COA TG-08 REEFER CONTAINERS: REGULATORY ISSUES CONCERNING REFRIGERANT F-GASES

Container Owners Association

TG-08
REEFER CONTAINERS: REGULATORY ISSUES CONCERNING REFRIGERANT F-GASES

CONTENTS

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FOREWORD

This Technical Guidance document has been compiled from information supplied by the COA Reefer Forum Work Group.

The document provides an overview of current and proposed regulations that restrict the use of refrigerant F-Gases and the consequential issues for consideration by the reefer container industry.

F-gas refrigerant R134a is used in 96% of the existing reefer container fleet. Regulations require that industries transition to alternative refrigerants that meet regulatory provisions. A 20-year transition period is required for the global reefer container industry.

There is no immediately available alternative refrigerant that meets all the required operational criteria of existing reefers. However, the HFO refrigerant R1234yf, which has an ultra-low global warming potential (GWP) of 0.5, is a suitable alternative which can be introduced for new reefers relatively quickly and would provide a significantly lower carbon footprint. Natural refrigerants R290 Propane and R744 CO_2 are potential longer-term alternatives under test and development but with demanding issues to overcome to meet the extreme operating demands of this sector.

The purpose of the document is to provide basis for debate within the COA membership with a view to reaching a consensus on the direction and development of a refrigerant strategy that will best represent the interests of COA members. The document also provides information for consultation with regulators.

Note:
F-gas is an abbreviation for “Fluorinated Greenhouse Gas”. It refers to a group of synthetic gases that contain fluorine and was originally used by the EU to describe HFCs. F-gases are used in various industrial applications, primarily as refrigerants, but also in air conditioning, heat pumps, and other equipment. The scope of EU regulations may widen to specifically include HFOs such as R1234yf and are currently referred to by EU 517/2014 as “other fluorinated greenhouse gases”.

F-gases were developed to replace ozone-depleting substances like chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), due to their harmful impact on the ozone layer. CFC and HCFC refrigerants have been phased out from the reefer container fleet.

Whereas F-gases such as R134a do not deplete the ozone layer, they are assessed to cause a comparatively high global warming potential (GWP). IPCC assessment reports provide GWP values and are amended periodically. This COA document includes values from the 6th Assessment Report.

Consequently, there have been international efforts to regulate and reduce the use of F-gases to mitigate their impact on climate change.

While most F-gases have a relatively high GWP most of the carbon impact of a reefer container is from the generating source of the electrical power it consumes. The impact on power consumption by alternative refrigerants is critical.

GLOSSARY

COP	Conference of the Parties
COP Protocol	Agreements e.g. Kyoto, Montreal, Paris, etc
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisation
ICCT	International Council on Clean Transportation
UNEP	United Nations Environment Programme
UNFCCC	United Nations Climate Change Conferences

COP	Coefficient of Performance
CII	Carbon Intensity Indicator
CFC	Chlorofluorocarbons
F-Gas	Fluorinated gas which includes CFCs, HCFCs and HFCs.
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HFO	Hydrofluoroolefins
PFAS	Perfluoroalkyl & Polyfluoroalkyl substances
TEWI	Total Equivalent Warming Impact

1.0 REGULATION OF F-GAS REFRIGERANTS

The 1987 Montreal Protocol is an international environmental treaty with the objective of protecting the earth's ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS) such as chlorofluorocarbons (CFCs) and other chemical substances.

Subsequent Conferences of the Parties e.g., COP Paris, proposed amendments which included the restriction of F-Gases. The 2016 Kigali Amendment specifically addresses the phase-down of HFCs and other fluorinated gases (F-gases).

Participating countries to the Protocol and its amendments commit to phasing down the production and consumption of HFCs and transitioning to alternative, more climate-friendly technologies.

Accordingly, several countries and regions have enacted regulations or have pending regulations with the aim to meet their obligations to the Montreal Protocol by restricting the production and use of F-gases.

The European Union has implemented regulations with arguably more rigid restrictions and shorter transitional measures and consequently is of more immediate concern to the Reefer Container Industry. Regulations from other countries and resolutions from organisations such as the IMO (International Maritime Organisation) are expected to increasingly affect the reefer container industry.

European Union EU 517 F-Gas Regulations provide for restrictions to the supply of F-Gases in phased steps. The regulation and imminently pending amendments, provide limited transition periods and adversely impact upon reefer container operations.

European PFAS restriction proposals also restrict F-gases as well as the supply of fluoropolymer materials such as PTFE (polytetrafluoroethylene) which is used to manufacture the critical sealing elements fitted within refrigeration compressors, pipework, electronics and other components.

Maritime reefer container operations are arguably out of the scope of EU Legislation. Containers enter Europe temporarily under a "Customs Seal". Nevertheless, F-Gas regulations affect maritime reefer containers. This is because of a probable reduction to the availability of F-Gases, consequential increased costs and potential restrictions to servicing reefer machinery in Europe. Manufacture of F-gas reefer equipment in Europe may be restricted.

EU regulations might be applied to marine reefer containers at a future date within the 18-year lifespan of the reefer container.

The reefer container and shipping industry contend that the counter-benefits of existing refrigerant gases and the transition practicalities of F-gases regulations have not been adequately balanced in respect of the global reefer container fleet which brings refrigerated products into and out of Europe. For this reason, there is a case for an industry strategy to highlight the exceptional operating requirements and benefits of reefer containers.

There are major issues and costs at stake if regulations do not provide a 20-year transition period for the production, availability and use of F-Gases and HFOs (Hydrofluoroolefins). Major operational issues and costs would ensue if a short regulatory phase-down forced the shipping industry to transition to alternative refrigerants before the performance of new refrigerants and their longevity is proven.

The timeline for development and the decision process to employ alternative refrigerant gases bears heavily on industry.

TABLE 1: EU REGULATIONS 2014

Regulation	Status	Summary
F-Gas 517.2014	- Applied 01.2015 Replaced 2006 legislation	- Phases down F-gases sold in EU by 2030 to one-fifth of sales in 2014. - Bans F-gases in new equipment where less harmful alternatives exist. - Reduces emissions from existing equipment by requiring checks, maintenance and recovery of gases at end of life. - Transport refrigeration (vans and ships) entry into force 01.2027 Trucks, trailers and land-based reefer containers, entry into force 01.2029
Link	https://www.eea.europa.eu/policy-documents/regulation-eu-no-517-2014 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517 https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?lang=en&reference=2022/0099(COD)	
Note	International shipping containers enter the EU under temporary customs seal and are not "imported". Thus, international maritime containers are arguably out of scope with the EU F-Gas restrictions which refers to substances that are "manufactured, used or placed on the market". However, the scope of EU regulations might change. Manufacture of equipment in the EU and servicing of international reefer containers is affected by EU regulations.	

TABLE 2: EU REGULATIONS 2014 REVIEW

Regulation	Status	Summary
F-Gas 517.2014 Review	- Initiated 2022 - EU Parliament and Council adopted 10.2023. Possibly applied 01.2024?	Align the F-gas Regulations with: - The European Green Deal - European Climate Law - Montreal Protocol – recent obligations - Stringent quota system for HFCs (HFC phase-down): reduce the amount of HFCs placed on the market by 98% by 2050 (compared to 2015). Additional restrictions on the use of F-gases in equipment. - Compliance with the Montreal Protocol, e.g. making phase-down steps also after 2030 and ending certain exemptions to the EU's HFC phase-down that do not exist under the Montreal Protocol - Improve enforcement and implementation, e.g. by making it easier for customs and surveillance authorities to control imports and exports. A quota price will be introduced, and penalties will become harsher and more homogenous across the EU. - Achieve more comprehensive monitoring, e.g. by covering a broader range of substances and activities and improving the procedures for reporting and verifying data. Package of measures that will prevent emissions amounting to 40 Mt of CO_2e (metric tons of carbon dioxide equivalent) by 2030 and 310 Mt CO_2e by 2050, on top of the amount the current Regulation would achieve.
Link	https://f-gas-regulation-review-2022.eu https://www.coolingpost.com/world-news/no-agreement-on-f-gas-revision/ https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?lang=en&reference=2022/0099(COD)	

TABLE 3: PFAS – PER FLUOROALKYL & POLY FLUOROALKYL SUBSTANCES

Regulation	Status	Summary
PFAS	Consultation process	ECHA / REACH industry consultation process, reporting to EU in 2024 - Part 1. complete, report published 02.2023. - Part 2. Industry submissions completed, ECHA report scheduled early 2024
	Proposal subject to change	Restriction to apply to refrigerants: - Refrigeration below -50 °C: until 6.5 years after EiF (entry into force) - In laboratory test and centrifuges: until 13.5 years after EiF - Refilling of HVACR equipment put on the market before [18 months after EiF] and for which no drop-in alternative exists until 13.5 years after EiF; - HVACR in buildings where safety standards and building codes prohibit the use of alternatives. - Mobile air conditioning-systems in combustion engine vehicles with mechanical compressors: until 6.5 years after EiF or 13.5 years if military. - In transport refrigeration other than in marine applications: until 6.5 years after EiF; Ref: ECHA A.1 Proposed restriction - Annex XVII entry PFASs (Restriction Option 2) page 4 of the report
		- Restriction of the use of solid-state fluoropolymers such as polytetrafluoroethylene (PTFE / Teflon) - Fluoropolymers are essential materials for refrigeration machinery and components e.g. electronic components, compressor O-rings, bearings, piston rings, valve seats.
	PFAS Table 9 & Table E Transport refrigeration	Strong evidence of low substitution potential. Entry into force derogation proposed for transport other than marine applications. Ban with a transition period 18mths. Significant modification of vehicle/ trailers and new refrigeration systems Ban with 18-mth transition and 5-yr and up to 12-yrs. derogation. In some areas , principally parts of the shipping sector, alternatives are established. In others e.g., road transport there is further work to do.
Link	All news - ECHA (europa.eu) Annex XV reporting format 040615 (europa.eu) Registry of restriction intentions until outcome - ECHA (europa.eu) https://comments.echa.europa.eu/comments_cms/AnnexXVRestrictionDossier.aspx?RObjectId=0b0236e1885e69de	

TABLE 4: IMO RESOLUTION

Regulation	Status	Summary
IMO 2023 Resolution MEPC.355 (78) refers to MEPC 78/17/Add/1 Annex 17	Applied 01.2023	Reduce carbon intensity of all ships by 40% by 2030 compared to 2008 baseline, ships are required to calculate two ratings: Energy Efficiency Existing Ship Index (EEXI) to determine their energy efficiency, Annual operational Carbon Intensity Indicator (CII) and CII rating. Carbon intensity links GHG emissions to amount of cargo carried over distance travelled.
Link	https://www.imo.org/en/OurWork/Environment/Pages/Index-of-MEPC-Resolutions-and-Guidelines-related-to-MARPOL-Annex-VI.aspx	
Note	Carbon impact measurements includes fuel consumed in the ship's electrical generators which are also used to power reefer containers. IMO calculate a power factor of 2.75 kW/h per reefer to be subtracted from overall emissions / fuel consumption of the vessel and include operating loss of refrigerant.	

TABLE: 5 OTHER REGULATIONS

Regulation	Status	Summary
USA: **American Innovation and Manufacturing (AIM) Act, as part of**	Applied 2021	Phasedown production and imports by setting limits. Directs the Environmental Protection Agency (EPA) to establish an HFC production and consumption baseline. Part of the Consolidated Appropriations Act
California Air Resources Board (CARB) Regulation	Applied 2021	Restricts the use of F-Gas refrigerants in new equipment, retrofits, and replacements. Requires reporting of usage, leaks, training https://ww2.arb.ca.gov
Canada: **Canadian Environmental Protection Act (CEPA)**	Applied 1999, last amended 2021	Achieve an 85% reduction in HFC consumption by 2036 compared to a baseline of 2017-2018.
Japan **Rational Use and Proper Management of Fluorocarbons**	Applied 2018	Reducing emissions of HFCs and other fluorocarbons.
Australia **Ozone Protection and Synthetic Greenhouse Gas Management Act**	Applied 1989 last amended 2022	Regulate the import, export, manufacture, and use of synthetic greenhouse gases, including HFCs. https://www.legislation.gov.au/Series/C2004A03755
India **Cooling Action Plan (ICAP)**	Applied 2019	Promoting the use of alternative refrigerants with lower global warming potential https://www.iea.org/policies/7455-india-cooling-action-plan-icap
Korea **Act on the Management of Fluorinated Greenhouse Gases**	Applied 2012, amended 2020	Regulate the use of high-GWP refrigerants, including HFCs, in various sectors. aims to control their emissions.
China **Management Measures for Fluorinated Greenhouse Gases" (Order No. 20)**	Applied 2020	Regulate the production, use, and trade of fluorinated gases, including HFCs. This regulation aims to control emissions, encourage the adoption of low-GWP alternatives, and promote leak prevention and proper disposal. China introduced regulations targeting the refrigeration and air conditioning sector to improve energy efficiency and reduce emissions. Includes requirements for equipment design, installation, and maintenance practices. https://theicct.org/wp-content/uploads/2022/02/lv-china-measures-reducing-GHGs-motor-AC-China.pdf http://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202005/t20200521_780130.html
Note	This table provides examples of some of the many regulations applied in different countries, excluding EU.	

2.0. REEFER CONTAINER GLOBAL FLEET

a. The global reefer container fleet is estimated to exceed 1.8 million reefer containers rising to about 2 million units by 2026 Ref: Drewry Maritime Census.

b. About half of the global fleet of reefer containers are owned by shipping lines with the other half owned by leasing companies who provide reefer containers under long-term contract to the shipping lines. Some reefer containers are also owned by shippers.

c. Two thirds of global reefer container cargo is carried by shipping lines headquartered in Europe.

d. Global shipments of perishable refrigerated cargo were 307 million tons in 2022. While some of this cargo is intra-regional and carried overland by road or rail, half of the global trade is carried in reefer containers on fuel-efficient ocean-going container ships.

e. The EU provides 23% of the global refrigerated cargo trade consisting of 10% of global refrigerated exports and 13% of imports. EU reefer exports are mostly high value meat, fish and dairy products plus fruits and vegetables as well as smaller amounts of chemicals and pharmaceuticals.

f. Most fresh produce cargoes are exported from developing countries such as Central and South America, Africa and South Asia.

g. Breakbulk refrigerated ships transport an estimated 12% of refrigerated cargo, predicted to decrease to 5% by 2030 and continuing the trend since the 1960's for cargo to transition to efficient reefer containers. Break-bulk ships have a predicted life of 25-years with many older ships having poor fuel efficiency and emissions compared to container ships.

h. Servicing of reefer containers must be undertaken prior to shipment by a network of qualified technicians located in global port areas. Servicing of complex reefer machines and refrigerants requires training to a high level and adherence to safety regulations.

i. The operating life of a marine reefer container is 18 years. The average age of today's fleet is 6.5 years. On eventual disposal from marine service, reefer containers might be used for another 10 years in static, land-based applications. By comparison, road based refrigerated trailers typically operate locally for 9 to 12 years.

3.0. REEFER CONTAINER OPERATING CRITERIA

a. Reefers must be designed to operate in ambient temperatures varying from -30° C to +50° C. This a much higher and technically challenging range than for other modes of transport refrigeration.

b. The ambient temperature where reefers are stowed on a container ship is between 35° C and 45° C for long periods. Most shipping routes carrying refrigerated cargo transit the tropics where high ambient temperatures combine with heat emissions from on-board equipment to cause the high stowage ambient temperature.

c. Cargo temperatures vary from -30° C to +30° C. Super-frozen cargo is shipped at temperatures of - 80° C to -30° C in specialised reefers using a different system design.

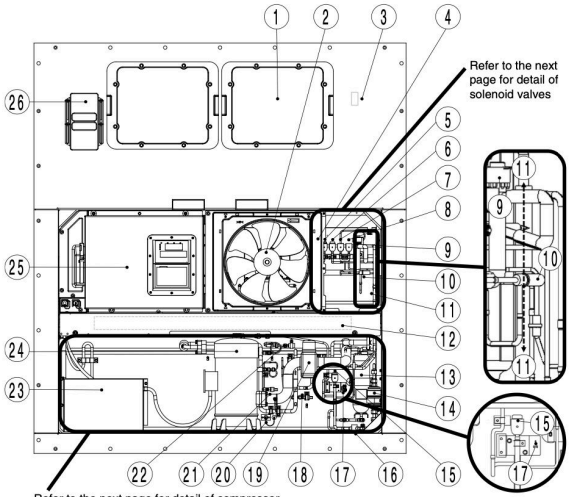
d. Power consumption of the reefer machine must be low to enable up to 2000 reefers to operate on-board within a ship's power generator capacity. In addition to the ship's power requirements, the generators power the reefer containers and ventilators for removing hot condenser cooling air.

e. Limiting power consumption is a strong focus of the shipping industry to provide a low carbon footprint, to comply with the IMO 2023 regulations as well as to mitigate the substantial cost of fuel for powering the ship and its electrical generators. Accordingly, it is essential to utilise low power consumption reefer containers.

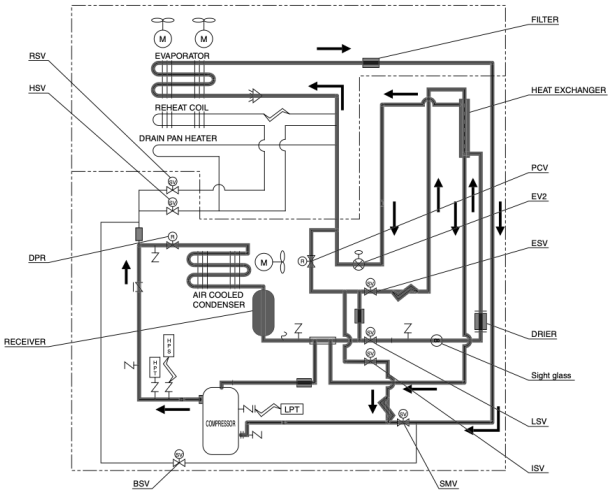
f. R134a refrigerant gas is used for 96% of the existing reefer fleet. R134a is a low-pressure refrigerant and provides efficiency and has a low power consumption over a wide operating temperature range. R134a yields a low carbon footprint over the life of the container but it is an F-gas and the GWP (Global Warming Potential) exceeds that allowed by F-Gas regulations.

g. Carbon impact calculations (ISO 14067) of reefers using R134a over an 18-year operating life indicate that 89.5% of the carbon impact is from power consumption and 10.5% from refrigerant loss.

h. Reefer machine dimensions are designed to fit within the exterior limits of the container (ISO 668). The reefer machine is also designed to fit within a minimum depth to optimise the container interior space and transport the maximum amount of cargo.



① Access panel
② Condenser fan motor (CFM)
③ Thermometer check port (Return air, optional)
※Thermometer check port is not fitted to some models.
④ Hot-gas solenoid valve (HSV)
⑤ Reheater Solenoid Valve for dehumidification control(Optional)
⑥ Discharge gas by-pass solenoid valve (BSV)
⑦ Economizer solenoid valve (ESV)
⑧ Injection solenoid valve (ISV)
⑨ Electronic expansion valve (EV)
⑩ Pressure Control Valve (PCV)
⑪ Economizer heat exchanger
⑫ Air-cooled condenser
⑬ Liquid receiver
⑭ Drier
⑮ Liquid solenoid valve (LSV)
⑯ Sight glass
⑰ Ambient temperature sensor (AMBS)
⑱ Low pressure transducer (LPT)
⑲ Suction modulating valve (SMV)
⑳ Thermometer check port (Supply air)
㉑ High pressure transducer (HPT)
㉒ High pressure switch (HPS)
㉓ Storage space for power cable
㉔ Compressor (CM)
㉕ Control box
㉖ Ventilator



BSV :Discharge gas Bypass Solenoid Valve
DPR:Discharge pressure regulator
ISV :Injection Solenoid Valve
LPT :Low Pressure Transducer
LSV :Liquid Solenoid Valve
PCV :Pressure Control Valve
SMV:Suction Modulation Valve
HSV:Hot Gas Solenoid Valve
RSV :Reheat Solenoid Valve
ESV:Economizer Solenoid Valve
EV :Electronic Expansion Valve
HPS:High Pressure Switch
HPT:High Pressure Transducer

4.0 REFRIGERANTS AND TRANSITIONAL OPTIONS FOR EXISTING REEFER CONTAINERS

a. Of the 1.8 million reefer container machines in the global fleet, around 1 million units cannot be charged with a different refrigerant.

b. R134a refrigerant gas is used for 96% of the 1.8 million reefer containers, each charged with between 4 to 6 kg. R134a provides the required operating range, and efficient COP (coefficient of performance). The demanding operating conditions limit the refrigerants that could replace R134a.

c. R404A or R452A is used for approximately 4% of reefers. A few specialized reefers are charged with R454A, R23 or R473A.

d. R134a, R452A, R454A, R513A, R1234yf, R23 and R473A are classified as HFCs or are blends with HFOs or natural refrigerants and their continued use is affected by F-gas regulation restrictions.

e. R1234yf cannot be charged into a reefer designed for R134a because of its mild flammability A2L class (ISO 817) but is potentially a better refrigerant:

- ultra-low GWP of just 0.5
- meets reefer container performance criteria with low electrical power consumption.
- used in the global automotive industry and is widely available.
- could be introduced in new reefer container machines in a lead time of 2 to 3-years.

f. The reefer container industry has been trialling the use of lower GWP refrigerants such as the natural refrigerants R744 carbon dioxide (CO_2) and R290 Propane but there are operating challenges with their use. R717 Ammonia (NH3) might be a possibility too though its toxicity may present a challenge for carriage of food.

g. R513A is a blend of R134a and HFO 1234yf with a GWP of 673 which is less than half that of R134a. Most reefer machines manufactured before 2018 can be modified to replace R134a with R513A and from 2018 onwards, reefer machines can be charged with R513A as a replacement to R134a without modification.

h. R513A is a practical replacement for R134a, offering high energy efficiency and low GWP but it is an F-Gas and subject to regulatory restrictions and is not currently widely available globally.

i. R744 CO_2 cannot be charged into a reefer designed for R134a because a R744 CO_2 refrigeration machine has a completely different system design with operating pressures of 150 bar compared to 22 bar for R134a.

TABLE: 6 REFRIGERANT TRANSITION OPTIONS

Refrigerant Gas	Remarks	Pros	Cons	GWP IPPC AR6
R134a	96% of existing reefer fleet HFC	Meets performance criteria. Low power consumption	Subject to F-Gas restriction	1530
R404A	4% of existing reefer fleet HFC	Meets performance criteria. Low power consumption	Subject to F-Gas restriction	4728
R452A	Interim replacement for R404A in existing machines	Meets performance criteria. Low power consumption	Subject to F-Gas restriction	2292
R454A	HFC/HFO blend Potential replacement for R404A in new machines	Meets performance criteria. Low power consumption Can replace R404A in new machines	Subject to F-Gas restriction Mild flammability Not widely available	270
R473A	HFC/HFO/CO_2 blend to replace R23 in ultra-low temperature application	Meets performance criteria. Low power consumption	Subject to F-Gas restriction	1835
R513	Blend of HFC R134a and HFO 1234yf	Replacement for R134a Meets performance criteria. Low power consumption	Subject to F-Gas restriction Not widely available	673
R1234yf	HFO	Meets performance criteria Low power consumption. Widely available (used in automotive industry). 3-yr lead time to develop new reefer containers. Ultra-low GWP.	Subject to F-Gas restriction Cannot be charged into a reefer designed for R134a Mild flammability	0.5
Note	HFC Hydrofluorocarbons HFO Hydrofluoroolefin			

5.0 REFRIGERANT OPTIONS FOR NEW GENERATION REEFER CONTAINERS

The demanding operating conditions for reefer containers and the essential need for low power consumption and safety, limits the choice of alternative refrigerants for the global shipping industry.

New refrigerant gases require the development of new designs of reefer machines. Development work is underway on different options but the most suitable replacement refrigerant to date from an owner/operator's perspective and in terms of providing a lower overall carbon impact for the reefer industry is HFO R1234yf. Other ultra-low GWP refrigerants present some significant challenges for use in reefer containers in the global shipping industry.

Accordingly, the reefer container industry requests that regulators provide extended transition periods for the use of F-Gas R134a and HFO R1234yf.

a. R1234yf :

R1234yf is an HFO but is a practical refrigerant to use in next generation reefers because:

- Its performance meets the demanding requirements for reefer containers.
- It has an ultra-low GWP of 0.5.
- Prototypes using it have a low electrical power consumption to reduce carbon impact.
- It is widely available being used in the automotive and other industries.
- There is only a 2 to 3-year lead time to prepare for its use in new reefer containers due to similar thermophysical properties and performance of R134a and R513A respectively".
- Its mild flammability makes it unsuitable for use in existing reefer containers.

Prototypes are being tested to confirm that possible flammability safety risks can be mitigated. It would give a 10% reduction in overall carbon impact compared to the existing R134a reefer containers due to the 0% contribution from its ultra-low GWP. R1234yf is not included in the existing EU F-Gas regulations but is proposed by regulators to be included in future F-Gas regulatory restrictions.

b. R744/ CO_2 :

R744/CO_2 is a 'natural' refrigerant with a low GWP of 1.0. It is widely used in static refrigeration systems such as in supermarkets. For use in reefer containers, the following factors need to be considered:

- R744/CO_2 operates at a high 150 bar pressure and requires a very different design of reefer machine.
- It is impossible to convert existing reefer machines designed for R134a to use R744.
- Electrical power consumption with R744 reefers recorded during in-service operating tests have shown it to be more than 23% higher than the best existing R134a machines and its use would increase the overall carbon impact of reefers by about 55% compared to using reefer containers charged with R134a.
- Power consumption is higher than R134a machines because the refrigeration machine is operating in the high air-temperatures experienced in the ships stowage that regularly exceed the 'critical temperature' of R744 CO_2 (31°C) for long periods.
- The high-power consumption of CO_2 units would lower the quantity of reefer containers that could be transported on a container ship due to the capacity of the ship's power generators which were designed to meet the low power consumption of R134a reefers. Installing increased capacity generators is often not feasible and would increase the carbon impact as more ships would be needed, each of which transporting fewer reefers.
- Trials of about 3000 units charged with R744/ CO_2 carried out with major European shipping lines have made the reefer container industry hesitant to consider R744/CO_2 as a viable refrigerant option because of its high-power consumption and the high operating pressures.

C. R290 Propane :

R290 Propane is also considered a 'natural refrigerant' and its low GWP, wide operating temperature range and efficiency have encouraged investigations of its suitability for use in reefer containers. The following factors need to be considered:

- R290 Propane is an efficient refrigerant that could be used in new reefer containers and provide similar operating performance to R134a reefers.
- GWP is ultra-low at 0.02.
- Electrical power consumption is acceptable.
- Flammability A3 Class (ISO 817) is a major concern. It's high flammability and the risk of explosion from gas leaks into the container interior are a major risk factor for its potential use on ships and in service facilities globally.
- Large ships carry up to 2000 reefer containers and the risk of a major fire or explosion incident has led to strong resistance from global shipping lines to the use of propane in reefers unless safety issues can be resolved.
- The challenge for reefer machinery manufacturers on prototype machines using propane is to reduce the fire and explosion risk to a very low level. It is predicted that it may take 7 years before this development work is completed and a final risk assessment carried out.
- Global servicing technicians would require additional, high-level training.

TABLE: 7 REFRIGERANT OPTIONS NEW GENERATION REEFERS

Refrigerant Gas	Pros	Cons	Conversion potential	GWP
R1234yf	Meets performance criteria. Low power consumption. Widely available (used in automotive industry. Ultra-low GWP	F-Gas restriction. Mild flammability	New design reefer machine only. 2 to 3-yr lead time to develop new reefer containers. Prototypes under test.	0.5
R744/ CO_2	3500 units under trial. Available design. Ultra-low GWP.	High power consumption. Higher carbon impact than existing F gas machinery. High-pressure refrigerant operating at 150 bar.	New design reefer machine only.	1
R290 / Propane	Meets performance criteria. Low power consumption. Ultra-low GWP.	Highly flammable A3 Class. Potential safety risk at sea.	New design reefer machine only.	0.02

6.0 GLOBAL WARMING POTENTIAL (GWP)

Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide (CO_2).

GWP values of refrigerants are derived from atmospheric lifetime models and the Climate-Carbon Feedback (CCF) which is calculated by the Intergovernmental Panel on Climate Change (IPCC) and are amended from time to time.

Consequently, the GWP values used in different refrigerant gas regulations are not consistent because the carbon dioxide equivalent emissions are based on the assessment at the time of the regulation, e.g. Regulation (EU) 517/2014 is based upon the IPCC AR4 (4th assessment report), while at the Paris agreement it was agreed to use values from AR5 or from a subsequent IPCC assessment reports (Ref: Decision 43 18/CMA.1, annex, paragraph 37).

The EU Commission for the revised F-gas revision combines values of AR4 (for HFCs) and the most recent assessment report for other substances,

TABLE: 8 GWP

Refrigerant Gas	GWP(100y) Second Assessment Report used under UNFCCC	GWP(100y) Fourth Assessment Report used in EU F-gas.	GWP(100y) Fifth Assessment report (excl. CCF)	GWP(100y) Fifth Assessment Report (incl. CCF)	GWP(100y) Sixth Assessment Report
Year of report:	1995	2007	2013	2013	2021
R134a	1300	1430	1300	1549	1530
R1234yf	NA	4a	<1	<1	0.50
R404A[b]	3260	3922	3943	4550	4728
R452A[b]	NA	2140	1946	2269	2292
R513A[b]	573	631	573	683	673
R290	NA	NA	NA	NA	0.02
R744	1	1	1	1	1
R23	11700	14800	12400	13856	14600
R473A[b]	NA	NA	NA	NA	1835
Notes	[a] Not stated in 4th Assessment report. In EU F-gas legislation, reference is made to the 2010 Assessment of the scientific assessment panel (SAP) of the Montreal Protocol, tables 1-11. [b] GWP for refrigerant blends is determined by weighted average (by mass) of GWPs of pure substances.				

7.0 SHIPPING INDUSTRY ISSUES MIGRATING TO NEW REEFER CONTAINERS.

a. From 2024 to 2030 shipping lines plan about 100,000 to 200,000 annual disposals (of old reefers) which are then replaced with new procurements, with added units for expected growth of cargo volumes.

b. The extreme operating conditions of reefer containers severely limits the viable refrigeration machine design options for migrating to lower GWP refrigerants.

c. Specification requirements when procuring new reefer containers ensure continued provision of the critical criteria of operating performance, low power consumption, safety, the regulatory requirement of using a low GWP refrigerant and if the system is suitable to be transitioned to a low GWP refrigerant gas (e.g., R513A) within the 18-year life of the reefer container.

d. The global availability of refrigerant gases is crucial. If availability is only assured in one area (such as Europe), but not in others, then the feasibility of using ultra-low GWP refrigerants in the global reefer container fleet is also greatly reduced.

e. Ongoing changes to regulation of F-gas refrigerants might make it difficult or impracticable for reefers to be operated into and out of the EU, a market that represents 23% of global refrigerated commodity trade.

f. Other countries are also implementing regulatory restrictions of F-gases but with less restrictive transition periods and essential use provisions than the EU. This might change over the life of the reefer container.

g. To enable decisions on procurement of new reefers, the shipping industry seeks a defined regulatory pathway that ensures operation over a full 18-year operating life. Premature disposal due to unforeseen regulatory changes would result in a major economic and carbon impact.

h. To avoid premature disposal of the existing reefer fleet that is using R134a and given the high efficiency and low overall carbon impact of reefers using R134a, the shipping industry requests that regulatory bodies consider a 20-year exemption to allow the continued use of R134a for servicing and the use of R513A as a transitional refrigerant.

i. The shipping industry could adopt the use of R1234yf in new reefer containers within 2 to 3 years which would quickly reduce the carbon impact of the global transportation of refrigerated produce if the EU were to put in place a 20-year exemption to allow the continued use of R1234yf for manufacture and maintenance/servicing.

8.0. CONCLUSION

a. The global reefer container fleet exceeds 1.8 million 20ft and 40ft reefer containers (3.3 million 20ft equivalent units). Reefer containers provide an essential service shipping perishable foods and other goods world-wide.

b. The exceptional operating requirements of marine reefer containers requires a 20-year F-gas regulatory transitional period for the existing global fleet of R134a reefer containers.

c. A 20-year transitional period from F-gas regulations is essential to avoid the very high carbon impact of premature disposal of existing R134a reefer containers which have an 18-year life.

d. A 20-year transitional period would enable the development of new, regulatory compliant refrigerants, new and safe designs of refrigeration machines and a global service network.

e. The 20-year transition of reefer containers that use F-gases to a regulatory compliant lower GWP refrigerants is necessary to enable the continued operation of low power consumption reefer containers.

f. The proposed PFAS regulations could prevent the migration to the only currently viable transition refrigerant (R513A) and the move for new equipment to the most suitable, ultra-low GWP refrigerant (R1234yf).

g. The proposed PFAS regulation could restrict the essential sealing-element fluoropolymer material being used in compressors, electronics and pipework.

h. If the shipping industry and reefer manufacturers could be assured of regulations allowing the required 20-year transition period, shipping lines would be able to approve investment in the ultra-low GWP refrigerant R1234yf reefer machines which could then become available in a 2 to 3-year lead time.

i. Reefer machines designed to use R1234yf cannot be transitioned to other ultra-low GWP refrigerants were future EU regulations to restrict or ban the use of R1234yf.

j. The carbon impact of reefer containers would be significantly reduced if the ultra-low GWP R1234yf could be assured of not being restricted by F-Gas or PFAS regulations. With a clear regulatory pathway, R1234yf reefers could start to become available within a 2 to 3-year lead time. Such a provision by regulators could also enable the use of R513A (a blend of R134a/R1234yf) to enable the industry to transition much of the existing reefer fleet to a lower GWP refrigerant in a shorter time span.

k. The carbon impact of the replacement of a reefer container is 30% of the carbon impact from operation over its life in the maritime sector.

l. Refrigerant R290 propane has a low GWP and power consumption, but its high flammability creates a major safety risk aboard ships.

m. Refrigerant R744 CO_2 has a low GWP but has a high-power consumption in the operating conditions of reefer containers in many of the trade routes. High-power consumption significantly increases the carbon impact of the global reefer fleet. It would require the number of reefers that can be transported at sea to be reduced due to the design capacity of ship's generators. It operates at a high working pressure and would require additional technician safety training worldwide.

n. A 20-year transition period would enable refrigerant gases to be available for servicing reefers within the EU and thereby enable continued EU imports and exports of perishable foods in low carbon impact reefer containers.