Final Report

The analysis of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions

Maritime, Rail, and Aircraft Sector

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Prepared for the European Commission (DG Environment)

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Summary

In the EU-27, emissions of fluorinated greenhouse gases are forecast to increase to around 100 MT CO_2 equivalent by 2010 if no additional mitigation measures are taken. In view of this projection, the Council and European Parliament agreed on a Regulation on certain fluorinated greenhouse gases. The objective of this Regulation is to put in place a legislative framework that contributes to the reduction of emissions of the powerful fluorinated greenhouse gases covered by the Kyoto Protocol.

There are provisions in the Regulation for a general review four years after the entry into application (mid-2007) which could include the need to introduce additional measures in order to reach environmental objectives in a cost effective and proportionate way. A provision in the Regulation (Article 10.1) requires the Commission to publish a report by the 31 December 2007 on refrigeration and air-conditioning systems in modes of transport other than motor vehicles.

This report by Öko-Recherche and its sub-contractor Ecofys, in line with the terms of reference presents initial findings on the environmental relevance of fluorinated refrigerant emissions from the maritime, railway and aircraft sectors, and on options to reduce these emissions.

1. In registers of EU states, there are approx. 9,000 sea-going merchant ships with air-conditioning and - to a smaller extent - provision cooling operational in 2006. Fishing vessels with small-sized refrigeration numbered 7,500, and large fishing vessels with freezing equipment onboard amounted to 700. R-22 was still the mostly used refrigerant; HFCs have been applied first from 2000 onwards. Consequently, the refrigerant stock in the EU maritime sector consists only partially of HFCs (25%), amounting to 775 metric tons (1,191 kilotons CO_2 equivalent), thereof 80% in merchant ships and 15% in fishing vessels, and 5% in inland ships. The prevailing HFC-type is R-134a with an 85% share, followed by R-404A/R507.

2. The rolling stock of the EU railway-, tram-, and metro operators amounted to 175,000 units. Approx. 65,000 of them were equipped with air-conditioners, charged with R-134a (75%) or R-407C (25%); chlorine-containing refrigerants are no longer in use. The HFC stock in these vehicles totalled 1,180 metric tons (1,605 kt CO_2 eq).

3. In the aircraft sector an HFC stock of only five to seven metric tons is estimated. The HFC emissions amount to 0.4 tons or 500 tons CO_2 equivalent.

4. In the maritime sector, the emission factor for air conditioning and refrigeration systems with direct expansion is very high, estimated at 40% per year. Even in indirect systems, a loss of 20% per year is common. Consequently, HFC emissions from ships amounted to 232 metric tons or 361 kilotons CO_2 equivalent.

5. Leakage rates of air-conditioning systems of rail vehicles are much lower, with 5% per year for the vast majority of the vehicles. Therefore, although the HFC stock in the rail sector is larger than in the maritime sector, 2006 emissions from rail vehicles are only a quarter of the maritime sector, namely 63.6 metric tons or 86.5 kilotons CO_2 equivalent.

Figure 1: HFC stock in the maritime and in the railway sector in the EU-27, 2006

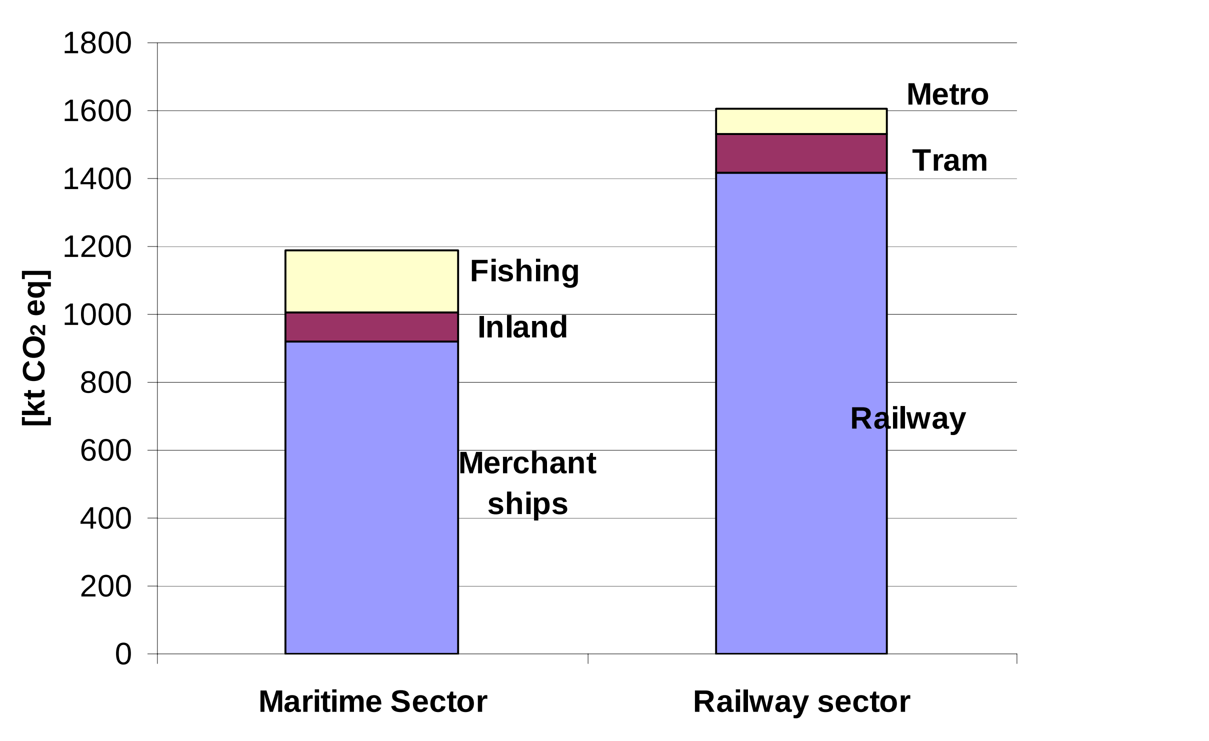

Figure 2: HFC emissions from the maritime and the railway sector in the EU-27, 2006

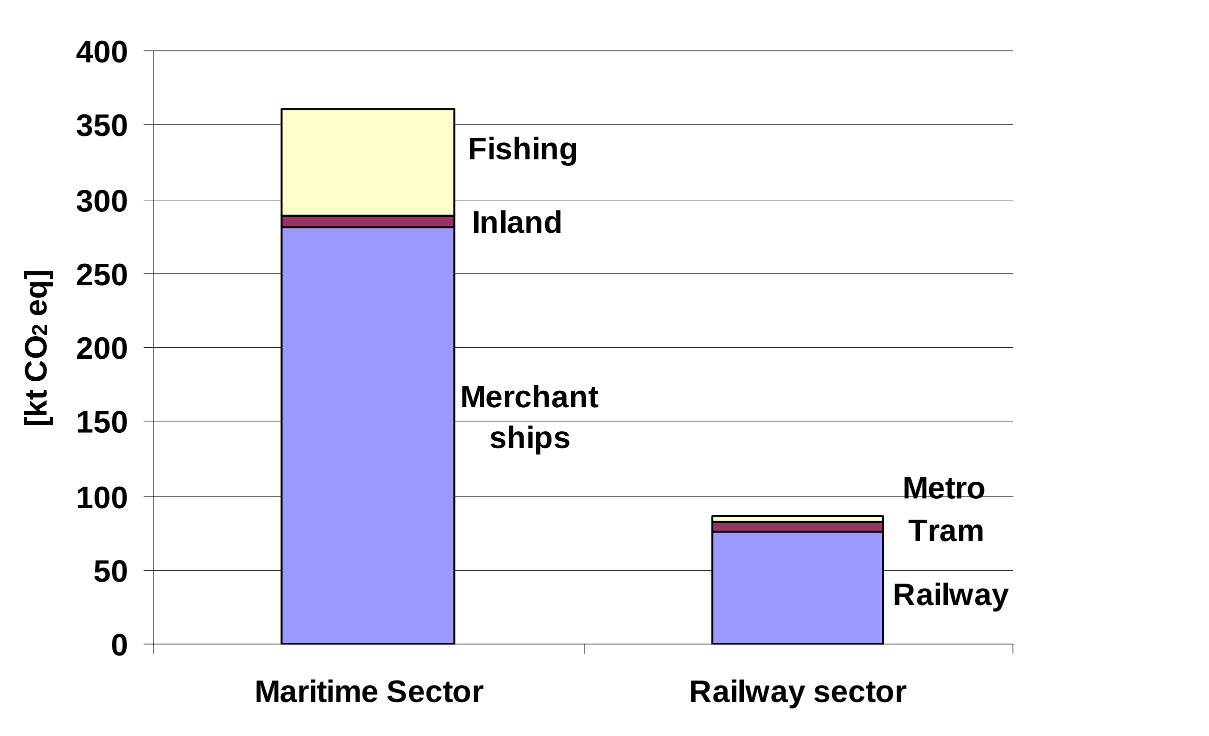

Figure 1 and 2. The comparison of the two figures shows that the 2006 HFC stock (figure 1) in the rail sector is bigger than that of the maritime sector. This is otherwise in emissions (figure 2); the maritime sector releases a multiple of the rail sector to the atmosphere because of the very high emission factor of ship systems. This indicates the necessity of containment measures to emission reduction particularly in the maritime sector.

6. In order to forecast 2020 emissions pursuant to a business-as-usual scenario, the 2001-2006 trend in HFC application is assumed to continue unaltered over the remaining fourteen years, for each category of ships and rail vehicles. This assumption includes ammonia continues to constitute half the refrigerants in new-built fishing vessels. Under these circumstances, the 2020 emissions from the maritime sector will amount to 1,141 kilotons CO_2 equivalent, and the HFC emissions from the rail sector will figure 174 kilotons CO_2 equivalent.

Table I: HFC emissions from the rail and the maritime sector in the EU-27 in 2006 and 2020 (business-as-usual scenario) [kt CO_2 eq.]

	2006	2020
Railway	76.4	144.4
Metro	3.8	13.2
Tram	6.3	17.0
Cruise Liners	37.2	111.6
Passenger Ships	51.2	153,6
Cargo Ships	180.8	542.4
Other Merchant Ships	11.6	34.8
Small Fishing Vessels <100 kg	15.6	59.3
Fishing Vessels 100-1,000 kg	12.3	46.8
Fishing Vessels >1,000 kg	44.7	169.7
Inland Navigation Vessels	7.8	23.3
Total	447.7	1,315.8

Figure 3: HFC emissions from rail and maritime sector in EU, by 2006 and 2020

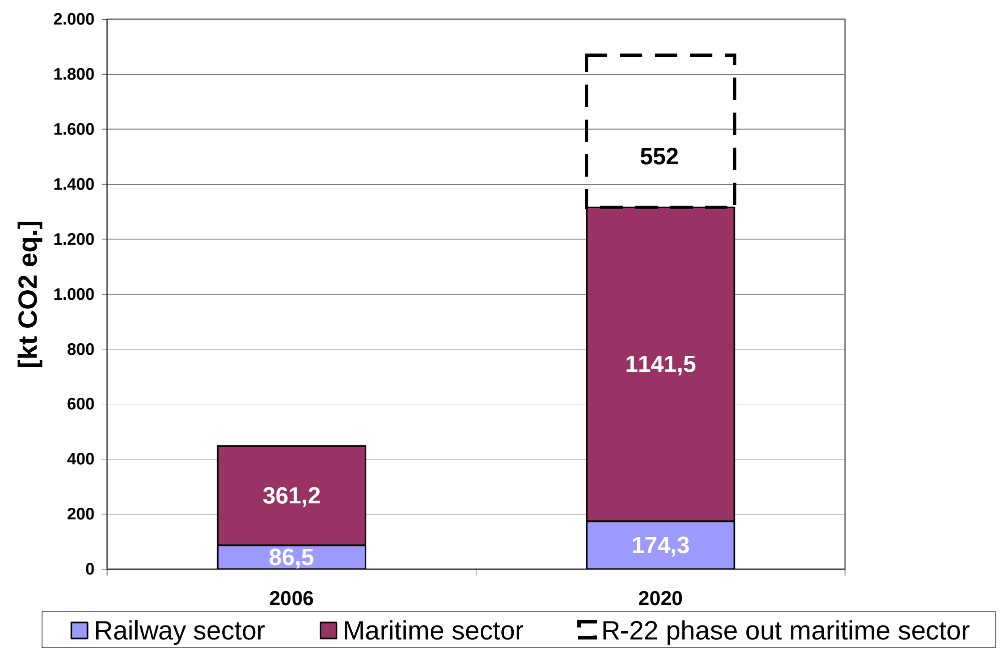

Figure 3. From 2006 to 2020, HFC refrigerant emissions are forecast to double in the rail sector (to 174 kt CO_2 eq) and to grow the threefold in the maritime sector (to 1,141kt CO_2 eq). Under a business-as-usual scenario that assumes the 2001-2006 trends to continue unaltered over the remaining fourteen years, the transition from R-22 to HFCs will not be finished by 2020 in the maritime sector. A complete R-22-phase-out, meeting the law, increases HFC emissions by additional 552 kt CO_2 eq.

7. Regulation (EC) No 2037/2000 on substances that deplete the ozone layer (June 2000) bans the use of HCFCs like R-22 from 1 January 2015. Under business-as-usual conditions, the transition from R-22 to HFCs will not be completed then in the maritime sector because R-22 had been used for new vessels up to 2001. A general and fast R-22 phase-out, meeting the law, leads to additional emissions of 552 kt CO_2 equivalent, compared with the 2020 business-as-usual scenario. As a consequence, the total 2020 emissions from the maritime sector grow from 1,141 to 1,693 kt CO_2 equivalent, while the rail sector emissions remain at 174 kt.

8. For comparison: We estimate the 2020 HFC emissions from the EU-27 passenger car fleet at roughly 20 million t CO_2 equivalent (not considering the HFC-134a phase-out). The maritime sector is expected to contribute 5 percent of the passenger car emissions. The 1.14 million tons from the maritime sector exceed the combined HFC emissions from air-conditioned buses and trucks. Rail vehicles will contribute 0.8% of the global warming emissions from all mobile air conditioners in the EU-27.

9. The analysis of options and costs of emissions reduction shows different results for the rail vehicles sector and for the two maritime sub-sectors merchant ships and fishing vessels.

9.1 In rail vehicles, additional efforts on HFC refrigerant containment are not expected to lead to significant emissions reduction because of the relatively small refrigerant charges and comparatively leak tight systems. So far, a changeover to natural refrigerants like CO_2 is costly and only partially compensated by the achievable reduction in HFC emissions and energy consumption. Present-day abatements costs in the rail sector amount to approx. € 1,000 per tonne CO_2 equivalent.

9.2 Key abatement option for merchant ships is limitation of the high leakage. By implementation of basic maintenance by trained staff and regular service by external experts, a significant reduction in HFC emissions is considered possible. As a result of these elementary measures, which include further containment measures like leak detection, use of control software, etc, approx. 30% of the overall HFC emissions or 339 kilo tonnes CO_2 equivalent could be saved at less than € 100 per tonne.

9.3 The forecast 2020 HFC emissions of 275 kilotons CO_2 equivalent from the fishery sector can be reduced in a cost effective way by extended use of the refrigerant ammonia in large vessels. Assuming that not only 50% of the new-built vessels with refrigerant charges over 1,000 kg but all new vessels over 1,000 kg are equipped with ammonia instead of HFCs, 125 kilotonnes CO_2 equivalent can be saved inexpensively because additional invest costs are compensated by lower operating costs due to less energy consumption. A further reduction of 20 kilotons CO_2 equivalent is possible at moderate cost by application of containment measures to medium sized vessels with refrigerant charges of from 100 to 1,000 kg.

10. It is understood that all emission reduction measures presented in this report like any measures that involve financial expenses will be implemented easier if they are regulated by legislation.

Contents

Chapter One

Air Conditioning and Refrigeration of Ships

I. Sea Going Merchant Ships

1. Design and refrigerants of air conditioning and refrigeration systems

Standard air conditioning equipment in cargo ships is a split system with direct refrigerant evaporation. In passenger ships indirect systems are installed with circulation of chilled water.

Cargo ships

The air-conditioning and refrigeration system outlined in the following is typical of cargo ships built in the last ten years, carrying the flag of an EU member state. Typical vessel size ranges from some 4,000 GT to over 100,000 GT, with lengths of from 100 to 300 metres. General cargo ships are mostly at the bottom of that scale, while Oil tankers and Container ships are on the top, with Bulk carriers in the middle.

By default, a condensing unit consisting of compressor and condenser is placed below deck, near to the engine room and the generator. The compressor is open or semi-hermetic (mostly of screw design); the condenser is flooded by sea water so that the liquefaction temperature is kept comparably low (up to maximum 35°C).

The evaporator is placed in the air-conditioning centre on deck, in the living area of the crew. It is connected with the condensing unit by an ascending and a descending refrigerant line (liquid and suction) of considerable length, and partly made of flexible hoses. The evaporator in the air conditioning centre directly cools down warm air from the crew's cabins, and the cool air is blown back through the distribution ducts. The evaporating temperature is ca. 0°C so that the air cools down to 15°C. It should be noted that no refrigerant pipes but only air ducts are laid to the cabins.

Typical quantity of refrigerant (generally R-134a[1]) in air-conditioning equipment is 150 kg[2] (KUE 07, NOK 07; KLH 07).This amount is necessary to cool the cabins of a 20-people crew in all climatic zones of the world. The amount of refrigerant does not primarily depend on the size of the vessel, which has been continuously increasing over the last years, but is determined by the number of cabins and of machine and computer rooms. This number does not grow with increasing size of ship and cargo.

In addition to air conditioning, on every ship a second, independent, refrigeration system is installed for provision refrigeration. As a rule, three cold rooms are chilled: one for frozen products, two for normal cooling of food and of drinks. On an average, 10 kg refrigerant, typically R-404A is necessary for the provision refrigeration system.

Passenger ships

In vessels with passengers on board like ferries or other passenger ships, the size of air conditioning systems is far larger than in pure cargo ships because much more cabins and common rooms need to be air-conditioned. In order to avoid long, voluminous air ducts or long, leak-prone refrigerant lines branching out through the

[1] In old vessels with R-22 air conditioners, R-404A is used as a replacement because R-404A and R-22 are similar in their properties. To this day, conversion of R-22 systems is very rare and negligible.
[2] In a few cases, two small compact systems are installed instead of one split system. Their combined refrigerant charge is only 100 kg.

whole vessel, water chillers are installed commonly. A (secondary) circulation system of cold water chilled by relatively short primary refrigeration circuits provides for air conditioning all over the ship, saving up to 50% of refrigerant compared to systems with direct expansion. The provision refrigeration usually runs directly.

Average refrigerant charge in indirect air conditioning systems on ferries and other passenger vessels is estimated 500 kg of R-134a (1,000 kW). This quantity is typical of large ferries (av. 1,500 passengers, no cabins, and 130 m long) or small passenger ships (av. 300 passengers, approx. 100 cabins, 50 m long). The refrigerant amount for cooling and freezing of food is approx. 20 kg of R-404A (20 kW) which is not much more than in cargo ships because frequent landing significantly reduces the storage time and, as a consequence, the size of cold rooms.

The default refrigerant charges of 500 kg (air conditioning) and 20 kg (refrigeration) are also applied to RoRo ships.

<u>Cruise ships</u>

Cruise liners present a ship type of their own. New built cruise ships have a capacity of more than 2,500 passengers and almost 1,700 crew members. Their size often exceeds 100,000 GT, and their length is more than 275 metres. Consequently, the refrigeration capacity of the air conditioning system is high, amounting up to 15 MW. It is provided by large water chillers that are often driven by centrifugal compressors.

For air-conditioning, the refrigerant charge of average sized new cruise liners (80,000 GT) is 6,000-7,000 kg (12 MW) (VINK 07), contained in three or four separate refrigeration circuits (one of them serving as spare circuit). Standard refrigerant is R-134a. For cooling and freezing of provision, there are two additional refrigeration circuits, with a typical refrigeration capacity of 400 kW (300 kW for cooling and 100 kW for freezing). (GRE 07) The charge of refrigerant (mostly R-404A) amounts to 400 kg. If the systems run directly, long refrigerant lines are necessary to provide for the 50-100 cold rooms, catering areas, etc. that are distributed all over the ship.

Table 1 summarises the above presented ship type-specific refrigerant charges in kg for air conditioning systems and plants of provision refrigeration.

Table 1: Refrigerant charges for air-conditioning and refrigeration, by ship types

Ship type	kg/AC	kg/Refr
Cruise liners	6,000	400
Passenger ships	500	20
Cargo ships (+ other ships)	150	10

AC = Air conditioner; Refr = Refrigeration system.

Other ships such as offshore, research, fire fighting, and search & rescue vessels are treated here in respect to size of air conditioning like cargo ships.

2. Ships by registration and application of EU law

Before estimating the number of MAC-equipped ships in the EU-27, it must be clarified what EU Member State means with respect to sea going ships.

In comparison to road and rail vehicles, the nationality of sea going ships frequently differs from the nationality of their owners or operators. Although an owner is e.g. located in Germany, his ship can be registered in Panama because taxation and the costs of the crew can be kept low in this way. On the ship the law of that state applies whose flag the ship flies, independently of the nationality of the owner.

In this study on vehicles of the EU-27, the question arises whether the country of the owner or the country of the registration of the sea gong ship should be considered as relevant for this analysis. Both assignments are meaningful in their way. We have opted for the country of registration because this study serves the review on whether legislative measures pursuant to the EU Regulation on certain fluorinated greenhouse gases should be applied to air conditioning systems other than those fitted to motor vehicles. EU legislation, however, can only be applied to ships that are subject to EU law, i.e. fly the flag of an EU member state. We are aware that in doing so we include a number of ships which is considerably smaller (by approx 20%) than the number of ships really controlled by owners from EU Member States.

It must be noted that registration in the ship register of one of the 27 EU member state is not identical to application of EU law.

1. Some Member States have established a "second" or "international" ship register that allows lower taxes and expenses for the crew than the first (regular) register so that it can compete with flags of convenience registers like Panama, Liberia, etc. EU environmental law completely applies to second registers of EU member states. This refers to Germany (GIS), Denmark (DIS), France (FIS), Spain (CSR), Netherlands (Antilles), and Portugal (Madeira).

2. EU law (Treaty of Rome, art 299) also applies to some "territories". These are Gibraltar and Isle of Man.

3. There are some overseas countries and territories (OCT) acc. to Treaty of Rome (art. 182-186) with special relationship to an EU Member State. EU law does not apply to them. Such territories are Falklands Islands, Cayman Islands, Virgin Islands (all UK related), Aruba (relation to Netherlands), French Antarctic lands (France related). Neither does EU law apply to Faeroe Islands.

The 31 registers of ships to which EU law applies are listed in Table 2. (Austria and Czech Republic as EU countries without registers are not included).

Table 2: Ship registers to which EU environmental law applies

Belgium	Irish Republic	Romania
Bulgaria	Italy	Slovakia
Cyprus	Latvia	Slovenia
Denmark	Lithuania	Spain
DIS	Luxembourg	Spain CSR
Estonia	Malta	Sweden
Finland	Netherlands	UK
France	NL-Antilles	Gibraltar
FIS	Poland	Isle of Man
Germany	Portugal	
Greece	PT-Madeira	

3. Total number of EU merchant ships

The number of units of merchant ships in service and entered in the above listed EU registers is determined in this study by means of the Lloyd's Register - Fairplay, which is the worldwide leading supplier of maritime information (FAI 07).

Every marine vessel for international waters (minimum size 100 GT) is inspected, certified and regularly surveyed by one of the worldwide fifteen non-governmental ship classification societies. The technical inspections follow the guidelines of the International Maritime Organisation (IMO) which is the United Nations' specialized agency responsible for improving maritime safety and preventing pollution from ships. The IMO keeps the database of over 80,000 ships, including movements, casualties, vessel characteristics (these do not include air conditioning or refrigeration), owners, flags, etc. On behalf of IMO, the British classification society Lloyd's Register of Shipping maintains this database in their organisation Lloyd's Register Fairplay Ltd., and makes it open to the world's maritime community.

From Lloyd's Register Fairplay arise the following figures on the structure of the EU merchant fleet (ships over 100 GT) at the end of 2006, as per Table 3.

Table 3: Number of merchant ships in EU registers, in service end of 2006	
Cruise liners	101
Passenger ships	2,064
Cargo ships	6,177
Other (offshore, research, rescue, etc)	621
All types	8,963

Source: Lloyd's Register Fairplay, State April 2007.

The number of EU registered sea going merchant ships over 100 GT (incl. offshore vessels, etc) in service at the end of 2006 totals approx. 9,000 units.

Detailed data on the total EU merchant fleet by 12 different ship types and 31 different registers are presented in Annex I. Here, only the following additional information on the fleet structure is given:

Approx. 70% of the 8,963 vessels are entered in the seven largest of the 31 EU registers: Malta (14%), Greece (14%), Italy (11%), Cyprus (10%), UK (7%), Netherlands (7%), and Germany (6%); all of these registers are first registers. By far most of the ships in the registers of Greece, Italy, The Netherlands, UK, and Germany belong to owners located in the same EU country. Malta and Cyprus are mainly registers for owners from other EU countries, particularly from Greece.

4. Number of EU sea going merchant ships with HFC-refrigerants

Merchant ships have been air-conditioned for a long time, beginning in the seventies of the last century. From the start, HCFC-22 was the general refrigerant because its properties qualify it well for air conditioning (and also for provision refrigeration).

Experts interviewed in the course of this study agree that from 100 GT onwards merchant ships must be assumed to be fitted with air-conditioning because vessels of this size navigate through every climate zone of the world. As the Fairplay ship statistics begin with the same vessel size (100 GT), the above presented number of EU registered ships can, at the same time, be regarded as number of EU ships with air conditioning. To this day, on the majority of ships the air-conditioner runs with R-22.

Regulation (EC) No 2037/2000 on substances that deplete the ozone layer (June 2000) bans the use of HCFC-22 from 1 January 2001, in refrigeration and air-conditioning equipment produced after 31 December 2000, in all member states. Some member states had banned the use of R-22 in new equipment a year earlier.

The year 2000 was the ultimate year when air conditioning and refrigeration plants on new EU ships were lawfully charged with R-22. In practice, the transition from R-22 to HFC-134a and certain HFC-blends took place in the time from 1998 to 2001. Here, the year 2000 is deemed the first year of general use of HFCs in new air-conditioning and refrigeration equipment on EU merchant ships. All EU ships completed in 2000 and after are treated as air-conditioned and refrigerated with HFCs.

Every ship in the directory of Lloyd's Register Fairplay is specified with the "year of completion". Summing up all the vessels built in the 2000-2006 period (seven years), the numbers of EU registered ships with HFC refrigerants in the air-conditioning and refrigeration equipment can be arrived at (see Table 4):

Table 4: EU merchant ships with HFC refrigerants (built from 2000), end of 2006	
Cruise liners	21 [101]
Passenger ships	365 [2,064]
Cargo ships	2,043 [6,177]
Other vessels	132 [639]
All types	2,561 [8,981]

Source: Lloyd's Register Fairplay, State April 2007. In brackets: Total of EU registered ships.

Table 4shows that at the end of 2006 approx. 2,550 EU registered merchant ships had air conditioners (and refrigeration plants) with HFC refrigerants. In addition, it emerges that the share of new ships in the total of the fleet is significantly higher for cargo ships (33%) than for ships with passengers (18%). This is because currently cargo ships grow in number while ships with passengers decrease[3].

5. HFC-refrigerant stock in the EU merchant fleet

The quantity of HFC refrigerants stocked in the EU registered merchant fleet is arrived at by multiplication of the number of units in Table 4 with the particular refrigerant charges presented in Table 1.

The total HFC refrigerant stock can be estimated to amount to 635 tons in air conditioners and 37 tons in systems for provision cooling.

[3] Given an average vessel lifetime of 25 years, annual new-buildings must average four percent of the total fleet, if the fleet shall keep the same size in the long term. Over six years (2000-2006), the new-buildings should make up 24%. Thus, the 18% for passenger ships indicate decreasing fleet size, while the 33% for cargo ships indicate considerable increase in the fleet size.

Table 5: HFC stock in the EU merchant fleet, air conditioning (AC) and refrigeration (Refr), in kg and tons, end of 2006					
Ship type	Number	kg/AC	kg/Refr	Total tons AC	Total tons Refr
Cruise liners	21	6,000	400	126.0	8.4
Passenger ships	365	500	20	182.5	7.3
Cargo ships	2,043	150	10	306.5	20.4
Other vessels	132	150	10	19.8	1.3
All types	2,561			634.8	37.4

The HFC type in air conditioners is, almost exclusively, R-134a. A few new systems use R-407C; some of the few converted old systems use R-404A or drop-in blends. The quantity of HFCs other than 134a is negligible and not considered further, here.

Prevailing refrigerant for provision refrigeration is R-404A because it is the best for both refrigeration and freezing with the same refrigerant. A drawback of R-404A is that it is always an additional refrigerant to R-134a which is used for air-conditioning. Consequently, in a considerable number of cases R-134a is also used for refrigeration. The interviewed experts estimate the share of R-134a in ship refrigeration at 33%.

6. Emissions of HFCs from merchant ships

The emission factor for air conditioning systems with direct expansion is estimated at 40% per year. For indirect systems, a loss of 20% per year is assumed.

- Interviewed service experts from the two leading European suppliers of ship air conditioning/refrigeration equipment (York, Germany, and Grenco, The Netherlands) estimate annual use-phase refills on merchant ships to range from “20 to 40%” and “from 35 to 40%”, respectively. (KUE 07, VINK 07).

- According to the Dutch “Inventory Refrigerant Emissions Sea Shipping” for the year 2000 the “yearly leakage rate of merchant shipping amounts to 33% and 39% for fishing” (INV 02).

- In our survey on 2005 refrigerant refills of 36 Scandinavian merchant ships with direct air conditioning systems the annual quantity averages 40% per year (see box below).

Survey: Annual refills on 36 Scandinavian merchant ships

In May 2007, three Scandinavian ship owners were interviewed about the 2006 refrigerant refills in their 36 vessels with air conditioning and provision refrigeration (the companies are not named her for confidentiality, but have been communicated to the Commission). The refilled refrigerant quantity totalled 7,092 kg (R-22, R134a, and R-404A), which is 197 kg annual loss per ship. The estimated refrigerant charges in the 36 vessels amount to approx. 17,700 kg in AC (492 kg per ship) and ca. 800 kg in refrigeration (22 kg per ship). Notwithstanding the high variety in individual refill rates, the refill per ship averages 38.3%. According to the service departments of the owners, refills per ships could be lowered substantially in the last five years.

- In our special survey on 2006 refrigerant refills in 10 Baltic ferries with indirect air conditioning systems and direct refrigeration systems the annual leakage rates (refill-rates) average 21.2% for the indirect air-conditioning systems and 25.1% for the (direct) refrigeration systems (details in Annex II to this report).

Survey on 2006 refrigerant refills *in 10 Baltic ferries with indirect air-conditioning and direct refrigeration systems – see Annex II.*

The main reason for the high level of emissions from sea-ships, compared to land based systems, is agreed to be the permanent exposition of the whole system to vibrations from sea-waves. The ongoing motion, repeatedly escalating to severe agitation, leads to damages and leakages, especially in the piping. This made worse because, there is no crewmember onboard skilled in refrigeration. When the ship is at sea for weeks, leakages are not repaired but simply topped up.

Lower leakage is assumed for indirect, water-chilling systems thanks to the compact design and the significantly shorter refrigerant lines.

Applying the emission factors of 40% to direct systems (pure cargo and "other" ships) and of 20% to ships with passengers (indirect), we obtain emissions as per Table 6.

Table 6: HFC emissions from the EU merchant fleet, air conditioning (AC) and refrigeration (Refr), in metric tons and kilotons CO_2 eq, end of 2006

Ship type	EF in %	Air conditioning		Refrigeration	
		Emissions metric t	kilotons CO_2 eq	Emissions metric t	kilotons CO_2 eq
Cruise liners	20	25.2	32.8	1.7	4.4
Passenger ships	20	36.4	47.3	1.5	3.9
Cargo ships	40	122.6	159.4	8.2	21.4
Other vessels	40	7.9	10.3	0.5	1.3
All types		192.1	249.7	11.9	31.0

Sources: Emission factor of 40%/20% applied to "Total tons" in Table 5.

All AC emissions consist of HFC-134a, the emissions from refrigeration consist one third of R-134a, and two thirds of R-404A. The global warming emissions are calculated by means of the GWP values of 134a (1,300/kg) and of 404A (3,260/kg). They total 280.8 kilotons CO_2 equivalent from both air conditioning and refrigeration.

7. Outlook 2020: 842 kilo tonnes CO_2 equivalent

In a business-as-usual scenario up to 2020 it is assumed for the growth rate of HFC-equipped new vessels that the seven-year trend from 2000-2006 continues unaltered over the remaining 14 years until 2020. Under these circumstances, emissions should increase threefold by 2020 compared to the present quantity, i.e. up to 842.4 kilo tonnes CO_2 equivalent.

Due to their high growth rate, HFC equipped cargo ships should reach the present fleet size by 2020. Because of their lower growth rates, cruise ships will be only 62% HFC equipped, passenger ships only 53% of their particular fleets, by 2020.

However the growth rates will be, in 2015 a considerable number of vessels from the 1990s would be in service, equipped with R-22 air conditioners. The EU legislation on ozone-depleting substances does not allow the use of this refrigerant after 2015. In order to meet the law, the transition from R-22 to HFCs must be carried out quicker than in the business-as-usual scenario. Considering a complete R-22 phase-out by 2020, the number of ships with HFC air conditioning will be 27% higher than under business-as-usual conditions; estimated HFC emissions are 1,071 kt CO_2 equivalent.

II. Ships for Refrigerated Cargo

Ships for refrigerated cargo or "reefer ships" are merchant ships and count as such in Lloyd's Register Fairplay, where most of the following information comes from. In reefer ships refrigerants are primarily used for refrigeration while air conditioning is of negligible importance. As a consequence, reefer ships are dealt with here separately.

The conventional reefer fleet shows a negative growth rate of 16% since 1994, while the number of refrigerated containers for transportation on sea-ships expanded at an even higher rate than anticipated. (UNEP 06) While reefer containers grew rapidly in number, reefer ships are increasingly seen as being a supplement to container liners. Reefer ships are now utilised where at irregular intervals large amounts of homogeneous goods need transportation, e.g. after fruit harvest. Consequently, the main cargo of today's reefer ships is bananas and citrus. Reefer ships are well-suited for this cargo because their refrigerated holds can provide good conditions for fruit maturation such as constancy of temperature, reduced oxygen level (controlled atmosphere), and appropriate humidity. Apart from fruit, reefers take fish from catching vessels at sea and bring it ashore. In order to compensate at least partially for the increasing use of containers for transported goods, new reefer ships are constructed "hybrid", i.e. they carry not only refrigerated cargo but can also carry containers and road vehicles (RoRo).

1. Number of reefer ships in the world and the EU

At the end of 2006, the worldwide number of reefer ships over 100 GT was 1,231 units of which only 158 were in EU registers. Three quarters (76%) of the latter were registered in Malta (43), NL-Antilles (25), UK (18), Lithuania (17) and Cyprus (17). The EU reefer fleet is rather old with an average ship age of almost 20 years.

The vast majority of the EU reefer ships use HCFC-22, with charges of 1 to 5 tons. A few run on ammonia technology temporarily installed in the early nineties, in indirect systems with refrigerant charges of 500 kg to 1,000 kg. In the 2006 UNEP RTOC assessment report, annual emissions from reefer ships are estimated at 20%; following this report, emissions can be lowered to 5-10% in indirect systems where, thanks to long brine pipes, leak prone refrigerant lines are significantly shorter.

HFC emissions from reefer containers (excursus)
Though reefer containers are out of the scope of this report, they are worth some words here. The worldwide stock of reefer containers for transportation of perishable goods on sea-ships is still rapidly growing and figures about 1.45 million TEU (Twenty Feet Equivalent Units), which means some 0.825 million container boxes in 2006. To the front wall of a container, a refrigeration set is mounted, which runs on board electrically. After transition from R-12 to R-134a in the early 90es, typical charge of HFC-134a refrigerant (approx. 20% is R-404A) is 6 kg per container. As a consequence, the worldwide bank of HFCs amounts to 5,000 tons. Applying an emissions factor of 15% to that stock, annual operating emissions of 750 tons arise. It is very difficult to estimate that part of emissions for which EU member states are responsible. With all due respect, to a certain degree it seems plausible to us to distribute the worldwide refrigerant emissions according to the share of the EU countries in the world trade (SCHW 04), which amounts to roughly one third. From this vague attribution to the EU-27, annual EU-27 emissions of over 250 tons result.

2. EU reefer ships from 2000

From 2000, only four new reefer ships were entered in EU registers; see Table 7.

Table 7: The new-built reefer ships in EU registers, from 2000 onwards

Name	Royal Klipper	Cala Palma	Cala Pedra	Salica Frigo
Completion	2000-02	2000-01	2000-03	2001-11
Shipyard	Kitanihon, Japan	Fincantierei, Ancona	Fincantierei, Ancona	Barreras, Vigo
Weight in GT	11,382	14,868	14,868	7,207
Length	150 m	174 m	174 m	133 m
Owner	Jaczon, NL	Fruttital, IT	Fruttital, IT	Albafrigo, ES
Flag	Netherlands	Italy	Italy	Spain (CSR)
Refrigerant	R-22 direct	R-22	R-22	NH_3 indirect

In 2000, three vessels were built, two for Italy, one for The Netherlands; all using R-22, which was lawful because it was banned for new installations first from 2001. After 2001, when R-22 was prohibited for new systems, only one new-built reefer was EU registered: The "Salica Frigo", built in Spain, was entered in the second Spanish register. The vessel is primarily used for transportation of deep frozen tuna. Since 1993, this ship is the first EU reefer with Ammonia (NH_3) as refrigerant.

For safety the refrigeration system is indirect. It consists of three units with NH_3 as primary refrigerant chilling a brine of calcium chloride that is circulated to the cargo holds. The brine distribution is a three-temperature system consisting of a main brine line for cooling, a freezing line and another line for defrosting. The three ammonia brine chillers run with Grenco screw compressors of 3 x 816 kW refrigerating capacity (at 0°C/+40°C). The temperature of the holds ranges from -25°C to +12°C (GRE 07).

To this day, in EU shipyards only two reefer ships with HFCs were built: the Carmel Ecofresh and the Carmel Bio-Top. (GRE 07) The two sister ships were ordered by a German owner and completed in 2003 by the Portuguese yard Estaleiros Navais. The vessels are not entered in EU registers but carry the Bermuda flag. Each of the two ships is 186 metres long and has 17,929 GT. They are designed as Reefer/RoRo/Container vessels with holds of 13,000 m^3 for refrigerated cargo or 500 cars alternatively; with additional space for 880 containers (TEU).

On both ships, the refrigeration system is indirect with the refrigerant R-407C and the brine $CaCl_2$. There are three circuits with refrigerating capacities of 1,200 kW at 0°C/+40°C (each).The refrigerant charges are 500 kg 407C, together 1,500 kg.(VINK 07) Refrigerating the direct way, twice this quantity would have been necessary.

3. Summary on reefers and outlook 2020

Until today, no reefer ship with HFC refrigerants has been entered in an EU register, but there is one with ammonia. Evidently, this single vessel cannot provide a firm basis for the prediction that in the near future only natural refrigerants will be used for new reefer ships, given that in the EU recently two new reefers for foreign registers were built with HFC systems. In the light of the strong competition from reefer containers the number of new buildings will likely keep on being small until 2020 although a robust forecast is impossible, now. In the light of this, we do not consider a business-as-usual forecast of the 2020 HFC emissions meaningful.

III. Inland Navigation Vessels

1. Design and refrigerants of air conditioning systems

Motorised Cargo vessels

In inland cargo vessels, ship-specific air conditioners are not installed by the yard. As far as cargo ships are air-conditioned the equipment is fitted subsequently, and the devices are those that are used for residential air conditioning by land. This kind of air conditioning has become common practice in recent years. (JAEG 07)

Standard case is a small multi-split system: an outside unit with compressor and condenser is connected, via refrigerant lines, to evaporators in the cabins of the living area. Usually there are four cabins and, as a consequence, four evaporating units cooling the inside air. The refrigerating capacity of the whole set amounts to 10 kW; the refrigerant charge is ca 3 kg. From 2001, R-22 has been banned, so that mostly R-407C and, increasingly, R-410A is used. In reality, the change from R-22 to HFCs took place some years earlier. The operating cabin is air conditioned separately, with a single split device of 3-4 kW refrigerating capacity or 1-1.5 kg refrigerant. (UEB 07)

Cabin boats

Unlike cargo vessels, EU passenger ships have been air conditioned for more than twenty-five years. Passenger ships split into two categories: cabin boats and excursion boats (without cabins). It is obvious that the refrigerating capacity for air conditioning (and provision refrigeration) of boats with cabins is higher than for excursion boats with only three or four large common rooms for all the passengers.

Characteristic of cabin boats are indirect air conditioning systems: water is chilled by a primary refrigerant circuit to approx. 6°C and circulated through air coolers in the 20-80 cabins. Compressors of the compact water-chilling unit are of the reciprocating or screw type; condensers are cooled with river or lake water. Split systems with direct refrigerant expansion are not common and only used in very small boats if at all. Refrigerating capacity in a modern boat (80-100 m long) with 50 passenger cabins on two decks, restaurant, cafes, crew rooms, etc. amounts to 400 kW, provided by two or three compressors. The refrigerant charge is ca. 200 kg. (DRE 07)

The independent system for provision refrigeration consists of three cold rooms: one for frozen products, two for normal cooling of food and of drinks. On an average, 5 kg refrigerant (direct expansion) is necessary to provide a refrigerating capacity of 5 kW. There is no need for larger storage because the boat lands every evening. (DRE 07) R-134a or R-404A is used for air conditioning as well as for refrigeration.

Excursion boats

The air conditioning system is mostly of the same indirect type as in cabin boats. Cold water circulation provides cool air all over the boat, in common rooms, catering areas, etc. The difference is in size: the quantity of refrigerant in the primary circuit is less than half the amount of cabin boats (HEI 07). Refrigerating capacity in a modern excursion boat (70 m long) is 200 kW, provided by two compressors/refrigerant circuits. The refrigerant charge is ca. 100 kg. In smaller boats (less than 40 m long), often one-loop systems for direct air-cooling are installed. The refrigerant charge is relatively higher than in indirect systems, but the absolute charge is the same because of the lower refrigerating capacity for smaller boats.

Provision cooling is not common on excursion vessels.

Table 8 summarises the presented ship type-specific refrigerant charges for air conditioning systems and, in case of cabin cruisers, plants of provision refrigeration.

Table 8: Refrigerant charges for air-conditioning and refrigeration, inland ships

Inland ship type	kg/AC	kg/Refr
Self-propelled cargo vessel	4.5	-
Cabin cruiser	200	5
Excursion boat	100	-

AC = Air conditioner; Refr = Refrigeration system.

2. Total number of EU inland waterway vessels

On inland waterway navigation, there are EU wide statistics available, since recently. They cover the entire ambit of commercial navigation on the rivers in the EU. Excluded is navigation of sea-ships between sea and inland ports (sea-river navigation) as well as recreational navigation both of which are not considered inland river navigation in its genuine form. This also applies to navigation on isolated lakes.

The EU inland waterways for commercial river navigation are usually divided into five geographical zones of large rivers and their riparian states ("corridors").

1. Rhine corridor: The Netherlands, Belgium, Germany, and Luxembourg.
2. Danube corridor: Austria, Hungary, Slovakia, Romania, and Bulgaria.
3. North-West corridor (Elbe-Odra): Czech Republic, Poland.
4. North-South corridor (Rhône/Saône, Seine): France.
5. Rest of EU: United Kingdom, Italy, Finland.

Germany, which is part of three different zones, is assigned to the Rhine corridor; France also sharing in the Rhine zone is represented by the North-South zone alone. Further countries with navigable waters like Sweden, Lithuania, Spain, and Portugal are not regarded because they have only sea-river or recreational navigation.

In the context of this study on air-conditioning of inland ships it is important that the statistics not only include data on cargo navigation, but also on river passenger ships of both common types (cabin cruisers and vessels for daily excursions).

Cabin cruisers are in operation on large and long waterways like Rhine, Main, Elbe, Rhône, Seine, and Mosel. In recent times, such type of passenger service appears again on the entire Danube waterway after more than ten years absence due to the Balkan wars. River passenger ships for daily excursions are present overall and their sizes are aligned with the waterways and services they operate.

Available statistics on inland navigation mostly do not contain data on passenger ships on lakes. Lake boats, which are principally of the excursion ship type, are common in some EU states including those that do not belong to one of the four corridors or the three above-mentioned countries in the "rest of EU". As a consequence, we have to estimate the number of lake ships ourselves.

Table 9 lists the total number of EU inland vessels for which air-conditioning comes into question, by different corridors.

Table 9: Number of self-propelled Cargo and Passenger Ships of the EU inland fleet, by geographical zones, end of 2005

	Cargo	Passenger			
	Dry + Liquid	Excursion all	*Excursion from 2000*	Cabin all	*Cabin from 2000*
Rhine	6,466	1,806	*133*	237	*51*
Danube	190	117	*5*	0	*0*
Elbe/Odra	171	143	*6*	0	*0*
Rhone/Seine	946	303	*18*	87	*10*
Rest of EU	188	125	*13*	0	*0*
Lakes (est.)		800	*80*		
Total	7,961	3,294	*255*	324	*61*

State: End of 2005 (Germany: End of 2006; France: End of 2002).
Sources: PINE 04; CCNR 07; DC 06; ZBBD 07; further national statistics.

In the cargo ship column dry cargo vessels and tankers are summed up; only self-propelled vessels are considered; barges and tugboats are not regarded because air conditioning is very rare in these vessels.

Passenger ships of the excursion and cabin type are presented twice, first their total number, after the number of buildings from 2000 (see next section of this chapter).

By the end of 2005, roughly 8,000 self-propelled cargo ships and 3,500 passenger ships were operated on EU inland waterways. The latter are split into 3,300 daily excursion boats and 324 cabin cruisers.

3. HFC-refrigerant stock in the EU inland fleet

From 2000 onwards new air conditioners are considered to run no longer with R-22 but with HFC refrigerants. In the light of this, the numbers of ships built "from 2000" in Table 9 count as the numbers of HFC containing ships.

The term "built" must be understood in a broader sense. It means not only new building but also refurbishment; this often includes conversion of old air-conditioners to new ones, at least substitution of the chlorine-containing refrigerant by HFCs. One third of the air conditioners "built" after 2000 are assumed to be such conversions.

The amount of HFC refrigerants stocked in the EU inland passenger fleet is achieved using the number of units "from 2000" in Table 9 and the charges in Table 8. The estimation of the HFC stock in cargo ships is simpler: The year of built is not relevant; air conditioners are fitted in existing vessels. According to the interviewed experts, roughly 1,000 vessels are equipped with air conditioning devices, today.

Table 10 shows the estimated HFC stocks in both cargo and passenger ships.

Table 10: HFC stock in the EU inland fleet, air conditioning (AC) and refrigeration (Refr), in kg and tons, end of 2006					
Ship type	Number	kg/AC	kg/Refr	Total tons AC	Total tons Refr
Cargo vessel	1,000	4.5	-	4.5	-
Cabin cruiser	61	200	5	12.2	0.3
Excursion boat	255	100	-	25.5	-
All types	1,311			42.3	0.3

4. HFC emissions from inland ships

The emission factor for air conditioning systems is estimated at 10% per year for air conditioning of passenger boats. The emissions from air conditioning devices on cargo vessels are estimated at 6%.

The lower emission level of air conditioning on inland ships compared to ocean-going vessels results from the smooth motion of inland waters the vessels are exposed to. In addition, in case of detected leaks, calling service is not as difficult as on the high sea. Furthermore, Passenger river ships are assumed to be principally equipped with compact indirect systems, which are considered less leak-prone than direct split systems.

Applying an emission factor of 10% to cabin cruisers and excursion boats, and of 6% to the devices on cargo ships, emissions as per Table 11 arise.

Table 11: HFC emissions from the EU inland fleet, air conditioning (AC) and refrigeration (Refr), in tons and kg, end of 2006					
Ship type	EF in %	Air conditioning		Refrigeration	
		Emission metric t	kilo tonnes CO_2 eq.	Emission metric t	kilo tonnes CO_2 eq.
Cargo vessel	6	0.27	0.4		
Cabin cruiser	10	1.2	2.3	0.03	0.06
Excursion boat	10	2.6	5.0	-	
All types		4.1	7.7	0.03	0.06

Sources: Emission factor of 6%/10% applied to particular stocks (Total tons) in Table 10.

The 4.1 metric tons of AC emissions consist two thirds of HFC-134a, one third of R-404A – aside from some kg of R-407C/R410A. The 30 kg emissions from refrigeration are mentioned here only for the sake of completeness. Global warming emissions from inland navigation amount to 7.7 kilo tonnes CO_2 equivalent.

5. Outlook 2020: 23 kilo tonnes CO_2 equivalent

In the business-as-usual scenario 2020 it is assumed that for the number of HFC-equipped new and converted vessels the seven-year trend from 2000-2006 continues unaltered over the remaining 14 years until 2020. Under these circumstances, emissions grow until 2020 to 23 kilo tonnes CO_2 equivalent. As in the sector of ocean-going ships, a large number of R-22 equipped vessels would be left unless accelerated conversion to ozone-friendly fluids takes place. Under a complete changeover from R-22 to HFCs the 2020 emissions are estimated at 42 kt CO_2 eq – 80% higher than in the business-as-usual scenario.

IV. Fishing Vessels

In the fishery sector, the specific refrigerant application is not air conditioning but refrigeration and freezing. The main focus onboard is the preservation of the catch in good quality on the way ashore, to the consumer or to the processing plant. Fishing vessels that are less than three days at sea can use ice for keeping the catch in the cargo hold fresh, without loss in quality. Ice not only generates and maintains the necessary temperature of zero degrees but also provides the adequate humidity which mechanical cooling fails to supply. Refrigeration is limited to the production of the ice itself. Fishing vessels that are at sea for a longer time rely on freezing. These freezer ships are equipped with large-scale facilities for both quick freezing down to at least -18°C and maintaining this low-temperature in the insulated, dry-storing, hold.

1. Medium sized fishing vessels (18-36 metres)

The vast majority, namely 91%, of the 89,000 fishing vessels in EU-25 (2005) are small boats of length below 18 metres (EUR 07). These vessels are used for coastal fishing. If there is ice aboard, it is produced ashore, often by means of ammonia systems. This land-based refrigeration equipment is out of the scope of this study.

On medium sized fishing vessels the ice is generated by ice-machines, and the insulated cargo hold is cooled by means of a refrigeration unit. This unit prevents the ice from quick smelting so that the amount of ice can be kept within reasonable limits. According to interviewed experts (FLI 07, SCHM 07, MAA 07) vessels from a length over 18 metres can be considered being equipped with refrigeration units for (mostly combined) ice-making and cargo hold cooling – at temperatures about zero degrees. The required refrigerating capacity for ice making and cold store depends on the size of the cargo compartment. For refrigeration details see Table 12.

Vessels over 36 metres generally do not use ice in cargo holds although some of them use ice (slurry) ice for buffer tanks before processing. Instead they have dedicated freezing equipment for catch and hold; this is dealt with in the next section. There are, however, some trawlers over 36 metres in service, which are not fitted with freezing equipment but do only cargo hold cooling and ice-making. Experts estimate their number at approx. 170. The refrigerant quantity for these vessels is estimated at 100 kg each. This is also shown in Table 12.

Table 12: Ice making and cargo hold cooling in medium-sized fishing vessels and non-freezing trawlers, by length in metres, in 2005

Length in metres	18-<24	24-<30	30-<36	Trawlers	*Total*
Number of EU-25 vessels	4,200	2,210	815	170	*7,395*
Av. hold volume, m^3	60	130	180	500	
Refrigerating cap. kW/hold	8	13	18	60	
Refrig. cap. ice maker, kW	5	9	12	40	
Refrigerant per vessel, kg	12	21	28	100	*18.5*
Refrigerant total, kg	50,400	46,410	22,820	17,000	*136,630*

Sources: EUROSTAT 07 (no. of vessels by length class); FLI 07, SCHM 07, MAA 07 and own evaluation of data in FAI 07 (refrigeration and cargo hold).

The EU fishing fleet uses ca 137 tons refrigerant aboard to cool fresh fish by means of ice. Standard refrigerant is R-22 followed by R-404A and R-134a as of 2002.

2. Large vessels with RSW tanks (36-76 metres)

Large vessels of over 36 metres length usually operate in remote deep sea waters so that they must be capable of preserving the catch over several weeks. Consequently, they are equipped with freezing facilities. However, this paragraph deals with an important exemption.

Numerous big North Atlantic trawlers from UK (Scotland), Ireland, Denmark, Sweden, Finland use refrigerated seawater (RSW) tanks for cooling and transportation of the fresh catch (mackerels, herring, etc). RSW systems are designed for rapidly cooling down seawater and fish in shipboard tanks to a temperature of approx. -1°C without freezing the fish. The use of such tanks in the cargo hold is suitable for short-term storage of particular species that are caught in large quantities (FAO 02). RSW equipped vessels do not process fish but bring it ashore to a processing plant.

The capacity of RSW tanks amounts up to 3,000 m^3 per vessel, with an estimated fleet average of 1,550 m^3. As the chilled water must frequently be changed, the refrigerating capacity must be high (av. 1,400 kW). The required refrigerant quantity is 1,000 kg (TEK 07) unless ammonia is used (which is the case from 2002).

The number of RSW equipped trawlers with length of from 36 to 76 metres is estimated at 75 (TEK 07). The most used refrigerant in existing vessels is still R-22. New vessels run with ammonia (direct), only a couple with HFC refrigerants.

Table 13: Trawlers with Refrigerated Sea Water (RSW) systems

Length in metres	36-42	42-70	70+	*Total*
Number of RSW vessels	20	43	12	*75*
Tank volume per vessel, m^3	1,100	1,500	2,500	*1,550*
Refrigerant per vessel, kg	700	1,000	1400	*984*
Refrigerant total, kg	14,000	43,000	16,800	*73,800*

3. Large vessels with freezing equipment

3.1 Tuna longliners (25-45 metres)

Vessels for catching fish (tuna) with lines up to 3 km long are called longliners. They differ from trawlers by their fishing method. The EU fleet consists of about 80 vessels of this type. They are 25 to 45 m long and operate in distant water mainly by Spanish and French fishermen, in equal shares. The tuna is deep-frozen in air blast tunnels to a core temperature of –18°C, and afterwards stowed in the frozen store, which is kept at the same low temperature.

Typical air blast freezers for tuna (2,000 kg/day) are driven by two compressors of 25-30 kW refrigerating capacity each and a 25 kW compressor for the hold of 300 m^3 volume on average. The 75-85 kW are provided by 150 kg refrigerant per vessel.

On vessels longer than 42 metres average refrigerating capacity and refrigerant quantity are higher, with 100 kW and 200 kg refrigerant. Before 2002, the standard was R-22; in new vessels from 2002 R-404A is used.

3.2 Tuna seiners (36-115 metres)

In contrast to tuna longliners, tuna seiners use large nets, called "seines", for catching tuna in the Atlantic, Indic, and Pacific Ocean. Most of the 100 EU ships carry the Spanish or French flag, Spanish owners hold additional 20-30 vessels in foreign registers like Seychelles etc. Tuna seiners are often very large vessels, eight ships under Spanish flag exceed 100 metres, and two are even 115 metres long (the Albatun Uno and Albatun Dos, both built in 2004) (INF 04).

The large amount of the catch per trip requires large-scale installations for freezing and frozen storage. For freezing, there are five to 25 shipboard tanks of 100 m^3 capacity each. These are filled with chilled salt brine (over 20% NaCl content) that allows a temperature of -18°C in liquid state. Evaporating refrigerant flows through coils that are fitted to bulkheads, ceilings, and floors of the tanks. The sorted catch is poured into the liquid tanks and is frozen there by immersion. Subsequently, the fish is dry-stored at approx. –20ºC. On tuna seiners of medium size (> 42 m) 40 t fish, on seiners of large size (> 70 m) over 200 t are frozen per day in cold brine; this is twenty to hundredfold the quantity of small tuna longliners. (SURV 07).

In addition to immersion freezing, on large seiners air blast tunnels are used for small-scale freezing (5,000 kg/day), often at temperatures of - 55°C.

The refrigerating capacity for freezing and storage is high, and averages 300 kW on small sized seiners, 500 kW on medium seiners (< 42 m). The required refrigerant amounts to approx. 600 kg and 1,000 kg, respectively, in direct evaporating systems.

On large-scale seiners of over 70 metres length a five-fold quantity of fish is frozen and stored. For the refrigerating capacity in the range of 2,000 kW a refrigerant amount of 4,000 kg is necessary. This quantity is often reduced to 2,500 kg by use of cold brine ($CaCl_2$) for chilling the freezing salt brine.

3.3 Freezer trawlers (25-45 metres)

The majority of trawlers from 25 to 42 metres length and a few trawlers longer than 42 metres run freezing equipment similar to that in tuna longliners. The typical equipment consists of a combined refrigeration unit that freezes the fish and cools the insulated cargo hold. The fish is frozen to -18°C in two ways, either in an air blast or in a plate freezing system before it is stowed in the frozen store for further processing onshore. Both freezing systems are widely used, not only for pelagic fish but also for shellfish, prawns, etc. As the catch must be held fresh before freezing, ice is often used, which is produced by ice-makers as described above.

The capacity of the freezing system on small trawlers (below 42 m) is approx. 2 t/day (air blast or plate systems) for which a refrigerating capacity of 50 to 70 kW is required. The frozen store and the ice-maker need further 30 kW so that a total of 90 kW can be assumed. Refrigerants in the order of 150 kg are necessary.

The freezing throughput on larger trawlers (over 42 m) is approx. 20 t/day; for this a refrigerating capacity of 250 kW is required, in addition to 50 kW for the hold. The refrigerant quantity amounts to 500 kg on an average.

In this study the number of EU vessels of this type is estimated at 320, of which 80 in the length class of over 42 m.

3.4 Factory freezer trawlers (42-145 metres)

The majority of freezer trawlers of length from 42 to 145 metres are called here processing freezer trawlers or factory trawlers. There are approx. 180 EU flagged vessels of this type in service; five of them are over 120 metres long. The largest are the Dutch-owned "Maartje Theadora" (register Germany) and "Annelies Ilena" (register Netherlands), both built in 2000 and freezing with R-22 plus $CaCl_2$-brine.

Factory trawlers operate far away from their home ports and are several weeks permanently on high sea. They do not bring frozen fish ashore for processing, as smaller trawlers do, but run processing facilities aboard to produce frozen fish blocks. Details on the refrigeration and freezing systems of super trawlers are given by means of a description of the large freezer trawler "Maartje Theadora" (Table 14).

The Maartje Theadora was built in 2000 by the Spanish yard Vulcano in Vigo. She is 140.8 m long and accommodates a crew of 50 men. She is owned by the Dutch company Parlevliet & van der Plas, and is registered in Germany. The vessel is outfitted with a refrigeration and freezing equipment which comprises ten screw compressors for 8,000 kg R-22 which cool circulating $CaCl_2$ brine down to - 47°C.

- Refrigerated sea water (RSW) tanks ensure that peaks in the catches can be used. These tanks and the fish grading and buffer tanks are periodically refreshed by a chilled water system. In addition, slurry ice is produced.
- The freezing system comprises both 48 plate freezers and the frozen cargo hold where the frozen blocks are stored.

Table 14: Refrigeration and Freezing on the Factory Trawler Maartje Theadora				
RSW capacity	1,100 m^3	+22/-1°C		
RSW chiller	25 m^3/h	+30/-1.5°C	3,000 kW (- 6°C)	3,000 kg
Water refresh		+30/-1.5°C	2 x 900 kW (-6°C)	1,600 kg
Plate freezers	360 t/day (48 units)	-28°C	2 x 1,400 kW (- 47°C)	3,000 kg
Hold capac.	10,880 m^3			
Slurry ice	40 t/day		400 kW	400 kg

Sources: GRE 07; VINK 07; Filing card Factorias Vulcano S.A., date 26.11.01.

Though not in size but in the main features, the refrigeration and freezing systems of the other factory trawlers with EU registration are identical to those on the Maartje Theadora. Some are not equipped with RSW or chilled water systems; other are additionally equipped with air blast tunnels. All of them run factory-like freezer systems to produce and store fish blocks that are (mostly) ready for sale.

On the basis of the Maartje Theadora the quantitative refrigeration data for smaller-sized factory trawlers can be extrapolated.

Vessels of 90 m length, which is the average length of some 90 large factory trawlers over 70 m, need a refrigerant charge of 5,000 kg if the refrigeration system is indirect and uses cold brine. For direct systems of the same refrigerating capacity twice this amount is necessary, 10,000 kg. The ratio of direct to indirect systems in the existing fleet is estimated by the interviewed experts at two thirds to one-third (2/1) (SURV 07). New built vessels use indirect systems.

Smaller-sized factory trawlers with average length of 50 m need approx. 3,000 kg refrigerant in direct systems and 1,500 kg in indirect systems (FRE 07). The ratio of direct to indirect systems in the existing fleet is two to one. (SURV 07)

4. Overview on the refrigerant data of fishing vessels

Table 15 summarises the quantitative refrigerant data on the EU fishing vessels with freezing equipment as presented above, and Table 16 repeats the corresponding data on non-freezing vessels. The refrigerant stock in the total fleet of 680 different-sized freezing units amounts to 1,226,500 kg (1,226 tons). The vast majority, namely 70 percent, is in tuna seiners and factory trawlers over 70 metres length. In addition, there are 210.5 tons in approx. 7,500 vessels with refrigeration equipment only.

Table 15: Number and Refrigerant Charges of Fishing Vessels with Freezing Systems, by type and length class, 2005/2006

	36-42	42-70	70+	*Total*
Longliners, number	50	30		*80*
Refrigerants per vessel, kg	*150*	*200*		
Refrigerants all, kg	7,500	6,000		*13,500*
Tuna seiners, number	20	50	30	*100*
Refrigerants per vessel, kg	*600*	*1.000*	*4.000/2.000**	
Refrigerants all, kg	12,000	50,000	100,000	*162,000*
Freezer trawlers, number	240	80		*320*
Refrigerants per vessel, kg	*150*	*500*		
Refrigerants all, kg	36,000	40,000		*76,000*
Factory trawlers, number		90	90	*180*
Refrigerants per vessel, kg		*3.000/1.500**	*10.000/5.000**	
Refrigerants all, kg		225,000*	750,000*	*975,000*
Total number of vessels	310	250	120	*680*
Total refrigerant, kg	55,500	321,000	850,000	*1.226,500*

* The ratio “direct systems/indirect systems” is estimated by sector experts at 2/1.

Table 16: Ice making and cargo hold cooling in medium-sized fishing vessels and non-freezing trawlers, by length in metres, in 2005

	18-<24	24-<30	30-<36	Trawlers	*Total*
Cargo hold coolers, number	4.200	2.210	815	170	*7,395*
Refrigerants per vessel, kg	12	21	28	100	*18.5*
Refrigerants all, kg	50,400	46,410	22,820	17,000	*136,630*
		36-42	42-70	70+	*Total*
RSW trawlers, number		20	43	12	*75*
Refrigerants per vessel, kg		700	1,000	1,400	
Refrigerants all, kg		14,000	43,000	16,800	*73,800*

5. Annual HFC Emissions from EU Fishing Fleet as of 2002

5.1 Non-R-22 refrigerants from 2002 onwards

When adding the refrigerant charges of the three partial fleets (vessels with simple hold refrigeration, RSW trawlers, and freezing vessels) the refrigerant stock of the total fleet can be estimated. It amounts to 1,437 tons (see Table 17, 2nd column). Numbers of vessels, total refrigerant quantities, refrigerant quantities from 2002, and calculated emissions of Non-R-22 refrigerants are entered in Table 17, by 12 different length and/or refrigerant charge categories.

General assumption as to air conditioning of merchant ships was that from 2001 new systems no longer run with R-22. This assumption is also made with respect to refrigeration/freezing of fishing vessels; but the point in time of R-22 phase out is considered a year later, 2002, when R-22 was definitely banned all over the EU.

From Lloyd's Register (FAI 07) we have got exact numbers of newbuildings in the 2002-2006 time period only for vessels over 70 metres: RSW trawlers (6), tuna seiners (7), and factory ships (8). Multiplying these numbers with the type-specific default charges in Tables 15 and 16 we arrive at the quantities of new refrigerants from 2002. They are entered in Table 17, in rows 10, 11, and 12.

Table 17: 2006 Refrigerant Stock of EU Fishing Fleet: Total and Newbuildings from 2002, and Annual Non-R-22 Emissions from 2002, in tons

	Total Number Vessels	Refrigerants total fleet (t)	Refrigerants as of 2002 (t)	*Calc. Emiss. Non-R22 (t)*
Refrigerants < 500 kg				
1. Cargo hold cooling vessels	7,395	137	17.1	*6.9*
2. Tuna longliners	80	13.5	1.7	*0.7*
Refrigerants 500 kg-1,000 kg				
3. RSW trawlers 36-42m	20	14	1.8	*0.7*
4. Tuna seiners 36-42m	20	12	1.5	*0.6*
5. Freezer trawlers 36-42m	240	36	4.5	*1.8*
Refrigerants > 1,000 kg				
6. RSW trawlers 42-70m	43	43	5.4	*2.2*
7. Tuna seiners 42-70m	50	50	6.3	*2.5*
8. Freezer trawlers 42-70m	80	40	5.0	*2.0*
9. Factory trawlers 42-70m	90	225	16.9*	*6.8*
10. RSW trawlers > 70m (6 new)	12	16.8	8.4	*3.4*
11. Tuna seiners > 70m (7 new)	30	100	14	*5.6*
12. Factory trawlers >70m (8 new)	90	750	40	*16.0*
All vessels	8,150	1,437.3	122.5	*49.0*

Explanation: The first nine rows include vessels <70 m. Their refrigerants as of 2002 (4th col.) are calculated as 12.5 percentage of the total fleet refrigerants (3rd col.). Rows 10-12 include vessels > 70 m. Their refrigerants as of 2002 are calculated by the actual number of new vessels from 2002 (known) and default charges in Tables 15 and 16.
* Newbuildings from 2002 only with indirect systems with half the former charge (1,500 kg).

In order to estimate the refrigerant quantities of the remaining 2002-2006 new vessels we assume that their number corresponds to the share of those five years in the average 40-year fishing vessel lifetime[4]. 12.5% of the existing fleet (5 in 40) are considered vessels new built from 2002 onwards. Consequently, the figures in 4th col. "Refrigerants as of 2002" represent 12.5% of the figures in the 3rd col. "Refrigerants total fleet".

The total stock of refrigerants *other than R-22* is shown in the 4th column of Table 17 It totals 122.5 tons.

The emissions from this stock are estimated by means of the same emission factor as applied to merchant ships (see section I.6). Like merchant ships, fishing vessels are supposed to lose annually 40% refrigerants from their systems. The emissions are shown in Table 17, last column. They total approx. 49 tons in 2006.

To guard against misunderstanding: The calculation does not indicate that all Non-R-22 emissions are actual HFC emissions. The total of 49 tons only marks the upper limit or the "potential" of HFC emissions. This shall be explained in the next section.

5.2 HFC Emissions from fishing vessels.

Our analysis (presented in Annex III of this report) of the 21 new-built and converted fishing vessels >70 metres shows that only four of them are equipped with HFCs. On 15 vessels ammonia is used, with $CaCl_2$ brine (15 cases) or with CO_2 as secondary refrigerant (2 cases). Taking account of this, actual HFC consumption for the 21 new vessels >70 m with 62 tons of Non-R-22 refrigerants is not 62 tons but minus 49 tons, namely 13 tons. HFCs make up only 21% of the Non-R-22 refrigerants. Consequently, instead of 25 tons there are only 5.2 tons of HFC emissions.

From 2002 onwards, there is a clear trend to natural refrigerants like ammonia and, by degrees, CO_2 in refrigeration systems that need large refrigerant quantities. Presently, the threshold value for the vessel size for the use of natural refrigerants in place of HFCs seems to amount to approx. 1,000 tons. From this mark upwards higher investment cost are obviously compensated by lower operating cost thanks to less energy consumption for identical refrigerating demand (SNO 06; VINK 07).

Therefore, it is not surprising that also some large fishing vessels shorter than 70 m were equipped with natural refrigerants in 2002-2006. A substantial number of new RSW trawlers, tuna seiners, factory ships, and freezer trawlers from 42 to 70 metres with refrigerant charges over 1,000 kg (see Table 17, rows 6-9) use ammonia in the refrigeration/freezing system (SURV 07). Experts estimate their share in the total number of newbuildings at one third, i.e. 11 in 33 new-built vessels (SURV 07) with 33 tons Non-R22 refrigerants.[5]

In addition to savings of 49 tons HFCs in large vessels over 70m, there are further savings of 11 tons HFCs in new vessels of 42-70 metres length. As a consequence, a further 4.4 tons of Non-R22 emissions are not transformed into HFC emissions.

The estimated annual HFC emissions in 2006 (end) are shown in Table 18:

[4] According to EUR 07, the median age of the EU fishing fleet was exactly 20.0 years in 2005.
[5] The Non-R22 refrigerants in Table 17 for vessel categories 6 to 9 are 33.6 tons: RSW trawler 5.4, tuna seiners 6.3, freezer trawlers 5.0, and factory trawlers 16.9. One third of them are natural fluids.

Table 18: Annual HFC Emissions from Refrigeration and Freezing on Fishing Vessels, in tons and CO_2 eq, 2006 and 2020				
	HFCs as of 2002	HFC emiss. per year	CO_2 eqiv. kt 2006	*CO_2 eqiv. kt 2020*
Refrigerants < 500 kg				
1. Cargo hold cooling vessels	17.1	6.9	15.6	*59.3*
2. Tuna longliners	1.7	0.7	2.2	*8.4*
Refrigerants 500 kg-1,000 kg				
3. RSW trawlers 36-42m	1.8	0.7	2.3	*8.7*
4. Tuna seiners 36-42m	1.5	0.6	2.0	*7.4*
5. Freezer trawlers 36-42m	4.5	1.8	5.9	*22.3*
Refrigerants > 1,000 kg				
6. RSW trawlers 42-70m	3.6	1.4	4.7	*17.8*
7. Tuna seiners 42-70m	4.2	1.7	5.4	*20.6*
8. Freezer trawlers 42-70m	3.3	1.3	4.3	*16.5*
9. Factory trawlers 42-70m	11.3	4.5	14.7	*55.7*
10. RSW trawlers > 70m (6 new)	0	0	0	*0*
11. Tuna seiners > 70m (7 new)	0.8	0.3	1.0	*4.0*
12. Factory trawlers >70m (8 new)	12.3	4.9	14.5	*55.1*
All vessels	62.0	24.8	72.6	*275.8*

The comparison of Table 18 with Table 17 shows that actual stock and actual emissions are much smaller for HFCs than for all Non-R22 refrigerants. While the numbers in rows 1 to 5 are the same in both tables, in the rows 6 to 12 (vessels over 1,000 kg charges) significantly smaller quantities are entered, indicating that to a considerable extent R-22 has not been replaced by HFCs but by ammonia.

In 2006, HFC emissions from all fishing vessels amounted to 24.8 metric tons (Table 18, bottom row). If all Non-R-22 refrigerants in vessels built from 2002 onwards were HFCs, the emissions would have amounted to 49.0 tons (Table 17). The difference between these "potential" HFC emissions of 49 tons and the actual HFC emissions of 24.8 tons is 24.2 tons, so that half the potential emissions could be saved by use of natural fluids.

The global warming HFC emissions from fishing vessels amount to 72.6 kilotons CO_2 equivalent (see 4th column in Table 18).

With respect to HFC types, in all applications except for no. 1 and 12, the refrigerant is R404A or R507, which are equal to each other in quality and almost completely in composition. We use as common GWP for both of them the R404A value 3,260. Emissions from cargo hold cooling (no 1) are half R134a (1,300) and half R404A, average GWP is 2.280. In large factory trawlers (no. 12), emissions are 80% R507 (GWP 3,300) and 20% R407C (1,525); the resulting average GWP is 2,945.

In its last column, Table 18 includes the global warming HFC emissions 2020, pursuant to a business-as-usual scenario. This is dealt with in the final paragraph.

6. Outlook 2020: 276 kilo tonnes CO_2 equivalent

In the business-as-usual scenario 2020 it is assumed that with respect to the number and size of new vessels including conversions the five-year trend from 2002-2006 continues unaltered over the remaining 14 years until 2020.

Under these circumstances, the expected HFC emissions would amount to 276 kilotons CO_2 equivalent (see Table 18, last col.). By then, the use of natural refrigerants will have saved another 286 kilotons CO_2 equivalent which would occur if R-22 would be replaced by HFCs exclusively.[6]

These additional, or saved, 286 kilotons must not be confused with the increase in HFC emissions as a result of a complete R-22 phase-out in existing vessels by 2020. Pursuant to Art 5 of the Regulation 2037/2000 all hydrochlorofluorocarbons shall be prohibited from 1 January 2015. Meeting the law, the overall HFC emissions from the fishery sector would grow to 580 kt CO_2 equivalent. This is 304 kt more than under the business-as-usual scenario used in this study (286 kt).

[6] This saving can be extended if the share of natural refrigerants in new refrigeration and freezing systems increases until 2020. Assuming that not only a part of the new-built fishing vessels with refrigerant charges over 1,000 kg but all vessels with more 1,000 kg refrigerant will be equipped with natural fluids instead of HFCs, another 125 kilotonnes CO_2 equivalent could be saved inexpensively.

Chapter Two

Air Conditioning of Rail Vehicles

I. Trend of Air Conditioning in Rail Vehicles in EU-27

1. Railway vehicles

Air conditioning of railway vehicles in EU states dates back to the early 1980s, beginning in southern, relatively warm countries like Spain, Italy, and France. The common refrigerant was R-22. Air conditioning was already widely used there when several years later, at the end of the 1980s, some industrialised countries in Central and Western Europe followed, equipping new high-speed trains, coaches for long-distance traffic, and driver's cabins of new locomotives with air conditioning. Here, the refrigerant was R-12. In Eastern Europe, air conditioning was infrequent and limited to sleeping cars and a few long-distance trains.

With the introduction of HFC refrigerants in the early 1990s, a general and rapid increase in air conditioning took place including all Southern and Western Europe and, with a five-year lag of time, those Eastern countries that joined the EU later-on, in 2004. Since the 1990s, railway operators all over Europe have acquired new vehicles almost exclusively with air conditioning. This general trend synchronises with a change in the rolling stock of all big railway operators: Locomotive-hauled trains are being replaced by fixed train-sets of self-propelled multiple units. The diesel multiple units (DMU) or electrical multiple units (EMU) are platform-based trains standardised within the entire EU. They are marketed by the major manufacturers of rolling stock under certain model names (e.g. Regina [Bombardier], Coradia [Alstom], Desiro [Siemens] and are ready-available with air conditioning.

By today, R-22 or R-12 in existing systems has almost completely been replaced by HFC refrigerants. Fast refrigerant substitution took place particularly because most of the national railway operators in the EU are regulated by public law and, as a consequence, particularly interested in or obliged to meet environmental protection laws. In addition, EU Regulation 2037/2000 has prohibited CFCs and HCFCs in rail transport air-conditioning equipment produced after 31 December 1997.

Given the use of R-22, in southern EU countries the refrigerant R-407C is popular today, while in countries which formerly used R-12, R-134a is now the common refrigerant. The split refrigerant market has some, though slight, consequence for the system design because air conditioners with R-407C can be smaller but must withstand higher pressure than R-134a systems.

So far, natural refrigerants do not play a major role in railway vehicle air conditioning. In 1989, the national Danish railway operator installed water-chilling systems for the passenger compartments in 150 cars of his intercity DMU “IC/3 Rubber Nose”. The primary refrigeration circuit needs only 6 kg refrigerant, instead of 12 kg that a direct system would have required (BOE 07). To this day, the Danish water chillers have been the only case of indirect systems in the EU-27.

The equipment of the 504 cars of the new German High-Speed train “ICE-3” with air-cycle systems in the year 2000 attracted more attention. To this day, this system has not yet been followed by another one of this kind elsewhere in the EU. It is discussed later on in this report (Chapter Four, I). It should only be mentioned here that the same High-Speed train that is being introduced in by the Spanish railway operator RENFE under the name “Velaro”, is going to run with a conventional HFC-system.

2. Tramway vehicles

Air conditioning of tram and light rail vehicles has taken place on large scale first from 2000 onwards. Beforehand, in southern Europe a number of tram trains had already been air-conditioned; however, the tramway density there is low (6% of the EU rolling stock) compared to classic tram countries like Germany or Eastern Europe. In the 1990s, German public transport operators started outfitting tram driver's cabins with air conditioners. However, it is not before 2000 that everywhere in the EU the newly-acquired tram vehicles have air-conditioned passenger compartments from the factory.

The EU wide air conditioning of new trams goes in parallel with the introduction of modern platform-based trams with two main features for quick passenger transport:

- Low floors, allowing level access of passengers,
- Open corridors in full length of the train, for fluent passenger distribution.

Since 2000, vehicles of this type have been replacing conventional high-floor trams consisting of traction units and trailers. Like modern railway multiple units, modern tram trains are standardised vehicles, made up of permanently connected cars (sections); they are air-conditioned, and they are supplied by the industry often under distinct model names, like e.g. Citadis (Alstom), Flexity (Bombardier), Combino (Siemens), or Sirio (AnsaldoBreda).

Like railway vehicles, trams use the refrigerant R-134a in air conditioners in Central and Eastern Europe; in Southern Europe and France often R-407C is used.

3. Metro vehicles

While a tram is a rail-borne street vehicle that shares the road with other traffic systems, underground vehicles or metros are always on completely segregated tracks and usually underground. By 2006, air conditioning of metros is still rare outside of Southern Europe. For instance in Germany, the EU country with the most air conditioned railway and tram vehicles, in absolute numbers, not a single metro car is air conditioned to this day.

There are approx. 50 cities in the EU with a metro system. So far, only eleven of them run cars with air-conditioned passenger compartments. Nine of them are in southern areas: Italy, Spain, Portugal, and - recently - Greece. Elsewhere in the EU, to this day only the London Underground (only the Northern Line) and the Vienna U-Bahn (as of 2006) use air-conditioned metro cars[7].

The design of metro trains has been unchanged for many years. Typically, the electrically driven trains are of the EMU type, i.e. they form sets of permanently connected individual cars: two end cars with driver's cabin and up to four centre cars.

For space reasons, air conditioning systems for passenger rooms are of compact design and fitted to the roof.

[7] In some further cities, driver's cabins are air conditioned, e.g. in Brussels or Bucharest.

II. Design and refrigerant charges of rail systems

In the maritime sector, air conditioning systems are custom made solutions for each individual ship. In the rail sector, the number of same size air conditioners is larger, sometimes amounting to 500 units, however still small compared with air conditioning of road vehicles. The devices are mostly developed for a particular train type. As a consequence, a multitude of dedicated technical solutions has emerged in spite of minor differences in refrigerating capacity and further marginal conditions.

1. Four main design types of air-conditioners

Generally, the system design depends on the space that is left within the construction of the rail vehicle; the passenger compartment must not be reduced in volume. On this basis, there are roughly four different main types of air conditioning devices: compact roof, compact under-floor, split, and compact central.

- Most popular in electric rail vehicles (multiple units, metro-cars, trams) are compact systems in or on the roof. The space under the floor is chiefly required for electric drive and power supply so that the entire air conditioning system must completely be fitted to the roof of the vehicle. The cooled air flows top-down into the passenger compartment.

- In railroad coaches and centre cars without propulsion there is mostly enough space left under floor. This allows the whole air conditioner to be positioned on the bottom side. Cooled air is blown bottom up to the vehicle’s interior.

- Split systems, with compressor and condenser under floor, and evaporator on or in the roof are often used if there is only little space both under-floor and on the roof. This applies both to coaches and to end cars of multiple units.

- A special case is double-decker coaches. There is no space left at top or under-floor so that two – solely compact - systems are mid-mounted, each supplying one side of the passenger compartment with cool air.

Driver’s cabins either are air conditioned by distinct devices or are linked to the air conditioner for the passenger compartment. Own devices are advantageous because of separate regulation. Mostly, they are of compact design and are fitted to the roof, under-floor, or in mid-position.

The refrigerating capacity for passenger compartments differs by climatic zones but varies within the EU-27 not more than from 20 to 40 kW with few exemptions beyond or under. The refrigerant charges are between 10 and 30 kg, in case of double-decker coaches even 50 kg are possible (for the two decks together). The capacity for driver’s cabins is lower with 3 to 8 kW, with refrigerant charges of from 1.5 to 4 kg.

2. The role of compressors

As to compressors, those mostly used in rail air conditioners are semi-hermetic piston or screw compressors, particularly in the upper performance range. For lower refrigerating capacity, e.g. in driver's cabins, also scroll and hermetic piston compressors are in use. The compressors are electrically driven, with current from the contact wire or, in diesel driven vehicles, from the vehicle's diesel generator.

A special case are diesel-driven multiple units (DMU) with open-drive compressors. The piston compressor is directly driven by the diesel engine, comparable to bus air conditioning systems. From the compressor on the bottom of the vehicle, refrigerant lines run up to the roof-mounted air conditioning device containing condenser and evaporator. Driver's cabin evaporators are integrated in the main refrigeration circuit, requiring additional refrigerant lines to the ends of the vehicle.

Air conditioners of new platform-based diesel train-sets are often equipped this way. Selected important recent DMU models are Talent (Bombardier), LINT (Alstom), Desiro (Siemens), and Regioshuttle (Stadler).

III. Railway vehicles

1. Air conditioning by vehicles types

By the end of 2006, all railway operators in the enlarged EU had a rolling stock of 108,000 passenger vehicles and 27,500 locomotives. The passenger stock consisted of coaches, cars of multiple units, and specialized cars for dining and sleeping. The number of units by different vehicle types is shown in Table 19, 1st column. The detailed presentation by individual countries is given in Annex IV to this report.

Table 19: EU 27 Railway vehicles by total number and by number and quota of vehicles with Air Condition, by 2006

Vehicle type	1. All vehicles	2. Air conditioned vehicles	3. AC quota
Coaches	43,513	13,871	32%
Cars of Multiple Units	59,756	37,430	63%
- thereof DMU	*14,447*	*9,185*	*64%*
- thereof EMU	*45,309*	*28,245*	*62%*
Locomotives	27,588	4,286	16%
Dining cars, Sleeping cars, Couchettes	4,706	4,706	100%
Total	135,563	60,293	44%
*EMU cabins with AC**		*20,670*	

Explanation: EU-27 means 25 member states (without Cyprus and Malta). * Two times the number of EMU trains (not cars) with air condition (each train has two end-cars with a cab). In DMU trains the cabin is air conditioned by the main circuit for the passenger compartment.

General passenger cars (coaches and cars of multiple units) amount to 103,269 units, roughly half of which (51,301) are air-conditioned (without air cycle systems). The share of air-conditioned cars in the total number is higher if only multiple units (EMU and DMU) are considered, namely 62%. DMU and EMU show similar AC quotas. The 4,700 special passenger cars like dining or sleeping cars are deemed completely air-conditioned (in dining cars refrigeration is included). The number of locomotives for both cargo and passenger transport is high, but locomotives with two air-conditioned diver's places at the ends are not frequent (16%).

It must be mentioned that there are more than 20,000 driver's cabins in electrical multiple units, which are air-conditioned by separate compact devices. As only the end-cars have such cabins, their number is calculated by the double number of air-conditioned EMU-trains (not EMU cars).

From the detailed data in Annex IV it emerges, that the air conditioning quota (AC quota) significantly differs by the three main geographic areas of the EU-27. A closer look at general passenger cars (coaches and multiple units), reveals:

- In the southern countries (Spain, Portugal, Italy, Greece) the AC quota is almost twice the EU average. Coaches: 62% and multiple units even 96%.

- In the eastern countries (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia) the coaches are air-conditioned only 8% and the multiple units 17%. These low figures express the old age of the rolling stock mainly consisting of vehicles from before 1990.

- In the rest of Europe (west, south, and central), the AC quota of coaches is 45%, the quota of multiple units is 62%, which is close to the EU average.

2. Refrigerant quantities in EU railway vehicles

From interviews in the course of this study with air conditioning experts from the European rolling stock industry as well as from the leading rail MAC suppliers (RMAC 07) specific refrigerant charges per railway vehicle could be established; cf. Table 20, col 1). As to coaches, special cars, and locomotives, the refrigerant charges per vehicle base only partially on real surveys, mostly on estimates of experts.

In the case of EMU and DMU vehicles, actual refrigerant charges were surveyed. The 17.8 kg average per EMU vehicle and the 12.6 kg per EMU car base on the data of 52 different multiple-unit models with air condition; representing more than 29,000 of the 36,900 MAC equipped cars in the EU-27. The relatively high average fill of EMU vehicles includes high-charged High-Speed trains as well as, likewise high-charged, double-decker trains of the EMU type, which are particularly common in France, Spain, and the Netherlands. The 52 models of multiple-unit trains also provide the data basis for the refrigerant charges of EMU driver's cabins.

Table 20: Refrigerant charges per railway vehicle, and total charge in the EU-27

Vehicle type	1. kg per vehicle	2. total refrigerant charge, kg
Coach	16*	220,383
EMU car	17.8	494,192
DMU car	12.6	115,828
Locomotive	5	21,430
Special car**	30	141,180
EMU driver's cabin	2.35***	48,568
Total		1.041,581

* The 16 kg figure results from 15 kg in single-deck and 22 kg in double-decker coaches, with 15% share of the latter. ** Sleeping cars, dining cars, and couchettes. *** Quantity per cabin.

In the second column of Table 20 the total refrigerant charge in the air-conditioned EU-27 railway stock is shown. The figures by vehicle types have been arrived at by multiplication of the number of units as per col. 2 in Table 19 with the specific refrigerant charges by vehicle types in the first column of Table 20.

The refrigerants total roughly 1.04 million metric tons. The majority is R-134a; a quarter (25%) is estimated R-407C.

3. The emission factor for rail vehicle air-conditioners

The annual use-phase emissions from rail vehicles are low, compared to ships. They amount to 5% in systems with electrical compressor drive. This is the result of our survey on the actual refrigerant refills at the biggest national railway operator in the EU, the German Deutsche Bahn, in the calendar year 2006 (see Annex V.) In each of the three central plants of Deutsche Bahn for the regular 1.2 million kilometres technical revision (intervals of 4-7 years operation) of double-decker coaches, of intercity coaches, and of EMU trains (high speed and local) the annualised refill quantities per vehicle average about 4%. As in the time interval between two revisions some refrigerant is likely to have been refilled elsewhere, a refill rate (leakage rate) of 5% must be deemed a robust value.

The annual refrigerant loss is significantly higher in case of DMU with open compressor systems. This is proved by data from the central revision plant of the Deutsche Bahn for DMU trains. An average leakage rate (refill quantity) of 7.6 percent per year can be established for the three models with open drive compressors and long refrigerant lines. In contrast, the train model with a compact roof air conditioner (electric compressor) shows a leakage rate in the range of coaches and EMU trains. In the light of these figures we consider the annual emissions from DMU air conditioners (open compressor type) ten percent. This amount is similar to the leakage rate of buses, which was established in the 2007 EU study (OEK 07). In fact, DMU systems are mostly supplied by companies of the automotive MAC sector.

4. HFC Emissions from railway vehicles 2006

From the application of the emission factor 5% and 10%, respectively, to the refrigerant stock as per Table 20, the following HFC emissions result (Table 21).

Table 21: HFC emissions 2006 from railway vehicles, in kg and kt CO_2 eq

AC Vehicles	EF in %	HFC emiss	134a	407C	kt CO_2 eq
All but DMU	5	46,288	34,716	11,572	62.29
DMU	10	10,416	7,812	2,604	14.13
Total	[5.44]	56,704	45,528	14,176	76.42

The 2006 HFC emissions from all the air conditioning systems in the rolling stock of the EU railway operators amount to 56.7 metric tons, or 76.4 kilotons CO_2 equivalent.

5. Outlook 2020: 144 kilotons emissions

The assumptions for the 2020 emission forecast pursuant to a business-as-usual (baseline) scenario are as follows.

1. The rolling stock will not change in absolute amount until 2020.
2. There is a clear shift from conventional coaches to DMU and EMU trains. Multiple units will double to 75,000; coaches will decrease from to 43,000 to 25,000.
3. All passenger vehicles will be air-conditioned by 2020 (locomotives: 10,000).
4. Air conditioning grows most rapidly in Eastern Europe.
5. The refrigerant charges remain the same until 2020.
6. Natural refrigerants like air or CO_2 will not play a noteworthy role.

From these suppositions HFC emissions can be derived, as per Table 22.

Table 22: Air-conditioned railway vehicles 2020, by number, refrigerant quantity, and emissions			
Vehicle type	Number of vehicles	Refrigerants, kg	Emissions, kg
Coaches	25,000	400,000	20,000
Cars of Multiple Units	75,000	1241,400	73,410
- thereof DMU	*18,000*	*226,800*	*22,680*
- thereof EMU	*57,000*	*1014,600*	*50,730*
Locomotives	10,000	50,000	2,500
Special pass cars*	5,000	150,000	7,500
Total	115,000		
EMU cabins with AC	*[40,000]*	94,000	4,700
Total		1.935,400	108,110

* Dining cars, Sleeping cars, Couchettes.

The HFC emissions from railway air conditioning are estimated to amount to 108 metric tons, by 2020. This is almost twice the present quantity.

Because of the strong increase in air conditioning in Eastern Europe, where R-134a is the standard refrigerant, the emission composition by HFC type will differ from today; the share of R-407C drops to 15%.

Consequently, the global warming emissions are forecast at 144.4 kilotons CO_2 equivalent.

IV. Trams

The number of tramway vehicles in the EU amounted to 18,430 units in 2006. Clearly main geographic areas of tramway traffic are Central and Eastern Europe. Germany alone has 30% of the EU wide rolling stock, followed by Poland with 20% and the Czech Republic with 12%. In Southern, Western and Northern parts of the EU, trams are not yet so common although this means of public transportation undergoes a revival there, especially in France and Spain, which have put into service a couple of new lines in recent years.

As said in the beginning of this Chapter Two, air conditioning of tram vehicles (passenger compartments) has taken place on large scale first from 2000 onwards, when modern low-floor vehicles were introduced. For lack of better data, we consider all trams activated from 2000 onwards air-conditioned. We are aware that even after 2000 new trams were sometimes put into operation without air conditioner, not only in Eastern Europe and Eastern Germany, but in the Netherlands too. Air conditioning is often not regarded so beneficial, e.g. in the light of frequent opening of doors, that urban operators spend narrow financial means on this equipment, which also increases the daily consumption of electricity. However, a number of EU cities have fitted tram vehicles with air condition already before 2000. As a consequence, the year 2000 can be taken as the general start of tram air conditioning with some justification.

Unlike railway and metro trains, modern trams do not consist of separate individual cars. Passengers can move freely throughout the entire length of the train, which consists of several "sections" of the same vehicle. Consequently, a tram train is the same as a tram vehicle - or a "tram". Modern trams are not equipped with an air conditioning system in each section; the number depends on the vehicle's length.

Based on our analysis of the tram commissions since 2000, we can say that an average tram is 33.8 metres long, has five sections, and is equipped with two air conditioners of 24 kW for the passengers and two of 4.5 kW for the driver. The former are charged with 13.5 kg each, the latter with 1.5 kg each, so that the refrigerants per tram figure 30 kg. These quantities underlie the following calculations.

1. HFC emissions from air-conditioned trams 2006

The 2006 HFC stock in tram air conditioning systems amounted to 85,500 kg, of which 17% is estimated to be R-407C, see Table 23.

Table 23: Trams 2006 in EU-27 by total number, number of air-conditioned vehicles, and refrigerant charges

EU trams	trams w AC	Refr per tram, kg	Refrigerants, kg	R-407C	R-134a
18,530	2,850	30	85,500	14,500	71,000

AC quota: 15.4%, relation of col. 2 to col. 3.

Applying to trams the same emission factor as to railway vehicles with electric compressors, we arrive at emissions of 6.3 kilotons CO_2 equivalent, see Table 24.

Table 24: Trams in EU-27, by refrigerant stock, emission factor and HFC-emissions, 2006			
Refrigerant stock, kg	Em factor	HFC emissions, kg	Kilotons CO_2 eq
85,500	5%	4,275	6.323

2. Outlook 2020: 17 kilotons CO_2 equivalent

Assumptions for the 2020 emission forecast pursuant to the business-as-usual scenario are.

1. The total EU rolling stock of 18,530 trams will not change in absolute numbers.
2. The tempo of new acquisitions over the next fourteen years will be the same as in the seven years from 2000 to 2006. Consequently, in 2020 the number of air conditioned trams will be the triple fold of today, namely 8,550 (AC quota 46.1%).
3. The growth in new trams in Eastern Europe increases the share of R-134a to 90%.
4. The HFC charges per tram remain constant at 30 kg.

Table 25: Refrigerant emissions from tram air-conditioners in 2020			
Refrigerant stock, kg	Em factor	HFC emissions, kg	Kilotons CO_2 eq
256,500 kg	5%	12,825	16.96

As shown in Table 25, assumptions for the baseline scenario 2020 make HFC emissions of (metric tons) and global warming emissions of 13.2 kilotons likely.

V. Metro

In 2006, eleven of 50 EU cities ran air conditioned metros. Most of them are in southern areas: Barcelona (since 1992), Madrid, Bilbao, Lisbon, Rome, Milan, Athens (2004), Valencia (2004), London Northern Line (1997), Turin (2006), and Vienna (2006). Some have introduced air conditioning first since 2004; some, with longer tradition in air-conditioning, are equipping only newly acquired trains. Typical trains consist of four cars; the total number of air-conditioned cars amounted to approx. 3,500 in the EU. This number represents 16% of the total EU stock (21,400 metro cars). The refrigerant quantities per car are high, averaging 15 kg. Mostly R-407C is used, as a consequence of the high share of Spain in the total EU stock.

1. HFC Emissions from metro vehicles 2006

The analysis of the rolling stock of the EU metro operators shows the picture, as per Table 26. There were 21,400 cars in operation, 3,500 of them were air-conditioned.

Table 26: Metro 2006 in EU-27 by total number, number of air-conditioned vehicles, and refrigerant charges					
EU metro cars	Cars w AC	Refr per car, kg	Refrigerants, kg	R-407C	R-134a
21,400	3,500	15	52,500 kg	35,000	17,500

Applying to metro air conditioners the same emission factor as to railway cars with electric compressor drive, we arrive at HFC emissions of 3.8 kilotons CO_2 equivalent.

Table 27: Metro in EU-27, by refrigerant stock, emission factor and HFC-emissions, 2006			
Refrigerant stock, kg	Em factor	HFC emissions, kg	Kilotons CO_2 eq
52,500 kg	5%	2,625	3.8

2. Outlook 2020: 13.2 kilotons CO_2 equivalent

The assumptions for the 2020 emission forecast in the baseline scenario are:

1. The total EU rolling stock of 21,400 cars will not change in absolute numbers.
2. Because of ongoing and foreseeable ample expenditure programmes in metro modernisation all over Western and Central Europe, the number of air conditioned metro cars will grow substantially faster than in resent years, up to 16,000 units.
3. The accelerated growth of air-conditioned cars outside of Southern Europe increases the share of R-134a from 33 to 66%.
4. The average HFC charges per car decrease from 15 kg to 12 kg.

These assumptions make 2020 global warming emissions of 13.2 kilotons likely. This is shown in Table 9.

Table 28: Refrigerant emissions from metro air-conditioners in 2020			
Refrigerant stock, kg	Em factor	HFC emissions, kg	Kilotons CO_2 eq
192,000 kg	5%	9,600	13.2

Chapter Three

Air Conditioning of Aircraft

This chapter is brief because use and emissions of HFCs in the aircraft sector are of negligible size compared with the maritime or rail sector. We confine ourselves to rough estimates of HFC stock and emissions in EU airplanes and helicopters, with a bias towards overestimating to be on the safe side.

In commercial aircraft as well as commuter aircraft and business jets for flight altitude over 10,000 ft, the HFC based vapour cycle is not used for air conditioning; the latter works with so called bleed air from the jet engine. Air cycle machines compress and expand the hot and pressurized air and make it breathable and comfortable - in terms of pressure, temperature, flow, and humidity - for passengers and crew in the cabin. Key components are air cycle machines and heat exchangers. This technique is utilised not only when the aircraft flies but also when it is on the ground. In the latter case the system is either driven by the auxiliary power unit (APU) fitted to the rear aircraft or by an external device (air connector) from the airport.

This applies to all the ca. 3,000 commercial transport aircraft of EU based airlines (AEA 07) as well as to further 1,000 commuter aircraft and business jets. All of them use pressurized cabins and rely on outside air for pressure balance (AIR 07).

In commercial aircraft, provision refrigeration sometimes runs with HFCs. In this case ca. 0.5 kg refrigerant is used in compact systems, with annual leakage rates of estimated 1%. Normally, food and drink on board is kept fresh with dry ice (LUF 07), not with HFC based refrigeration. This is used in 20% of aircraft at most (LIE 07).

Airplanes for lower altitudes are not equipped with pressure cabins and use for air-conditioning the vapour cycle. This does not apply to the approx. 24,000 small airplanes with only one engine (below 2 tons) (LBA 07); these aircraft are equipped with air-conditioner only exceptionally (FLU 07). There are, however, about 2,500 medium-sized multi-engine airplanes in service (from 2 to 5.7 tons) the majority of whom (90%) is outfitted with an HFC air conditioning system which is not only used for passengers but also for cooling of instruments (LIE 07). The average refrigerant charges amount to 2 kg (LIE 07).

Helicopters are operated in low altitudes, and a considerable number is equipped with air conditioning systems, particularly rescue helicopters and military helicopters. In the EU-27, approx. 2,700 civilian and almost 1,000 military helicopters are in service (LBA 07; NAT 07). Experts assess the share of air-conditioned units at maximum 30% (LIE07; FLA 07). Average refrigerant charges are estimated 2 kg.

From this the refrigerant stock in aircraft in the EU-27 can be roughly assessed. It amounts to approx. 7,000 kg, namely

1. Provision cooling in 600 commercial aircraft: 300 kg.
2. Air conditioning in 2,250 multi-engine airplanes: 4,500 kg.
3. Air conditioning of 1,110 helicopters: 2,220 kg.

Even if a relatively high emission factor of 5% were applied, the annual HFC emissions (R-134a) would not exceed 400 kg, or 500 t CO_2 equivalent.

From this it follows that aircraft air conditioning with HFCs is of minor importance for global warming emissions from the EU-27.

Chapter Four

Reduction Options and Costs

Introduction

The main strategies or options to abate greenhouse gas emissions from mobile air conditioning and refrigeration in the transport sector are (i) reduction in energy consumption, (ii) reduction in refrigerant emissions, and (iii) research and development of new refrigerants with low or no global warming potential.

This part of the study focuses on the economic evaluation of key abatement options in the maritime and rail sector. Emissions from aircraft are not considered high enough to subject them to an analysis of reduction costs. This chapter does not give an overview on the variety of possible reduction technologies. Key abatement options are defined here as existing technologies with applicability across the entire sector, being feasible under the criteria of cost and energy efficiency. Cost estimations are conservative, i.e. with a bias towards overestimating cost because new technologies are often still developing so that they cannot perform at equal prices.

I. Key Abatement Options

1. Rail vehicles

The majority of rail vehicle air conditioning systems in the EU-27 use HFC-refrigerants. The charges are relatively small, ranging from 1.5 to 30 kg. The use-phase emission factors for most of the rail vehicles are comparably low, amounting to approx. 5% annually. Only systems with open compressors in Diesel Multiple Units show high emissions with 10% per year.

Since the transition from CFCs and HCFCs to HFCs the awareness of leak tightness has substantially grown at manufacturers and operators of rail vehicles. Further efforts on refrigerant containment are not expected to lead to significant emissions reduction because of the relatively small refrigerant charges and - mostly - comparably leak tight design. From this it follows that additional efforts on reducing refrigerant emissions should focus on new technologies with natural refrigerants.

1.1 Carbon dioxide (CO_2) systems

Several European manufacturers have already developed prototype CO_2 systems for different types of rail vehicles. This emerges from the expert interviews in the course of our study (RMAC 07). On the 2006 International Trade Fair for Transport Technology in Berlin, Innotrans, CO_2 systems were presented for the first time to the public. Some of the displayed prototype systems provide a refrigerating capacity of 10 kW, others provide even 16 kW; single systems can be combined to two or three devices per vehicle so that the whole performance range of rail vehicle air-conditioning can be covered (INN 06).

CO_2 systems require completely redesigned components to withstand the high operating pressures, as well as additional components and control instruments to allow operation at, or near, optimum energy efficiency. As a consequence, in our expert survey the majority expect in the short term both investment costs and operating costs to be significantly higher, by up to 30 %, than those of conventional systems, at least for the first generation of the serial production. For our abatement cost analysis we use a reference price of € 40,000 for a conventional air-conditioning system in railroad vehicles; prices for light rail systems (tram, metro) are assumed 25% lower (BOM 07). New CO_2 systems cost € 52,000 and € 39,000, respectively.

Since 2006 a leading supplier of rail air conditioning systems has tested a tram with a prototype CO_2-system of the driver's cabin (FAV 07). Compared to a conventional HFC-134a system the energy consumption of the prototype system is approx. 10 % higher. Further concerns of the system developers are higher investment costs and safety reasons, like displacement of atmospheric oxygen in case of leaks. Therefore this company does not consider further research on tram CO_2-systems promising. [8]

Other experts in our survey expect the EU legislation to give a legal signal for the introduction of CO_2 systems by a ban on HFCs with high global warming potential as it is the case in the sector of passenger cars for road traffic.

A 100% reduction in refrigerant emissions would save almost 175,000 tonnes CO_2 equivalent by 2020, assuming all conventional systems replaced by new CO_2 systems (see Table 29). Abatement costs per tonne reduced CO_2-equivalent is considerably high, ranging between € 600 and € 2,000 annually.

1.2 Air Cycle

Air is not toxic, not inflammable, and has no direct global warming impact. It is already in use as a refrigerant in air conditioners of rail vehicles. In the German high speed train ICE-3 (introduced in 2000) all the 504 individual cars use air cycle systems for air conditioning. Demonstration units with air cycle are also operated in the UK. The British systems are based on the German ICE-3 and are available as an under-floor system for EMU and as a rooftop system for DMU (LIE 04). Due to the one-phase nature of air cycle systems, the energy consumption in these systems is significantly higher than in vapour compression cycles. Experts estimate the additional energy demand at 20 to 30% (ADO 07; ILK 01).

Air cycle systems allow regenerative heat recovery for cooling and for heating. In this case, annual energy consumption ranks in the same order as the energy consumption of conventional HFC-134a systems. Some authors point out the low amount of system components which reduces maintenance costs, and the improved system reliability, in addition to the environmental advantage of no direct greenhouse impact (UNEP 06).

One of the interviewed experts stated a limited market potential for air cycle systems in Northern Europe, where high refrigerating capacity is needed only during a few days in the year. Thereby higher energy consumption in the time of high load could be compensated by saving HFC emissions over the whole operating time (FAV 07).

Nevertheless, with the exception of the German ICE system, air cycle systems are not yet considered energy efficient enough to replace the vapour compression technology.

[8] CO_2 has the advantage that it can be used in a heat pump system (reversible A/C system), allowing both heating and cooling of the vehicle (UNEP 06). This advantage is not yet consequently put into practice (BOM 07).

2. Merchant ships and fishing vessels

This sector is highly diverse because it consists of several sub-sectors that widely differ from each other such as fishing and cruise-shipping. Abatement options and costs are discussed for the following types of ocean-going ships:

- Cruise ships,
- Cargo ships,
- Passenger ships and
- Fishing vessels.

Unlike cruise ships and fishing vessels with more than 1,000 kg refrigerants onboard, ships of the EU merchant fleet, particularly cargo ships, are equipped with medium-sized air-conditioning systems and small refrigeration systems. The refrigerant charges amount to approx. 150 and 10 kg, respectively. Air conditioning systems are used for the crew cabins, and refrigeration systems serve the cold store of provisions.

2.1 Refrigerant Containment[9]

In our position, the key abatement option for merchant ships and a part of fishing vessels is reduction of leakage by better containment. As laid out earlier in this report, the leakage rates of air conditioning and refrigeration systems with direct expansion are very high with estimated 40% per year. Even from indirect systems a loss of 20% per year is common.

From a technical point of view, leakage rates could substantially be lowered, even in the rough environment of sea borne transport, if the maintenance of air conditioning/refrigeration equipment would only meet elementary requirements, and if at least one of the crewmembers would be trained in basic techniques. So far, trained people on board of merchant ships are rare because owners do not consider air conditioning equipment essential, and an unskilled crew is less costly in a short term.

A basic training should qualify the crew to safe and reliable handling of refrigerants in and outside of the equipment. Such training should include information on the environmental and safety hazards of refrigerants, the proper techniques for recovery, recycling and leak detection, and local legislation towards refrigerants.

A well kept maintenance document (logbook) makes it easier for the crew to monitor filling and recovery of refrigerant as well as occurrence and repair of leaks.

Further useful measures are regular inspections by external service experts. A full system inspection on an annual basis, including the repair of minor leaks is offered by several maritime service companies (PET 07).

Benefits of a regular external inspection are:

- Identification of system leaks that are rarely detected by ships' crew members,

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[9] Please notice the sceptical comments of ECSA (European Community Ship-owners Association) on the following deliberations and calculations – quoted in Annex VI to this report.

- Detection of possible system failures,
- Reduction of refrigerant consumption caused by leaks,
- Meeting various regulatory requirements for system inspections (UNI 05).[10]

Further containment measures are the introduction of leak detectors, which are now being increasingly used, but have not spread throughout the merchant fleets yet.

By appropriate maintenance by better-trained staff and regular external service an emission reduction of 40 % is deemed possible by 2020.

We estimate the annual costs of onboard maintenance at € 2,000 per ship. These expenses include costs of the initial and the further training of the crew. Though the costs are estimated low, abatement costs per tonne CO_2 equivalent are still high for merchant ships (see Table 30), and make voluntary implementation of the required containment measures unlikely. The extension of the EU F-Gas regulation to mobile systems would be helpful.

A full external inspection on an annual basis, including the repair of minor leaks is offered by a leading maritime service company for approx. €1,000 per ship (PET 07).

Consequently, the annual costs of a 40% emission reduction total €3,000 per ship.

For large cruise liners the costs are estimated twice as high as for cargo ships.

Current cost of leakage
Critics of the cost burden should take account of the high expenses of refrigerants in consequence of the high leakage. The annual compensation for approx. 1,000 tonnes (1 million kg) of HFC emissions amounts to 10 million Euro per year. This is 1,000 Euro annually per EU registered ship, and equals to the costs of one inspection by an external service company.

The resulting annual costs per tonne abated CO_2 eq. range from € 8.50 for Cruise Liners to € 85.00 for Cargo ships and other merchant vessels.

It must be noted that the experts from ECSA (European Community Ship-owners Association), who do not deny the high emissions of ships, disagree on the possible mitigation effect of training and maintenance as set out in this report. ECSA: "better containment by raising awareness, checks by external, certified companies and additional training of crew will have a very limited effect on the reductions". As a consequence, "it is virtually impossible to set quantitative reduction targets". We do not discuss this position in this report but have decided, in coordination with the EU Commission, to quote the complete position paper as an Annex (V) to this report.

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[10] A leading refrigeration service company has introduced Refrigerant Handling Guide (UNI 05) and a system that allows importing commonly used ODS refrigerants like CFCs, HCFCs and Halons for final treatment in an approved and environmentally sound manner. The system is called Enviro Return Management (ERM) and shall be implemented on a global basis. There is already an EU approved solution for selected major ports (BAR 07). In southern European ports (Marseille, Barcelona, Algeciras) the price per kg recovered refrigerant is € 17.80, in northern European ports (Antwerp, Rotterdam, Hamburg/Bremen) price per kg recovered refrigerant is € 14.40.

For small fishery ships with less than 100 kg refrigerant charge, the fixed containment costs of €3,000 per ship gives rise to even higher abatement costs of € 444 per tonne CO_2 equivalent because the fishing vessels with cargo hold refrigeration and ice maker are significantly smaller than merchant ships.

In contrast, applying containment measures to fishing vessels with higher refrigerant charges of from 100-1,000 kg refrigerant charge, abatement cost can be considered reasonable amounting to approx. € 27 per year and vessel (see Table 30.

2.2 Ammonia

Ammonia is often used as a refrigerant in stationary systems; it has not yet been used for air conditioning of ships in the EU. Since 2000, it is increasingly used for refrigeration and freezing systems on fishing trawlers, tuna seiners and reefer ships.

Major concerns towards ammonia as refrigerant result from its toxicity and its flammability. Ammonia requires specific equipment design as well as dedicated safety precaution on board (UNEP 06) such as gas detection systems, etc. The machine rooms must be separated from the engine rooms and accommodation areas. Safety facilities like eye showers, water curtains, safety suits, and escape masks are needed (SNO 06). The need for additional safety equipment leads to significant higher investment costs compared to conventional HFC systems.

Matching all onboard safety requirements, ammonia is a high performance refrigerant and is particularly suited to high refrigerating capacities. Its energy efficiency on fishing vessels is reported up to 25% higher compared to HFC refrigerants. For safety reasons, ammonia is mostly used in indirect refrigeration systems with a chilled brine or CO_2 in the secondary circuit.

As shown in Chapter One (IV, 3) of this report, ammonia is broadly used in large fishing vessels over 70 metres length and even in vessels between 42 and 70 metres, with refrigerant quantities > 1,000 kg. In our estimates, the extra investment cost for ammonia equipment varies between € 200,000 and € 900,000, depending on the size of the refrigeration system. Thanks to energy savings by up to 25%, investment costs are assumed to amortise within the lifetime of the system (SNO 06).

Using ammonia in all fishing vessels with refrigerant charges above 1,000 kg, another 125 kilo tonnes of CO_2 equivalent emissions can be saved by 2020. Costs calculations for fishing vessels with refrigerant charges over 1,000 kg are based on extra investment cost of € 400,000 per system and energy savings of 20 % compared to conventional systems with HFCs. The resulting annual abatement cost is € 0.00 per tonne abated CO_2 equivalent (see Table 30). Higher investment cost and lower energy cost balance out each other.

On board air conditioning systems with ammonia are currently not applied, not even in indirect systems which are common on land. The safety reservations of owners and operators and ship classification societies are still too high so that this study does not consider this refrigerant an option to reduce HFC emissions in the near future.

II. Abatement Cost Estimates

Abatement costs were calculated from the sum of annualised investment costs and annual operating and maintenance costs divided by mean annual emission savings:

$$\text{Specific costs} = \frac{\text{Annualised capital costs} + \text{annual O\&M}}{\text{Annual abated } CO_2 \text{ emission}}$$

The annual operation and maintenance costs were assumed to remain fixed over the depreciation period. The annualised capital costs are calculated by multiplying the total investment with the annuity factor¸ where d = the discount rate (100%=1) and n is the technical lifetime of the measure in years:

$$\text{Annuity Factor} = \frac{d}{(1 - (1+d)^{-n})}$$

Investment costs were annualised over the lifetime with discount rates of 4 %. The approach using annualised costs evaluates measures according to their long term suitability to mitigate global warming.

Due to the inherent complexity of the sector, there is little transparent and representative information on the costs of abatement options. The effect of increases or decreases in energy consumption on CO_2 emissions has been estimated but is not included in the cost estimates.

Table 29 shows the 2006 base year emissions and the projected total business-as-usual emissions for 2020. The figures are presented in Chapter One and Two of this report. In the following, we use the business-as-usual scenario for all cost estimates in the knowledge that in the maritime sector the actual 2020 HFC emissions will be higher (by 48%) in consequence of an accelerated R-22 phase-out stipulated by EU legislation (Regulation 2037/2000). We consider this approach viable because the relative costs per tonne abated CO_2 equivalent emissions are the same in both 2020 scenarios. Cost estimates of reduction options for 2020 are shown in Table 30.

Table 29: Base year (2006) & projected total emissions [kt CO_2 eq.]

	2006	2020
Railway	76.4	144.4
Metro	3.8	13.2
Tram	6.3	17.0
Cruise Liners	37.2	111.6
Passenger Ships	51.2	153.6
Cargo Ships	180.8	542.4
Other Merchant Ships	11.6	34.8
Small Fishing Vessels <100 kg	15.6	59.3
Fishing Vessels 100-1,000 kg	12.3	46.8
Fishing Vessels >1,000 kg	44.7	169.7
Inland Navigation Vessels	7.8	23.3
Total	447.7	1,315.8

Table 30: Abatement cost estimates of reduction options for the 2020 business-as-usual emissions of HFCs[11]

No.	Measure	Total emissions [ktCO_2 eq./yr.]	Abated emissions [ktCO_2 eq./yr]	Total invest cost [M€]	Annual costs [M€]	Abatement cost [€/t CO_2 eq.]
1.1	Railroad EMU AC: CO_2 eq	67.4	67.4	427.5	25.7	847
1.1	Railroad DMU AC: CO_2 eq	30.1	30.1	135	8.1	598
1.1	Railway coaches AC: CO_2 eq	27.1	27.1	300	11,3	1,231
1.1	Tram AC: CO_2 eq	17.0	17.0	102.6	3.8	672
1.1	Metro AC: CO_2 eq	13.0	13.0	144	7.2	1,362
2.1	Cruise Liners AC /Refr.: Leakage reduction	111.4	44.6	-	0.38	8.5
2.1	Cargo/Oth. Merchant AC/ Refr.: Leakage reduction	577.0	230.8	-	18.4	85
2.1	Passenger Ships AC/ Refr.: Leakage Reduction	153.8	61.5	-	3.3	53
2.1	Small fishing Vessels <100kg Refr.: Leak Red.	59.3	23.7	-	10.5	444
2.1	Fishing Vessels 100-1,000kg Refr. Leakage Reduction	46.8	18.7	-	0.53	27
2.2	Fishing Vessels > 1,000kg: NH_3	169.7	125.0	55.2	-3.2	0

Note: The numbering of the measures in the first column follows the numbering in section I (Key Abatement Options) of this Chapter IV.

The abatement costs for air conditioning in the railroad sector are very high because of the relatively small refrigerant charges and the comparably leak tight systems with HFCs. A changeover to more expensive CO_2 systems is expected to produce only a small emission reduction compared to measures in the maritime sector (see also Figure 1). Given the high costs, broad application of CO_2 systems is not very likely at present time.

Emissions abatement costs in the maritime sector are significantly lower, both in merchant and in fishing vessels. This is because containment of existing systems is not as expensive as the introduction of a new technology. At feasible investment costs a reduction of 40% can be considered possible (see Table 31).

[11] All abatement cost estimations are calculated using cost estimates from the chapters above.

Figure 1: Abatement cost potential curve

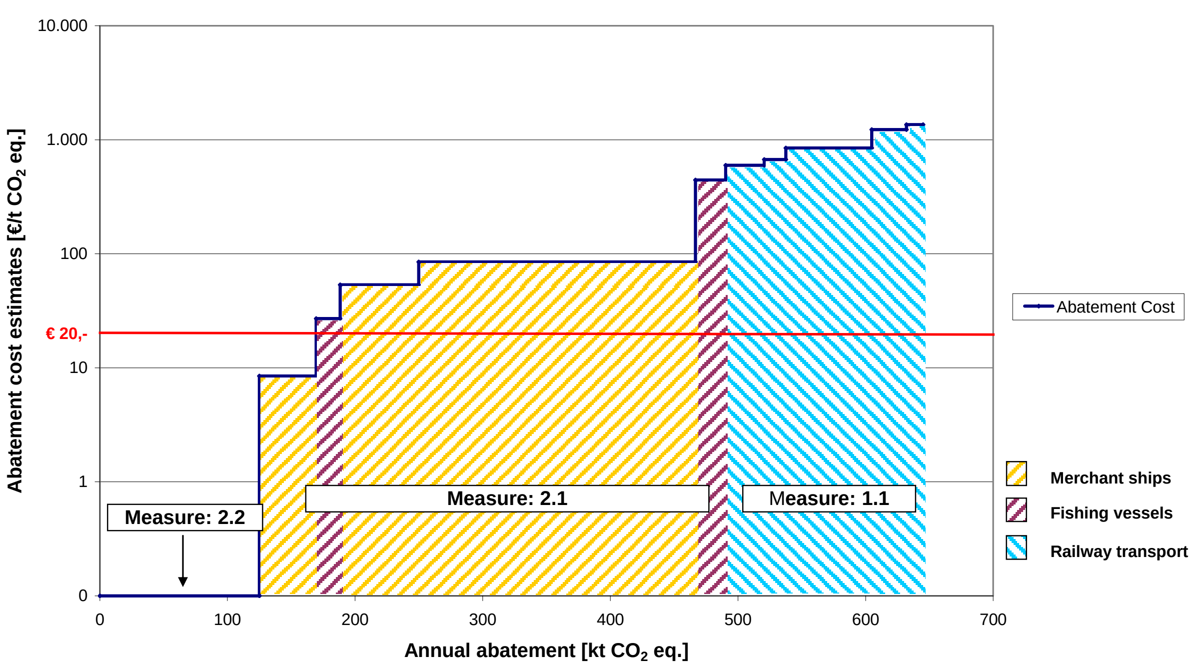

Figure 1 Cumulated annual abatement costs for reduction measures in the maritime and rail sector. Approx. 125 kilo tonnes CO_2 equivalent can be abated gratis by use of ammonia on fishing vessels with refrigerant charges over 1,000 kg (measure 2.2), and further 45 kt can be saved by implementation of leakage reduction measures on large cruise ships, for less than € 20 per tonne CO_2 equivalent. Leakage reduction measures on fishing vessels with refrigerant charges from 100-1,000 kg would lead to a further reduction of 18.7 kt CO_2 equivalent at € 27 per tonne abated CO_2 equivalent. Costs of further 294 kilo tonnes abated CO_2 eq. from leakage reduction measures on merchant ships (for cargo and passengers) remain below the mark of € 100 per year (measures 2.1). Additional 23.7 kt CO_2 equivalent can be abated on small sized fishing vessels as a result of containment measures at costs of ca. € 444 per tonne CO_2 equivalent. A switch to CO_2 systems in the railway sector (measures 1.1) would lead to a further reduction of 150 kilo tonnes at abatement costs up to more than € 1,000 per tonne abated CO_2 eq.

Table 31: Reduction potential of the 2020 baseline emissions

	Abated Emissions [kt CO_2 eq.]	abated fraction [%]
Railroad EMU	67.4	100
Railroad DMU	30.1	100
Coaches	27.1	100
Tram	17.0	100
Metro	13.0	100
Cruise Liner	44.6	40
Cargo Ship	230.8	40
Passenger Ship	61.5	40
Small fishing Vessels < 100kg	23.7	40
Fishing Vessels 100-1,000kg	18.7	40
Fishing Vessels > 1,000kg	125	74
Total	659	50

III. Conclusions

In a baseline scenario under business-as-usual conditions it is estimated that HFC emissions from air conditioning and refrigeration in the rail and maritime transport sector of the EU contribute approx. 1.3 million tons CO_2 equivalent in 2020. Considering the abatement options discussed in this chapter, a reduction potential of 35 % or approx. 484 kt CO_2 eq. seems to be achievable at reasonable costs of less than € 100 per abated tonne CO_2 eq.

From the cost analysis of ammonia-based fishing vessels with refrigerant charges over 1,000 kg it emerges that 125 kt CO_2 equivalent can be saved without additional specific cost because higher investment and lower energy costs balance each other out.

In the other sectors the reduction measures involve additional costs. As abatement costs vary widely a least cost policy should attempt to start with low cost options. In past EU assessments the threshold value was € 20 per tonne abated CO_2 equivalent. When using this threshold value for the calculated abatement costs, reduction measures can be considered cost-effective only for cruise liners, saving HFC emissions of approx. 45 kt CO_2 equivalent.

In the other HFC applications, the costs of reduction measures are higher than € 20 per tonne abated CO_2 equivalent. As a consequence of relatively moderate abatement costs for refrigerant containment in other merchant ships (< € 100 per tonne of abated CO_2 eq.) the barriers to emission reduction measures might be overcome there. As a result of containment measures in the entire EU merchant fleet, further 294 kilo tonnes of CO_2 eq. could be saved for less than € 100 per tonne CO_2 eq. (see Figure 1). In the fishery sector, additional 19 kt CO_2 equivalent can be saved at moderate cost (€ 27 per tonne abated CO_2 eq.) if containment measures are applied to vessels with refrigerant quantities of from 100 to 1,000 kg.

Further 23.7 kt of CO_2 eq. can be abated at € 444 per tonne CO_2 eq. by extension of containment measures to the cargo hold refrigeration of small sized fishing vessels < 100 kg.

Reduction options for air conditioning in the rail sector are significantly higher. The costs of key abatement options range from € 650 up to more than € 5,000. Although rail AC systems are not subject to the phase out of HFCs with global warming potential over 150 [Directive 2006/40/EC], several companies are working on the market maturity of CO_2 systems for railway and tram vehicles. Due to the high investment costs, a general changeover to the new technology is not yet likely in short term.

It is self-evident that all presented emission reduction measures that involve financial expenses will be implemented easier if they are regulated by legislation.

ANNEX I EU-27 Merchant Fleet by Registration, from 2000 onwards

REGISTER	Cruise	Passenger	RoRo	Ferry	Reefer	Container	Bulk	Gen. Cargo	Tanker	Chemical	Offshore	Other	Total
Belgium	1	0	1			3	16	0	10	0			31
Bulgaria		0	0	0			1	0	0	0			1
Cyprus	0	2	1	1	0	73	82	33	25	35	7	0	252
Denmark		2		8				1	2		0	3	13
DIS	0		4	2	0	44	7	1	17	33	9	0	108
Estonia		0		6				0	0	0			6
Finland	0	2	0	2		1		1	3	0		0	9
France	0	6	1	12	0			3	0	0	1	1	22
FIS			1			24			17	18	28	1	60
Germany	0	2	0	3	0	122	0	8	9	9	0	7	153
Greece	1	18	0	34	0	23	107	0	136	26	0	2	345
Irish Republic		3	0	0				15	0	2			20
Italy	7	30	17	32	2	8	19	14	23	87	9	3	239
Latvia		0	0	0				0	1				1
Lithuania				2	0	0		0	0			0	2
Luxembourg	1		2	0		3	7		0	10			23
Malta	3	0	4	6	0	9	87	42	43	53	0		247
Netherlands	5	4	11	6	1	30		181	7	14	3	1	259
NL-Antilles	0	0	2	0	0	1	2	17	0	0			22
Poland		0	0	0				0	0	0	0		0
Portugal	1	11	0	0	0	0		1	0	1			14
PT-MAR	0	0	3	1		0		9	2	5			20
Romania		0	0	0				0	0	0			0
Slovakia					0		1	0	0	0			1
Slovenia									0				0
Spain		2	3	9	0	0		1	4	4	3	2	23
Sp-CSR		2	4	13	1	3		2	14	6	0		45
Sweden	0	4	18	6				3	10	26		1	67
UK	2	11	21	26	0	85	11	18	11	36	28	4	221
Gibraltar		0	1			15	0	45	4	30	4	1	95
Isle of Man		0	3	0	0	5	7	17	64	38	14	0	134
Total	21	99	97	169	4	449	347	412	402	433	106	26	2433

ANNEX II Öko-Recherche Survey on 2006 Refrigerant Refills in 10 Baltic Ferries (Two Owners)

2006 Refrigerant Refills in ten Baltic Ferries with Indirect Air-Conditioning and Direct Refrigeration Systems, in kilograms											
Vessel No*	1	2	3	4	5	6	7	8	9	10	TOTAL
Construction year	2001	2001	2001	2002	2004	1979	1974	1997	2006	1968	
AC charge											
22						756	5,9			48	810
134a	1140	1100	1122	920	640			400	762		6084
Total Charge											**6894**
AC refill											
22						164	1			0,5	166
134a	166	150	200	500	60			200	14		1290
Total Refill											**1456**
Refrig charge											
134a						20				90	110
404A	185	130	102,6						99	4	521
407C				50					52		102
Total Charge											**733**
Refr refill											
134a						5				15	20
404A	25	35	0						93	0	153
407C				0					11		11
Total Refill											**184**
AC rate	15%	14%	18%	54%	9%	22%	17%	50%	2%	1%	**21,1%**
R 22											**20,4%**
R-134a											**21,2%**
Refrig rate	14%	27%	0%	0%	no	25%	no	no	69%	17%	**25,1%**

* The names of the ships and of the owners are not released here for confidentiality. They were communicated to the EU Commission in Oct. 2007.

ANNEX III

Natural refrigerants increasing on large fishing vessels

The in-depth analysis of the 21 large newbuildings over 70 metres from 2002 for EU registers shows the following result by vessel types.

Six new RSW trawlers

As of 2002, six new vessels > 70 m (partial fleet size: 12 units) were built, all on Norwegian shipyards. Five of them are registered in UK, one in Denmark.

Name and (in brackets) flag, length year of built of these vessels are: Charisma (UK - 2003 – 70.7), Kings Cross (UK – 2003 – 70.0), Altaire (UK – 2004 – 76.2), Research W (UK – 2004 – 70.7), Chris Andra (UK – 2006 – 71.2), Isafold (DK – 2006 – 76.2).

All the six new ships are equipped with ammonia refrigerant (direct systems).

Yet in 2002, two RSW trawlers (< 70 m) for an UK owner were outfitted with the HFC R-507. According to the RSW system supplier, 2002 was the year when the British authorities ceased their reservation towards ammonia, so that since 2003 new RSW trawlers for EU flags have generally been equipped with this natural refrigerant. The two 61.5 metres long HFC-vessels are Ocean Quest and Ocean Venture (TEK 07). These are the only HFC equipped EU RSW trawlers known to this company.

Seven new Tuna seiners

As of 2002, seven new vessels > 70 m (partial fleet size: 30 units) were built, on Spanish and French shipyards. Five of them are registered in Spain, two in France.

The data of these vessels are: Txori Argi (ES - 2004 – 106.5), Izurdia (ES – 2004 – 106.5), Albatun Dos (ES – 2004 – 115), Albatun Tres (ES – 2004 – 115), Alakrana (ES – 2006 – 104.3), Glenan (FR – 2006 – 84.1), Trevignon (FR – 2006 – 84.1).

All the seven new ships are equipped with ammonia refrigerant and $CaCl_2$ brine.

HFC-404A is used on two of them, but only to a small extent: The air blast freezing system that is installed as a supplement to the large immersion freezing system runs with R-404A at the low temperature of -55°C which is not achievable with $CaCl_2$ brine. In addition, two of the 26 fish tanks are cooled by the R-404A system. The combined HFC quantity of these two ships is estimated 800 kg, at most (INF 05).

Four new built factory trawlers

As of 2002, four new vessels > 70 m (partial fleet size 90 units) were built on a Spanish shipyard. Three of them are registered in Spain, one in the Netherlands. *The data are: Wiron 5+Wiron (NL - 2002 – 2x55.6[12]), Playa de Aritztatxu (ES – 2002 – 72.6), Playa Pesmar Uno (ES – 2003 – 70.9), Playa Pesmar Dos (ES – 2004 – 70.9).*

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[12] These two count here as one because they are used together. In shallow seawater one net is trawled between the two vessels, the catch is processed by one, while the nets are prepared on the other.

While in 2002 this shipyard delivered their last vessel with R-22 (Manuel Angel Nores (ES – 2002 – 72.2), they completed in the same year the twin-ships Wiron 5 + 6 for a Dutch owner and the Playa de Aritztatxu for a Spanish owner with ammonia and $CaCl_2$ brine. Two years later the first new freezer trawlers with R-507 were completed: the sister ships Playa Pesmar Uno and Dos for a Spanish owner.

The amount of R507 on each of the ships (capacity of the 2 plate freezers 40 t/day; 6 air blast freezing tunnels 15 t/day, cargo hold 957 m^3, combined refrigerating capacity of the three freezer compressors 500 kW) is estimated at 1,400 kg (direct system).

Converted four factory trawlers

Partly supported by the Dutch government, in 2002-2006 four Dutch owned vessels with R-22 refrigeration and freezing system were retrofitted, on Dutch yards.

The vessel data are: Oceaan VII (NL – 1986/2003 – 90.2), Dirk Dirk (DE – 1983/2004 – 95.2), Cornelis Vrolijk (UK – 1988/2004 – 113.5), Sandettie (FR – 1981/2005 – 86).

On Oceaan VII, the world first NH_3/CO_2 system (300 kW) with CO_2 as evaporating secondary refrigerant partly replaced the existing R-22/$CaCl_2$ system for vertical plate freezers and the cargo hold.

On Dirk Dirk, the existing R-22/$CaCl_2$ system was completely replaced by an NH_3/CO_2 cascade system.

On Cornelis Vrolijk an R 507/CO_2 cascade system was installed to replace the existing R-22 system because ammonia was considered too expensive in this case. The refrigeration capacity of the new freezing system is 1,700 kW. The quantity of R-507 required for this and further equipment amounts to 7,000 kg.

On Sandettie the R-22 system was completely replaced by an HFC system with R-407C and $CaCl_2$ brine. The ca 1,500 kW for Plate freezers, RSW tanks, and hold are provided by ca 2,500 kg refrigerant.

Summary

The analysis of the 21 new-built and converted large fishing vessels > 70 metres for EU registers from 2002 to 2006 shows that only four of them were equipped with HFCs in their main refrigeration circuit. (On further two vessels HFCs supplement the main system of ammonia/$CaCl_2$ to a small extent.) On fifteen newbuildings and two conversions the main refrigerant is ammonia with $CaCl_2$ brine (15 cases) or CO_2 as secondary refrigerant.

The actual HFC consumption for the 21 newbuildings > 70 m is 13.1 tons, namely 9.8 t R507 (2 x 1,400 for Playa Pesmar Uno/Dos; 7,000 for Cornelis Vrolijk), 2.5 t R407C, and 0.8 t R404A. The total of Non-R-22 refrigerants in the 21 newbuildings is estimated 62.4 t. HFCs have only a share of 21% in them.

ANNEX IV Data on Railway Air Conditioning in the EU Member States, 2006

	AC coaches	AC EMU	EMU ch/kg	AC DMU	DMU ch/kg	AC cabs	Dining cars	Couchettes	Sleep. cars	Locomotives	Loco 1990+
AT	931	694	10,2	120	12,0	342	44	88	46	1244	703
BE	277	510	15,6	192	14,0	454	4	30	11	759	230
BG	48	0	0	50	12,0	0	17	72	59	580	0
CZ	217	124	21,6	71	12,0	166	44	38	56	2167	40
DE	2827	5220	10,8	1920	13,1	4608	182	204	170	4787	1220
DE oth	0	133	8,8	1318	14,8	308	0	0	0	166	0
DK	80	248	10,3	506	8,9	402		8		63	0
DK oth	0	0	0,0	136	18,6	0					0
EE	19	0	0	0	0	0	3		28	113	0
ES	1232	3247	21,1	355	14,5	1860	21	57	262	821	140
ES oth	22	453	16,0	38	16,0	408	8		14	225	
FI	166	168	17,1	16	12,0	96	55		113	545	46
FR	1944	7063	23,8	1081	12,9	3330		613	22	4372	680
FR oth		215	22,0	0		86				216	
GR	157	100	15,0	207	13,0	144	24	29	25	164	66
HU	121	40	10,0	126	12,0	100	65	27	16	1024	10
HU oth		354	11,0	0	0,0	236					
IE	83	0	11,0	267	0,0	170				94	34
IT	4194	2572	20,4	945	12,0	3576	105	585	272	3389	958
LT	70	0	0	0	0	0	3	32	103	240	0
LU	49	36	22,0	0	0,0	24	0	0	0	96	50
LV	72	0	0	0	0	0	8	58	91	205	0
NL	432	1180	16,4	80	10,0	696	kA	kA	kA	121	85
NL other		0	0,0	161	15,4	86					
PL	415	14	13,0	124	13,0	202	179	177	256	3766	0
PT	113	713	14,5	96	12,0	404	6		4	154	0
PT oth	0	88	22	0	0	44					0
RO	90	0	0	240	12,0	0		19		973	0
SE	200	696	15,6	24	6,0	414	kA	kA	kA	533	0
SE oth	0	604	9,3	52	13,4	236	12	55	56		
SI	55	89	11,9	0	0	66	5	4	6	149	24
SK	111	0	0,0	42	13,5	42	25	71	52	212	0
UK	300	3684	15,4	1018	12,6	2170	2		65	410	0

ANNEX V Railway Vehicles Survey at DB

Survey on Leakage Rates of Railroad Vehicle Air Conditioners at Deutsche Bahn, Plants for Technical Revision Wittenberge, Neumünster, Krefeld, and Kassel. Calender Year 2006.

Wittenberge	
Doubledeck Coaches	
refill kg	700
interval, years	4
cars	200
charge/car, kg	22
refrigerants, kg	4400
refrig x interval, kg	17600
annual leakrate	**4,0%**

Neumünster	
IC Coaches	
refill kg	1953
interval, years	4
IC/EC pass coaches	
cars	730
charge/car, kg	15
refrigerants, kg	10950
Dining cars	
cars	41
charge/car, kg	30
refrigerants, kg	1230
Sleeping cars	
cars	18
charge/car, kg	30
refrigerants, kg	540
Bistro cars	
cars	31
charge/car, kg	15
refrigerants, kg	465
all refrigerants, kg	13185
refrig x interval, kg	52740
annual leakrate	**3,7%**

Krefeld	
Electrical Multiple Units	
refill kg	810
ET 423,424,425	49
interval, years	6
cars	196
charge/car, kg	11
cabins	98
charge/cabin, kg	2
refrigerants, kg	2352
refrig x interval, kg	14112
ICE-2 (EMU-7)	6
interval, years	3,5
cars	42
charge/car, kg	15
cabins	12
charge/cabin, kg	5
refrigerants, kg	690
refrig x interval, kg	2415
ICE-T	10
interval, years	3,5
centre cars	48
charge/car, kg	15
end cars	20
charge/car, kg	7,5
refrigerants, kg	870
refrig x interval, kg	3045
all refrigerants, kg	3912
refrig x interval, kg	19572
annual leakrate	**4,1%**

Kassel I	
DMU compact AC	
refill kg	103
VT 612 (DMU-2)	
interval, years	4
cars	92
charge/car, kg	10
cabins	92
charge/cabin, kg	2
refrigerants, kg	1104
refrig x interval, kg	4416
annual leakrate	**2,3%**

Kassel II	
DMU open compressor	
refill kg	579,5
interval, years	7
VT 643/VT644	
cars	56
charge/car, kg	14
refrigerants, kg	784
VT 642	
cars	2
charge/car, kg	12
refrigerants, kg	24
VT 650	
cars	20
charge/car, kg	14
refrigerants, kg	280
all refrigerants, kg	1088
refrig x interval, kg	7616
annual leakrate	**7,6%**

Explanation: The plant's refill in the calendar year 2006 is related to the refrigerant quantity in all vehicles coming to inspection after a certain time interval (in years) since last revision. The annual leak rate is refill in kg divided by "refrigerants x interval, kg" (all vehicle refrigerants multiplied by the interval years).

The data were provided in March/April 2006, by DB Fahrzeuginstandhaltung GmbH: Jürgen Wicklein and Robert Gründl (Werk Kassel), Helmut Schröers (Werk Krefeld), Ralf Meinsen (Werk Neumünster), Klaus Letto (Wittenberge).

ANNEX VI ECSA Position on the Report

European Commission
DG Environment
Att. Mr. Dr. Peter Horrocks
Avenue de Beaulieu 5
B-1160 BRUSSEL
BELGIUM

RF/rf/9.17.01/07-01184 Rotterdam, 1 October 2007

Dear Mr. Horrocks

Subject : ECSA position on the draft interim report on HFC's

Comments of the European Community of Ship-owners Associations (ECSA) on the interim report on *the analyses of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions*.

On behalf of ECSA, Mr. Ronaldo Valadares Fonseca of the Netherlands Ship-owners Association (KVNR) and Mr. Tom Peter Blankestijn of Maersk Line, attended the stakeholders meeting of 25 September 2007 at Avenue de Beaulieu 5, Brussels.

At this meeting ECSA raised the following key points with regards to the contents of the draft interim report:

Key points

- We support, in principle, every effort which is aimed at enhancing quality in the operation & maintenance of cooling installations on board of sea-going ships, the use of refrigerants and standards of training for crew with the overall aim of reducing emissions of greenhouse gases and ozone depleting substances to the atmosphere.

- Ships and their cargoes represent an enormous economic value and as such they are manned by well trained crew according to international standards (STCW-95, ILO). Extensive preventive maintenance plans have been developed and used according to ISM standards.

- The vast majority of leakages of refrigerant from cooling installations on board of sea-going ships is caused by external factors such as ambient meteorological conditions; (varying) temperatures, wind force, wind type, relative humidity, salty corrosive environment, the sea state (wave & swell characteristics), resulting vibrations (sea state and machinery), bending moments, shear forces & torsion.

- As such leakages mainly have an “incidental” character and therefore abatement options such as better containment by raising awareness, checks by external, certified companies and additional training of crew will have a very limited effect on the reductions. Above all, it is virtually impossible to set quantitative reduction targets on a ship by ship basis, since incidents very often result in a 100% loss of refrigerant in a very short amount of time. In this context it is said that: “A ship leaks or it does not leak”. On board engineers are therefore often confronted with force major situations.

- The detection of a leakage is complicated by varying loads and consequently varying levels of refrigerant in the liquid receiver, by the sea state, defrosting processes, engine room ventilation which disperses the emitted refrigerant et cetera.

- Finding the source(s) of a leakage is complicated by the very limited accessibility of the installation and piping due to the shape of the ship and engine room, the limited space available, the design & building process, insulation of piping, HACCP (food safety / hygiene rules) engine room ventilation, the size & complexity of the installation(s), et cetera. For example in cruise ships or reefers piping is often difficult to access as it may well be located behind linings et cetera. Weather conditions can further aggravate the accessibility, as well as for example the presence of cargo under controlled atmosphere can.

- The ship’s crew will always attempt to carry out repairs, but can be restricted in doing so by the factors described above.

- Cooling installations on board of existing ships, of which the majority is equipped with the ozone depleting HCFC-22, the only available option seems to be conversion to the use of alternative HFC’s.

- For new (future) ships one should aim at the development and use of small, compact and robust, indirect installations, preferably using natural refrigerants. Till now, such installations have not been developed specifically for ships, let alone that extensive testing has been carried out. The latter being very important due to safety hazards related to the use of natural refrigerants on board of sea-going ships. We would suggest technical cooperation between all involved industries, including the ship-owners.

- The cost estimates that have been used as the basis of the cost benefit study in the report seem to be overly optimistic (i.e. low).

- In the Netherlands most of the abatement measures, as described in the *interim report on the analyses of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions*, have been good practice for years. This includes the use of logbooks to keep track of refrigerant consumption. Unfortunately this has not led to a significant reduction in leakages, which is in line with all arguments stated above.

- The Netherlands are taking the initiative within IMO to establish rules on the mandatory use of logbooks for cooling installations on board of sea-going ships. This should apply to all refrigerants. We welcome support of these initiatives from other EU member states and the European Commission.

Yours sincerely

R. Valadares Fonseca

References

ADO 07: Ulrich Adolph, Leipzig, pers. comm. 26 March 2007.
ADO 95: Ulrich Adolph, Klimatisierung von Schienenfahrzeugen, Die Kälte und Klimatechnik, 9/1995, 662-670.
ADO 98: Ulrich Adolph, Entwicklungsstand und Tendenzen der Klimatisierung von Schienenfahrzeugen, in: Ki Luft- und Kältetechnik 3/1998, 134-140.
AEA 07: AEA - Association of European Airlines, Brussels. http://www.aea.be
AIR 07: Survey on air conditioning of air craft in June 2007. Interviews with experts from:
Liebherr-Aerospace Lindenberg GmbH, Lindenberg (Germany), Mr Lehle, 29 June 2007;
Liebherr-Aerospace Toulouse SAS, Toulouse, Mr Eglem 29 June 2007.
Flugrevue, Aerospace Magazine, editorial office Bonn, Mr Gründert, 28 June 2007;
Luftfahrtbundesamt, Projekte kleine Flugzeuge/Drehflügler, Braunschweig, Klaus Flatter, 28 June 2007;
Lufthansa Technik, Hamburg, Mr. Ramspeck 28 June 2007.
BLE 07: Butzbach-Licher Eisenbahn AG, Butzbach, Mr Hoppe, pers. comm. 6 April 2007.
BOM 07: Michael Eckhardt; Bombardier Transportation, Berlin (DE) pers. comm. 15 May 2007.
CCNR 07: Market Observation for European Inland Navigation, published by the Secretariat of the Central Commission for Navigation on the Rhine, on behalf of the European Commission, DG Energy and Transport.
DC 06: Danube Commission 2006 Statistisches Jahrbuch der Donau-Kommission für das Jahr 2004.
DRE 07: M. Balthause, Drews Marine GmbH, Hamburg (DE), pers. comm. 25 April 2007.
EIS 07: Eisenbahn-Kurier, Freiburg, several issues from 2000 to 2007.
EUR 07: Eurostat. The EU-25 Fishing Fleet in 2005, Statistics in focus, AGRICULTURE AND FISHERIES 50/2007, 02.04.2007.
http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-07-050/EN/KS-SF-07-050-EN.PDF
FAI 07: Lloyd's Fairplay Register. Sea-Web, the Register of Ships online, http://www.sea-web.com.
FAO 01: J. H. Kelman, Ministry of Agriculture, Fisheries, and Food, Stowage of Fish in Chilled Sea Water, FAO in partnership with Support unit for International Fisheries and Aquatic Research, SIFAR, 2001, http://www.fao.org/wairdocs/tan/x5944e/x5944e00.HTM
FAV 07: Lutz Boeck, Manager Systems Engineering, Faiveley Transport Leipzig GmbH, Schkeuditz (DE), pers. comm. 19 June 2007.
FLA 07: Klaus Flatter, Luftfahrtbundesamt, Referat T 3, Projekte kleine Flugzeuge/Drehflügler, Braunschweig, pers. comm. 28 June 2007.
FLI 07: Gretel Flindt, Managing Director of Fischverwertung Heiligenhafen (DE), pers. comm. 8 May 2007.
FLU 07: Flugrevue – German Aerospace Magazine, Mr Gründert, editorial office, Bonn, pers. comm. 28 June 2007.
FRE 07: Ms Pilar, Freire Shipyard, Vigo (ES), pers. comm. 13 June 2007.
http://www.freireshipyard.com/
GRE 07: Grenco BV (GEA Refrigeration Division), Brochures on the website: Cruise Ships; Grenco cooling system for new Princess Cruise liners; Industrial Fishing; Reefers; Grenco carbon dioxide (CO_2) freezing systems; The Grenco NH_3/CO_2 cascade system is a world first; This super trawler features state of the art refrigeration technology; Grenco Ammonia-Brine Chillers for the Salica Frigo; New generation Flexcon Reefer vessels.
HAM 05: Hamilton Sundstrand Corporation: Air Management Power Systems.
http://www.hamiltonsundstrand.com/hsc/details/0,,CLI1_DIV22_ETI3026,00.html (20.05.2007).
HEI 07: Mr. Blockhuis, Heinen & Hopman Engineering BV, Spakenburg (NL), pers. comm. 26 April 2007.

HON 02: Harry Hondius, Straßenbahnen und ihre Antriebe, ETR – Eisenbahn-technische Rundschau, Hamburg, 51 (2002), H. 1-2. http://www.ilkdresden.de/de/leistungen/klima/klimatisierung_entfeuchtung.htm (02.06.2007).
ILK 01: Franzke, U.,Hackeschmidt, K.: Kaltluftklimatisierung mit sorptiver Entfeuchtung, ILK Dresden, 2001.
INF 04: Infomarine - Actualidad y Tecnología de la Industria Naval y Marítima, Barcelona (ES), 101, May 2004. http://www.infomarine.com.
INN 06: Neues von der Klimatechnik für Schienenfahrzeuge – InnoTrans 2006 in: Die Kälte & Klimatechnik 10/2006, p. 56-58.
INV 02: Inventarisatie Koudemiddelenemissie Zeescheepvaart, July 2002, Haskoning (NL), 542511.C0, cited in SNO (SenterNovem) 2006.
IPCC 05: IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons. Prepared by Working Group I and III of the Intergovernmental Panel on Climate Change, and the Technology and Assessment Panel. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 254-267.
JAEG 07: Joachim Schmitt, Reederei Jaegers, Duisburg (DE), pers. comm. 25 April 2007.
KLH 07: Sven v. d. Heide, KLH-Montage, Bad Doberan (DE), pers. comm. 21 May 2007.
KUE 07: Wolfgang Kügel, Service Coordinator, Johnson Controls Systems & Service GmbH (formerly York Marine), Hamburg (DE), pers. comm. 18 April 2007.
LBA 07: Bestand an Luftfahrzeugen in der Bundesrepublik Deutschland 31/12/2006, http://www.lba.de/cln_009/nn_53936/DE/_C3_96ffentlichkeitsarbeit/Statistiken/Bestand.html
LIE 04: Liebherr-Transportation Systems, Luftgestützte Klimasysteme, S.7, Korneuburg, Österreich 2004. http://www.liebherr.com/downloads/2004_Prospekt_TS_D.pdf (02.06.2007)
LIE 07: Mr Eglem, Liebherr-Aerospace Toulouse SAS, Toulouse, pers. comm. 29 June 2007.
LIL 07: Liebherr-Aerospace Lindenberg GmbH, Lindenberg (Germany), Mr Lehle, pers. comm. 29 June 2007.
LUF 07: Lufthansa Technik, Hamburg, Mr. Ramspeck, pers. comm. 28 June 2007.
MAA 07: Ben Bout, Maaskant Shipyards Stellendam, Stellendam (NL), pers. comm. 6 June 2007.
NAT 07: Web-based data compilation Nationmaster, Military Statistics > Forces in Europe > Helicopters by country, http://www.nationmaster.com/graph/mil_for_in_eur_hel-military-forces-in-europe-helicopters.
NOK 07: Christian Scharfetter, Noske-Kaeser GmbH, Hamburg (DE), pers. comm. 21 May 2007.
OEK 07: Öko-Recherche, Establishing the leakage rates of mobile air conditioners in heavy duty vehicles (070501/2005/422963/MAR/C1). For the European Commission (DG Environment), part I trucks, and part II buses, Brussels 2007.
PAB 07: Martin Pabst, Straßenbahn- und Stadtbahnfahrzeuge. Das aktuelle Typen-Taschenbuch, München 2007.
PAR 07: Parlevliet & van der Plas B.V, Euro-Baltic Fischverarbeitungs GmbH, Sassnitz, Uwe Richter, pers. comm. 25 April 2007.
PET 07: Pettersson, T.: Technical Sales Manager, Refrigeration Europe, Barwill Unitor Ships Service, Norway, pers. comm. 5 June 2007.
PFA 07: Pelagic Freezer-trawler Association (PFA), Gerard van Balsfoort, Rijswijk (NL), The Netherlands, pers. comm. 7 May 2007.
PINE 04: Prospects of Inland Navigation within the Enlarged Europe, Buck Consultants International (The Netherlands), ProgTrans (Switzerland), VBD European Development Centre for Inland and Coastal Navigation (Germany), via donau (Austria), March 2004.
RMAC 07: Survey on air conditioning of rail vehicles in the time from February to June 2007. Interviews with experts from:
Bombardier Transportation GmbH, Berlin, Michael Eckhardt, 7/8 May 2007;
Alstom LHB GmbH, Salzgitter, Frank Mackedanz, 28 March 2007;

Siemens AG Transportation Systems, Frank Elsenheimer, 2 May 2007;
Liebherr Transportation Systems GmbH, Korneuburg, Heinz Ebner, 30 March 2007;
Liebherr Transportation Systems Mannheim GmbH, Mannheim, Walter Kirchgessner, 30 March 2007;
Stadler Pankow GmbH, Berlin, Ronny Wandtke, 7 May 2007;
Faiveley Transport Leipzig GmbH, Schkeuditz, Lutz Bock, March/May 2007;
Konvekta AG, Schwalmstadt, Peter Möller, Carsten Eichstätter, Uwe Wagner, 2 March 2007;
Spheros GmbH (Webasto), Stockdorf, Klaus Ellinger, 2 May 2007;
Adolph Ulrich, Leipzig, 26 March 2007.

On trams and metros, there are no public statistics available on the rolling stock in the EU countries, not to mention on air conditioned vehicles or trains. Statistical data were compiled from both internet websites from all over Europe and from specialist literature, i.e. books and journals. The most important are: PAB 07, STR 07, VOC 07, HON 02, EIS 07, STA 07. Data on vehicle-specific refrigerating capacities and refrigerant charges were inquired from several experts from the European rolling stock industry as well as from the leading rail MAC suppliers (RMAC 07), in addition to tram and metro operators.

SCHM 07: Werner Schmidt, Public Appointed Expert on Ship Appraisal in Lower Saxony, Oldenburg (DE), pers. comm. 7 May 2007.

SCHW 04: Winfried Schwarz (Öko-Recherche), Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002, on behalf of the German Umweltbundesamt, Berlin 2004, 12-18.

SNO 06: SenterNovem: Fishery with environmentally friendly cooling systems, made by order of the Dutch Ministry of Public Housing, Spatial Planning and Environment (VROM), the Ministry of Agriculture, Nature Management and Food Quality (LNV), and the Ministry of Economic Affairs (EZ), 2006.

STA 07: Stadtverkehr. Fachzeitschrift für den öffentlichen Personen-Nahverkehr auf Schiene und Straße, Freiburg, several issues from 2000 to 2007.

STR 07: Straßenbahn-Magazin, München, several issues from 2000 to 2007.

SURV 07: Survey on Refrigeration equipment on new-built fishing vessels.
Interviews with experts from:
Armon Vigo Shipyard S. A., Vigo (ES), Ricardo Garcia, 22 May 2007;
Freire Shipyard, Vigo (ES), Ms Pilar, 13 June 2007;
Astilleros de Murueta, Murueta (ES), Mr Enrique, 12 June 2007;
Cantiers Piriou, Concarneau (F), Ms Pascal, 11 June 2007; and
Grenco Iberica S. A., Vigo (ES), Mr J. Alvarez, 21 May 2007.

TEK 07: Teknotherm Marine & Refrigeration, Mr Torp and Mr Ivo Kravic, Halden, Norway, pers. comm. 21 May and 14 June 2007.

UEB 07: Ueberfeld Kälte-Klimatechnik, Rheinberg (DE), pers. comm. 25 April 2007.

UIC 06: International Union of Railways (UIC), Paris, Railway time-series data 2005, Table B22 Passenger transport stock.
Starting point of the railway data are the statistics of the International Union of Railways (UIC), Table 22) on Passenger transport stock in the 25 EU member states with rail transport (UIC 06). For every country (excl. Denmark and Netherlands) the 2004 number of "coaches" and of "railcars and trailers" (cars of multiple units) is presented, and the combined number of air-conditioned passenger vehicles (cars of multiple units plus coaches). These statistics (which show many errors in the figures) do not inform on the number of multiple units (trains) nor do they distinguish between cars of electric and cars of diesel multiple units, or between air-conditioned coaches and air conditioned cars of multiple units of both drives. Apart from that, there are no UIC data available on air conditioned locomotives. To find all data needed for this study (including the years 2005 and 2006), ample internet research, inclusive of private websites of rail fans (e.g. http://www.railfaneurope.net), and research in expert literature (e.g. ADO 95, ADO 98) was carried out, in addition to interviews with sector experts (RMAC 07) and railway operators.

UNEP 06: UNEP, Report of the Refrigeration, Air conditioning, and Heat Pumps Technical Options Committee, 2006 Assessment, Nairobi, January 2007.
UNI 05: Unitor ASA: Unicool Environmental, Norway 2005
VINK 07: Bert Vink, Grenco BV (GEA Refrigeration Division), s' Hertogenbosch (NL), pers. comm. 21 May, 15 June 2007.
VOC 07: Stefan Vockrodt, Straßenbahn-Jahrbuch Deutschland und Europa 2007 München 2007.
ZBBD 07: Zentrale Schiffsbestandsdatei, Veränderung des Schiffsbestandes der deutschen Binnenflotte im Jahr 2006, Mainz (DE) 2007.