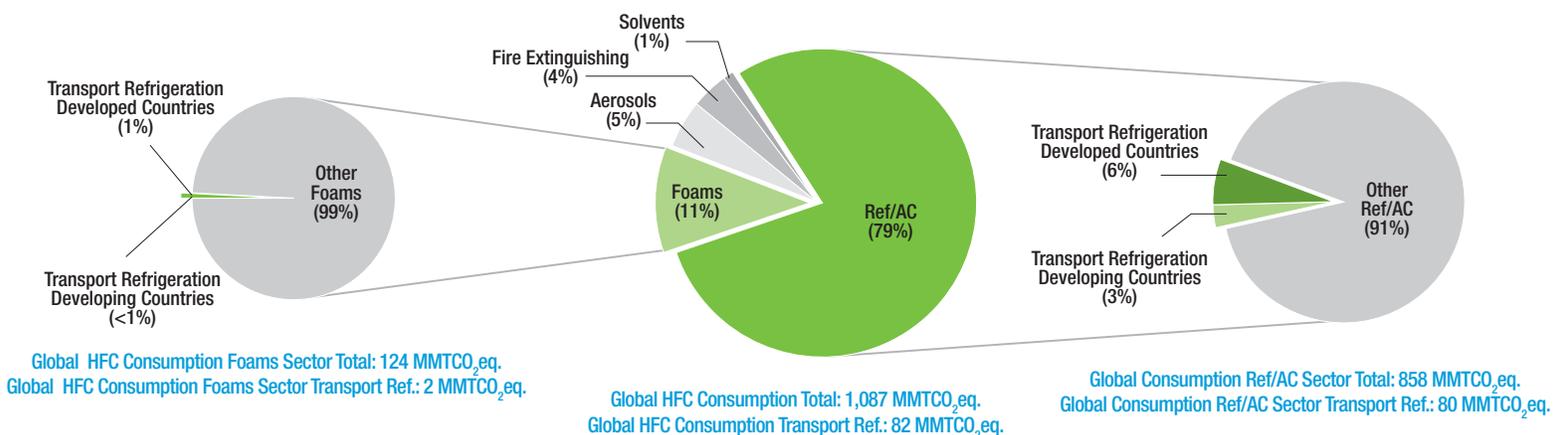
the global HFCs consumed as refrigerants within the refrigeration/AC sector, and 38% of global HFCs consumed as refrigerants in the transport refrigeration end-use specifically.

HFC Alternatives and Market Trends

Historically, the main refrigerant in the transport refrigeration sector was HCFC-22, although other ODS were also used (e.g., R-502, CFC-12). In response to the global ODS phaseout, many equipment manufacturers in developed countries converted to HFCs in the 1990s—primarily to R-404A, R-507A, R-410A, R-407C, and HFC-134a—because these were the most widely available and studied options at the time. By 2010, global market penetration of HFC refrigerants in the installed base of transport refrigeration equipment was estimated at 40% for ships, 70% for road vehicles, and 95% for intermodal containers. Over time, low-GWP options began to enter the market; the transition to low-GWP alternatives, such as ammonia (R-717) or carbon dioxide (R-744, CO₂), has begun in some

2010 HFC Consumption

(Estimates Presented in MMTCO₂eq.)



transport refrigeration end-uses. For example, R-717 and R-744 are used in refrigerated ships, accounting for nearly 5% of the installed global market in 2010. R-744 is also being considered as an alternative for intermodal containers. Hydrocarbons (HCs) and liquid R-744, as well as alternative technologies—cryogenic (open-loop) systems, secondary loop systems, eutectic places, hermetic/semi-hermetic systems, and cascade systems—are under limited use or are being explored for use in road vehicles. Combinations of stationary HCs or R-717 with liquid R-744, as well as alternative technologies (e.g., eutectic plates), are being explored for refrigerated railcars. In addition, HFOs¹ are also being researched and developed and may become available for use across the various transportation modes in future.

Foam insulation in transport refrigeration traditionally used CFC-11 and HCFC-141b blowing agents. Over 50% of foams in this sector are manufactured in developing countries, with China being a dominant manufacturer of reefers. In response to the global ODS phase out, developed countries have transitioned to substitute blowing agents. Europe transitioned to HCs, and North America and Japan transitioned largely to HFCs, including HFC-245fa and HFC-365mfc/HFC-227ea blends. In developing countries, HCFCs (primarily HCFC-141b) continue to be used, although some HFCs have been adopted in Latin America. In addition to HCs, other low-GWP alternatives are being explored, including methyl formate and low-GWP fluorinated compounds.

Alternative Refrigerants

- **R-744**
 - Limited use in refrigerated ships and road applications; under evaluation for use in intermodal containers and in combination with HCs or R-717 for rail applications
 - Carrier Transicold announced production of high-efficiency R-744 refrigerated marine containers; demonstration units are being tested in various locations worldwide, including the United States and Singapore
 - Use in compression systems (including hermetic/semi-hermetic compressors) likely to be enabled in road transport if/when refrigeration equipment becomes electrified
 - Solid R-744 used in some small containers and boxes; requires external mechanical refrigeration system to generate
- **R-717**
 - Limited application in indirect and cascade systems on new refrigerated ships; specifically in ships that carry professional crew only (no passengers) and those with relatively high refrigeration capacity (e.g., fishing ships)
 - Under evaluation for use in refrigerated railcars
- **HCs (isobutane, propane)**
 - Under evaluation for use in road or rail transport refrigeration (in secondary loop systems)
 - Use in compression systems (including hermetic/semi-hermetic compressors) likely to be enabled in road transport if/when refrigeration equipment becomes electrified
- **HFOs (e.g., HFO-1234yf,² blends)**
 - Under consideration for use across transport refrigeration modes beyond 2014, particularly road

Alternative Refrigerant Technologies

- **Cryogenic (Open-Loop) Systems**
 - Cryogenic (open-loop) systems cool cargo by injection of stored liquid R-744 or nitrogen (R-728, N₂) to the cargo space or an evaporator
 - Used in small and large trucks, primarily in northern Europe
 - Low noise, reduced maintenance, and strong refrigeration performance

Norway's Experience

In 2007, liquid CO₂ refrigerant-based cryogenic systems were introduced into Norway's road transport refrigeration market. Cryogenic truck and trailer systems use liquid CO₂ for refrigeration to minimize environmental impact and noise while providing high reliability and lower maintenance.

In 2011, approximately 16% of new refrigerated truck and trailer systems sold in Norway were equipped with cryogenic refrigeration systems. One of Norway's largest food distributors has committed to making cryogenic system-equipped vehicles the standard for all of their future purchases. In addition, a major manufacturer of cryogenic systems has partnered with one of Norway's largest refrigerant suppliers to provide CO₂ filling stations across the country. Cryogenic systems are currently used in other European countries (e.g., Sweden, Denmark, Finland, France, the Netherlands, and Germany), and are being piloted in the United States. Use of liquid CO₂ refrigerant-based cryogenic systems is expected to expand further in the future, particularly in Western Europe.

Chemical	GWP	ODP
Refrigerant		
R-12	10,900	1
R-502	4,657	0.334
R-507A	3,985	0
R-404A	3,922	0
R-410A	2,088	0
R-22	1,810	0.055
R-407C	1,774	0
R-134a	1,430	0
R-1234yf	4	0
R-290 (Propane)	3.3	0
R-600a (Isobutane)	3	0
R-744 (CO ₂)	1	0
R-717 (Ammonia)	0	0
R-728 (Nitrogen)	0	0
Blowing Agent		
CFC-11	4,750	1
HFC-227ea	3,220	0
HCFC-22	1,810	0.055
HFC-245fa	1,030	0
HFC-365mfc	794	0
HCFC-141b	725	0.11
Cyclopentane	<25	0
n-Pentane	<25	0
Methyl Formate	<25	0
Methylal	<25	0
Isopentane	11	0
FEA-1100	9.4	0
HBA-2	7	~0
HFO-1234ze	6	0
Isobutane	3	0

- **Secondary Loop Systems**

- Systems chill an intermediate fluid, which is circulated from the refrigerant-containing equipment to the areas to be cooled
- Under evaluation for use in road transport refrigeration applications
- Reduces concern of leaks and flammability associated with use of some refrigerants (e.g., HCs, R-717)

- **Eutectic Plates**

- Based on a frozen salt solution which removes heat from the environment as it melts and provides refrigeration; they must be periodically regenerated by freezing in an external mechanical refrigeration system
- Limited use in conjunction with standard cooling systems (with reduced refrigerant charge) for short distance distribution, particularly of frozen products, in road transport and intermodal container applications and explored for rail transport applications

- **Hermetic/Semi-Hermetic Vapor Compression Systems**

- May be used in place of open-drive compressors to enable use of low-GWP refrigerants that are high pressure or flammable (e.g., transcritical R-744, HCs)
- Currently being tested in road transport refrigeration applications in North America and Europe

- **Cascade Systems**

- Currently used on refrigerated transport ships, using R-717, R-744, or combination of R-717/HCs/HFOs
- Systems combining vapor compression cycle and heat-driven adsorption equipment under development for refrigerated trucks

Alternative Foam Blowing Agents

- **HCs (e.g., cyclopentane, n-pentane)**

- Provides greater gas pressure in foam cell and allows reduced foam density
- Production process for handling flammable agents required
- Used in intermodal containers, refrigerated ships, and truck bodies
- Under consideration for use in railcars (co-blown with HFCs or HFOs)

- **Methyl Formate**

- Under evaluation for use in road transport applications

- **Methylal**

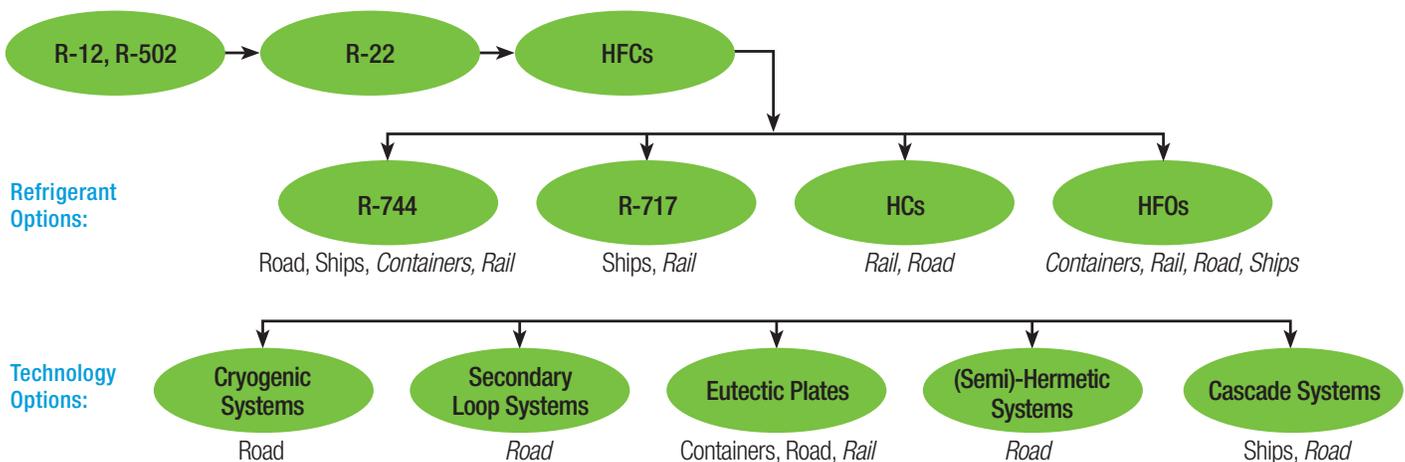
- Under early evaluation as a co-blowing agent with HCs and HFCs in rigid foams in rail applications; possibly in future for road and ship applications as well

- **Low-GWP Fluorinated Compounds (e.g., HFO-1234ze, HBA-2, FEA-1100)**

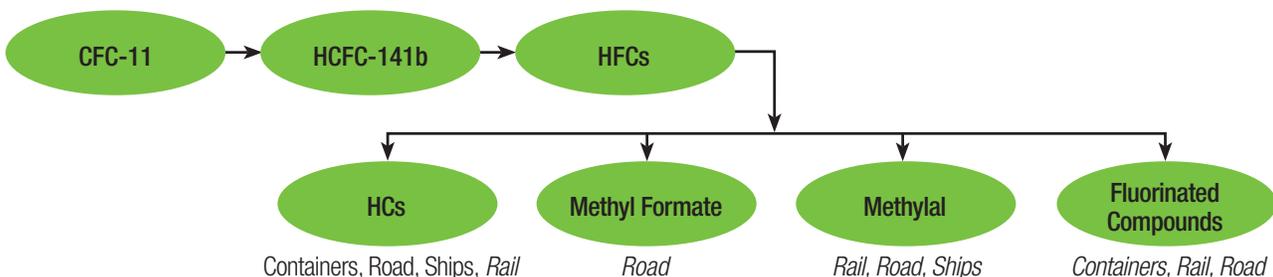
- Non-flammable
- Good solubility properties
- Under evaluation for intermodal containers, rail applications, and particularly in truck bodies
- Liquid HFOs as replacements for HFC-245fa and HFC-365mfc may become available after 2014

The actual and potential transition to these alternatives in transport refrigeration applications is illustrated in the diagrams below.³

Refrigerant Transition in the Transport Refrigeration End-Use



Blowing Agent Transition in the Transport Refrigeration End-Use



Challenges to Market Entry and Potential Solutions

The following table summarizes the challenges associated with the adoption of various alternatives as well as potential solutions to overcoming the challenges.

Alternative	Mode of Transportation	Challenges to Market Entry	Potential Solutions
Alternative Refrigerants			
R-744	<ul style="list-style-type: none"> • Intermodal Containers • Rail • Road • Ships 	<ul style="list-style-type: none"> • Safety Risks • High Operating Pressure 	<ul style="list-style-type: none"> • Engineering Design • Test Procedures • Training and Education
R-717	<ul style="list-style-type: none"> • Rail • Ships 	<ul style="list-style-type: none"> • Toxicity • Slight Flammability 	<ul style="list-style-type: none"> • Engineering Design • Standards and Safety Regulations
HCs	<ul style="list-style-type: none"> • Rail • Road 	<ul style="list-style-type: none"> • High Flammability • Liability Concerns • Safety Code Restrictions 	<ul style="list-style-type: none"> • Safety Devices • Standards and Service Procedures • Training and Education
HFOs	<ul style="list-style-type: none"> • Intermodal Containers • Rail • Road • Ships 	<ul style="list-style-type: none"> • Slight Flammability 	<ul style="list-style-type: none"> • Research and Development
Alternative Refrigerant Technologies			
Cryogenic Systems	<ul style="list-style-type: none"> • Road (small and large trucks) 	<ul style="list-style-type: none"> • Complex Safety Mechanisms • Requires Recharging with Liquid Coolant at Stops 	<ul style="list-style-type: none"> • Engineering Design • Research and Development
Secondary Loop Systems	<ul style="list-style-type: none"> • Road 	<ul style="list-style-type: none"> • Limited Experience 	<ul style="list-style-type: none"> • Research and Development
Eutectic Plates	<ul style="list-style-type: none"> • Intermodal Containers • Rail • Road 	<ul style="list-style-type: none"> • Technical Constraints; Periodic Regeneration Through External Freezing Necessary 	<ul style="list-style-type: none"> • Engineering Design • Research and Development
Hermetic/Semi-Hermetic Compression Systems	<ul style="list-style-type: none"> • Road (HC/R-744 systems) 	<ul style="list-style-type: none"> • Complex Safety Mechanisms 	<ul style="list-style-type: none"> • Engineering Design • Research and Development
Cascade Systems	<ul style="list-style-type: none"> • Road • Ships 	<ul style="list-style-type: none"> • Limited Experience • Requires System Calibration 	<ul style="list-style-type: none"> • Engineering Design • Research and Development
Alternative Foam Blowing Agents			
HCs	<ul style="list-style-type: none"> • Intermodal Containers • Rail • Road • Ships 	<ul style="list-style-type: none"> • High Flammability • Lower Thermal Performance 	<ul style="list-style-type: none"> • Engineering Design and Pre-Blending • Research and Development • New Equipment Required to Handle Flammable Agents
Methyl Formate	<ul style="list-style-type: none"> • Road 	<ul style="list-style-type: none"> • Limited Experience • Slight Flammability • Uncertainty About Long Term Physical Properties, Including Insulation 	<ul style="list-style-type: none"> • Engineering Design • Research and Development
Methylal	<ul style="list-style-type: none"> • Rail • Road • Ships 	<ul style="list-style-type: none"> • Limited Experience as the Sole Blowing Agent 	<ul style="list-style-type: none"> • Research and Development
Low-GWP Fluorinated Compounds	<ul style="list-style-type: none"> • Road • Rail • Intermodal Containers 	<ul style="list-style-type: none"> • Market Availability 	<ul style="list-style-type: none"> • Research and Development

Future Outlook

Many transport refrigeration applications have readily available, low-GWP foam blowing agent and refrigerant alternatives that will be adopted as HCFCs are phased out. However, in the case of some applications, such as foam in refrigerated railcars, continued research and development are needed to identify and commercialize technically feasible, low-GWP alternatives. Together, the suite of known alternative chemicals and new technologies can significantly reduce HFC consumption in both the near and long term, while simultaneously completing the HCFC phaseout. Although much work remains to fully adopt these chemicals and technologies, and some unknowns still remain, the industries currently using HCFCs and HFCs have proven through the ODS phaseout that they can move quickly to protect the environment.

¹ HFOs (hydrofluoro-olefins) are unsaturated HFCs.

² HFO-1234yf refrigerant is also commonly referred to as HFC-1234yf or R-1234yf, as it is referred to in the remainder of this fact sheet.

³ For all diagrams, non-italicized font represents alternatives previously used or currently available in the market for the given transport mode; italicized font indicates those likely to be available in the future.



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