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SKM ENVIROS

Phase Down of HFC Consumption in the EU – Assessment of Implications for the RAC Sector

FINAL REPORT

- Version 11
- September 2012

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Executive Summary

Background and Methodology

1. This report provides the results of a study into the potential for the phase down of HFC consumption in the EU refrigeration, air-conditioning and heat pump (RAC) markets. The study was carried out by SKM Enviros on behalf of EPEE in the period March to June 2012.

2. The objective of the study is to investigate the potential costs and the reduced greenhouse gas (GHG) emissions of alternative profiles for the phase down of HFC consumption in the EU.

3. Detailed modelling of European RAC markets was carried out. A new model, the SKM Refrigerants Model, was developed to provide the level of detail required to fully assess the emission reduction potential and economic implications of an HFC phase down. The new model builds on the outputs of previous work carried out for EPEE (Erie-Armines, 2011).

4. The RAC market was modelled using 7 main sectors and 43 sub-sectors. A large number of sub-sectors ensures that the varying circumstances of the RAC market are taken into account. Other recent studies use less sub-sectors (Oko Recherche 2011 has 18 sub-sectors and Erie-Armines 2011 has 34). This report provides greater granularity for more accurate modelling.

5. For each sub-sector a "standard current system" was defined. Key characteristics were identified including current market size, rates of market growth, refrigerant charge and leakage rates, energy efficiency and capital cost. Alternative refrigerants that could be used in each sub-sector were evaluated. The impact of each alternative was assessed in terms of energy efficiency, capital and operating costs and any potential barriers to use (e.g. safety legislation). Most of the alternatives considered were for new equipment, although in some markets the possibility of retrofilling existing systems with an alternative refrigerant was also assessed.

6. A Base Case that forecasts the likely refrigerant consumption between now and 2040 was defined using assumptions of the mix of refrigerants used for new equipment on an annual basis. In the Base Case current practices and trends of refrigerant use are continued over the next 30 years. Alternative scenarios were defined for comparison against the Base Case. Each scenario introduces changes that will lead to reduced HFC consumption.

7. The economic impact of each scenario was modelled and compared to the Base Case, providing an estimate of the cost of emission savings, in terms of € per tonne CO_2 saved. The annual consumption of refrigerant for each scenario was established and compared to the phase down profiles that have been proposed via the Montreal Protocol process.

8. The installed base data used as inputs into the SKM Refrigerants Model shows significant growth in some sub-sectors between 2010 and 2030. In particular the use of stationary air-conditioning is forecast to increase by 90% during this period and heating-only heat pumps by 290% (average 7% per year, from a small starting size). This high level of growth will significantly increase the demand for refrigerants in these markets. Assessment of HFC phase down must fully account for these changes in market size.

Scenarios Analysed

9. Four main scenarios are presented in this report. These are:

Scenario	Description	Comments
A	Low impact, base case (all scenarios are compared to Scenario A for economic impact assessment)	Scenario A reflects a conservative view of current changes in the use of refrigerants and is used as a BAU forecast against which the other scenarios can be compared. Scenario A reflects the possible use of HFCs under the current regulatory regime (in particular, the 2006 F-Gas Regulation).
B	Medium impact	Scenario B introduces cuts in HFC use for new systems and improvements in leakage levels created by full implementation of the F-Gas Regulation.
C	High impact	Compared to Scenario B, this scenario assumes (i) greater use of very low GWP alternatives, (ii) early use of medium GWP alternatives in new equipment to avoid the installation of any new systems that use the very high GWP refrigerants and (iii) retrofill of part of the bank of high GWP refrigerants (in particular HFC 404A) in appropriate circumstances.
D	Highest Impact	This scenario improves on Scenario C by assuming more widespread use of A2L (mildly flammable) refrigerants from 2020 in the stationary air-conditioning and industrial markets.

Alternative Refrigerants Considered

10. Fourteen different refrigerants were considered as alternatives to the relevant HFCs in current use. These were split into 3 groups, based on global warming potential (GWP):

- **Group 1**: 6 refrigerants with a very low GWP (below 10) including ammonia, CO_2 hydrocarbons (HCs) and 3 new unsaturated fluorocarbons (HFOs).
- **Group 2**: 4 refrigerants with a low GWP (in the range 100 to 1,000) including HFC 32, HFC 245fa and 2 HFO based blends (a mildly flammable blend with a nominal GWP of 300 and a non-flammable blend with a nominal GWP of 700).
- **Group 3**: 4 refrigerants with a medium GWP (in the range 1,000 to just over 2,000) including HFC 134a, HFC 410A, HFC 407A and HFC 407F. It is important to note that these refrigerants have a GWP that is only a third to a half of the widely used HFC 404A and can provide early and low cost reductions in HFC consumption.

Phase Down Profiles for the Whole RAC Market

11. A key output of the modelling is the comparison of future refrigerant consumption with phase down profiles from a North American proposal (NA) and EU RED scenarios developed by Oko Recherche. Figure ES 1 shows the consumption for a range of scenarios compared to the phase down proposals. The 3 "stepped" lines are phase down proposals and the 4 curves labelled A, B, C and D are 4 of the consumption scenarios analysed in this study.

Figure ES 1: RAC Consumption and Phase Down Profiles Mtonnes CO_2

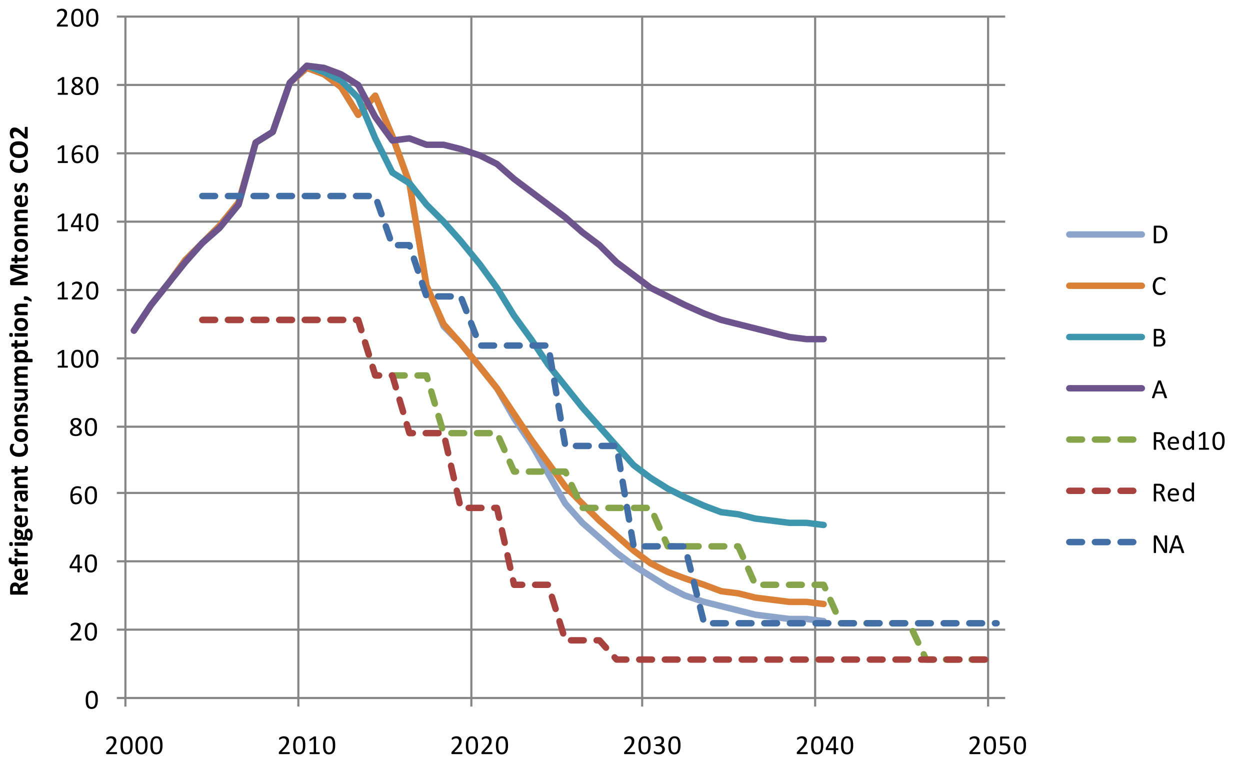


Figure ES 1 clearly shows that:

- Scenario A (the Base Case) shows only a modest decline in refrigerant consumption.
- Scenario B only meets the NA profile in 2024 and 2028.
- Scenario C meets the NA phase down profile between 2018 and 2032, although it misses the targets in the early years and after the final step of phase down in 2033.
- Scenario D creates deeper cuts than C, but just fails to meet the final step in the NA profile.
- The targets in 2014 to 2018 are very hard to meet because the baselines defined in each proposal do not take account of the market growth between 2005 and 2012.
- The depth of cuts proposed in the EU phase down profiles will be very hard to achieve in the RAC sectors under the scenarios analysed.

Cost of Abatement

12. The overall emission reduction potential for 3 scenarios is summarised in Table ES 1.

Table ES 1: Reduction in Gross Emissions (Mtonnes CO_2) - relative to Scenario A, 2030

	B	C	D
1 - Domestic Refrigeration	0.1	0.1	0.1
2 - Commercial Refrigeration	24.2	34.6	34.6
3 - Transport Refrigeration	0.9	1.4	1.4
4 - Industrial Refrigeration	2.7	5.2	5.4
5 - SAC and Heat Pumps	14.5	15.4	16.9
6 - Chillers & Hydronic Heat Pumps	5.0	5.8	5.8
7 - Mobile AC	2.3	2.5	2.5
Total	**49.6**	**64.8**	**66.6**

This table shows that 65 to 67 Mtonnes CO_2 can be saved in 2030 via Scenarios C and D. Over half the potential savings come from the commercial refrigeration sector.

13. The economic impact of each scenario in terms of cost of abatement (€ per tonne CO_2 saved) is summarised in Table ES 2.

Table ES 2: Abatement Cost (€/tCO2) - relative to Scenario A, 2030, mid-case

	B	C	D
1 - Domestic Refrigeration	-119	-95	-95
2 - Commercial Refrigeration	15	23	23
3 - Transport Refrigeration	5	-11	-11
4 - Industrial Refrigeration	10	-1	16
5 - SAC and Heat Pumps	24	27	45
6 - Chillers & Hydronic Heat Pumps	-7	4	4
7 - Mobile AC	7	11	11
Total	**15**	**19**	**25**

This table shows that the overall cost of emissions abatement, using "mid-case" economic assumptions, is in the region of €15 to €25 per tonne CO_2. The abatement cost values in Table ES 2 are for 2030.

14. The economic analysis is very sensitive to input assumptions related to (a) the extra capital cost related to using alternative refrigerants, (b) the extra maintenance cost and (c) the difference in energy efficiency. Many of the refrigerant alternatives considered in the analysis (in particular HFOs and HFO blends) are only due to enter the market from around 2015 – forecasting cost and performance of RAC systems using these refrigerants is very difficult. Other important options such as CO_2 are only in early stages of their market development – again making it difficult to predict performance and cost.

Results of sensitivity analysis are shown in Table ES 3. These show that the uncertainty in abatement costs is in the range from around €4 to €43 per tonne CO_2.

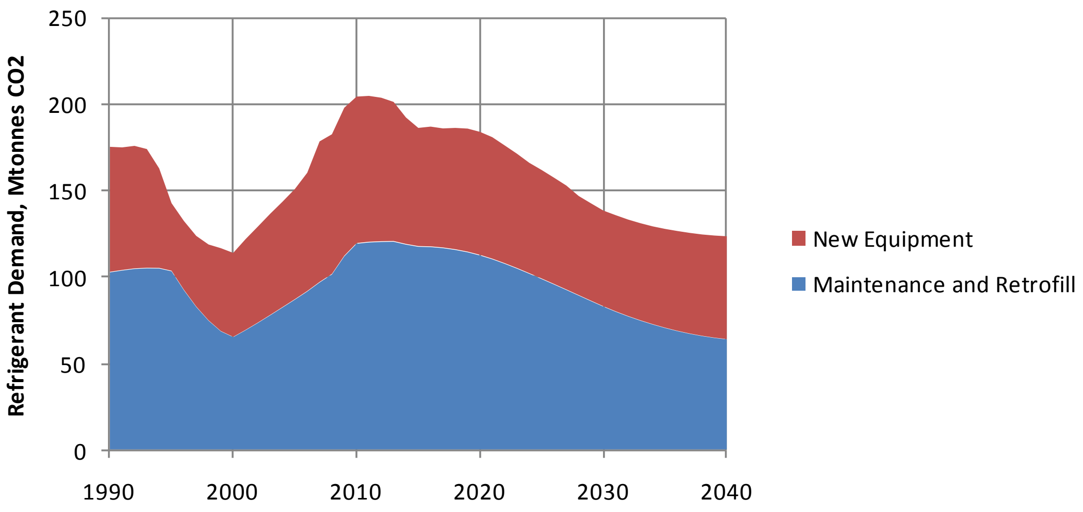
Table ES 3	Abatement Costs € per tonne CO2		
Scenario:	B	C	D
High capital, high maintenance, low efficiency	25	34	43
Mid-case values	15	19	25
Low capital, low maintenance, high efficiency	4	4	7

15. Abatement cost figures in Oko Recherche 2011 use optimistically high assumptions for the improved energy efficiency of alternatives such as ammonia. This study provides a more realistic assessment of energy efficiency differences between refrigerants.

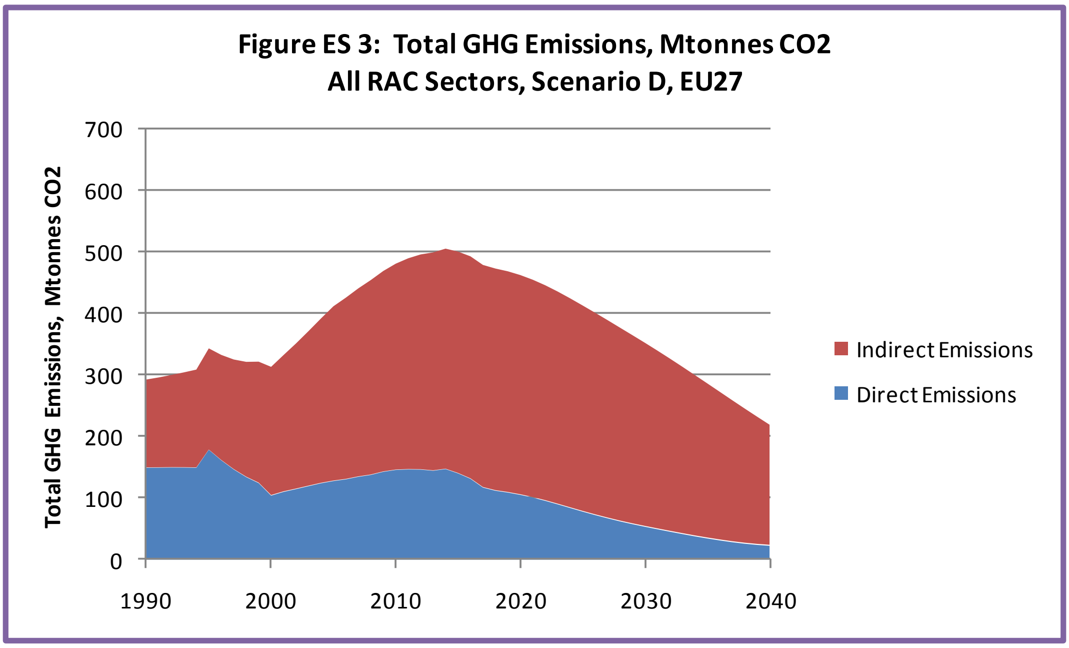
GHG Emissions

16. Modelling outputs show that top up of leakage emissions represent 60% of total GHG weighted refrigerant demand in 2030 under Scenario A (base case). This emphasises the importance of continuing to improve leakage rates via the framework established in the 2006 F-Gas Regulation. Figure ES 2 illustrates the split in demand between new equipment and maintenance.

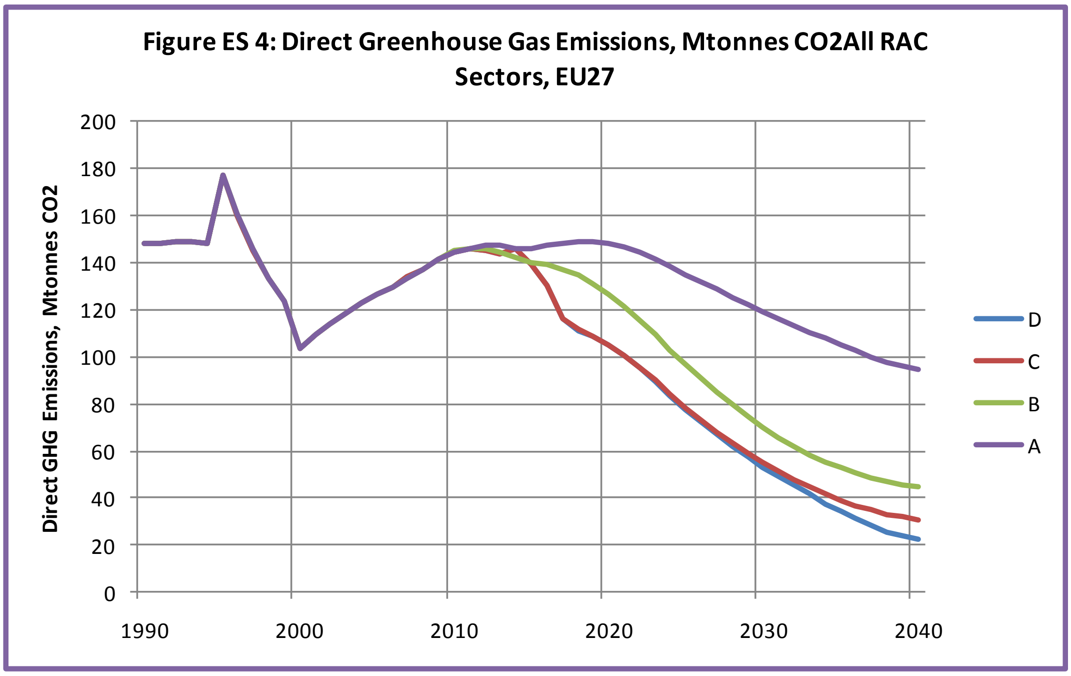
Figure ES 2: Refrigerant Demand, Mtonnes CO2
All RAC Sectors, Scenario A, EU27



17. The modelling shows the importance of energy related “indirect” CO_2 emissions. In 2030, the energy related emissions are 85% of total emissions, as shown in Figure ES 3. To achieve maximum reduction in total emissions it is clearly essential that energy efficiency of RAC systems is further improved. The choice of refrigerant must not be allowed to constrain efforts to improve energy efficiency.



18. Figure ES 4 shows the forecast of direct GHG emissions from all RAC sectors for each of the 4 main scenarios. By 2030 the emission reductions achieved compared to 2010 are 74 Mtonnes CO2 for Scenario B and 91 Mtonnes CO2 for Scenario D.



Heat Pump Emission Reductions

19. The model has been used to assess the environmental benefits of heat pumps (both heating only and reversible air-conditioning / heat pumps). The results show the enormous importance of heat pumps. In 2030 it is predicted that net GHG emission reductions of 155 Mtonnes CO_2 can be attributed to heat pumps used in place of gas boilers. This is around 3 times larger than the likely level of emission reduction achieved via phase down of HFCs. Even under the base case scenario the direct refrigerant emissions related to these heat pumps is only

estimated to be 15 Mtonnes CO_2. These data emphasise the importance of a flexible phase down scheme that will give heat pumps sufficient room for market growth using refrigerants that deliver maximum energy efficiency.

Availability of Recovered Refrigerant

20. The model forecasts that in 2025 around 28 Mtonnes CO_2 of HFC refrigerant is available for recovery and re-use from old equipment at end-of-life. This falls to about 20 Mtonnes CO_2 in 2033. This recovered refrigerant can make a significant contribution towards meeting phase down targets in the period up to 2035 if a good market for recycled / reclaimed HFCs can be established and if use of recycled / reclaimed material is allowed under phase down rules.

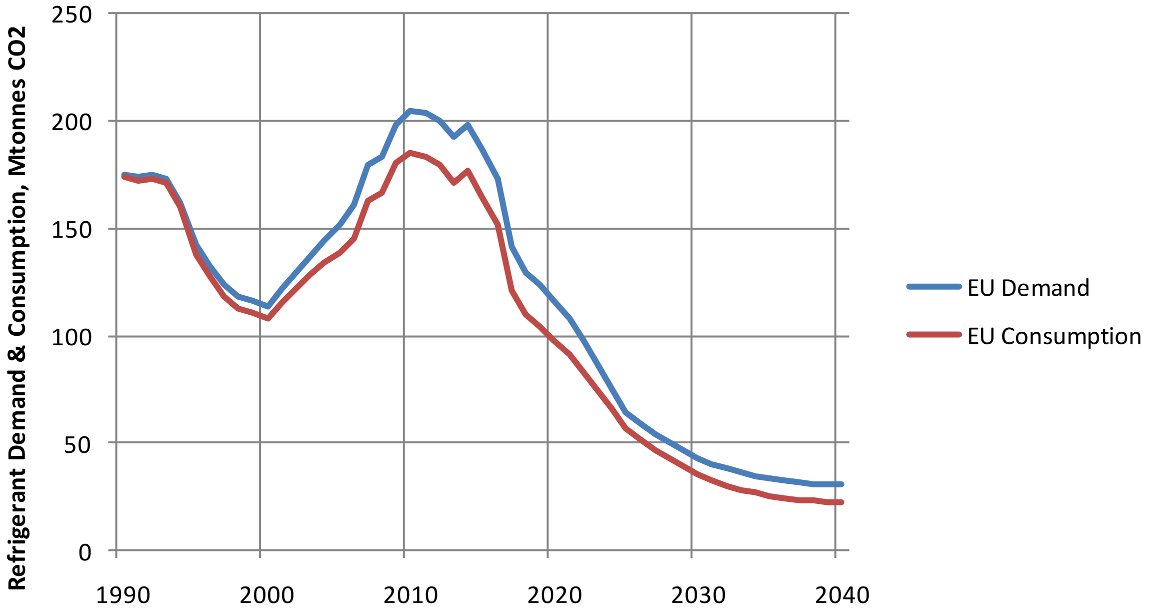
Consumption and Demand

21. There is a difference between EU consumption of refrigerant (Montreal Protocol definition that excludes imports / exports in pre-charged equipment) and EU demand (which includes such imports / exports). Most of the difference is related to the small air-conditioning market, for which there are significant levels of pre-charged imports. The difference between consumption and demand forecasts in the SKM Refrigerants Model is illustrated in Figure ES 5.

    Note: re-use of recovered refrigerant is not included in the definitions of consumption or demand, which only include use of virgin refrigerant.

    In this report, the word "consumption" always refers to the Montreal Protocol definition of consumption and the word "demand" always means consumption + imports in products – exports in products.

Figure ES 5: Demand and Consumption, Mtonnes CO2
All RAC Sectors, Scenario D, EU 27



The need for early phase down of HFC 404A

22. The analysis shows the relative importance of HFC 404A in terms of consumption and emissions. The SKM Refrigerants Model shows that HFC 404A accounts for around 50% of direct emissions in the period 2015 to 2020, under Scenario A.

23. Recent reports such as Oko Recherche 2011, Erie Armines 2011 and TEAP 2012 do not highlight the important opportunity related to an early phase down of HFC 404A – indeed TEAP 2012 refers to a single group of "medium / high GWP" refrigerants that include HFC 134a in the same group as HFC 404A, despite a factor of 3 difference in their GWPs. This over-simplifies the categorisation of refrigerants and gives policy makers poor guidance about the best options available for HFC phase down. None of the above reports makes proper reference early use of other medium GWP refrigerants for new equipment in the short term, or to the possibility of retrofilling existing systems with an alternative.

24. Avoiding the use of very high GWP refrigerants has the dual benefit of reducing direct emissions by between 50% and 70% (assuming equal leakage rates). HFC phase down policies should help end users understand the opportunity. Policy makers need to understand that the short term use of extra medium GWP HFCs will be beneficial to the environment. In the period 2013 to 2018 the use of HFC 404A can be substantially reduced via use of medium GWP alternatives. In that period very low GWP refrigerants such as CO_2 can also be used, but only on new systems.

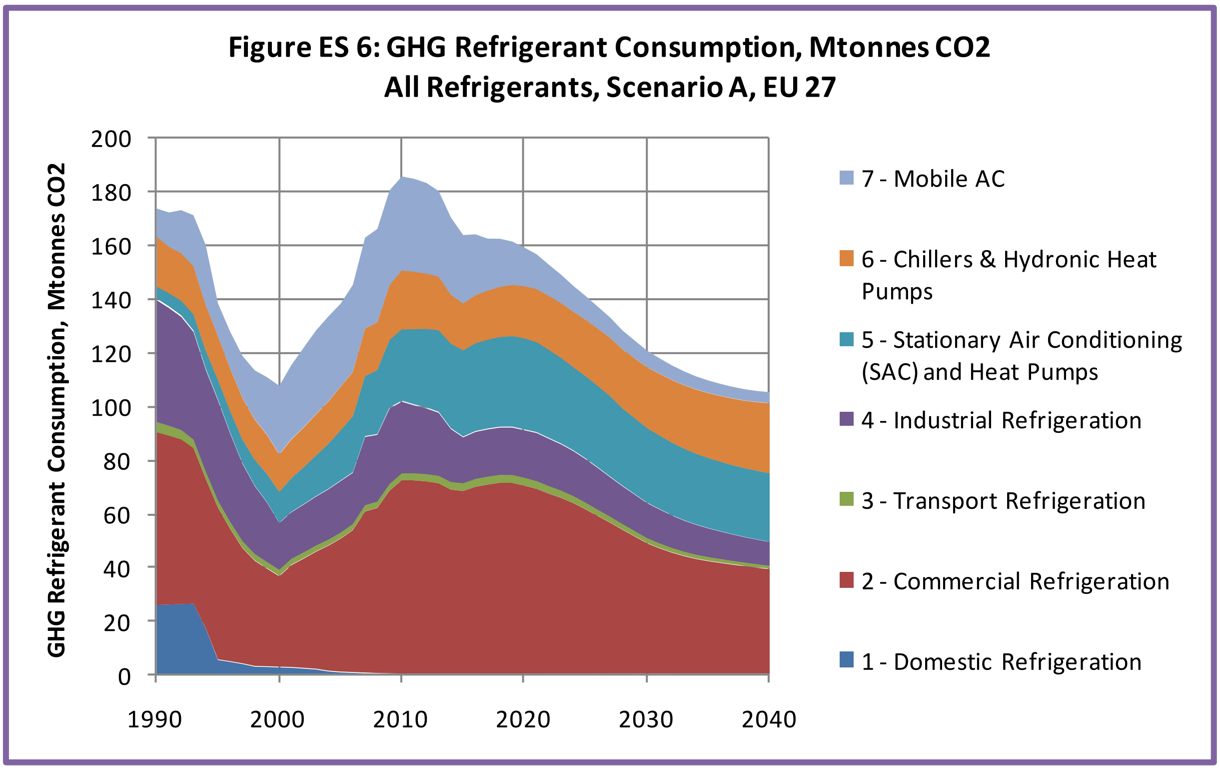
25. The analysis shows that an early phase down of HFC404A is essential to reach an overall phase down target of 30% by 2020

Use of Mildly Flammable Refrigerants

26. Use of mildly flammable refrigerants is likely to be an important strategy to achieve deep HFC consumption cuts. Refrigerants such as HFC 32, HFOs and HFO blends offer low or very low GWPs combined with good performance. However, "institutional" barriers related to Codes of Practice and national safety legislation are likely to restrict usage in the short term It is important for the RAC industry to improve understanding of the risks related to mildly flammable refrigerants and for relevant bodies to update standards and regulations to allow more widespread use.

Results for the 7 Main RAC Market Sectors

27. Figure ES 6 shows a split of refrigerant consumption, measured in terms of tonnes CO_2 equivalent, between the 7 main RAC market sectors. This figure shows that the commercial refrigeration market is the largest, representing 40% of total consumption in 2010 and 46% in 2020. In the paragraphs below the key results for each market sector are summarised.



28. The **Domestic Refrigeration Sector** represents only 0.2% of 2010 refrigerant GHG consumption. This figure is low because (a) this sector already makes widespread use of very low GWP refrigerants (HCs) and (b) leakage levels are very low, hence there is little consumption for maintenance. In 1990 the domestic sector represented around 15% of consumption, due to the use of CFC 12 which has a very high GWP. The domestic sector represents 10% of total 2010 RAC electricity consumption. This illustrates that the domestic sector is much larger than the 2010 refrigerant GHG consumption figures indicate. It is estimated that 90% of new equipment in this sector already uses HCs. The remainder uses HFC 134a. It is possible that R134a usage in new equipment could be replaced with either HCs or HFO 1234yf before 2020.

29. The **Commercial Refrigeration Sector** represents 40% of 2010 refrigerant GHG consumption. The largest part of this consumption (85%) is for large refrigeration systems in supermarkets, most of which utilise the high GWP refrigerant HFC 404A. The remaining consumption is split between small hermetic systems and single condensing unit systems. Historic rates of leakage are high in the commercial sector. A number of new technologies are being trialled in the supermarket sector and it is likely that CO_2 refrigeration systems will be widely used in the future. HFO blends and HCs are also likely to have an important role in the commercial sector. There is good potential for retrofill of existing HFC 404A systems with HFC 407A or 407F. These alternatives have around half the GWP of HFC 404A and can also provide an energy efficiency improvement.

30. The **Transport Refrigeration Sector** represents 2% of 2010 refrigerant GHG consumption. This sector includes refrigeration used on vans, lorries and containers. Current systems make significant use of the high GWP refrigerant HFC 404A. There has been little uptake of

alternative refrigerants in this sector. In the short term medium GWP refrigerants such as HFC 407A or 407F could be used instead of HFC 404A. By 2020 HFO blends might provide the most cost effective alternative. CO_2 might also be applicable in this sector.

31. The **Industrial Refrigeration Sector** represents 15% of 2010 refrigerant GHG consumption. This is a complex sector with a wide range of requirements in terms of system size and temperature level. A significant amount of HCFC 22 is still in use – this must be phased out by the end of 2014 under the Ozone Regulation. Ammonia is widely used in large systems. HFCs are mainly used in relatively small industrial systems, between 20 and 200 kW. Current HFC systems make significant use of the high GWP refrigerant HFC 404A. Various alternatives can be adopted. Ammonia is well suited to large systems and CO_2 could play a role especially if heat recovery is a useful secondary benefit. By 2020 HFO blends might provide an important alternative for smaller sized systems.

32. The **Stationary Air-Conditioning and Heat Pump Sector** represents 15% of 2010 refrigerant GHG consumption. This rapidly growing sector includes various types of air to air system including cooling only units, reversible units (providing air-conditioning in summer and heat pumping in winter) and heating only heat pumps. The current refrigerant of choice for many systems is HFC 410A which is a medium GWP refrigerant (GWP 2,088). This refrigerant provides high levels of energy efficiency and compact systems (due to small compressor size). In the short term there are no non-flammable alternatives that can cost effectively be used in this sector. If mildly flammable refrigerants are acceptable then HFC 32 is a currently available option (GWP 675). By 2020 a cost effective mildly flammable HFO blend may also be widely available. The high level of growth in this market will create increasing HFC consumption until lower GWP alternatives are introduced. Heat pumps in this sector will make an important contribution to energy related CO_2 emission reductions, especially as the electricity supply becomes decarbonised.

33. The **Chillers and Hydronic Heat Pump Sector** represents 9% of 2010 refrigerant GHG consumption. This sector includes various types of hydronic (water based) systems including water chillers, reversible chillers (for cooling and heating purposes) and heating only heat pumps. Leakage rates are low compared to many other market sectors as the majority of equipment is factory built. For small and medium sized systems there is good potential for using mildly flammable alternatives such as HFC 32 or HFO blends. For larger systems HFO 1234ze is already being trialled as an alternative to HFC 134a and ammonia or HCs can also be considered.

34. The **Mobile Air-Conditioning Sector** represents 20% of 2010 refrigerant GHG consumption. This sector includes car air-conditioning and air-conditioning in larger vehicles including buses and trains. The consumption and emissions from this sector will fall rapidly after 2020 as the impact of the MAC Directive begins to have maximum effect. Consumption in the car MAC sector will have fallen from 18 Mtonnes CO_2 in 2010 to just 0.04 Mtonnes CO_2 in 2030. Consumption for buses and trains will not fall as quickly because there are no cost effective alternatives yet available. By 2020 a suitable non-flammable HFO blend may become available.

Study Conclusions

35. Key conclusions from this study are as follows:

a) Making accurate forecasts over a 20 to 30 year period is very difficult, especially as some of the refrigerants that will be used are not yet commercially available or are only in the early stages of commercial development.

b) Leakage prevention is a key strategy within an HFC phase down. Leakage creates 60% of refrigerant demand under Scenario A. There is excellent scope to significantly reduce leakage via the current F-Gas Regulation. Extra measures in the revised Regulation to maximise leak reduction will help an overall HFC phase down be achieved.

c) Phasing down consumption of HFC 404A can deliver early and deep cuts. There are already alternatives available for this high GWP refrigerant in virtually all types of new equipment and many existing systems can be retrofilled using medium GWP refrigerants.

d) Energy efficiency is always of crucial importance. 80% of total RAC emissions in 2015 are from energy, with 20% from direct refrigerant losses. The proportion of energy related emissions will rise as an HFC phase down comes into effect. Efforts to improve efficiency must not be compromised by inappropriate constraints on refrigerant use,

e) Heat pump energy benefits are potentially much greater than the results of an HFC phase down. Net emission reductions from heat pumps (compared to gas fired boilers) in 2030 could be over 150 Mtonnes CO_2, compared to approximately 65 Mtonnes CO_2 reduction for HFC phase down. To maximise this benefit it is vital that a cost effective and energy efficient heat pump refrigerant is available.

f) The baselines in the North American (NA) and EU RED phase down proposals are unrealistic, being based on consumption in 2005 to 2008 and 2004 to 2006 respectively. They ignore the increases in consumption since 2008, which makes the early stages of a phase down impossible to achieve. Baselines set for the period 2010 to 2012 would provide a better start point for a phase down profile.

g) To get near the NA phase down proposal deep cuts in consumption are required. Avoiding HFC 404A as soon as possible (through use of medium GWP HFCs in the short term) and leak reduction initiatives are both important and low cost strategies. Use of CO_2, ammonia, HCs, HFOs and HFO blends in new equipment in relevant markets will provide the majority of the longer term HFC cuts.

h) The EU RED and RED 10 phase down profiles are too difficult to achieve in a cost effective way. The early cuts are too steep (due to unrealistic baselines that do not reflect market growth) and the final step too is too deep (10% of baseline compared to 15% for NA proposal).

i) Early availability and commercial development of HFO blends could have an important influence in certain market sectors, especially the fast growing air-conditioning and heat pump markets.

j) Efforts to remove barriers to the use of mildly flammable refrigerants (e.g. changes to national fire regulations or to safety codes of practice) will help enable a much faster take up of low GWP alternatives.

k) Average cost effectiveness of phase down measures in RAC sectors as whole are in the region of €15 to €25 per tonne saved. These figures are sensitive to input assumptions – abatement costs in range €4 to €43 per tonne saved are possible.

l) Average cost effectiveness of phase down measures in non-RAC sectors are better at around €10 per tonne saved for aerosols, foams and fire protection.

m) It is important to understand the distinction between EU consumption (use of bulk supplies in EU) and EU demand (which also takes into account HFCs in pre-charged imported products). A phase down process that only addresses consumption could allow unlimited imports of pre-charged equipment containing gases being phased down – this “loophole” in a phase down policy needs to be avoided.

1. Introduction

This document is the draft report for the study "*Phase down of HFC consumption in the EU – assessment of implications for the RAC sector*". The study was carried out on behalf of EPEE by SKM Enviros during March to July 2012. The study provides analysis of the consumption and emissions of HFCs in the EU refrigeration, air-conditioning and heat pumps markets (RAC) to provide a detailed assessment of the impact of HFC phase down policies.

1.1. Study Objectives and Report Structure

The objective of this study is to investigate the potential costs and the environmental benefits, in terms of reduced greenhouse gas (GHG) emissions, of alternative profiles for the phase down of HFC consumption in the EU. This objective is met by:

a) Detailed modelling of the future use of HFCs in RAC markets between now and 2040

b) Assessment of the cost impact of using alternative refrigerants in each market sub-sector

c) Analysis of a range of phase down scenarios, with varied timing and depth of cuts.

This report is structured as follows:

Section 1, Introduction – background to the project and study objectives.

Section 2, Use of Alternative Refrigerants in RAC Markets – discussion about the key issues that influence the use of low global warming potential (GWP) alternatives to high GWP HFCs.

Section 3, Basis of Modelling – a description of the modelling carried out to estimate HFC consumption and the cost impact of using alternative fluids / technologies.

Section 4, Market Sector Profiles and Refrigerant Options – a description of the summary profiles prepared for each market sub-sector and a review of the alternative refrigerants that are suitable for each sub-sector.

Section 5, Future HFC Consumption Scenarios for RAC – forecasts of the level of HFC consumption to 2040 under a range of possible scenarios for the introduction of alternatives.

Section 6, Interaction with non-RAC Market Sectors – analysis of HFC use and alternatives in non-RAC sectors, to complete the overall picture of future EU demand for HFCs.

Section 7, Phase Down Profiles – assessment of a range of phase down profiles, showing the practicality and cost impact of different rates of phase down.

Section 8, Conclusions and Recommendations

The report also includes Appendices that support the main sections with extra detail.

1.2. Background to F-Gas Use

F-Gases are the most powerful GHGs in the "basket" of gases covered by the Kyoto Protocol. Although they only represent around 2% of global GHG emissions it is important that emissions of this group of gases are minimised. F-Gases include HFCs, PFCs and SF_6 and they have global warming potentials (GWPs) that can be several thousand times higher than CO_2.

The majority of F-Gas emissions come from the HFC family of fluids which are used for a variety of applications including refrigeration, air-conditioning, heat pumps, aerosols, foam blowing and fire protection. Use of PFCs and SF_6 is more limited – key end use sectors include magnesium smelting, high voltage switchgear and semiconductor manufacture. Table 1.1 shows estimates of F-Gas emissions from EU 27 in 2010 and 2030. The figures are taken from Öko-Recherche 2011 and are based on the successful implementation of the EU F-Gas Regulation (842/2006) and MAC Directive (40/2006).

Table 1.1 EU 27 Emissions of F-Gases

Sector	2010		2030	
	million tonnes CO_2	% of 2010 total	million tonnes CO_2	% of 2010 total
RAC (refrigeration, air-conditioning, heat pumps)	89.0	79%	87.0	78%
Other HFC (foams, aerosols, fire protection)	12.4	11%	16.3	15%
PFCs, SF_6 and halocarbon production	11.9	10%	7.5	7%
Total F-Gas Emissions	**113.3**	**100%**	**110.8**	**100%**

Source: Öko-Recherche 2011

The table clearly shows that:

- RAC sectors are the dominant source of emissions (nearly 80% of total)
- Total HFC applications (RAC plus "other HFC") represent over 90% of F-Gas emissions
- There is little change in the total emissions forecast between 2010 and 2030 – this is because it is predicted that significant emission reductions in some markets (e.g. mobile air-conditioning) will be offset by market growth in most markets (growth of stationary air-conditioning and heat pump markets expected to be especially high).

These figures show that if EU emissions of F-Gases are to be substantially reduced it is essential that HFC applications are carefully addressed and, in particular, the emissions of high GWP HFCs in the RAC sector must be cut.

Many experts in the RAC industry believe there is good potential to reduce HFC emissions to levels well below those shown in Table 1.1. The projections for 2030 emissions in this table are based only on implementation of the current F-Gas Regulation and other "business-as-usual" activities. During the last 5 years there has been rapid development of a range of new refrigerant options which, if widely adopted, could lead to substantial cuts in 2030 emissions. A key issue is to understand the level of reductions that can be achieved in a cost effective way and the dates by which different types of measure can be introduced.

1.3. Policies to Reduce F-Gas Emissions

Policies to reduce F-Gas emissions are being discussed (a) at an international level via the Montreal Protocol and (b) within the EU via the current review of the EU F-Gas Regulation. Various different types of policy measures can be considered, including:

- Voluntary agreements with specific end user sectors
- Regulations to ban the use of F-Gases in specified applications from appropriate dates
- Fiscal measures, in particular a GWP weighted tax on the sale of F-Gases
- Quantitative limits for the placing on the market of F-Gases based on a programme of defined consumption cuts. Many stakeholders believe that the use of F-Gases cannot be cut to zero, but an international phase down towards a residual consumption of 10% to 15% of current consumption may be possible by a suitable date between 2030 and 2040.

It is likely that a range of different policies will be used to address the highly varied end use markets for F-Gases – this will maximise the cost effectiveness of achieving emission reductions.

At the international level, the main option being considered is an HFC phase down, using similar principles to those used to reduce CFC and HCFC consumption under the Montreal Protocol. Proposals for HFC phase down have been made by North America (a joint proposal by USA, Canada and Mexico) and the Federated States of Micronesia. Little progress was made at the 2011 Meeting of the Parties, but further efforts to reach an international agreement will be made in 2012.

The European Commission is considering a wide range of policy options as part of the review of the F-Gas Regulation. Öko-Recherche 2011 presents results of a detailed study of policy options. One of the most cost effective policies presented is an HFC phase down. However, the cost effectiveness of the phase down proposals presented in Öko-Recherche 2011 is based on numerous assumptions about costs and energy efficiency that might exaggerate the cost benefits of this approach. A key aim of this study is to provide a more robust assessment of the costs and benefits of HFC phase down in the RAC markets in order to inform EU policy makers about the best approach.

1.4. Understanding HFC Emissions, Demand and Consumption

It is very important to understand the significant differences between direct emissions, indirect emissions, demand and consumption of HFCs. These can vary significantly in magnitude and across market sectors.

a) **Annual Direct GHG Emissions** represent the annual quantity of HFCs that enter the atmosphere. The physical tonnes of HFC emissions are multiplied by the GWP to calculate a GHG emission in tonnes CO_2 equivalent.

   For RAC systems, key sources of emissions are (a) losses during product manufacture and installation, (b) leakage during product life and (c) losses during end-of-life decommissioning. Annual emissions are calculated using emissions factors for each source (e.g. an annual leakage loss of 10% of the refrigerant charge) together with data for the installed bank of refrigerant, the new equipment being added to the bank and the old equipment being retired. These calculations must be carried out separately for relevant sub-sectors of the RAC market because the emission factors vary between sectors.

In most RAC market sub-sectors the annual leakage losses are topped up during maintenance to ensure that the equipment operates in a satisfactory and efficient way. This is not true of all HFC applications: e.g. insulating foam slowly loses HFC blowing agent through the product use phase, but this cannot be "topped up".

Some HFC applications are emissive in nature and all the HFC is lost during product use. In particular this applies to aerosols, where 100% of the HFC propellant is emitted to atmosphere when an aerosol can is fully used.

b) **Annual Indirect Emissions** represent energy related CO_2 emissions emitted from power stations that generate the electricity being used to operate the RAC equipment. In almost all situations, the energy related indirect emissions for RAC systems are significantly greater than the leakage related direct HFC emissions in terms of tonnes CO_2 emitted. Not all HFC applications create indirect emissions – for example, aerosols.

c) **Annual EU Demand** represents the total amount of HFCs used in the EU in a market sector. This is the sum of virgin HFCs:

- used to fill new pre-charged RAC equipment in EU factories
- imported into the EU in pre-charged equipment
- used to fill new RAC equipment on site during installation
- used for regular maintenance to top-up any leakage
- MINUS any HFCs contained in pre-charged equipment exported from the EU

The annual EU demand represents all the HFCs used to fill new systems and to maintain existing systems that are used in the EU.

d) **Annual EU Consumption** is related to definitions in the Montreal Protocol. Consumption is defined in the Montreal Protocol only in terms of bulk supplies of virgin HFCs – it is the sum of production plus imports minus exports. Montreal Protocol consumption does not include HFCs in products that are imported into or exported from the EU. Hence Annual EU consumption is the sum of HFCs:

- used to fill new pre-charged RAC equipment in EU factories
- used to fill new RAC equipment on site during installation
- used for regular maintenance to top-up any leakage

EU consumption ignores any HFCs imported in pre-charged equipment – in some RAC market sectors that makes a considerable difference e.g. small split system air-conditioning. EU consumption includes HFCs used for equipment that is subsequently exported from the EU.

Phase down assessments have been made in terms of both EU Demand and EU Consumption so that the different definitions can be fully understood in relation to proposed phase down schedules.

Please note: in this report, the word "consumption" always refers to the Montreal Protocol definition of consumption and the word "demand" always means consumption plus imports in products less exports in products.

2. Use of Alternative Refrigerants in RAC Markets

2.1. Selection of a Suitable Refrigerant

The RAC sector uses many different types of refrigerant that are chosen to suit the wide range of requirements for RAC applications. Key variables include:

Size – RAC applications vary in size by nearly 5 orders of magnitude from under 1 kW (e.g. domestic refrigerators) to over 10,000 kW (for very large air-conditioning, heat pump or industrial systems). Size has a big influence on refrigerant choice e.g. very small systems can safely use flammable refrigerants whereas larger systems cannot do so without extra cost or are restricted through national safety regulations or Codes of Practice.

Temperature level – RAC applications operate from ultra-low temperatures (towards absolute zero) up to around 100^oC (for delivery of heat from a heat pump). The most common applications of **refrigeration** are carried out in 2 temperature zones: LT (low temperature) for frozen products, usually in the -20^oC to -30^oC range and MT (medium temperature) for chilled products, usually in the $+1^oC$ to $+6^oC$ range[1]. For **comfort applications**, the desired room temperatures in buildings usually vary between 20°C and 27°C and can be reached by a cooling (**air conditioning**) or heating (**heat pump**) function. The temperature level has a big impact on the choice of refrigerant as it has a direct impact on operating pressures inside the refrigeration circuit.

Equipment location – some applications are used in areas with public access (e.g. supermarkets, office buildings, domestic dwellings) whilst others are confined to areas of restricted access (e.g. industrial facilities or special machine rooms adjacent to an office building). The choice of refrigerants is strongly influenced by location.

In a specific application the refrigerant is carefully selected to ensure:

Good energy efficiency – this is crucial in relation to both global warming impact ("indirect" CO_2 emissions from generating the electricity used) and running cost.

Safe operation – systems with flammable or toxic refrigerants are not permitted in all applications and when used must be fitted with extra safety features, which add to investment costs.

Compatibility with key components – e.g. operates at a reasonable pressure; requires a compressor of reasonable size; does not react chemically with materials used in the system (e.g. metals, flexible seals, lubricant).

Low direct environmental impact – in particular zero Ozone Depletion Potential (ODP) and lowest practical Global Warming Potential (GWP).

Compliance with relevant regulations – a range of legislation applies and this can vary at national level across the EU. It is important to note that the legislation regarding the use of highly flammable or toxic refrigerants (e.g. HCs and ammonia) might allow a certain application in one Member State but ban the same system in another.

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[1] Note: these are product temperatures – refrigerant evaporating temperatures will be at lower values.

2.2. Market Sectors and Sub-Sectors

A crucial aspect of the analysis carried out in this study has been to select an appropriate set of market sectors and sub-sectors. This is important because the cost impact of an alternative refrigerant will be affected by the characteristics of the market in terms of the factors described in Section 2.1. If a market covers a range of such factors it is important to sub-divide the market into sub-sectors so that the correct alternative refrigerants can be considered for each sub-sector.

A good example of poor sub-sector selection is in Öko-Recherche 2011 where industrial refrigeration has been split into two subsectors: small and large. The “small” system was characterised as having a refrigerant charge of 630 kg and a “large” system has 4,000 kg. The Öko-Recherche analysis concludes that ammonia is a suitable low GWP refrigerant for all industrial systems. The flaw in this analysis is that there are large numbers of industrial systems with between 25 and 75 kg of refrigerant. This is around 10 times smaller than Öko-Recherche’s “small” sub-sector and equipment price information shows that ammonia is not a cost effective alternative for such small systems.

It is important to distinguish between low temperature (LT) and medium temperature (MT) applications of refrigeration as this has a strong influence on both refrigerant selection and system energy efficiency. This distinction is not required for air-conditioning applications as the temperature level is similar for most types of air-conditioning. However, the stationary air-conditioning market is complicated because of the wide range of equipment configurations e.g. cooling only systems and “reversible” heating and cooling systems that can operate as an air-conditioning system in warm weather and as a heat pump in cold weather. In warm climates reversible systems of this type are very common. In cooler climates there is also a growing market for “heating only” heat pumps.

The sectors and sub-sectors used for analysis in this study are summarised in Table 2.1. There are seven main market sectors, four for refrigeration and three for comfort cooling and heating (air-conditioning and heat pumps). These seven sectors have been used in many recent studies including Erie-Armines 2011 and Öko-Recherche 2011. A total of 43 sub-sectors are used in this study. This is more than the number used in these recent studies –providing extra granularity in a number of key markets that gives more confidence in the conclusions drawn.

Öko-Recherche 2011 used only 18 sub-sectors. They did not distinguish between LT and MT refrigeration and they only used 2 sub-sectors for industrial refrigeration.

Erie-Armines 2011 used 34 sub-sectors. A split similar to this study was used in some markets. A key difference is the industrial sector where Erie-Armines uses 8 sub-sectors based on the type of product (e.g. meat, dairy, frozen food, soft drinks). These sectors do not distinguish between the size or temperature level of equipment. As shown in Table 2.1 this study uses 10 industrial sub-sectors based on size, type of system and temperature level.

Table 2.1: RAC Market Sectors and Sub-Sectors

	Sector	Sub-Sector and Product Temperature Level[2]		Example charge (kg)	Example duty [3](kW)	Reference number
Refrigeration	1. Domestic refrigeration	Refrigerators	MT	0.13	0.20	1.1
		Freezers	LT	0.13	0.20	1.2
	2. Commercial refrigeration (food retail, food service (hotels, restaurants, pubs etc.)	Small hermetic units	MT	0.3	1	2.1
			LT	0.3	1	2.2
		Single condensing units	MT	4	5	2.3
			LT	3	2	2.4
		Multipack centralised systems	MT	200	100	2.5
			LT	100	50	2.6
	3. Transport refrigeration	Vans and light trucks	LT + MT	2	3	3.1
		Large Trucks and Iso-Containers	LT + MT	7	9	3.2
	4. Industrial refrigeration	Small direct expansion (DX)	LT	30	20	4.1
			MT	45	30	4.2
		Medium DX	LT	120	80	4.3
			MT	150	100	4.4
		Large DX	LT	450	300	4.5
			MT	600	400	4.6
		Medium industrial chillers	MT	150	200	4.7
		Large industrial chillers	MT	600	1000	4.8
		Large pumped / flooded	LT	3500	1000	4.9
			MT	3500	1000	4.10
Comfort Cooling and Heating	5. Stationary air-conditioning and heat pumps	Small portable units, cooling only (air-to-air)		0.5	2.2	5.1
		Small split systems, cooling only (air-to-air)		0.8	3.5	5.2
		Small split systems, heating & cooling (air-to-air)		1.2	3.5	5.3
		Medium split systems, cooling only (air-to-air)		2.0	7	5.4
		Medium split systems, heating & cooling (air-to-air)		2.5	7	5.5
		Large split systems, cooling only (air-to-air)		5.6	14	5.6
		Large split systems, heating & cooling (air-to-air)		5.6	14	5.7
		Packaged systems, cooling only (air-to-air)		20	80	5.8
		Packaged systems, heating & cooling (air-to-air)		20	80	5.9
		VRF systems, cooling only (air-to-air)		25	50	5.10
		VRF systems, heating & cooling (air-to-air)		25	50	5.11
	6. Chillers & hydronic heat pumps	Small - cooling only (scroll/screw, air-cooled)		30	100	6.1
		Medium - cooling only (scroll/screw, air-cooled)		150	500	6.2
		Large - cooling only (screw, air-cooled)		360	1,200	6.3
		Small - cooling only (scroll/screw, water-cooled)		30	100	6.4
		Medium - cooling only (scroll/screw, water-cooled)		150	500	6.5
		Large - cooling only (centrifugal, water-cooled)		750	2,500	6.6
		Domestic - heat only, air-source, hydronic		3	10	6.7
		Small - heat only, air-source, hydronic		30	100	6.8
		Small - reversible heating/cooling, air-source, hydronic		30	100	6.9
		Medium - reversible heating/cooling, air-source, hydronic		150	500	6.10
	7. Mobile air-conditioning	Cars, vans, cabs		0.6	4	7.1
		Buses, trains		15	25	7.2

[2] MT = medium product temperature (+1°C to +6°C)   LT = low product temperature (-20°C to -40°C)

[3] Example duties here are for cooling. The model also takes into account heating duty

2.3. Current Refrigerant Usage

Selecting a suitable refrigerant, based on the needs described in Section 2.1, is complex and has led to a range of refrigerants used in different parts of the RAC market. The most commonly used refrigerants are HFCs or HCFCs, used in commercial refrigeration, most types of air-conditioning, heat pumps, smaller industrial systems and transport. Ammonia is widely used in large industrial and cold storage systems. Hydrocarbons (HCs) are dominant in domestic systems. Five refrigerants dominate the current consumption in terms of global warming impact, as illustrated in Table 2.2. The top 5 refrigerants in Table 2.2 represent 95% of the 2010 GHG consumption.

Table 2.2: Consumption of Refrigerant for RAC Applications in 2010, EU 27

Refrigerant	Physical consumption (tonnes)	% of 2010 physical consumption	GWP[4]	GHG consumption MT CO_2	% of 2010 GHG consumption
HFC 404A[5]	20,600	24%	3,922	81	44%
HFC 134a	30,100	35%	1,430	43	23%
HFC 410A	9,700	11%	2,088	20	11%
HCFC 22[6]	9,000	10%	1,810	16	9%
HFC 407C	7,500	9%	1,774	13	7%
Ammonia	3,400	4%	0	0	0%
HCs	1,000	1%	4	0.004	0%
Other	4,600	5%		12	6%
Total	85,900	100%		186	100%

Source: SKM Refrigerants Model

HFC 404A has the largest share of the GHG consumption (44% of the 2010 consumption). It has a GWP that is nearly twice as high as the other commonly used HFCs and HCFCs.

HCFC 22 is being phased out via the EU Ozone Regulation but is still a significant part of the 2010 bank especially for industrial and air-conditioning systems. Some HCFCs will be replaced by new equipment (an opportunity to introduce lower GWP alternatives) but much will be replaced with “drop-in” HFC alternatives with GWPs in the range 2,000 to 3,200. Ammonia and HCs have significant physical banks but zero or very small GHG banks because of their very low GWP.

The 2010 consumption of HFCs predicted by the SKM Refrigerants Model is within 1% of the 2010 HFC consumption for RAC applications in the “top down” data for F-Gas consumption published by the European Commission (EC 2011).

It must be noted that the EU-27 consists of various climate zones which will influence the choice of refrigerant and future consumption levels in different parts of the EU.

[4] GWPs from IPCC 4th Assessment Report, 100 year values

[5] HFC 507 has been included in figures for HFC 404A. These refrigerants are used for similar applications and have a similar GWP. In the EU, HFC 404A represents over 95% of the total bank of these 2 refrigerants.

[6] The SKM Refrigerants Model predicts an on-going requirement for R22 to 2014. This will be satisfied via use of reclaimed or recycled refrigerant as virgin HCFC sales were banned from January 2010.

2.4. Reducing the Consumption and Emissions of HFCs

There are four main strategies that can be considered to reduce the GWP weighted consumption and emissions of HFCs. These are use of:

Strategy 1) Low charge and low leakage technologies and improved maintenance to reduce the leakage of gas from existing and new RAC systems.

Strategy 2) Very low GWP alternatives (GWPs less than 100).

Strategy 3) Low / moderate GWP alternatives (GWPs between 100 and 1,000).

Strategy 4) Medium GWP alternatives (GWPs between 1,000 and 2,000) to replace very high GWP refrigerants (e.g. to replace HFC 404A which has a GWP of 3,922).

Strategy 1 (leak reduction) has important benefits and should always be combined with each of the other strategies. Apart from the obvious impact of reducing the annual leakage emissions of refrigerants with a medium or high GWP, leak reduction has 2 other important benefits:

a) It helps maintain high energy efficiency – this reduces the “indirect” energy related emissions from RAC equipment.

b) For flammable or toxic refrigerants it reduces the safety related risks.

Strategy 2 will often deliver the maximum long term emission reductions, but will not be applicable to all RAC markets with currently available technology. Strategy 2 is only environmentally effective if low direct emissions can be combined with low energy consumption.

The lowest cost way of achieving emission reductions might include a combination of all four strategies, with different measures applied to different market sub-sectors. In some markets it may be best to start with one strategy and switch to another over the next decade. For example:

- In the domestic refrigerator sector a single stage approach can be applied in the near future using Strategy 2 i.e. encouraging the use of very low GWP refrigerants from, say, 2015.
- In the small industrial sector (e.g. systems with 50 kg of refrigerant) a very low GWP alternative is not be available or cost effective now. A 2-stage approach may deliver the most rapid and cost effective emission reductions: Stage 1 (now), using Strategy 4 e.g. using HFC 407A or 407F instead of HFC 404A. Stage 2 (by approximately 2020), using Strategy 3 e.g. using a non-flammable HFO/HFC blend with a GWP of around 700.

It is important that all relevant strategies are considered for each sub-sector to encourage early emission reductions and to minimise the cost impact of phase down. The analysis in Öko-Recherche 2011 fails to do this – it concentrates only on use of Strategies 2 and 3, which leaves some markets with high emissions for many years. Incorporating Strategies 1 and 4 into the policy mix should deliver the best result in terms of cost and environmental benefits.

Taking the above issues into account there are currently 14 alternative refrigerants with a lower GWP than the ones currently used. These alternatives are summarised in Table 2.3. It should be noted that there are rapid developments in the refrigerants field and new alternatives can be expected over the next few years. Two rows in Table 2.3 (“Blend 300” and “Blend 700”) represent a range of possible refrigerant blends that are expected to be introduced by 2015. Other blends with GWPs in the range 1,000 to 1,500 may also be introduced in this timescale.

Table 2.3: Options for Lower GWP Alternative Refrigerants

	No.	Refrigerant	GWP	Current key constraints to usage	Example markets (current)
Very Low GWP	1	Ammonia	0	Highly toxic; mildly flammable; incompatible with copper components. National regulations in some countries require manned engine rooms.	Large and medium sized industrial refrigeration, large and medium sized air-conditioning chillers
	2	CO_2	1	High operating pressure; lower efficiency in high ambient temperatures; lack of available components; technical design complexity	Large and medium sized commercial and industrial refrigeration
	3	HCs	3 to 5	Highly flammable and potentially explosive. National regulations in some countries limit charge to a very low level	Domestic refrigerators, small commercial hermetic systems, chillers and large industrial systems
	4	HFO 1234yf	4	Mildly flammable; not commercially available until 2015; lack of available components; not technically well proven	MACs
	5	HFO 1234ze	6	Mildly flammable; lack of available components; not technically well proven; large compressor size	Water chillers
	6	HFO DR2 / N12	7	Not commercially developed yet	Not in current use. Will be used in large low pressure chillers and high temperature heat pumps
Low / Moderate GWP	7	Blend 300	200 to 500	Mildly flammable. Not commercially developed yet	Not in current use. These refrigerants represent a range of blends that can be considered in many RAC market sub-sectors.
	8	Blend 700	500 to 1,000	Not commercially developed yet	
	9	HFC 32	675	Mildly flammable	Being introduced for small air-conditioning systems
	10	HFC 245fa	1,030	Large compressor swept volume	High temperature heat pumps
Medium GWP	11	HFC 134a	1,422	Medium GWP	HFC 404A alternative (MT)
	12	HFC 407F	1,825	Medium GWP	HFC 404A alternative
	13	HFC 410A	2,088	Medium GWP	HFC 404A alternative and Small air-conditioning
	14	HFC 407A	2,107	Medium GWP	HFC 404A alternative

Group 1 Refrigerants: Options 1 to 6 in Table 2.3 all have very low GWPs ("Strategy 2"). The direct global warming emissions from RAC systems using these six refrigerants are zero or negligible. Unfortunately each of these refrigerants has constraints including:

- Safety issues – flammability and toxicity
- Commercial issues – lack of refrigerant availability; lack of components; large compressor size (in some applications, compared to current refrigerants – e.g. versus HFC 410A in small air-conditioning); lack of design and maintenance experience.

Group 2 Refrigerants: Options 7 to 10 have low or moderate GWPs between 100 and 1,000 ("Strategy 3"). They include HFC 32, an HFC with a lower GWP (not used as a pure fluid in the past due to mild flammability) and possible future blends of HFOs and HFCs that have been announced by refrigerant manufacturers. "Blend 300" represents a family of possible blends with GWPs between around 200 and 500 – it is likely that such blends will be mildly flammable. "Blend 700" represents a family of possible blends with GWPs between around 500 and 1,000 – it is likely that such blends will not be flammable. These blends will be developed to meet the needs discussed in Section 2.1. Each blend will be "optimised" for a range of specific applications which should maximise efficiency and overcome issues such as increased compressor size. However, it is likely to be some years before these blends are proven in the market.

Group 3 Refrigerants: Options 11 to 14 have medium GWPs between 1,000 and just over 2,000 ("Strategy 4"). They represent an important short term opportunity to reduce the use and emissions of HFCs 404A and 507, both of which have very high GWPs (3,922 and 3,985 respectively). HFC 404A is currently in widespread use for both low and medium temperature refrigeration systems in the commercial and industrial sectors. Certain medium GWP refrigerants can be used in place of HFC 404A for most new systems – providing a short term solution in markets without a cost effective low GWP option. In some markets, especially for MT refrigeration systems, they can be retrofilled into existing HFC 404A systems – this has the benefit of (a) quickly reducing the GHG bank of refrigerants in these sectors and (b) reducing energy consumption because HFC 404A is not a very efficient refrigerant in MT applications.

In Section 4 of this report the potential future refrigerant strategies for each RAC market sub-sector are considered, using the 14 alternatives discussed above.

2.5. The Impact of Refrigerant Selection on Energy Efficiency

A crucial issue regarding the use of alternative refrigerants is energy efficiency. The energy related GHG emissions from RAC systems are much higher than the direct emissions associated with refrigerant leakage. Table 2.4 provides outputs from the SKM Refrigerants Model that gives an estimate of the direct and indirect GHG emissions from each of the seven main RAC market sectors.

Table 2.4 shows that across the whole RAC market the CO_2 emissions from energy used in 2010 represents 70% of total GHG emissions. This clearly illustrates the importance of achieving high energy efficiency. Any alternative needs to (a) have equal or better efficiency than current best practice and (b) have potential to support further efficiency improvements that are being driven by other EU programmes such as Eco Design.

Table 2.4: Direct and Indirect Emissions from RAC sectors, EU 27, 2010

Sector	Direct Emissions (from leakage)	Indirect Emissions (from energy consumed)	% Indirect emissions 2010
	kTonnes CO_2 (2010)		
Domestic refrigeration	11,000	44,000	80%
Commercial refrigeration	50,000	70,000	58%
Transport refrigeration	2,000	5,000	67%
Industrial refrigeration	18,000	34,000	66%
Stationary AC and heat pumps	26,000	105,000	80%
Air-conditioning chillers	11,000	26,000	71%
Mobile air-conditioning	27,000	51,000	66%
Total for all RAC Sectors	**144,000**	**335,000**	**70%**

Source: SKM Refrigerants Model

It is worth noting that the % indirect emissions will vary over time as alternative refrigerants are introduced. This is well illustrated by the figures for the domestic sector. In 2010 there are still considerable CFC 12 emissions from refrigerators reaching end of life. This creates a high direct emissions value of 11,000 kTonnes CO_2. The model shows direct emissions from domestic refrigeration falling to 2,000 kTonnes CO_2 by 2015 and to under 1,000 kTonnes CO_2 by 2020. This is due to the introduction first of HFC 134a (from 1994) and then HC 600a (from 2000). These changes have a massive influence on the % indirect emissions for the domestic refrigeration sector. These rise from 80% in 2010 to 95% in 2015 and 98% in 2020.

How Important is Refrigerant Selection in Relation to Energy Efficiency?

The efficiency of an RAC system used in a specific application depends on many variables. The difference between a well designed and operated system and a poor system can be massive – efficiency variation of 25% is common and a variation of well over 50% is sometimes encountered.

One of the relevant variables is the choice of refrigerant. For a given level of capital investment some refrigerants produce higher levels of efficiency than others e.g. because of more favourable thermodynamic properties or because of better heat transfer characteristics. Efficiency variations of this type are important as they have an impact on total GHG emissions and also on the annual running cost of a new refrigeration plant. The modelling carried out in this study takes efficiency variations into account, although it must be noted that this is not a simple process. A number of “refrigerant independent” design decisions can have a massive impact on efficiency, e.g.:

- adding doors to chiller cabinets in supermarkets may improve efficiency by 25%
- using “free cooling” in a data centre air-conditioning system can improve efficiency by well over 50%
- in contrast, the refrigerant selection is generally a “second order effect”, with efficiency variations in the range of 0% - 10% to be expected.

The cost benefit analysis in Öko-Recherche 2011 makes significant claims for the higher energy efficiency of certain refrigerant alternatives as summarised in Table 2.5. These efficiencies are used as input assumptions in the cost benefit analysis, resulting in a relatively low cost (in terms of € per tonne CO_2 saved) for the use of very low GWP alternatives in many RAC markets. A key question is whether these claims are reasonable?

There is strong evidence that the efficiency gains assumed in Öko-Recherche 2011 are too large. For example, ammonia is shown to have a 15% to 20% efficiency advantage over HFCs. A well designed HFC system can equal the efficiency of an ammonia system in many circumstances, hence the Öko-Recherche efficiency assumptions for some alternatives are considered to be too high.

It is important to recognise that differences in climate zones in the EU are an important factor for the selection of energy efficient fluids. For example transcritical CO_2 can be more efficient than conventional HFC cycles in Northern Europe but is less efficient in the warmer ambient temperatures found in Southern Europe.

Table 2.5: RAC Efficiency Assumptions in Öko-Recherche 2011

Sector	Alternative	Improved efficiency compared to HFC
Industrial (small and large)	Ammonia	15%
Commercial packs	CO_2 + HC cascade	7.5%
Small chiller (100 kW)	HCs	10%
Small chiller (100 kW)	Ammonia	20%
Large chiller (1000 kW)	HCs	10%
Large chiller (1000 kW)	Ammonia	15%

3. Basis of Modelling

3.1. Introduction to Modelling of RAC Sectors

This section of the report summarises details of the modelling carried out for this study. A sophisticated model has been built to assess the characteristics of each of the 43 RAC market sub-sectors. The key outputs from the SKM Refrigerants Model are given as a time series from 1990 to 2040. The outputs include annual estimates split by refrigerant type of:

a) Refrigerant bank

b) Refrigerant demand and consumption for new installations (following the definitions given in Section 1.4 above)

c) Refrigerant demand and consumption for top up of leaks

d) Refrigerant emissions during life and at end-of-life (EOL)

e) Refrigerant available at end of life for re-use

f) Energy consumption

g) Cost information for new equipment installation and running costs.

Refrigerant data is split by type and is given in both physical tonnes and as GWP weighted GHG emissions (in tonnes CO_2 equivalent). The outputs can be aggregated at 3 different levels:

- individually for the 43 sub-sectors (as listed in Table 2.1)
- in groups for the 7 main markets
- for the whole RAC market.

The model uses a "standard size" for equipment in each of the 43 market sub-sectors. For example, all commercial refrigeration condensing units (MT) are assumed to have a cooling duty of 6 kW. This is a significant simplification – in reality there are single condensing units with a range of cooling capacities from around 2 kW to 30 kW. However, without this simplification it would be necessary to use hundreds of sub-sectors, which is clearly impractical. As discussed in Section 2.2 the sub-sectors were chosen with great care to minimise the impact of this simplification. A similar approach is adopted in other recent studies including Öko-Recherche 2011 and Erie-Armines 2011.

3.2. Scenario Analysis

The model has been developed to allow scenario analysis of possible future refrigerant usage patterns in each market sub-sector. The split of refrigerants used for new equipment can be changed for each year of the model to calculate the impact of different phase down strategies in terms of emission reduction, consumption reduction and cost. All other input parameters can also be varied on an annual basis, providing a very comprehensive modelling capability.

In most market sub-sectors it is the choice of refrigerants for new equipment that will be the main influence on the future HFC consumption and emissions. However, in some situations there could be retrofill of an alternative refrigerant into an existing system e.g. HFC blends to replace

HCFC 22 or HFC 407A / 407F to replace HFC 404A. The model allows such retrofills to be evaluated, recognising that the life of retrofilled plants will be shorter than brand new equipment.

Table 3.1 gives an illustration of the way different scenarios can be modelled, using different refrigerant strategies and different dates when each measure is introduced.

Table 3.1: Illustration of Scenario Analysis – Refrigerants Used for New Equipment

Year	**Base Case** Continued use of 404A in new equipment	**1) Early HFO B700** Early switch from 404A to B700, starting in 2016 (earlier start not possible – B700 unlikely to be available till 2017)	**2) Late HFO B700** Slower start to the use of B700, with first introduction in 2019 and a slower 4 year transition away from 404A	**3) Dual Strategy** No 404A from 2014 using an "intermediate technology" (407A or 407F) followed by a switch to B700 when available (e.g. 2018)
2014	100% 404A	100% 404A	100% 404A	100% 407 A or 407F
2015	100% 404A	100% 404A	100% 404A	100% 407 A or 407F
2016	100% 404A	20% B700 80% R404A	100% 404A	100% 407 A or 407F
2017	100% 404A	40% B700 60% R404A	100% 404A	100% 407 A or 407F
2018	100% 404A	60% B700 40% R404A	20% B700 80% R404A	20% B700 80% R407A/F
2019	100% 404A	100% B700	40% B700 60% R404A	40% B700 60% R407A/F
2020	100% 404A	100% B700	60% B700 40% R404A	60% B700 40% R407A/F
2021	100% 404A	100% B700	80% B700 20% R404A	100% B700
2022	100% 404A	100% B700	100% B700	100% B700

The amount of new equipment entering a sub-sector market each year is calculated using data about the historic bank, the typical life of equipment and the projected growth of the sector. In the example illustrated in Table 3.1, the "Base Case" assumes the use of HFC 404A in all new equipment between 2014 and 2022. The 3 alternative scenarios lead to the use of "Blend 700" in all new equipment by 2021. Scenarios 1 and 2 represent different timings for the introduction of Blend 700. Scenario 3 uses a "dual strategy" with HFC 407A or 407F being used in place of HFC 404A in the early years, followed by the introduction of Blend 700. A further strategy that can be evaluated in appropriate circumstances is the retrofill of HFC 404A in existing systems.

3.3. Input Parameters

The modelling makes use of numerous important input parameters. The input data used is summarised for each sub-sector in Appendix C. The most important input parameters are:

a) **Market growth**: the model between 1990 and 2010 reflects the historic and current state of the RAC market. Going forward to 2040, assumptions have been made about growth in demand at a sub-sector level. In all cases there is some growth, but in certain markets, especially stationary air-conditioning and heat pumps, the growth is particularly high. The growth data is based on the views of numerous industry experts.

b) **Refrigerant choices**: as described in Section 3.2 the choice of refrigerants used in new equipment in each market sub-sector is a critical input parameter. The model allows for a different mix of refrigerants used in new equipment to be selected on an annual basis. The model also allows existing equipment to be retrofilled with an alternative.

c) **Refrigerant emission factors**: the model uses emissions factors to reflect leakage of refrigerant during the main stages of the equipment lifecycle: (a) manufacturing, (b) installation, (c) product use and (d) end-of-life decommissioning. For existing systems, these factors can be changed over time either to reflect reduced leakage through the impact of the F-Gas Regulation or to reflect worsening leakage for old equipment. The leakage rates from new systems can be reduced over time to reflect improved design and installation standards. The end-of-life factors enable an estimate to be made of annual quantities of each refrigerant available for re-use.

d) **Energy consumption**: to estimate the annual energy consumption we use data about system efficiency (cooling and heating COP) together with data that represents the typical load factor and operating hours of equipment in a particular sub-sector. A particularly important issue is how the energy efficiency will change with alternative refrigerant options. This was discussed in Section 2.4. The data sheets in Appendix C show the assumed changes in energy efficiency for alternatives in each market sub-sector. Energy use can be converted into CO_2 emissions using an electricity carbon factor that can be changed on an annual basis. An average value for the whole of Europe is used in the model (0.412 kg CO_2 per kWh in 2010, EcoDesign).

e) **Cost data**: to understand the cost effectiveness of alternative strategies we use data that represents changes in capital cost and running cost for alternatives compared to the base case. As with energy efficiency data, cost information is not easy to forecast. New technologies are expensive in the early years but if they take a large market share capital costs can reduce significantly. The capital cost data is based on the views of industry experts. Running costs, including electricity, maintenance and gas top-up, represent over 75% of the total owning cost of an RAC system. Around 85% of the running costs are for electricity consumption (this varies by market sector) – emphasising the importance of making reasonable assumptions about the difference in energy efficiency between alternative options. We have used average electricity prices and carbon emission factors across the EU – these parameters can be varied annually e.g. to account for EU policies to reduce the carbon emissions of the electricity grid.

f) **Other Market Sector Factors:** Various other factors are used to fully characterise each market sector, including average equipment life and specific refrigerant charge (this varies by refrigerant). The amount of equipment imported into the EU pre-charged with refrigerant is input for each market sub-sector and can also be varied on an annual basis. There is a substantial level of uncertainty in the market estimates. For example, the impact of internet shopping on commercial and transport refrigeration could be substantial.

The model can test the sensitivity of conclusions against all input parameters by varying them across a range of uncertainty. This gives maximum confidence in the model outputs.

The 1990 to 2010 data has been carefully modelled to match the outputs of the Erie-Armines 2011 model which was reviewed carefully by industry experts and is believed to represent a very robust “base case”.

3.4. Economic Analysis Methodology

In the economic analysis the costs and benefits of each scenario are compared to the Base Case (Scenario A) in order to calculate the cost of achieving emission reductions – expressed in € per tonne CO_2 saved.

To achieve this it is necessary to:

a) Estimate the relevant costs, including capital costs, energy costs and maintenance costs.

b) Assess the GHG emission reduction including reductions in direct emissions (refrigerant leakage and end of life losses) and indirect emissions (energy related emissions.

The key parameters used in the model are as follows:

1) **Capital cost**. The capital cost of a "standard system" is specified for each market sub-sector. The alternative refrigerants that can be used in each sub-sector are allocated a "capital cost factor" which is applied to the cost of a standard system. For example a capital cost factor of 1.1 means that a new system using an alternative refrigerant will cost 10% more to buy than a standard system. The total capital cost in a given year takes into account the number of new installations in that year and the mix of refrigerants used for those systems.

2) **Annualised capital cost**. The annualised cost is calculated by spreading the capital cost over the specified life for each subsector, using a 4% interest rate for the cost of capital.

3) **Energy consumption**. The cooling capacity, COP, operating hours and load factor are specified for each market sub-sector. These parameters are used to calculate the annual kWh of electricity required to operate a standard system. The energy used by alternative refrigerants is calculated using a "COP factor" which can either increase or decrease the annual kWh depending of the impact of the alternative refrigerant on COP.

   For heating only heat pumps, the annual heating hours and load factor are specified together with a heating COP.

   For reversible systems, the summer time cooling hours and load factor are specified together with a cooling COP. A second calculation is then carried out using winter time heating hours and load factor with a heating COP.

   The energy used to supply heat from heat pumps is compared to the amount of gas that would be required to supply the same amount of heat from a gas fired boiler with 80% efficiency.

4) **Energy cost**. Energy cost is based on €0.14 per kWh in 2010 which is increased steadily to €0.20 per kWh by 2030 to take into account the cost of decarbonising the electricity supply industry.

5) **Maintenance cost**. This is calculated as a percentage of capital cost. Standard HFC refrigerants in non-hermetic systems are all given a "low" maintenance cost of 3% of capital cost per year. Alternative refrigerants are split into 3 maintenance groups with low, medium and high costs. The low cost group includes medium GWP refrigerants such as HFC 134a and HFC 407F. The medium group includes mildly flammable refrigerants such as HFC 32 or HFOs and HFO blends. The high cost group includes highly flammable, toxic and high

pressure refrigerants (including HCs, ammonia and CO_2). The "mid-range" costs used in the economic model are 3.1% for medium and 3.2% for high[7]. Lower and higher values were also used in sensitivity analysis.

6) **Annual direct emission reductions**. These come from the SKM Refrigerants Model, being the difference in direct emissions (tonnes CO_2) between a selected Scenario and Scenario A. This includes all sources of emissions i.e. manufacturing / installation losses, in-life leakage and end of life emissions.

7) **Annual indirect emission reductions**. These are based on the difference in annual kWh energy used between a selected Scenario and Scenario A. The kWh difference is converted into tonnes CO_2 using an average carbon emission factor for electricity generation in the EU. This changes in different years due to decarbonising the electricity supply industry (we have used values, based on Ecodesign studies, of 0.458 kg CO_2 per kWh in 2005 falling to 0.229 kg CO_2 per kWh in 2030).

8) **Cost of emission reduction € per tonne CO_2 saved**. This is calculated for a specific year. Most of the costs presented in this report are for 2030, although the cost in any year can be output from the SKM Refrigerants Model. The calculation for costs in Year X compares the values for a given scenario with Scenario A using the following equation:

$$\text{Cost of emission reductions in Year X (€ per tonne } CO_2\text{)} = \frac{\text{Increase in (annualised capital cost + energy cost + maintenance cost)}_{\text{in Year X}}}{\text{Reduction in (direct emissions + indirect emissions)}_{\text{in Year X}}}$$

The cost of emission reduction is calculated for each scenario. It is available as an overall value for all RAC sectors or as individual values for each main market and for the 43 sub-sectors.

Equivalent values of €/tCO_2 are also available for the cost of reductions in annual gas consumption and gas demand.

[7] For hermetic systems in Sub Sectors 1.1, 1.2, 2.1 and 2.2, the corresponding midrange maintenance cost factors were 2.0%, 2.0% and 2.1% - chosen to reflect the low maintenance costs associated with this type of equipment.

4. Market Sector Profiles and Refrigerant Options

4.1. Sub-Sector Descriptions

Market sector profiles have been produced for the 43 sub-sectors listed in Table 2.1. Two example profiles are shown in Table 4.1 (for a small hermetic system) and Table 4.2 (for a large supermarket system). A full set of profiles is given in Appendix C.

For each sub-sector we have given:

a) A brief description of the end use markets and the type of cooling application.

b) The definition of a standard "2010 system" that is used in the model to represent new equipment being installed in the sub-sector in 2010. This is defined in terms of refrigerant type, refrigerant charge (kg), cooling duty (kW) and COP. The cooling duty is full load design duty and the COP is an average annual figure for system COP (taking into account compressor power and auxiliaries such as pumps and fans).

c) An estimate of the baseline (2010) split of refrigerants used (a) in the bank of all systems in the sub-sector and (b) in new equipment being purchased in 2010.

d) Various modelling factors. Emission factors are given for manufacturing and installation losses, annual leakage losses and refrigerant lost at end-of-life during decommissioning. Cost factors include typical capital cost for new equipment and annual running costs (mostly energy related, plus an allowance for maintenance). Operating factors (annual running hours and percentage load factor) are used to estimate total energy use.

e) Pre-filled imports and exports. This gives an estimate of the proportion of net imports (i.e. imports minus exports) of new equipment that is brought into the EU already containing all or some of the required refrigerant charge. For some imported equipment (e.g. split system air-conditioning units) it is common practice to add refrigerant during installation if pipe runs are long – a factor is estimated to reflect the amount of charge added during installation. This is always zero for factory built systems such as small hermetic systems or water chillers, but can be significant for split systems.

f) Market size, expressed in terms of the number of new systems being installed, given for 2010 and 2030.

g) A list of alternative refrigerant options that are considered applicable for the market sector. The impact of each alternative (compared to a standard "baseline" 2010 system) is specified in terms of changes to (a) capital cost and (b) running cost. Comments are given about the current and future availability of each alternative.

It should be noted that the sub-sector profiles are intended as short summary sheets giving a range of information about the sub-sector. In the SKM Refrigerants Model we use much more detailed data for each parameter, with key modelling factors (e.g. market size; leakage factors) specified annually between 1990 and 2040.

Table 4.1: Sub-Sector Profile, Example 1

Reference: 2.1	**Commercial Refrigeration, Small Hermetic, MT**			
Description: Small systems used for chilled products in food retail and food service (restaurants, pubs, hotels, canteens etc.). Includes a wide variety of applications including small chilled retail display cabinets, bottle coolers, in-line drink coolers, vending machines. Hermetically sealed factory built units always sold pre-charged with refrigerant.				
Standard system 2010	HFC 134a	Charge: 0.24 kg	Cooling: 0.8 kW	COP: 2.1
Refrigerant split 2010	Bank: 84% HFC 134a; 14% HCFC 22; 2% CFC 12; <1% HCs; <1% CO_2			
	New Equipment: 93% HFC 134a; 5% HCs; 2% CO_2			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 0%	Annual leakage: 1% Top-up factor: 100%	End of life: 91%	
Cost factors 2010	Lifecycle: 15 years	Capital: €1200	Energy: €330 per year Maintenance: €24 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 630,000 units	2030: 760,000 units		
Installed base	2010: 8,200,000 units	2030: 11,000,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HC 600a	+8%	-7.5%	+13%	Available for some models in 2012, but limited range. Uptake likely to grow significantly.
2	HFO 1234yf	+4%	0%	+9%	Not available in 2012. Becomes available 2015 to 2018. Could take share of market where HC flammability is a problem.
3	CO_2	+8%	-2.5%	+13%	Limited availability in 2012. Energy use higher in warm climates, lower in cold climates.
4	HFO B700	0%	0%	0%	Potential use of a non-flammable HFO blend, with properties similar to HFC 134a, GWP around 700, available from 2016.

Table 4.2: Sub-Sector Profile, Example 2

Reference: 2.5	**Commercial Refrigeration, Large Multipack, MT**			
Description: Large multipack centralised systems used in large food retail including supermarkets and hypermarkets. MT packs serve chilled display cases (e.g. for fresh meat, dairy products etc.). A typical system may have 4 to 6 compressors (usually semi-hermetic reciprocating or hermetic scroll) in a factory built "pack" located in a plant room, connected to external air cooled condensers and to a number of retail display cabinets and sometimes to a chilled store room.				
Standard system 2010	HFC 404A	Charge: 200 kg	Cooling: 100 kW	COP: 2.2
Refrigerant split 2010	Bank: 77% HFC 404A; 9% HFC 134a; 11% HCFCs; 2% other HFCs; 1% NH_3			
	New Equipment: 88% HFC 404A; 10% HFC 134a; 2% NH_3			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 21% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 15 years	Capital: €300,000	Energy: €39,000 per year Maintenance: €9,000 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 19,000 units	2030: 18,000 units		
Installed base	2010: 198,000 units	2030: 264,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+3%	-8%	+3%	Fully available in 2012. Improved efficiency and GWP.
2	HFC 407A/F	0%	-8%	0%	Fully available in 2012. Improved efficiency and GWP.
3	CO_2	+8%	-2.5%	+15%	Good availability in 2012, although limited skills in service sector. Energy use higher in warm climates, lower in cold climates. Both transcritical systems and cascade systems are in use now and more likely in the future.
4	HC hermetics plus chiller	+11%	0%	+15%	Limited use in 2012
5	HFO Blend 700	+4%	-7.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
6	NH3	+38%	0%	+45%	A small number of ammonia systems (with secondary coolants) may continue to be used.

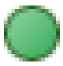
4.2. Traffic Light Analysis of Refrigerant Options

As discussed in Section 2.4, there are 14 main refrigerant options that can be considered for RAC equipment in the future to reduce the current level of GHG emissions. The 43 market sub-sector profiles in Appendix C each provide a list of the alternatives that are considered suitable. In Table 4.3 we provide an overall summary of refrigerant options, using a “traffic light analysis”.

Each refrigerant is given a traffic light marker for each sub-sector, using the following rules:


Not suitable on safety, efficiency or cost grounds


Technically feasible but other options usually preferable in terms of capital cost and / or energy efficiency


Suitable for application

In the modelling scenarios used in this study we have only selected refrigerants with a “green” light for use in newly installed equipment.

In Table 4.3 the traffic lights are assessed for the 3 groups of refrigerants introduced in Table 2.3. The 3 groups are:

Group 1: Very low GWP refrigerants, with a GWP below 10

Group 1 includes:

Ammonia, CO_2, Hydrocarbons (e.g. HC 600a, HC 290, HC 1270

HFOs 1234yf, 1234ze and DR2 / N12

Group 2: low / moderate GWP refrigerants with GWPs in the range 100 to 1,000

Group 2 includes:

HFCs 32 and 245fa

Blend 300, representing mildly flammable HFO / HFC blends with GWPs in the range 100 to 500

Blend 700, representing non-flammable HFO / HFC blends with GWPs in the range 500 to 1,000

Group 3: Medium GWP refrigerants, with GWPs in the range 1,000 to just over 2,000

Group 3 includes:

HFCs 134a, 410A, 407A, 407F

Table 4.3: Traffic Light Analysis of Refrigerant Alternatives

Code	Main Sector	Sub-Sector		Group 1 Very low GWP (<10)	Group 2 Low GWP (100 to 1,000)	Group 3 Medium GWP (1,000 to 2,200)
1.1	Domestic Refrigeration	Refrigerators	MT	Green	Red	Green
1.2		Freezers	LT	Green	Red	Green
2.1	Commercial Refrigeration	Hermetic Units (Medium Temp)	MT	Green	Red	Green
2.2		Hermetic Units (Low Temp)	LT	Green	Red	Green
2.3		Single condensing units (MT)	MT	Green	Green	Green
2.4		Single condensing units (LT)	LT	Red	Green	Green
2.5		Multi-pack centralised systems (MT)	MT	Green	Green	Green
2.6		Multi-pack centralised systems (LT)	LT	Green	Green	Green
3.1	Transport Refrigeration	Vans and light trucks	LT & MT	Green	Green	Green
3.2		Large Trucks and Iso-Containers	LT & MT	Green	Green	Green
4.01	Industrial Refrigeration	Small DX LT (low temp.)	LT	Amber	Green	Green
4.02		Small DX MT (medium temp.)	MT	Green	Green	Green
4.03		Medium DX LT (low temp.)	LT	Amber	Green	Green
4.04		Medium DX MT (medium temp.)	MT	Amber	Green	Green
4.05		Large DX LT (low temp.)	LT	Green	Green	Green
4.06		Large DX MT (medium temp.)	MT	Green	Green	Green
4.07		Medium-size Industrial Chillers	MT	Green	Green	Green
4.08		Large Industrial Chillers	MT	Green	Green	Green
4.09		Large Flooded LT (low temp.)	LT	Green	Amber	Red
4.10		Large Flooded MT (medium temp.)	MT	Green	Amber	Green
5.01	Stationary Air Conditioning (SAC) and Heat Pumps	Small portable units, cooling only (air-to-air)		Green	Green	Green
5.02		Small split systems, cooling only (air-to-air)		Amber	Green	Green
5.03		Small split systems, heating & cooling (air-to-air)		Amber	Green	Green
5.04		Medium split systems, cooling only (air-to-air)		Red	Green	Green
5.05		Medium split systems, heating & cooling (air-to-air)		Red	Green	Green
5.06		Large split systems, cooling only (air-to-air)		Red	Red	Green
5.07		Large split systems, heating & cooling (air-to-air)		Red	Red	Green
5.08		Packaged systems, cooling only (air-to-air)		Red	Red	Green
5.09		Packaged systems, heating & cooling (air-to-air)		Red	Red	Green
5.10		VRF systems, cooling only (air-to-air)		Red	Red	Green
5.11		VRF systems, heating & cooling (air-to-air)		Red	Red	Green
6.01	Chillers & Hydronic Heat Pumps	Small - cooling only (scroll/screw, air-cooled)		Amber	Green	Green
6.02		Medium - cooling only (scroll/screw, air-cooled)		Green	Green	Green
6.03		Large - cooling only (screw, air-cooled)		Green	Green	Green
6.04		Small - cooling only (scroll/screw, water-cooled)		Amber	Green	Green
6.05		Medium - cooling only (scroll/screw, water-cooled)		Green	Green	Green
6.06		Large - cooling only (centrifugal, water-cooled)		Green	Green	Green
6.07		Domestic - heat only, air-source, hydronic		Amber	Green	Green
6.08		Small - heat only, air-source, hydronic		Green	Green	Green
6.09		Small - reversible heating/cooling, air-source, hydronic		Amber	Green	Green
6.10		Medium - reversible heating/cooling, air-source, hydronic		Green	Green	Green
7.1	Mobile AC	Cars, vans, cabs		Green	Red	Green
7.2		Buses, trains		Green	Green	Green

Summary comments about the application of each of the 14 refrigerants are:

Group 1 Refrigerants

Ammonia is suited to large industrial systems and to large chillers. Toxicity and materials compatibility issues make it unsuitable for small and medium sized systems.

CO_2 is suited to large commercial and industrial refrigeration systems and certain types of small hermetic system. It has potential for smaller refrigeration applications and transport refrigeration applications and is well suited to systems that combine cooling with a heat recovery requirement. Energy efficiency is a significant barrier for all types of CO_2 air-conditioning.

HCs are suited to small hermetic systems in the domestic, commercial and air-conditioning sectors. HCs can also be used for large systems and remotely located chillers providing high flammability is addressed. HCs have limited opportunities for use in medium sized distributed systems (with site installed pipework) because of high flammability.

HFO 1234yf is suited to small systems such as mobile air-conditioning and domestic / commercial hermetic systems. It can also be considered for large chillers.

HFO 1234ze is suited to large air-conditioning and industrial chillers.

HFO DR2 / N12 are low pressure refrigerants with characteristics similar to the phased out refrigerants CFC 11 and HCFC 123. They have potential for use in large, high efficiency water chillers using centrifugal compressors and for high temperature heat pumps.

Group 2 Refrigerants

HFO "Blend 300" (which represents a range of mildly flammable blends with a GWP in the 200 to 500 range) is suited to certain commercial and industrial refrigeration systems where a mildly flammable refrigerant can be used safely. Blend 300 may also be applicable to small air-conditioning systems and chillers.

HFO "Blend 700" (which represents a range of non-flammable blends with a GWP in the 500 to 1,000 range) is suited to a large set of commercial and industrial refrigeration systems where a non-flammable refrigerant is considered important. Blend 700 is unsuitable for most DX air-conditioning applications but can be considered for chillers.

HFC 32 is suited to various types of small air-conditioning system, providing the mild flammability can be tolerated. It might also have a role for small industrial systems.

HFC 245fa is a low pressure refrigerant that can be considered for certain types of large high temperature heat pump. It is also of interest outside the RAC field for Organic Rankine Cycles.

Group 3 Refrigerants

HFC 134a has the lowest GWP of the commonly used HFCs (1,430). It can be used in many chiller and MT refrigeration applications providing an efficient medium GWP alternative to HFC 404A in new equipment. It requires a much larger compressor (+30%) than HFC 404A but should use less energy for MT systems. It is not well suited to LT applications.

HFCs 407A and 407F are both possible alternatives to HFC 404A. They can be considered for both new equipment and for retrofill into existing systems. These refrigerants have the potential to provide an early cut in HFC consumption / emissions through retrofill in sectors such as commercial and industrial refrigeration.

HFC 410A is in widespread use for many types of air-conditioning and heat pump system. It provides high energy efficiency combined with small compressor size. Currently there are no non-flammable alternatives to HFC 410A with a GWP below 1,000. In some applications (especially small sized air-conditioning equipment) a mildly flammable refrigerant (e.g. Blend 300 or HFC 32) may be suitable, but for medium sized systems HFC 410A still provides the best environmental impact when energy efficiency is taken into account. It is also applied as an alternative for R404A in certain refrigeration applications.

5. Future HFC Consumption Scenarios for RAC

5.1. Introduction to RAC Scenarios

The SKM Refrigerants Model has been used to evaluate a range of future scenarios in each RAC market sub-sector. The outputs from the model provide an assessment of the consumption and emissions of HFCs between 1990 and 2040, with estimates of the cost impact of each scenario.

Base Case to 2010

In all the scenarios the input parameters used up to the end of 2010 are identical. This provides a consistent population of RAC equipment in 2010 in each market sub-sector with a representative age profile and mix of refrigerants. The base case to 2010 provides a good match (within 1%) with top down data for EU refrigerant consumption (EC, 2011).

The Base Case data is used to calculate the "baseline" demand and consumption for HCFCs and HFCs that is used in the various phase down proposals i.e. the proposals made by North America, and the EU. The definition of the baseline consumption is slightly different for each proposal – the SKM Refrigerants Model has been used to evaluate the baseline for each proposal. Details of the various phase down proposals are given in Section 7.

Future Scenarios

As discussed in Section 3, the SKM Refrigerants Model allows a wide range of input parameters to be varied on an annual basis between 2011 and 2040. This gives the model great flexibility to assess many different future scenarios, although it also creates the possibility of generating impractically large sets of data which will not necessarily help improve the overall understanding of different phase down proposals. In this report we have provided results from a small range of representative types of future scenario. At a later date the model can easily be used for further evaluations of phase down e.g. to investigate the impact of a new refrigerant option or to test the assumptions made during this study.

Four main scenarios have been evaluated in this study for each RAC market sub-sector, as described in Table 5.1.

In addition to analysing the four main scenarios, we have used the model to test the sensitivity of certain key input parameters, in particular:

- market sub-sector growth
- energy efficiency
- capital and maintenance cost

Table 5.1: Modelling Scenarios

Scenario	Description	Comments
A	Low impact, base case (all other scenarios are compared to Scenario A for economic impact assessment)	Similar to the "F-Gas" scenario used in Erie-Armines 2011[8]. Scenario A reflects a conservative view of current changes in the use of refrigerants and can be used as a BAU forecast against which the other scenarios can be compared to assess (a) the extra GHG emission reductions achieved and (b) the cost impact of these extra emission reductions. Scenario A represents the possible use of HFCs under the current regulatory regime (in particular, the 2006 F-Gas Regulation).
B	Medium impact	Similar to the "F-Gas+" scenario used in the Erie-Armines study in terms of refrigerants used. Scenario B introduces cuts in HFC use for new systems, representing various technologies being used in different RAC market sectors. Scenario B also introduces improvements in leakage levels created by full implementation of the F-Gas Regulation.
C	High impact	Compared to Scenario B, this scenario assumes: (i) greater use of very low and low GWP alternatives in new equipment as they become widely available and cost effective, (ii) the early use of medium GWP alternatives in new equipment to avoid the installation of any new systems that use the very high GWP refrigerants (iii) retrofill of part of the bank of high GWP refrigerants (in particular HFC 404A) with medium GWP refrigerants in appropriate circumstances.
D	Highest Impact	This scenario improves on Scenario C by assuming more widespread use of A2L (mildly flammable) refrigerants from 2020 in the stationary air-conditioning and industrial markets. Requirements for this scenario are; (i) better understanding of where mildly flammable refrigerants can be safely used (ii) revisions to safety codes and legislation

[8] Note, the SKM Refrigerants Model uses different assumptions to Erie-Armines for Sector 5 (Stationary Air-conditioning and Heat Pumps) as the Erie-Armines data creates an excessively large estimate of the refrigerant bank and consumption in this sector.

5.2. Results for Total RAC Market

Various outputs from the SKM Refrigerants Model for the whole RAC market are presented in this section. The data presented here is a small fraction of the detailed information that is available from the model. For each type of output the data is available (a) for each of the 4 scenarios analysed, (b) for each of the 7 main market sectors and (c) for each of the 43 market sub-sectors.

It is important to recognise which of the 4 scenarios is represented in a particular graph. Each graph is labelled with the Scenario name. Also we have added the Scenario letter to the figure name. For example, Figure 5.1A is for Scenario A.

Many of the graphs are presented in terms of tonnes CO_2 equivalent, as this is the most relevant measure for this project, representing the global warming impact (units of Mtonnes CO_2 are usually used). Where relevant graphs show physical tonnes (units of ktonnes are usually used).

5.2.1. Physical Bank

Figure 5.1A shows the **refrigerant bank** in tonnes, split by refrigerant types for Scenario A. The bank is the total amount of refrigerant stored in the millions of pieces of refrigeration equipment across the EU. The bank for the total RAC market is complex as many different refrigerants are used in the highly varied market. Some of the graphs for individual market sectors (in Appendix D) show simpler profiles that more clearly illustrate trends in specific markets.

Figure 5.1A clearly shows the overall growth of the RAC market. The bank is forecast to grow by nearly 50% from 2010 to 2030, from 460 to 680 thousand tonnes of refrigerant. This growth has an important impact on phase down rates.

Figure 5.1A: Physical Refrigerant Bank, ktonnes
All RAC Sectors, Scenario A, EU27

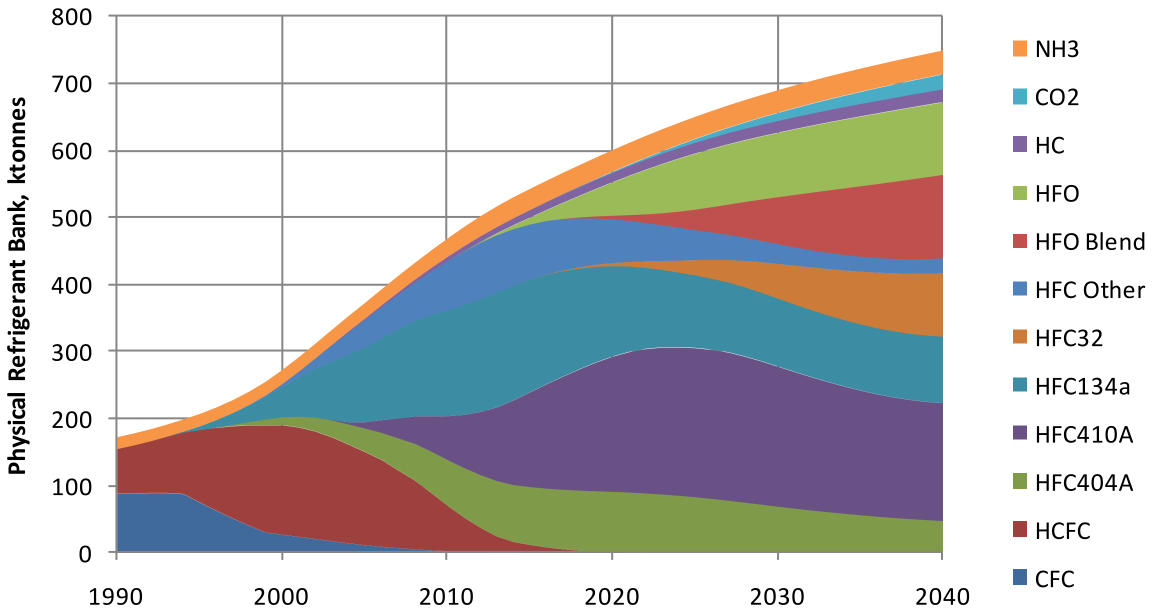
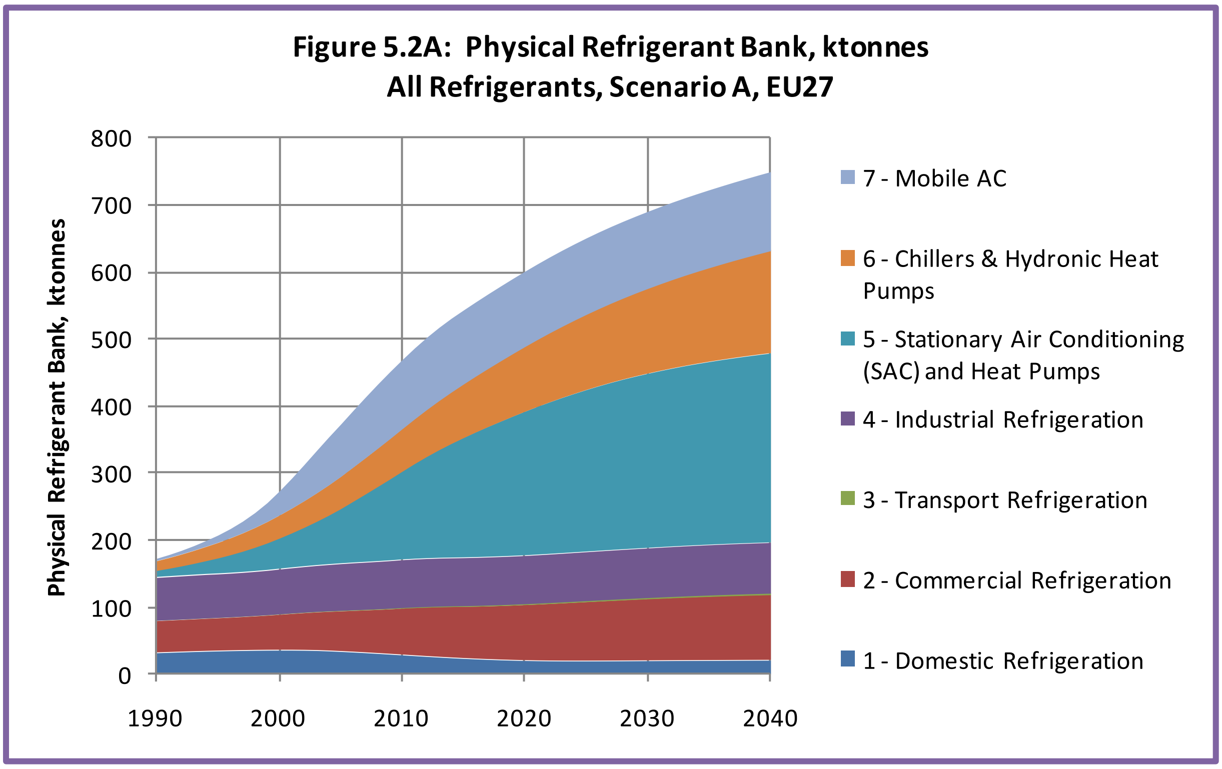


Figure 5.2A shows the physical bank split by main market sector for Scenario A. This shows that most of the market growth after 2010 is in Sectors 5 and 6 (air-conditioning and heat pumps).



5.2.2. GHG Bank

Figures 5.3A and 5.3D show the **GHG bank** in tonnes CO_2 equivalent, split by the main refrigerant types for Scenarios A and D. The GHG bank is the physical tonnage of each refrigerant in the bank multiplied by the relevant GWP.

The profile for the GHG bank is totally different from the physical bank, due to the changes in GWP of refrigerants being used in the period 1990 to 2040. The peak in the early 1990s is caused by the influence of CFCs. Despite the much smaller physical bank in 1990, the GHG bank at that time was very high. CFC 12 has a GWP of 10,900 which is much higher than currently used HFCs such as HFC 134a (GWP 1,430) or HFC 404A (GWP 3,920).

There is a clear difference in the bank size in terms of GHG equivalent between Scenarios A and D, due to the greater use of low GWP refrigerants in Scenario D. Under Scenario A the GHG bank grows steadily between 2010 and 2020 and then begins to fall. Under Scenario D the GHG bank peaks around 2015 and then falls much more significantly than Scenario A.

The relative importance of each refrigerant type is different in the physical and GHG banks because of the impact of varying GWPs. HFC 404A has a much greater share of the GHG bank than of the physical bank due to its very high GWP. Ammonia, HCs and CO_2 are part of the physical bank but do not appear in Figure 5.3 due to the zero or negligible GWP.

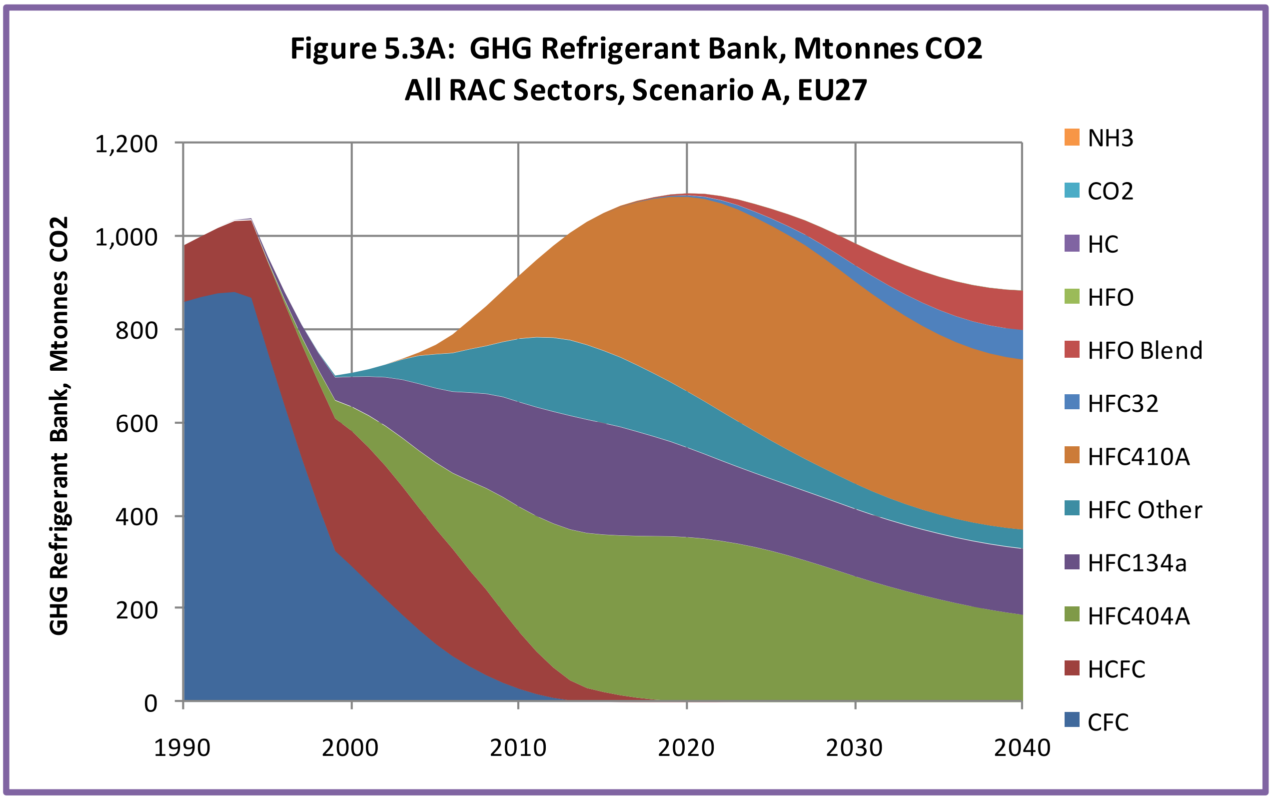


Figure 5.3A: GHG Refrigerant Bank, Mtonnes CO2
All RAC Sectors, Scenario A, EU27
GHG Refrigerant Bank, Mtonnes CO2
1,200
1,000
800
600
400
200
0
1990
2000
2010
2020
2030
2040
NH3
CO2
HC
HFO
HFO Blend
HFC32
HFC410A
HFC Other
HFC134a
HFC404A
HCFC
CFC

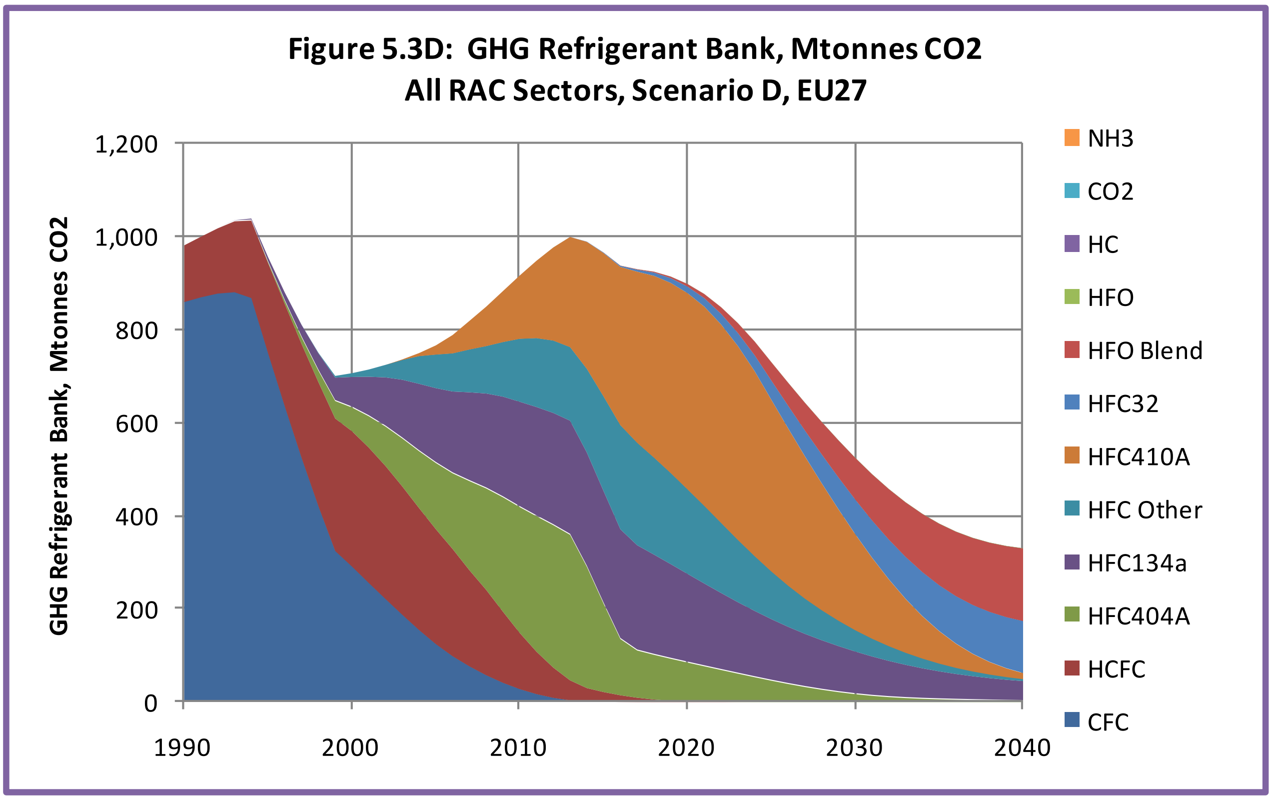
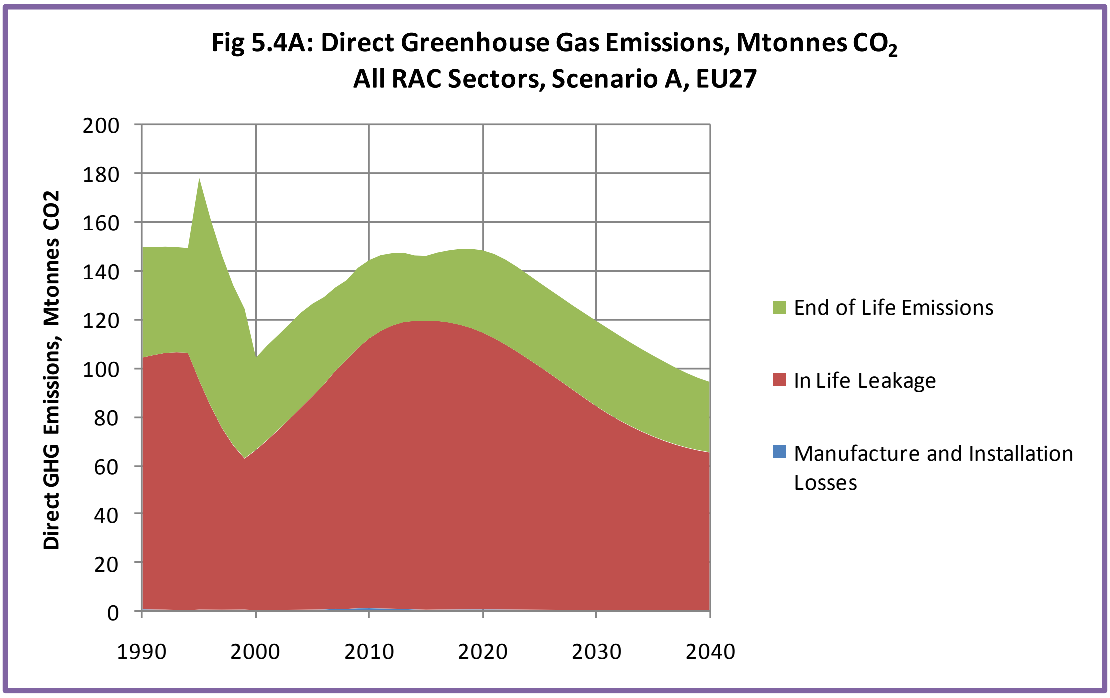
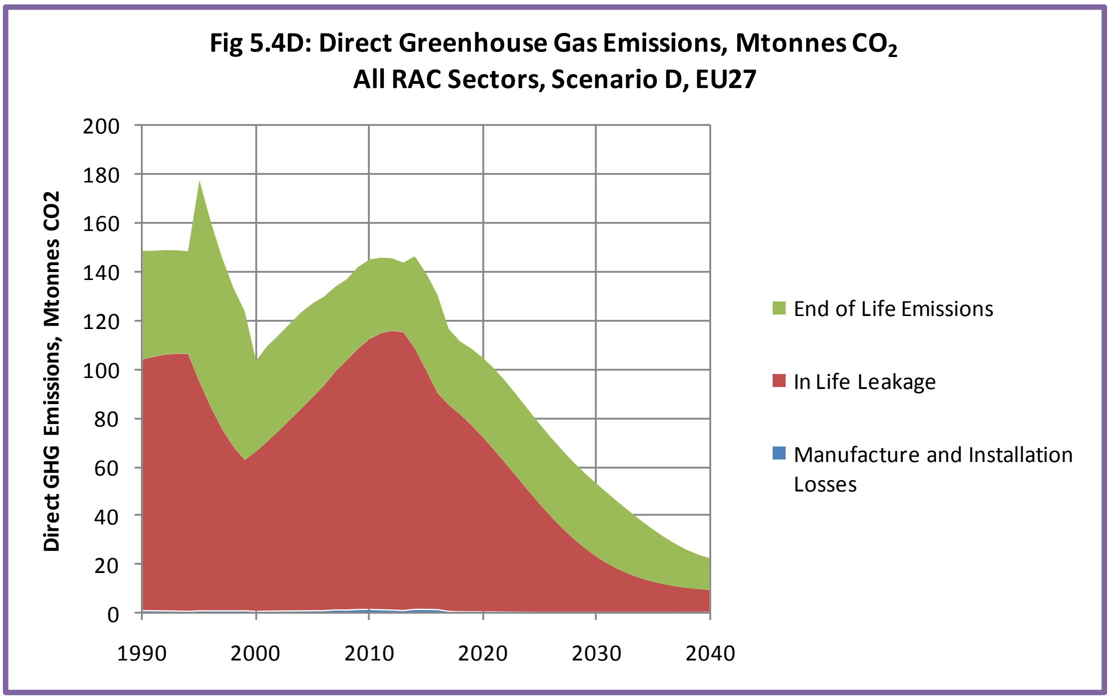


Figure 5.3D: GHG Refrigerant Bank, Mtonnes CO2
All RAC Sectors, Scenario D, EU27
GHG Refrigerant Bank, Mtonnes CO2
1,200
1,000
800
600
400
200
0
1990
2000
2010
2020
2030
2040
NH3
CO2
HC
HFO
HFO Blend
HFC32
HFC410A
HFC Other
HFC134a
HFC404A
HCFC
CFC

5.2.3. Direct GHG Emissions from the Bank

Figures 5.4A and 5.4D show the **direct GHG emissions** from the bank in tonnes CO_2 equivalent, split by source of emissions. Refrigerant is emitted in 3 main life cycle phases: (a) during RAC equipment manufacture and installation, (b) during the operating life of the system and (c) at end of life. This clearly illustrates the significance of "in use leakage" emissions which represent about 75% of total direct GHG emissions under Scenario A. Emissions during product manufacture and installation are negligible (and can hardly be seen on the graph). End of life emissions are particularly important in sectors with small hermetically equipment (e.g. domestic refrigerators). The in use leakage emissions are much lower under Scenario D as this assumes significantly reduced rates of leakage compared to Scenario A.



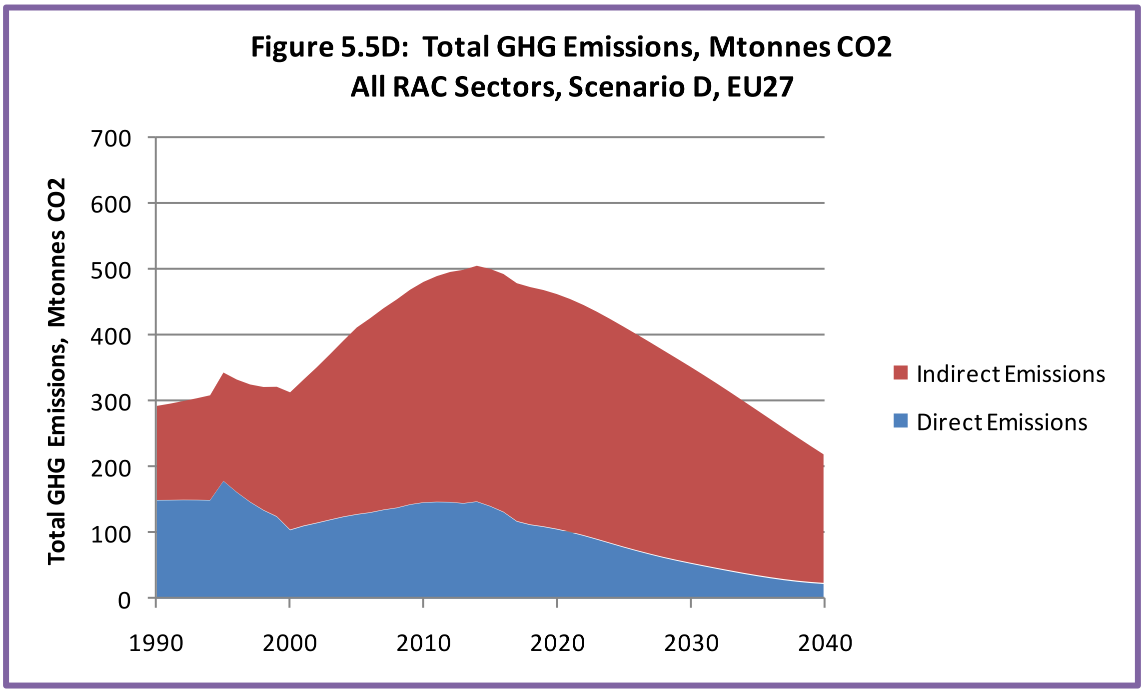


5.2.4. Total GHG Emissions from the Bank

Figure 5.5D shows the **total GHG emissions** in tonnes CO_2 equivalent. This is the sum of the "direct emissions" caused by refrigerant losses (as shown in Figure 5.4) and the "indirect emissions" related to the energy consumed by the refrigeration plant.

The figure clearly shows the importance of energy in the overall global warming impact of refrigeration systems. The growth in energy related emissions between 2000 and 2015 reflects the rapid growth of some parts of the RAC market. The fall in energy emissions after 2020 is related to the reductions expected in the average carbon emissions from power generation.

Under Scenario D there is a steady reduction in direct emissions after 2015. The equivalent graph for Scenario A does not show this reduction in direct emissions.



In 1990 the energy related emissions are 49% of total emissions – this figure is much lower than in later years due to the influence of CFCs which have very high GWPs.

In 2010, the energy related emissions are 70% of total emissions. In 2010 there is still some CFC influence in the domestic sector and significant use of HFC 404A.

By 2030, the energy related emissions are 85% of total emissions. The significant reduction in direct emissions between 2015 and 2030 (62%) is due to reduced leak rates and use of lower GWP refrigerants. The reduction in energy related emissions is only 17% due to grid decarbonisation. Further energy efficiency improvements can be expected in addition to the impact of grid decarbonisation, although these have not been modelled at this stage. To achieve maximum reduction in total emissions it is clearly essential that energy efficiency of RAC systems is improved.

5.2.5. Annual Demand and Consumption

Figures 5.6A and 5.6D compare the **annual demand for refrigerant** in tonnes CO_2 equivalent, with the **annual "Montreal Protocol consumption"** (see Section 1.4 for definitions). The demand for refrigerant includes the gas required to fill new equipment (including refrigerant in pre-charged equipment imported into the EU) and the gas used during maintenance to top up leakage. The control of the demand or consumption of refrigerant would be the main impact of an HFC phase down; hence these graphs are very important to this analysis. The data is used as a basis for the phase down analysis in Section 7 of this report.

The difference between demand and consumption profiles is related to imports and exports of pre-charged RAC equipment, which is a market dependent issue. . Many of the equivalent graphs for individual market sectors show identical values for demand and consumption. In some cases this is because there is no net trade in pre-charged equipment (e.g. domestic refrigerators) whilst in other cases it is because the sector only uses equipment that is charged with refrigerant during installation (e.g. supermarket pack systems). The key markets that lead to the differences between demand and consumption shown in Figure 5.6 are (a) small stationary air-conditioning systems for which there are very significant product imports and (b) the car air-conditioning sector for which there is a small net export.

There is a significant difference in the demand profiles across the 4 main scenarios although the difference between demand and consumption does not alter significantly across the scenarios. Figures 5.6A and 5.6D show both demand and consumption for scenarios A and D. These graphs clearly illustrate the magnitude of the difference between demand and consumption. Demand is typically around 15% higher than consumption.

Figure 5.7 shows the demand profiles for 4 Scenarios and Figure 5.8 shows the equivalent consumption profiles. The consumption and demand is highest for the Base Case (Scenario A) and drops progressively towards Scenario D.

Table 5.2 shows demand / consumption reductions for each scenario between 2010 and 2030. For example, demand for Scenario A falls from 205 to 139 Mtonnes CO_2, which is a reduction of 32%.

Table 5.2: Reductions in Demand and Consumption between 2010 and 2030

Scenario	Demand, MT CO_2			Consumption, MT CO_2		
	2010	2030	Reduction from 2010	2010	2030	Reduction from 2010
A	205	139	32%	186	121	35%
B		79	61%		65	65%
C		52	75%		40	79%
D		43	79%		36	81%

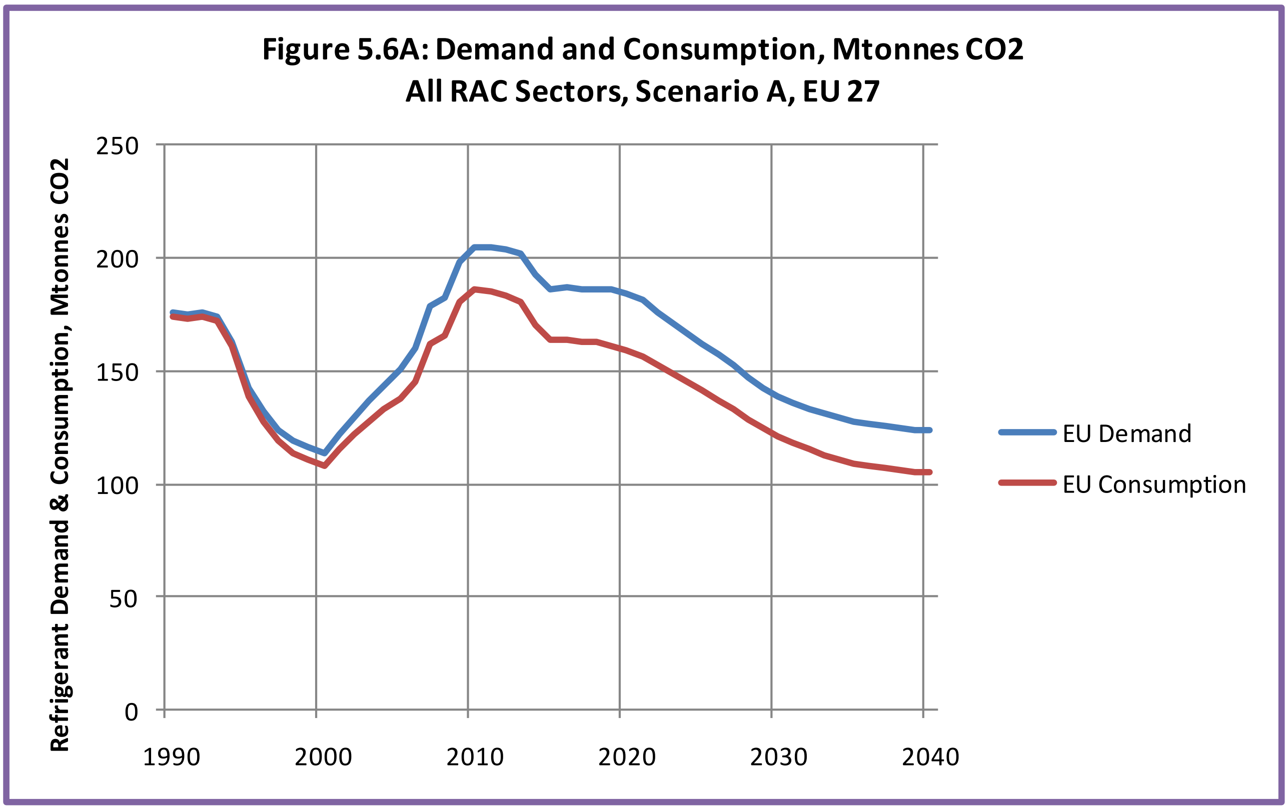


Figure 5.6A: Demand and Consumption, Mtonnes CO2
All RAC Sectors, Scenario A, EU 27
Refrigerant Demand & Consumption, Mtonnes CO2
0
50
100
150
200
250
1990
2000
2010
2020
2030
2040
EU Demand
EU Consumption

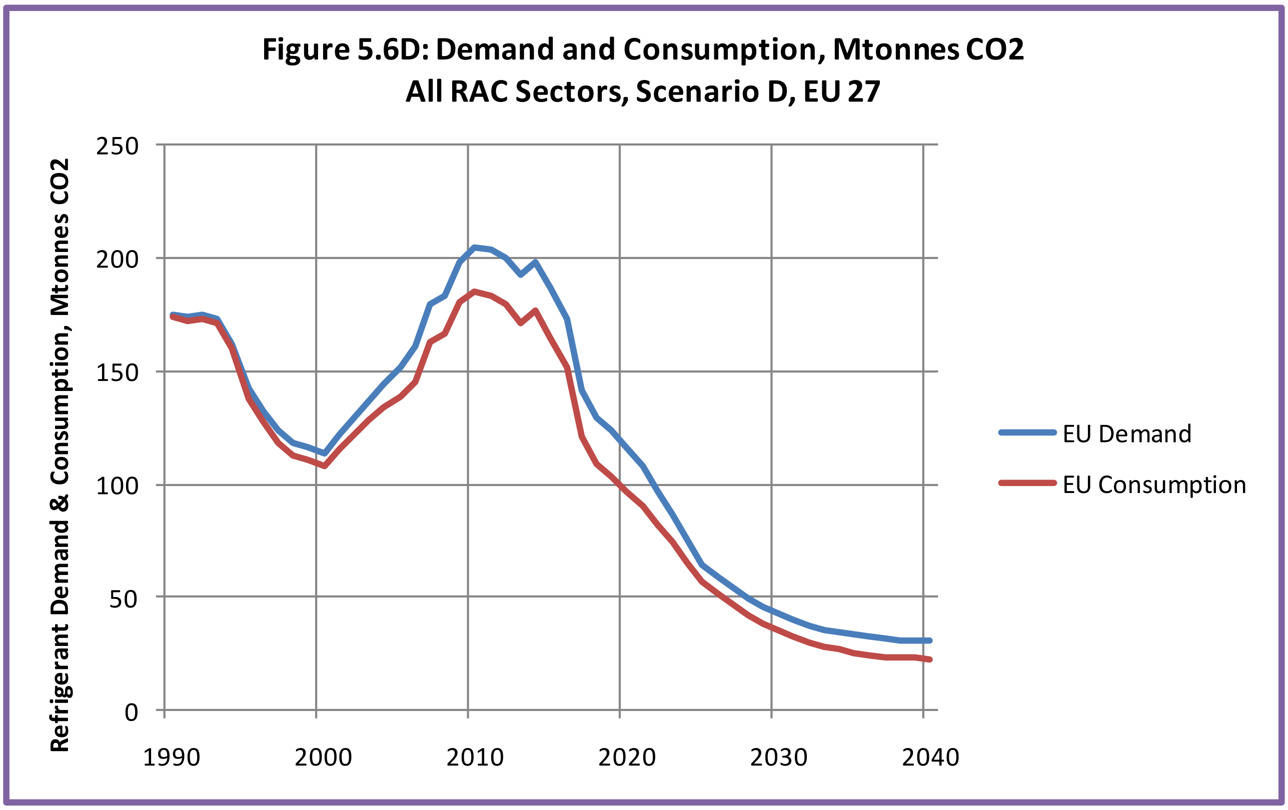


Figure 5.6D: Demand and Consumption, Mtonnes CO2
All RAC Sectors, Scenario D, EU 27
Refrigerant Demand & Consumption, Mtonnes CO2
0
50
100
150
200
250
1990
2000
2010
2020
2030
2040
EU Demand
EU Consumption

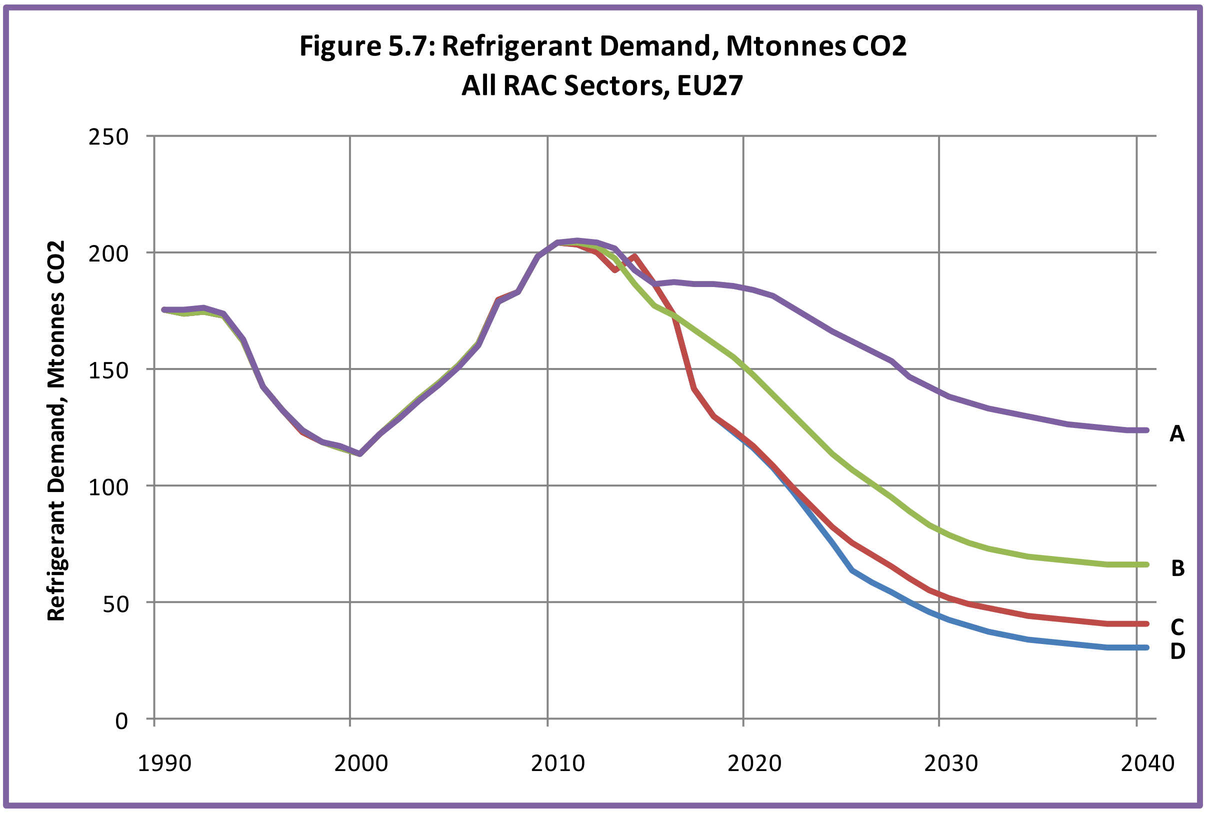


Figure 5.7: Refrigerant Demand, Mtonnes CO2
All RAC Sectors, EU27
Refrigerant Demand, Mtonnes CO2
250
200
150
100
50
0
1990
2000
2010
2020
2030
2040
A
B
C
D

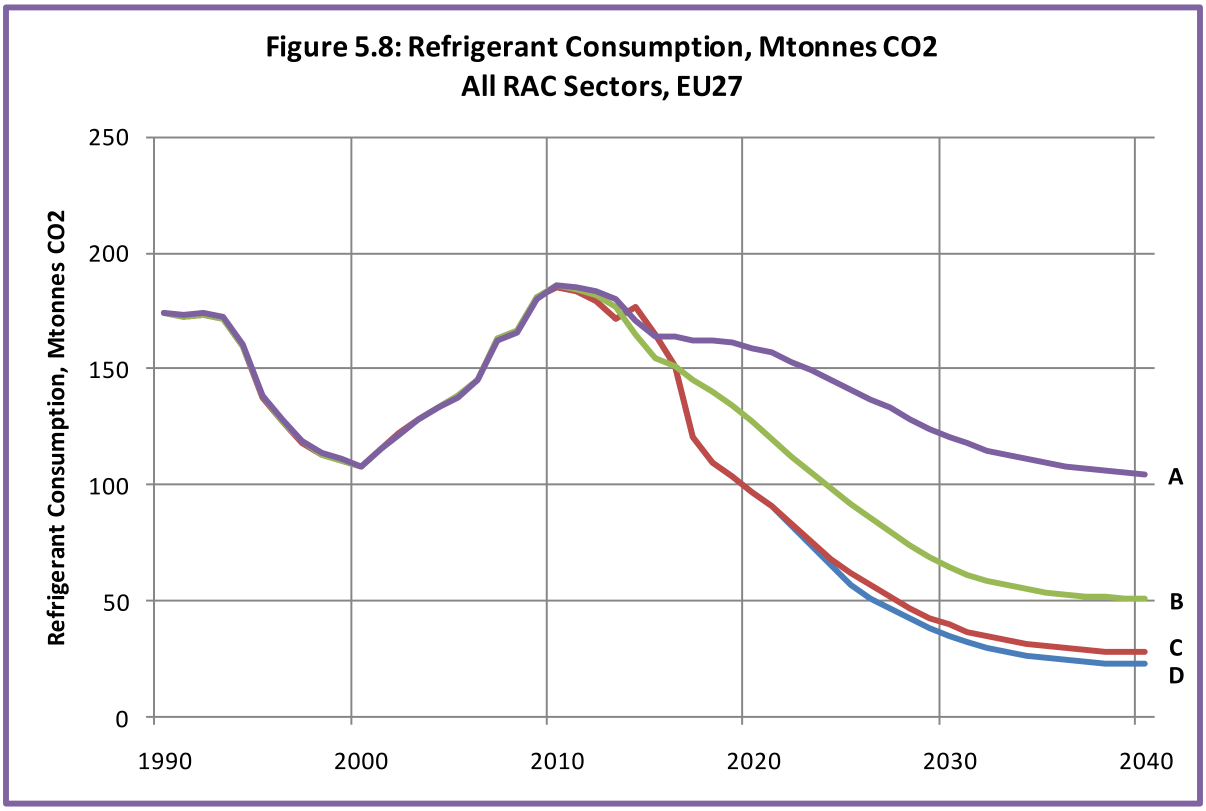


Figure 5.8: Refrigerant Consumption, Mtonnes CO2
All RAC Sectors, EU27
Refrigerant Consumption, Mtonnes CO2
250
200
150
100
50
0
1990
2000
2010
2020
2030
2040
A
B
C
D

5.2.6. Balance of Demand between Maintenance and New Equipment

Figures 5.9A and 5.9D show the demand split into demand for new equipment and demand for maintenance. Under Scenario A demand for maintenance is 60% of the total demand in 2030. This emphasises the importance of "Strategy 1, leak reduction", described in Section 2.4 as one of the 4 strategies to reduce HFC demand. Scenarios B, C and D all include a significant reduction in leak rates. The demand for maintenance under Scenario D is 24 Mtonnes CO_2 in 2030 – this is 70% lower than the maintenance requirement under Scenario A.

Figure 5.9A: Refrigerant Demand, Mtonnes CO_2
All RAC Sectors, Scenario A, EU27

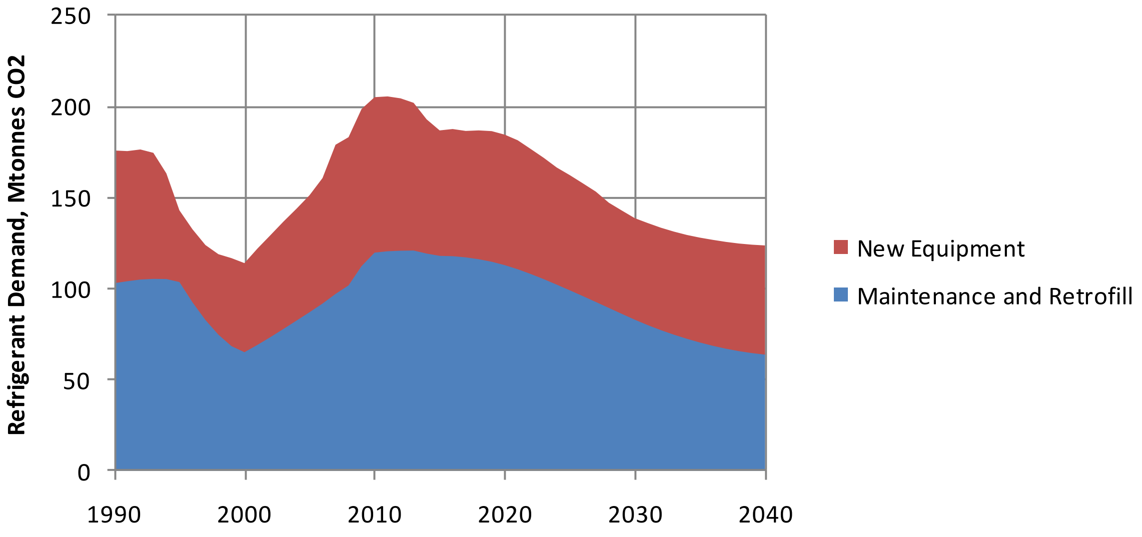
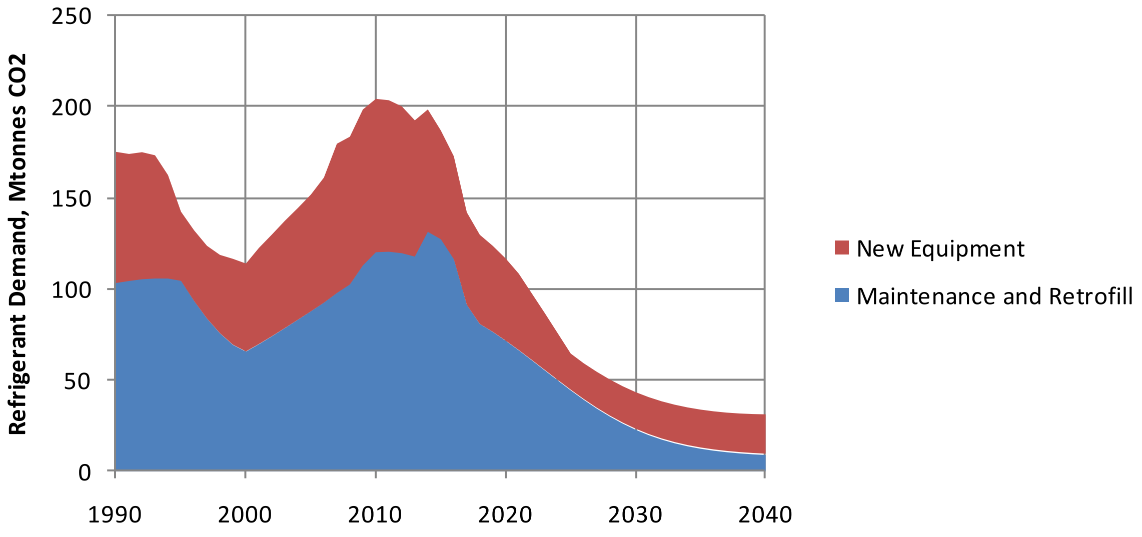


Figure 5.9D: Refrigerant Demand, Mtonnes CO_2
All RAC Sectors, Scenario D, EU27



5.2.7. Refrigerant Available for Re-Use

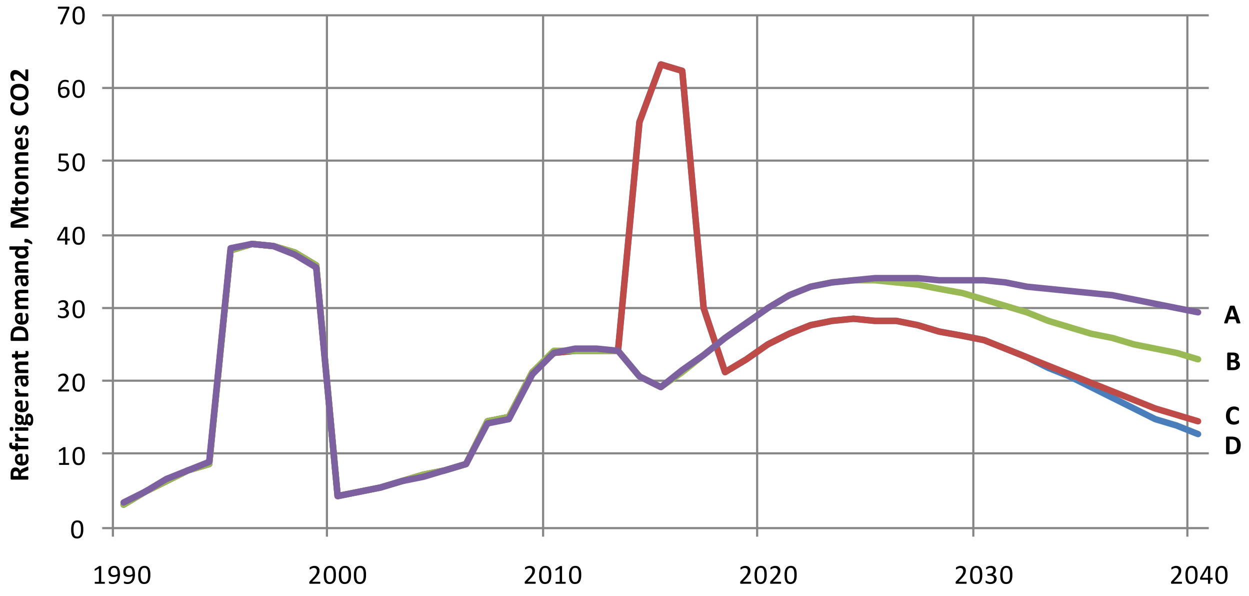
Figure 5.10 shows the amount of **refrigerant available for re-use** in Mtonnes CO_2 equivalent. This has been plotted for 4 Scenarios.

The unusual shape of this graph relates to campaigns of retrofilling, which makes the refrigerant being replaced available for re-use. The "hump" between 1994 and 2000 relates to retrofill of CFC systems. The increase between 2008 and 2013 relates to HCFC systems being retrofilled. Prior to 2013 all 4 scenarios have the same amount of refrigerant available for re-use – hence only 1 line is visible on the graph. Scenarios C and D include retrofill of existing HFC 404A systems – this retrofill creates the large hump in the graph between 2014 and 2020. Scenarios A, and B follow a different track to Scenarios C and D up to around 2025. After that date the tracks of A and B begin to diverge as the different mix of equipment that was installed between 2012 and 2015 begins to reach end of life. The tracks for C and D do not diverge until around 10 years later as the main changes in refrigerant mix between these 2 scenarios only began in 2020.

It is very useful to compare the quantity of HFC refrigerant available for re-use with the demand shown in Figure 5.7. In 2025 there is around 34 Mtonnes CO_2 available under Scenario B compared to a demand of 107 Mtonnes. Hence recovered refrigerant could contribute around 30% of demand under Scenario B. Under Scenarios C and D there is around 28 Mtonnes CO_2 available for compared to a demand between 64 and 76 Mtonnes CO_2. Recovered refrigerant could contribute between 35% and 45% of demand in 2025 under Scenarios C and D.

These figures show that recovered refrigerant could make a significant contribution to achieving a phase down in the use of virgin refrigerant. It is worth noting that there is currently almost no market for recovered HFCs. This is not surprising as HFCs were only used in significant quantities from the late 1990s and little HFC equipment has yet reached end of life.

Figure 5.10: Recovered Refrigerant available for Re-Use, Mtonnes CO_2
All RAC Sectors, EU27

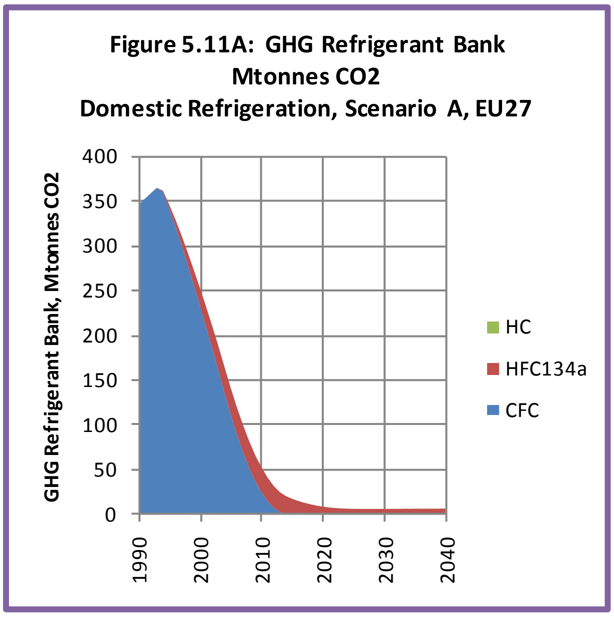


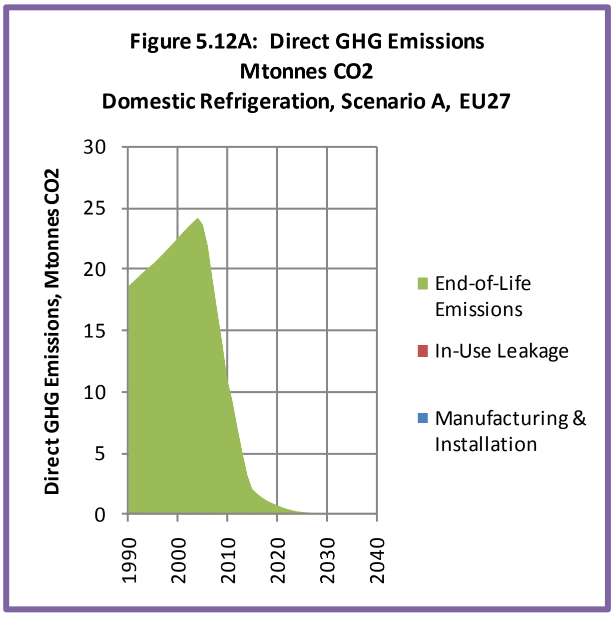
5.3. Results for the 7 Main RAC Market Sectors

In the paragraphs below we provide some comments related to the 7 main market sectors.

5.3.1. Domestic Refrigeration Sector

The domestic sector has almost achieved HFC phase out already. The fall in bank (Figure 5.11A) and direct GHG emissions (Figure 5.12A) has been dramatic since 1990, firstly due to the phase out of CFC 12 which has a very high GWP and then through the move from HFC 134a to hydrocarbons for most EU refrigerators and freezers. The small residual consumption of HFC 134a can be replaced with a combination of HCs and HFOs by 2020. As shown in Figure 5.12A, virtually all emissions from this sector relate to end of life losses.

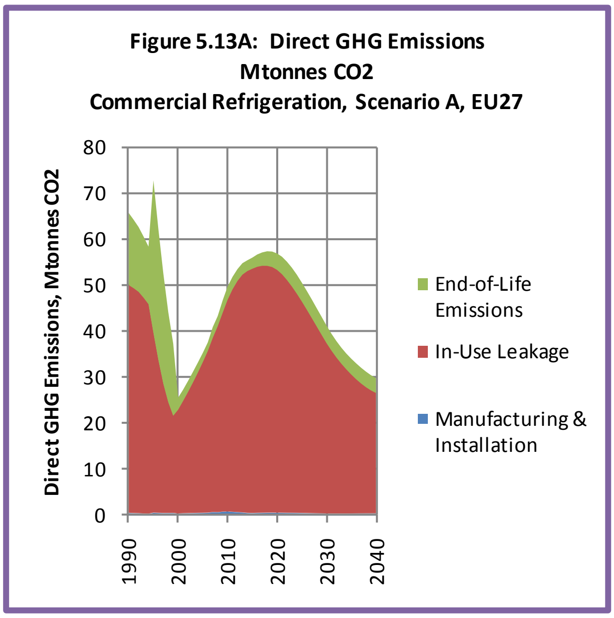


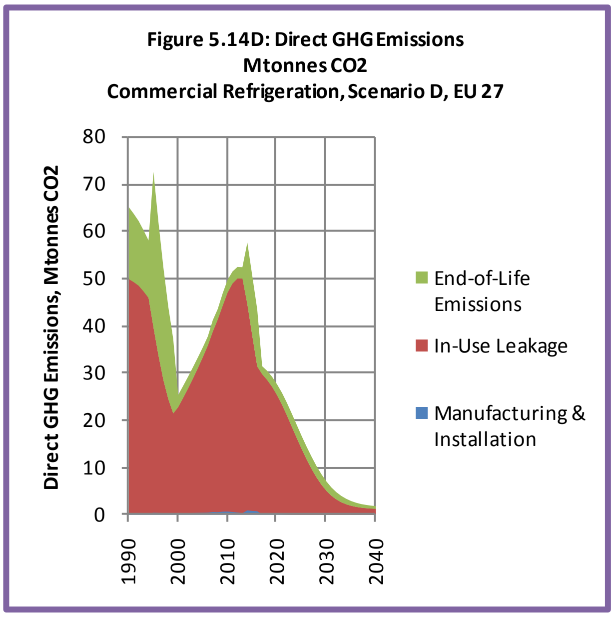


5.3.2. Commercial Refrigeration Sector

The commercial refrigeration sector has made significant progress during the last 5 years, with significant leakage reduction and the use of various alternatives including CO_2. This sector has the potential for significant further emission reductions, especially if the major supermarket companies continue their current corporate responsibility initiatives in the refrigerants area.

Figure 5.13A shows direct emissions from this sector under Scenario A. Figure 5.14D illustrates the excellent potential for emission reduction. This sector uses a large amount of HFC 404A. In the short term medium GWP refrigerants including HFC 407A and HFC 407F can be used in place of HFC 404A in new and existing equipment. Other refrigerants, in particular CO_2, can be used in new systems. Leak reduction is also an important short term strategy as this sector has historically had high rates of leakage.



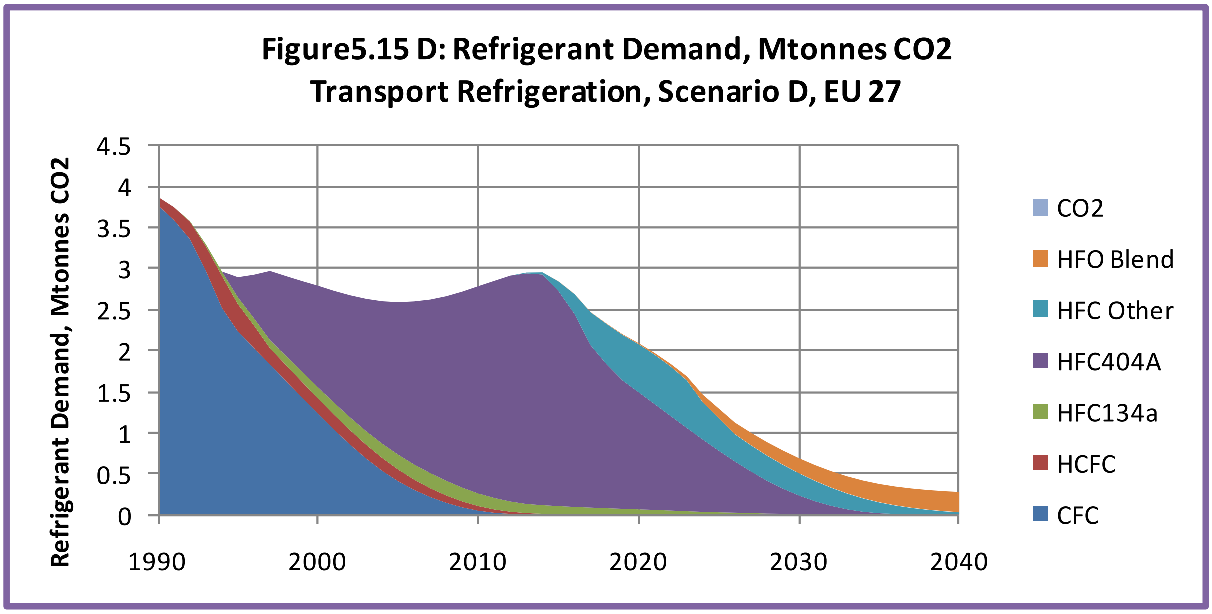


5.3.3. Industrial Refrigeration Sector

A key issue for the industrial sector is to recognise the wide spectrum of equipment size used in the sector. Most HFC systems in this sector are relatively small – with refrigerant charge between 20 and 100 kg. Whilst ammonia and CO_2 will be cost effective alternatives for larger systems, there are less clear options for small and medium sized systems. HFC 404A is popular in the industrial sector and could be a target for early reductions through use of medium GWP alternatives in new equipment and retrofill of existing equipment.

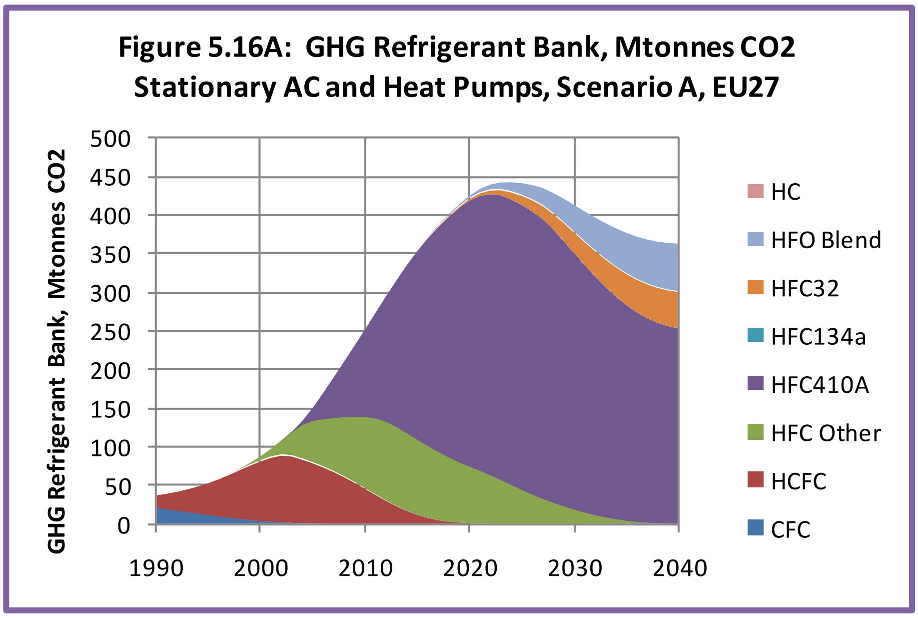
5.3.4. Transport Refrigeration Sector

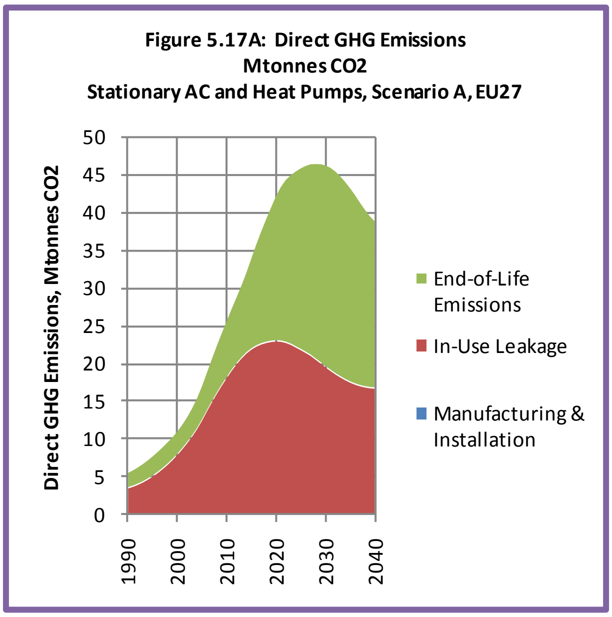
A significant part of this sector uses HFC 404A. There are relatively few short term options apart from medium GWP HFCs. In the longer term (from around 2020) demand is expected to reduce through the introduction of HFO blends and CO_2.

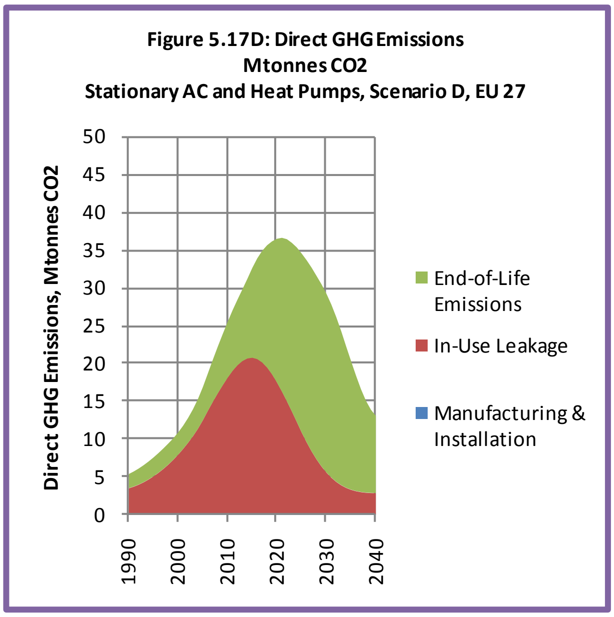


5.3.5. Stationary Air-Conditioning and Heat Pumps (air to air) Sector

This is a crucial sector because of rapid market growth. The bank, HFC demand and direct GHG emissions are forecast to grow dramatically from 2010 levels. It is unlikely there will be a cost effective non-flammable low GWP alternative in the short term (e.g. before 2020). This means that there will be slow progress away from medium GWP fluids such as HFC 410A unless the use of mildly flammable refrigerants becomes acceptable.







The energy use characteristics of this market are very important. HFC 410A is the current standard refrigerant for many systems in this market and it delivers very good energy efficiency.

Key constraints on the use of alternatives are the rules that apply to the use of mildly flammable refrigerants. Some of the most promising alternatives cannot be used because of national level fire regulations. There could be significant “institutional” barriers to the more widespread use of mildly flammable fluids.

5.3.6. Chillers and Hydronic Heat Pumps Sector

This is also a rapidly growing market, with increased demand for air-conditioning and growing popularity of heat pumps. There are a wider range of technical alternatives than for the small air-to-air air-conditioning sector. The graphs below show a significant difference in refrigerant bank between Scenarios A and D. Note that although ammonia and HFOs are in the mix of refrigerants (and hence shown in legends of the graphs below) they are not visible in the plots because of zero or very low GWPs.

Figure 5.18A: GHG Refrigerant Bank Mtonnes CO2 Chillers and Hydronic Heat Pumps Scenario A, EU 27

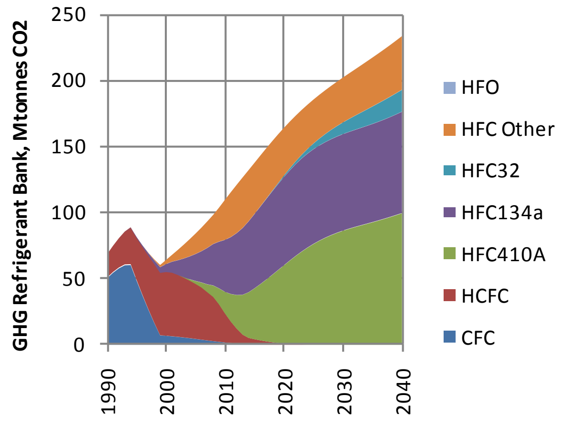
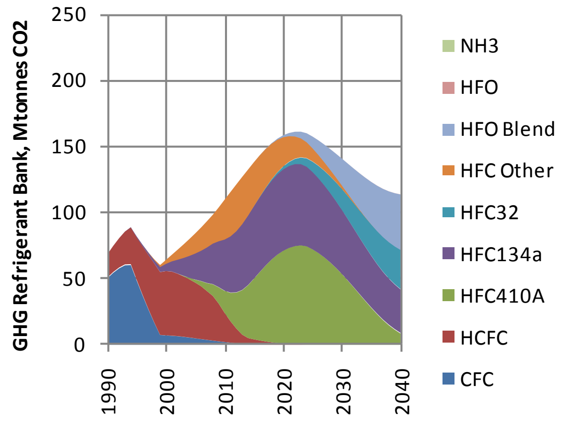


Figure 5.18D: GHG Refrigerant Bank Mtonnes CO2 Chillers and Hydronic Heat Pumps Scenario D, EU 27



5.3.7. Mobile Air-Conditioning Sector

Through the MAC Directive this large market sector will achieve a significant move away from HFCs during the next 10 years. Most of the small residual demand is for larger vehicles such as buses and trains.

In the MAC sector there is a small difference between demand and consumption due to a small net export of cars.

Figure 19A: GHG Refrigerant Bank Mtonnes CO2 Mobile AC, Scenario A, EU27

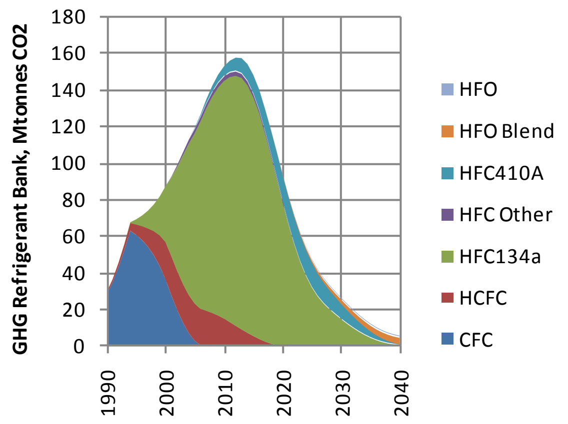
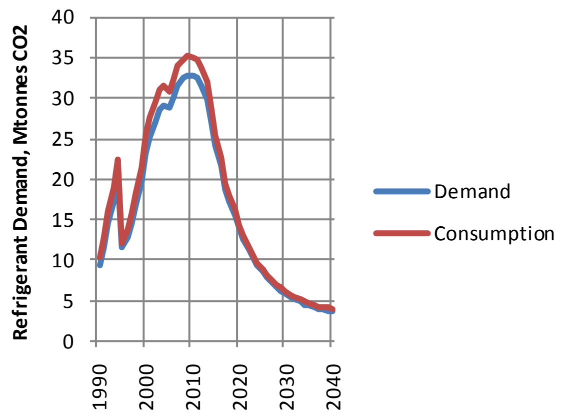


Figure 5.20A: Refrigerant Demand and Consumption, Mtonnes CO2 Mobile AC, Scenario A, EU27



5.4. Environmental Benefits of Heat Pumps

The SKM Refrigerants Model provides a useful assessment of the environmental benefits of using heat pumps. The model provides an estimate of the total amount of heating provided by heating only heat pumps and by reversible air-conditioning / heat pump systems. Table 5.3 shows the key outputs from the model under Scenario A.

Table 5.3: Assessment of Heat Pumps

		2010	2020	2030	2040
Heat Supplied by heat pumps	TWh	600	1,000	1,300	1,500
Gas use avoided	TWh	700	1,300	1,600	1,900
Electricity used by heat pumps	TWh	230	420	530	600
Grid emissions factor	kg CO_2 per kWh	0.41	0.32	0.23	0.14
Energy CO_2 reduction	Mtonnes CO_2	30	100	170	260
Annual direct refrigerant emission	Mtonnes CO_2	22	42	49	43
Allocation of direct emission to HPs	Mtonnes CO_2	5	10	15	12
Net benefit of heat pumps	Mtonnes CO_2	25	90	155	248

It should be noted that many of the systems in Table 5.3 are reversible air-conditioning / heat pumps. Many reversible systems are purchased primarily for the air-conditioning capability, with heat supply as a secondary benefit. It is reasonable to allocate the direct emissions between the air-conditioning and heat pumping activities. In 2010 there are only a small number of heating only systems, hence only a small allocation is given to heat pumps. The proportion of heating only heat pumps (or reversible systems purchased primarily for heating capability) will probably increase, hence the allocation to heat pumps in Table 5.3 gets higher in the later years.

This data shows the large environmental benefits of heat pumps, especially when the average EU grid carbon emissions factor falls below 0.2 kg CO_2 per kWh. Highlights from this data include:

- The emission reduction from heat pumps is much greater than the emission reductions that will be achieved by HFC phase down in RAC markets. In 2030 heat pumps are forecast to save around 155 Mtonnes CO_2 compared to around 65 Mtonnes CO_2 that may be saved from HFC phase down in RAC sectors.
- The direct refrigerant emissions are much lower than the heat savings being achieved, even under Scenario A, which gives a very conservative forecast of the use of alternative refrigerants. For example in 2030 the direct emissions allocated to heat pumps are under 10% of the energy related emission saving. Under Scenario D, the impact of direct emissions is even lower than that illustrated in Table 5.3.
- This shows how important it is to find an alternative refrigerant for heat pumps that can help deliver maximum heat pump COP. A medium GWP refrigerant with high COP will deliver more CO_2 savings than a very low GWP refrigerant that would result in a lower COP. A poorly considered restriction of the use of medium GWP refrigerants for heat pumps could result in an overall increase in GHG emissions.

5.5. Economic Analysis

One of the most important aspects of the SKM Refrigerants Model is the economic modelling capability. As described in Section 3.4, the various operating costs are calculated for each scenario on an annual basis (including annualised capital cost, energy cost and maintenance cost) and the relevant direct and indirect emission reductions are also calculated. These data are used to compare the impact of each scenario with the base case (Scenario A) and hence to make an estimate of the cost of CO_2 saved in € per tonne CO_2 saved. Results from this analysis are presented in this section of the report.

5.5.1. Reduction in GHG Emissions

Table 5.4 shows the reduction in GHG emissions for each main market sector and each scenario.

Table 5.4: Reduction in Gross Emissions (Mtonnes CO_2) - relative to Scenario A, 2030

	B	C	D
1 - Domestic Refrigeration	0.1	0.1	0.1
2 - Commercial Refrigeration	24.2	34.6	34.6
3 - Transport Refrigeration	0.9	1.4	1.4
4 - Industrial Refrigeration	2.7	5.2	5.4
5 - SAC and Heat Pumps	14.5	15.4	16.9
6 - Chillers & Hydronic Heat Pumps	5.0	5.8	5.8
7 - Mobile AC	2.3	2.5	2.5
Total	**49.6**	**64.8**	**66.6**

This shows a general progression from Scenario B, with an emission reduction of 50 Mtonnes CO_2 in 2030 up to Scenario D with a reduction of around 67 Mtonnes.

It is useful to note the high emission reduction potential in the Commercial Refrigeration sector – at around 50% of the total. This emphasises the importance of getting good engagement with end users in the commercial sector.

The 3 sectors that make most use of HFC 404A are commercial, transport and industrial refrigeration. These 3 sectors represent between 56% of the total emission reduction for Scenario B and 64% for Scenario C. There is good potential for an early phase down in HFC 404A use (see Section 5.6) – these data show the significant impact such an approach might have.

5.5.2. Cost of Abatement

Table 5.5 shows the cost of CO_2 abatement for each main market sector and each scenario, using “mid-case assumptions”. The cost of abatement is very sensitive to input assumptions. The data in Table 5.5 uses assumptions that can be considered a mid-case. The impact of high and low assumptions is discussed below.

Table 5.5 shows that for the whole RAC market, the abatement cost ranges between €15 per tonne CO_2 for Scenario B and €25 per tonne CO_2 for Scenario D. Scenario D has the highest emission reduction (see Table 5.4). Scenario C achieves a slightly lower emission reduction but the abatement cost is also slightly lower.

Table 5.5: Abatement Cost (€/tCO2) - relative to Scenario A, 2030, mid-case

	B	C	D
1 - Domestic Refrigeration	-119	-95	-95
2 - Commercial Refrigeration	15	23	23
3 - Transport Refrigeration	5	-11	-11
4 - Industrial Refrigeration	10	-1	16
5 - SAC and Heat Pumps	24	27	45
6 - Chillers & Hydronic Heat Pumps	-7	4	4
7 - Mobile AC	7	11	11
Total	**15**	**19**	**25**

The table also shows that the abatement cost varies considerably in different parts of the market. The domestic, transport and industrial sectors show negative abatement costs for at least one scenario – that means that the cost benefits of reduced energy consumption are higher than the extra capital and maintenance costs. Industrial refrigeration has a small negative abatement cost under Scenario C due to the impact of low cost alternatives to HFC 404A. The costs in commercial refrigeration are higher because of the higher capital cost of CO_2 refrigeration systems. The SAC and chiller sectors both have somewhat higher abatement costs because the input assumptions assume no energy cost benefit (because of the need to meet Eco Design targets).

The data used to establish the overall abatement cost can be broken down into constituent parts to illustrate the main drivers behind the abatement cost. This is illustrated in Figure 5.21. The left hand chart shows the split of emission reduction between direct and indirect. The right hand chart shows the increase in cost split between annualised capital, energy and maintenance.

In this example the extra capital and maintenance costs are greater than the energy savings, hence there is an overall net increase in costs.

Figure 5.21: Sector: 2 - Commercial Refrigeration

Scenario: D, 2030

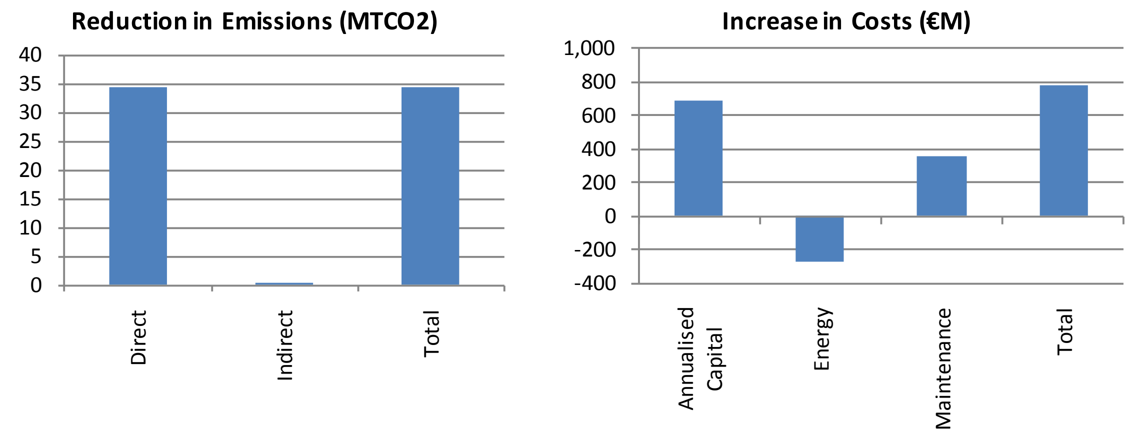
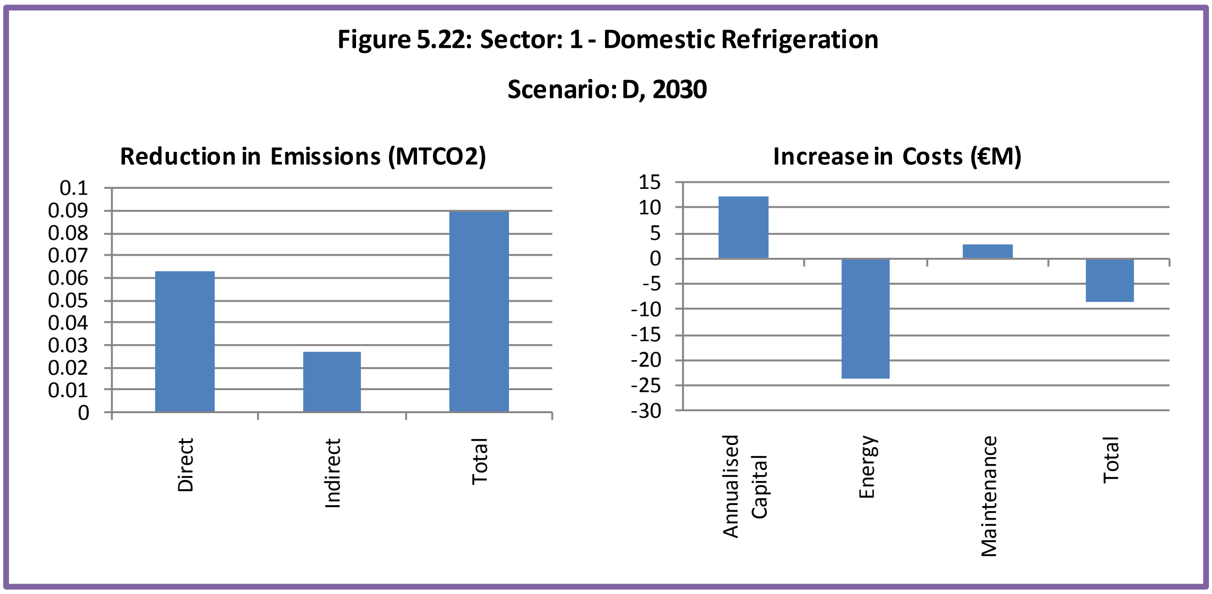


Figure 5.22 shows another example, for domestic refrigeration. The energy efficiency gain dominates the costs, providing energy cost savings that are higher than the increased capital and maintenance cost – hence a negative cost increase and a negative cost of abatement.



5.5.3. Sensitivity of Abatement Costs to Input Assumptions

The abatement cost calculations are quite sensitive to the input parameters and can swing from negative values to nearly €100 per tonne CO_2 for apparently small changes in input values. The 3 key parameters are:

a) The capital cost factor i.e. the extra capital cost for an alternative refrigerant compared to the standard refrigerant.

b) The maintenance cost factor i.e. the difference in maintenance cost applied to the 3 refrigerant groups described in Section 3.4.

c) The energy efficiency factor i.e. the change in efficiency for an alternative refrigerant compared to the standard refrigerant.

The abatement costs given in Table 5.5 are for mid-case values of the 3 parameters described above. Sensitivity tests have been carried out using high and low values for each parameter. Examples of high, mid and low values are given in Table 5.6.

Table 5.6: Sensitivity Testing - Example Values

		Low	Mid	High
Capital cost factor		50%	100%	150%
Energy efficiency factor		5%	7.5%	10%
Maintenance cost per year (% of capital)	Group 1: e.g. HFC 134a, 410A	3%	3%	3%
	Group 2: e.g. HFC 32, HFOs	3.05%	3.1%	3.15%
	Group 3: HCs, ammonia, CO_2	3.1%	3.2%	3.3%

The results of sensitivity tests are given in Table 5.7. These show a significant variation from the mid-case. For example Scenario D has a mid-case of €25 per tonne CO_2, with a low value of €7 and a high value of €43.

Bearing in mind that the model is trying forecast performance and cost of new or developing technologies in 2030 it is not surprising that there is a high level of uncertainty about the key input parameters. It is important to be aware of these uncertainties and take them into account during the policy development process. It is believed that the abatement cost values in Table 5.7 give a realistic representation of the range of uncertainty in these values.

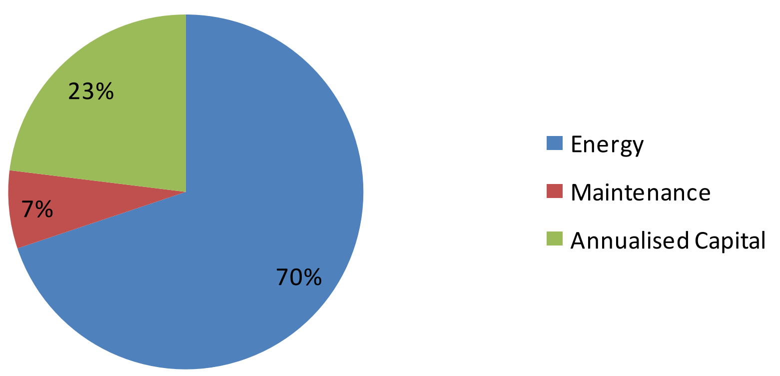
Table 5.7: Abatement Costs Sensitivity Results

	Abatement Costs € per tonne CO2		
Scenario:	**B**	**C**	**D**
High capital, high maintenance, low efficiency	25	34	43
Mid-case values	15	19	25
Low capital, low maintenance, high efficiency	4	4	7

5.5.4. Split of Operating Costs

The economic modelling data provides information about capital, energy and running costs. When calculating abatement costs the model looks at differences in cost between each Scenario and the base case, as illustrated in Figures 5.21 and 5.22. The absolute values of this data can be used to show the overall split of operating costs. This is shown in Figure 5.23. The data shows the dominance of energy in the overall cost balance and emphasises the importance of getting the right balance between capital cost and energy efficiency (i.e. it is worth spending more capital if the energy efficiency can be improved.

Figure 5.23: Split of Operating Costs, All RAC Sectors, Scenario A, 2030



5.5.5. Environmental Benefits of Unrelated Efficiency Investments

This study provides a detailed analysis of the costs and benefits of HFC phase down. As shown in Table 5.4 the overall emission reduction potential of HFC phase down in RAC sectors is around 67 Mtonnes CO_2 in 2030. It is worth emphasising that the energy related emissions from all RAC sectors are about 5 times higher than this i.e. around 300 Mtonnes CO_2. Projects that can improve the energy efficiency of RAC systems must be given appropriate emphasis and should not be ignored by focussing too much effort on phase down issues.

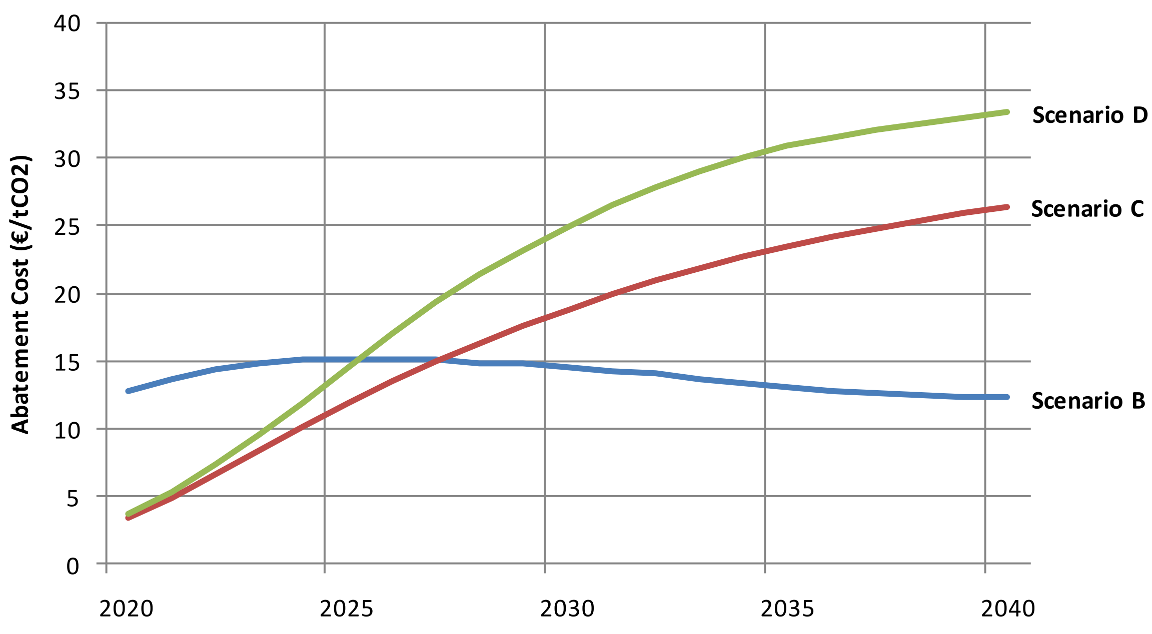
An interesting example is the opportunity to reduce energy use in commercial refrigeration through the use of doors on chilled display cases. The SKM Refrigerants Model shows that the annual energy related emissions from commercial refrigeration are around 50 Mtonnes CO_2 in 2030. It is estimated that between 10 and 15 Mtonnes CO_2 could be saved by fitting doors to all display cases. The abatement cost for this measure is zero or negative, as the cost of installing doors is offset by the energy cost reductions.

There are numerous ways in which energy efficiency of RAC systems can be improved. It is vital that suitable policy measures are in place to maximise such improvements.

5.5.6. Variation in Cost of CO_2 Saved by Year

The abatement cost (in €/tCO_2) is calculated for a particular year (2030 has been chosen as the assessment year for this study). However, the actual cost €/tCO_2 will vary from year to year. Capital costs are annualised and spread over the life of the equipment. Energy, maintenance and retrofill costs (if applicable) are allocated to the year in which they arise. Figure 5.24 provides an illustration of how the costs will vary for each of the scenarios.

Figure 5.24: Variation of Cost of CO_2 Saved, by Year



There are a number of points to notice from this graph:

- The low values for Scenarios C and D from 2020 to around 2025 correspond with the period following the accelerated phase out of R404A. By this time, there are few ongoing costs due to the R404A retrofill, but benefits are being accrued by the lower GWP and expected improvement in energy efficiency.
- The abatement costs for Scenario B fall to around 15 €/tCO_2, by 2040, while that for Scenarios C and D approach 30 and 35 €/tCO_2 respectively. This is mainly due to the significant benefits of the "Low Leakage" component of Scenario B, without significant increase in costs.
- It is important to note the accumulated benefit of the early phase-out of R404A, in Scenarios C and D during the 2018 to 2030 period. Although not permanent in relative terms, this benefit is significant and in 2020 alone accounts for reduction in emissions of around 22 Mtonnes CO_2 (compared to Scenario B), at a marginal abatement cost of around -5 €/tCO_2 (negative, representing a marginal cost saving).

5.6. Early Phase Down for HFC 404A

Table 2.2 shows that HFC 404A[9] represents 44% of GWP weighted consumption of refrigerants in 2010. The SKM Refrigerants Model shows that HFC 404A accounts for around 46% of direct emissions in the period 2015 to 2020, under Scenario A. The main uses of HFC 404A are in the commercial, industrial and transport refrigeration sectors. It is not used in any of the air-conditioning sectors or in domestic refrigeration.

The reason for the dominance of HFC 404A in the above figures is that the GWP is so high compared to "medium GWP" refrigerants such as HFC 134a and HFC 410A. Table 5.8 shows a comparison of refrigerant GWPs. HFC 404A has around twice the GWP of HFCs 407A and 410A and 3 times the GWP of HFC 134a.

Table 5.8: Comparison of GWPs

Refrigerant	GWP[10]	% of HFC 404A GWP
HFC 404A	3,922	100%
HFC 507	3,985	102%
HFC 407A	2,107	54%
HFC 410A	2,088	53%
HFC 407F	1,825	47%
HFC 134a	1,430	36%
HFC 32	675	17%

[9] Please note that HFC 507 is used for very similar applications to HFC 404A and it has a similar GWP. In the EU HFC 404A represents over 95% of the consumption of these 2 gases. In the SKM Refrigerants Model we have combined the consumption of both gases and simply refer to HFC 404A.

[10] GWPs based on IPCC 4th Assessment Report

Recent reports such as Oko Recherche 2011, Erie Armines 2011 and TEAP 2012 do not highlight the important opportunity related to an early phase down of HFC 404A – indeed TEAP 2012 refers to a single group of "medium / high GWP" refrigerants that include HFC 134a in the same group as HFC 404A, despite the factor of 3 difference in their GWPs. This over-simplifies the categorisation of refrigerants and gives policy makers poor guidance about the best options available for HFC phase down. None of the above reports makes proper reference to early use of other medium GWP refrigerants for new equipment in the short term, or to the possibility of retrofilling existing systems with an alternative.

HFC 404A has helped the market move from ozone depleting refrigerants but it has often been used in non-ideal circumstances. It was designed as a replacement for CFC 502, which was historically used in low temperature systems such as frozen food retail displays. CFC 502 was never used for chilled food displays – most commercial end users used CFC 12 as it was a more efficient refrigerant at medium temperature. However, when end users moved from CFC 502 to HFC 404A many of them took the opportunity to rationalise their use of refrigerants and used HFC 404A for medium temperature systems as well. This significantly increased the demand for HFC 404A and also reduced the efficiency of many medium temperature systems.

HFC 404A is still the refrigerant of choice for many end users investing in new equipment. There are more efficient alternatives for all medium temperature systems such as HFC 134a and HFC 407A / 407F. It is beneficial in cost terms to use such alternatives, but HFC 404A remains popular due to familiarity amongst both end users and refrigeration contractors. For low temperature systems there are alternatives with equal or better efficiency.

Some end users, especially large supermarkets have recognised that there is also a good opportunity to retrofill existing stationary refrigeration systems using HFC 404A with either HFC 407A or 407F. These refrigerants have been reported to improve energy efficiency by between 7% and 12% on medium temperature systems and 2% and 5% on low temperature systems. In stationary refrigeration systems, the cost of retrofill may be paid for by the energy savings with a payback period in the range of 1 to 3 years (depending on system size and retrofill procedure).

Avoiding the use of very high GWP refrigerants has the dual benefit of reducing direct emissions by between 50% and 70% (assuming equal leakage rates). HFC phase down policies should help end users understand the opportunity. Policy makers need to understand that the short term use of extra medium GWP HFCs will be beneficial to the environment. In the period 2013 to 2018 the use of HFC 404A can be substantially reduced via use of medium GWP alternatives. In that period very low GWP refrigerants such as CO_2 can also be used, but only on new systems. By 2018 lower GWP HFO based blends should be available that can be used in place of medium GWP refrigerants.

Scenarios C and D both include:

a) retrofill of HFC 404A in 50% to 75% of existing stationary refrigeration systems (in the industrial and commercial sectors) during the period 2014 to 2017 (actual % and dates are sub-sector specific)

b) avoidance of use of HFC 404A in new systems from 2015 to 2019 (date varies by sector)

These measures combine high levels of emission reduction with reasonable abatement cost. Figures 5.25 and 5.26 show an interesting comparison of EU refrigerant demand for all refrigerants (top figure) and for HFC 404A (lower figure). The HFC 404A only curve for Scenarios C and D (identical curves, hence only one shows on graph) show much deeper cuts in demand and a much earlier impact, between 2015 and 2020.

An even earlier start and faster move away from HFC 404A is technically feasible. This would result in improved environmental benefits, although it is unlikely that legislation could come into effect fast enough for this to be achieved.

Figure 5.25: Refrigerant Demand, All Refrigerants, Mtonnes CO2

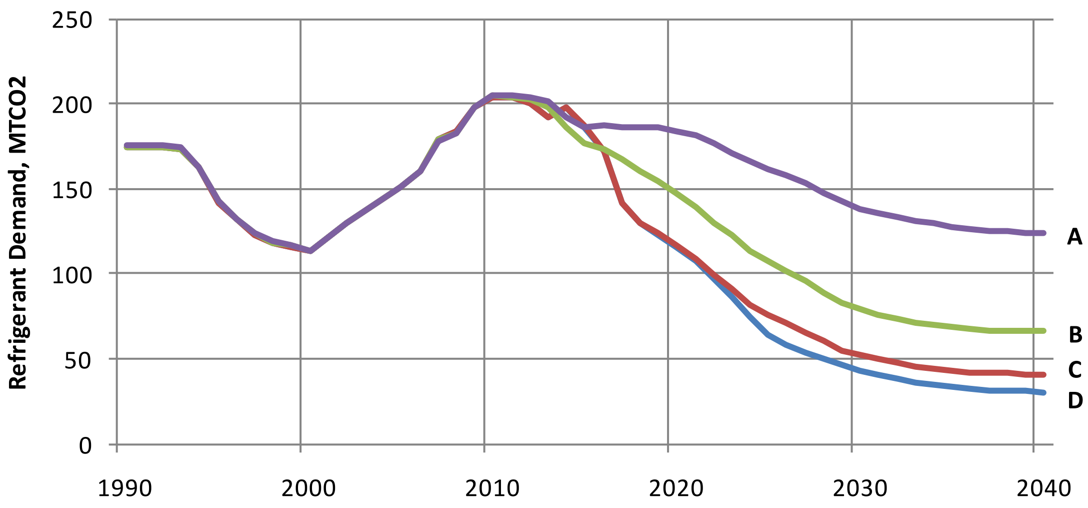
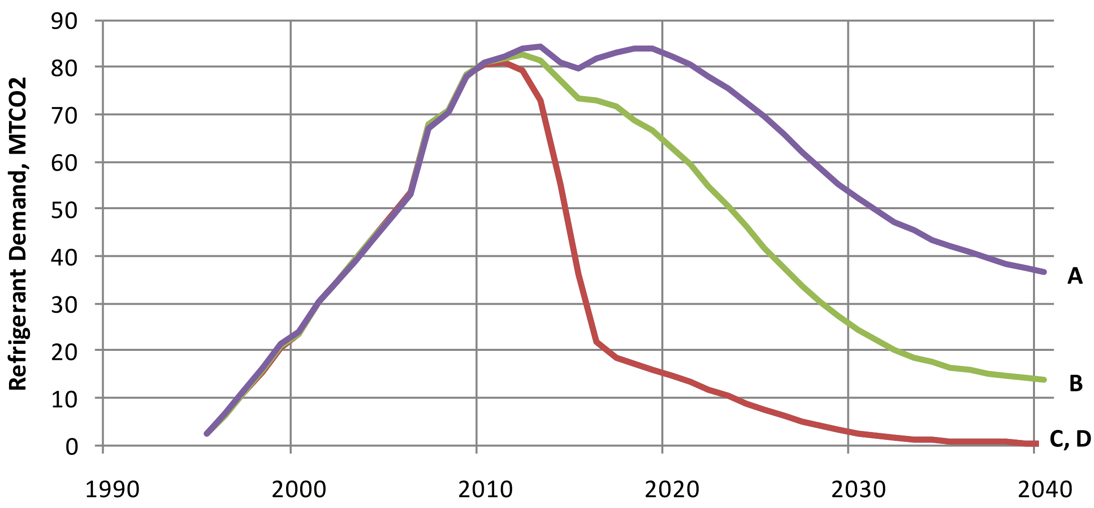


Figure 5.26: Refrigerant Demand, HFC 404A, Mtonnes CO2



5.6.1. Timing of Phase Down Steps

As described above, there is excellent potential for early emission reductions via a policy that will encourage the move away from HFC 404A. This is such an important early opportunity that policy makers should consider a 2-stage approach as follows:

a) An early phase down that concentrates only on the high GWPs refrigerants i.e. HFC 404A and HFC 507. This should provide a clear message to end users that the on-going use of these refrigerants should be minimised.

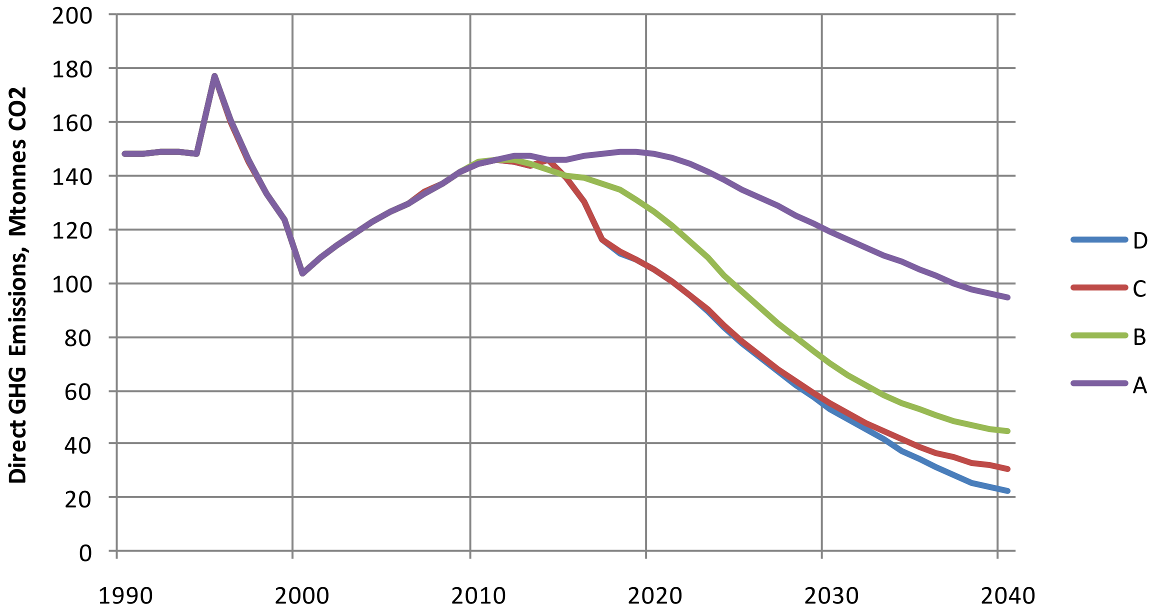
b) A second phase down profile that applies to other HFCs. This can start somewhat later, allowing the technical development of alternatives such as CO_2 and HFO blends to be completed before phase down starts.

A dual approach of this type can maximise the cumulative benefits of phase down.

5.7. Reductions in Emissions

Figure 5.27 below shows a comparison of the forecast of total direct GHG emissions for each of the 4 main scenarios. By 2030 the emission reductions achieved compared to 2010 are 74 Mtonnes CO_2 for Scenario B and 91 Mtonnes CO_2 for Scenario D.

Figure 5.27: Direct Greenhouse Gas Emissions, Mtonnes CO2
All RAC Sectors, EU27



Scenarios C and D both show the benefit of an early, active move away from the use of R404A, as described in Section 4.6 above. This is illustrated in more detail in the charts 5.28A to 5.28D below.

Figure 5.28.A
Direct Greenhouse Gas Emissions
Mtonnes CO2, All RAC Sectors, EU27
Scenario A

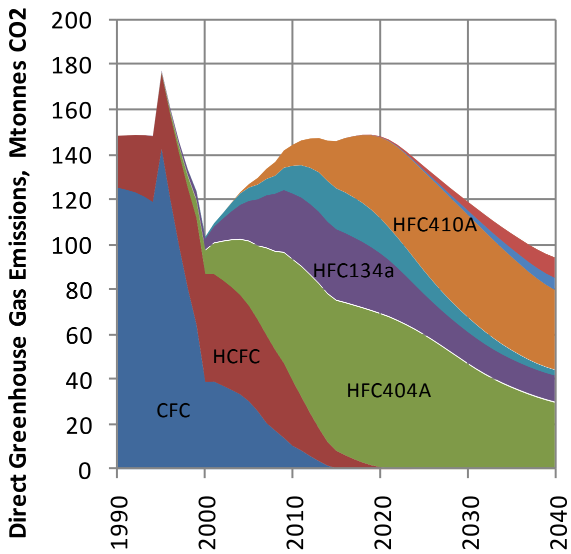
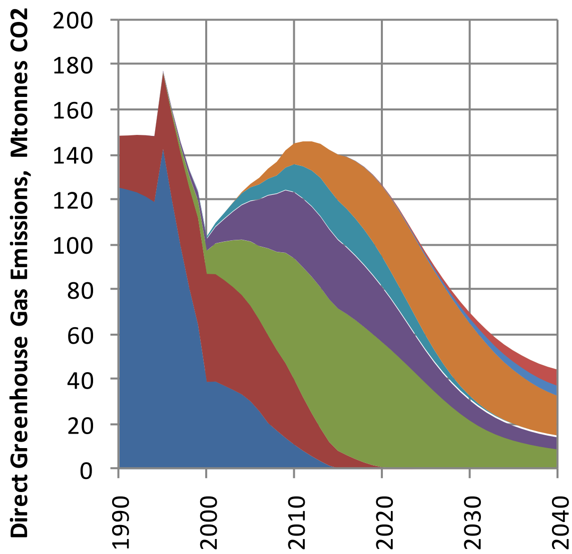


Figure 5.28.B
Direct Greenhouse Gas Emissions
Mtonnes CO2, All RAC Sectors, EU27
Scenario B



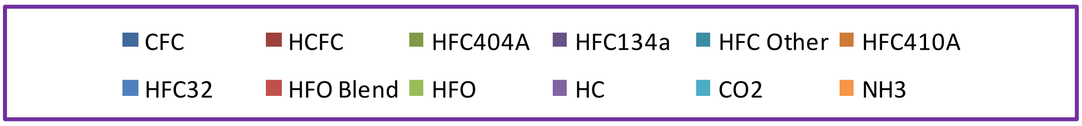


Figure 5.28.C
Direct Greenhouse Gas Emissions
Mtonnes CO2, All RAC Sectors, EU27
Scenario C

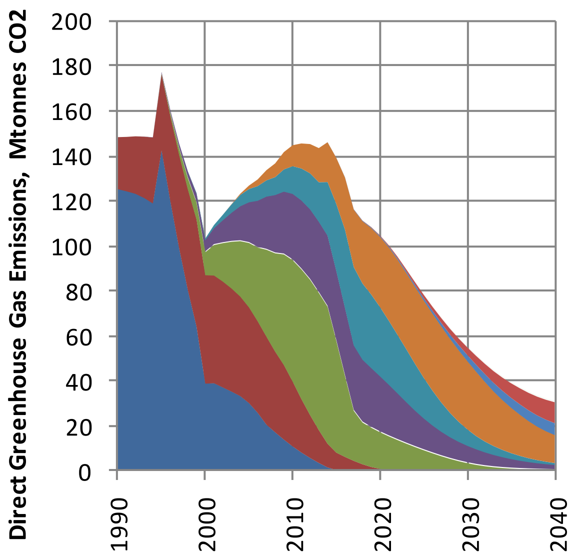
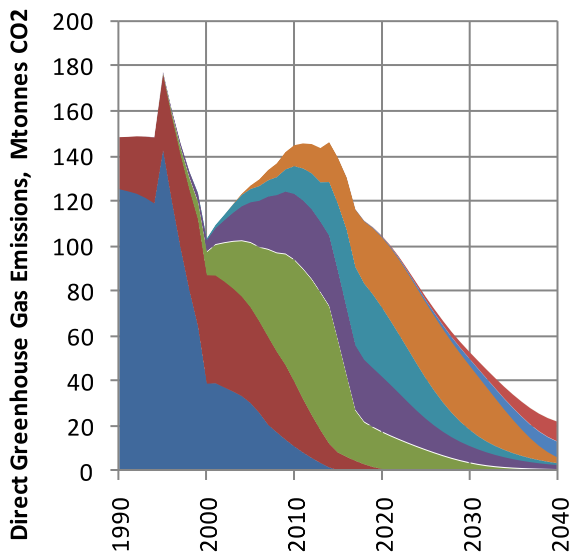


Figure 5.28.D
Direct Greenhouse Gas Emissions
Mtonnes CO2, All RAC Sectors, EU27
Scenario D



6. Interaction with non-RAC Market Sectors

The RAC sectors are responsible for around 80% of F-Gas emissions. As shown in Table 1.1, other HFC applications account for around 12% of emissions in 2010 and are forecast to represent 15% in 2030 (Öko-Recherche 2011). The remainder of the emissions are from PFC and SF_6 sources.

The PFC and SF_6 sources are mainly from a small number of specialised industrial uses; in particular from: magnesium smelting, high voltage switchgear, aluminium smelting and semiconductor manufacture. None of the current phase down proposals for HFCs include PFCs and SF_6 as it is believed that the best policies to reduce these emissions should be customised to the relevant end users (e.g. bans for SF_6 in magnesium smelting, voluntary agreements with high voltage switchgear users etc.).

If HFC phase down is adopted either in the EU or internationally, it will be important to consider the non-RAC emissions and how these might influence the overall phase down profile. No new research has been carried out in the non-RAC sectors during this study, but it is helpful to use data available from Öko-Recherche 2011 and SKM Enviros 2011 to consider costs of phase down in these sectors.

The key non-RAC uses of HFCs are:

- Technical aerosols
- Medical aerosols
- Foam blowing
- Fire protection

In the following sections we summarise key information about emissions from these sectors.

6.1. Technical Aerosols

Most aerosols (e.g. for consumer products such as hair sprays, cleaning fluids etc.) use flammable propellants (such as HCs or dimethyl ether) as they are effective propellants, cheap and have very low GWP. However, in some markets the use of flammable propellants is considered too dangerous e.g. where there is an ignition source and the aerosol is used in a confined space. In these situations a non-flammable propellant is required. HFCs are used as an aerosol propellant for a number of specialised technical aerosols e.g. air dusters, freezer sprays, lubricants, solvents, safety devices etc. The majority of HFC propellants are HFC 134a.

Two aerosol markets that historically used HFC propellants have HFC bans under the 2006 F-Gas Regulation i.e. one component foam (HFCs banned in 2008) and novelty aerosols (HFCs banned in 2009). The one component foam market has moved to flammable propellants as it was shown these can be used safely. The novelty aerosol market still requires a non-flammable propellant in many applications – novelty aerosols are now manufactured using a newly developed non-flammable propellant – HFO 1234ze.

Öko-Recherche 2011 states that 95% of technical aerosols could move from HFC 134a to HFO 1234ze by 2030. They show a cost of abatement of €10 per tonne CO_2 saved. This corresponds to a similar cost assessment made in SKM Enviros 2011. The main element of cost is the price difference between HFC 134a and HFO 1234ze. It can be expected that this price difference might fall as larger quantities of HFO 1234ze are produced.

Given the successful move to HFO 1234ze in the novelty aerosol sector (achieved by 2010) there seem to be few technical barriers to prevent all technical aerosols moving away from HFCs within a fairly short timescale. The commercial barriers are (a) possible shortage of supply of HFO 1234ze and (b) the price increase created by the difference in propellant price. The easiest way of forcing a move away from HFCs would be a ban in the revised F-Gas Regulation. A ban from 2015 is feasible although a later ban e.g. 2018 could also be considered. Without a ban the aerosol sector would simply be part of the phase down process. Aerosol manufacturers would need to make commercial decisions about how long to continue using HFC 134a.

6.2. Medical Aerosols

Medical aerosols, known as metered dose inhalers (MDIs), are used to dispense drugs for a number of lung diseases including asthma and chronic obstructive pulmonary disease. All MDIs use HFC propellants – the majority use HFC 134a and around 5% use HFC 227ae.

Öko-Recherche 2011 has made no comments about opportunities to reduce use and emissions of HFCs from MDIs. SKM Enviros 2011 has reviewed MDI alternatives and costs.

It would take at least 10 years to develop a new propellant for MDIs because of the extremely detailed toxicity tests that would be required. In the period to 2030 it is unlikely that MDIs could switch to another propellant. However, there are two other opportunities to reduce MDI emissions. These are:

a) To change the design of MDIs to use less propellant per dose. This has recently been done by one major manufacturer – it should reduce emissions in the EU by around 15%.

b) To use dry powder inhalers (DPIs) instead of MDIs. All drugs available as MDIs are also available as DPIs. However, some doctors and patients prefer MDIs as they are considered more convenient. A small proportion of patients cannot use DPIs as they rely on a fairly sharp intake of breath. It is interesting to note that the split of drugs administered by MDIs versus DPIs varies considerably between different countries. This is illustrated in Table 6.1. The highest proportion of DPI use is around 65% for Japan and China. The EU is at the average level of 38%.

The cost of moving from MDIs to DPIs is difficult to establish because of the way that different drugs are priced and the impact of bulk sales to national health authorities. SKM Enviros 2011 indicates a range of cost between €50 and €200 per tonne CO_2 saved. However, the fact that some countries already use a lot more DPIs implies that the cost difference could be smaller than this. Combining the impact of valve design and some shift towards DPIs in the EU it is reasonable to expect a cut of 30% to 50% in MDI use and emissions by 2030.

It is worth noting that the EU is a major exporter of MDIs. The difference in actual EU demand and Montreal Protocol consumption is likely to be considerable in this market.

Table 6.1: Regional Variation in Use of MDIs and DPIs

Geographic Area	MDI (million doses)	DPI (million does)	% DPI
Russia and Ukraine	600	50	8%
North America	7,700	2,500	25%
Australia	1,050	400	28%
Latin America	1,000	500	33%
Other Africa / Asia	2,000	1,100	35%
EU top 5	9,000	5,500	38%
India	1,300	1,000	43%
New EU Entrants	750	1,000	57%
Other	1,600	2,500	61%
Japan	420	800	64%
China	80	150	65%
World	**25,500**	**15,500**	**38%**

6.3. Foam Blowing

The foam market has 4 distinct parts which each face different technical challenges in terms of moving to alternatives. These are:

a) Factory produced thermosetting foams including rigid polyurethane (PU) foam and similar products such as polyisocyanurate foam (PIR) and phenolic foam.

b) Extruded polystyrene foam (XPS).

c) Sprayed PU foam (made in-situ at end user site).

d) One component foam (dispensed via aerosols, already subject to HFC ban – see Section 6.1).

Current Blowing Agents

A large part of the market for thermosetting foams has moved to HCs. This has led to raw material cost savings, although a significant capital investment is required to move to this technology. Factories producing large quantities of PU foam have found this to be cost effective, although smaller producers cannot shift to HCs so easily. A negative aspect of HCs is that they have poorer insulating qualities than HFCs – which could lead to higher energy related CO_2 emissions in some circumstances e.g. in domestic appliances where insulation thickness is restricted by the appliance size. The parts of the market for factory produced thermosetting foams that still use HFCs are those that (a) are only made in small quantities, (b) require either maximum thermal performance or (c) require the lowest possible product flammability. HFCs used to manufacture PU are either HFC 245fa or blends of HFC 365mfc + HFC 227ea.

Some of the XPS market has moved to using CO_2 as a blowing agent, but this has proved technically challenging, with some restrictions on product thicknesses still prevailing. A large part of the current HFC consumption in foams relates to the use of HFCs to manufacture XPS. HFCs used to manufacture XPS are either HFC 134a or blends of HFC 134a + HFC 152a.

Spray foam is primarily used to service the building refurbishment market. It is used to spray insulating foam onto a building in situ and requires a non-flammable blowing agent. It is a popular market in Spain and Portugal, where an HFC 365mfc/227ea blend is typically used.

Future Options

In the last 12 months there has been good progress made with new generation very low GWP fluids that can be used as blowing agents. HFO 1234ze, which is already commercially available, is showing good performance for XPS. Another product under development "HBA2" has shown good results with PU and similar types of foam and FEA-1100 has also been successfully tested. In recent trials both XPS and PU foams made with these new blowing agents have been of good quality and, most importantly, have an improved insulation value compared to HFCs and the recently used alternatives (HCs and CO_2). There are also potentially a number of oxygenated HCs which could also be used as blowing agents (e.g. methyl formate).

Öko-Recherche 2011 indicates that the whole foam market can move away from HFCs by 2030, with some factories moving to HCs and others adopting the new HFO blowing agents. Costs, which vary between different parts of the foam market, are in the range €0 to €5 per tonne CO_2 saved. SKM Enviros 2011 indicates an approximate cost of €10 per tonne CO_2 saved, although this was difficult to establish as the prices of new HFO blowing agents are not clear. There are still some technical barriers to be overcome i.e. to prove the effectiveness of new blowing agents and to demonstrate the conversion and reformulation requirements. If the insulation effectiveness is improved with the new blowing agents then there could be considerable lifetime cost benefits related to improved energy savings. Commercial barriers are similar to technical aerosols i.e. (a) availability of new blowing agents and (b) costs of conversion and (c) on-going higher price of blowing agent.

6.4. Fire Protection Systems

Historically, halons represented a significant part of the fire protection system (FPS) market. When halons were banned under the EU Ozone Regulations the majority of the old halon market moved to alternative technologies such as water mist or inert gases. A small proportion moved to HFCs. FPS represent around 1% of HFC consumption. The market for HFC fire protection is in a small niche in buildings containing high value equipment. Most of the market uses HFC 227ae which has a GWP of 3,220. A small number of systems use HFC 23 (GWP 14,800) and HFC 125 (GWP 3,500).

An alternative low GWP fluid with similar fire suppression performance to HFCs is available. This is a fluoro-ketone, FK 5-1-12, which has a GWP of 1. The main disadvantages of FK 5-1-12 are (a) it may require slightly more space for storing the required bottles of gas, (b) it is more expensive than HFCs and (c) it is only available from one manufacturer. In the UK the FK 5-1-12 share of the FPS gaseous chemical market has grown from around 20% in 2007 to nearly 50% in 2010, partly because of environmental impact and also because of recent price increases for HFC 227ae. Most of the large FPS specialist suppliers can offer both HFC and FK 5-1-12 solutions.

Öko-Recherche 2011 indicates that over 90% of the FPS market can move away from HFCs by 2030, with costs in the range €1 to €8 per tonne CO_2 saved. SKM Enviros 2011 estimates similar costs and identifies no technical barriers to using non-HFC alternatives in all new FPS.

6.5. Future HFC Consumption Profiles for non-RAC Sectors

Table 6.2 shows current demand for HFCs in the non-RAC sectors and a range of alternative demand scenarios based on the discussion in Sections 6.1 to 6.4.

The first scenario shows a BAU profile, with approximately constant demand for HFCs in all sectors. The low impact scenario assumes slow uptake of alternatives for technical aerosols, foam and fire protection with a 90% cut in HFC demand from around 2030. Demand for medical aerosols is only assumed to fall by around 25%. The high impact scenario assumes quicker uptake of alternatives for technical aerosols, foam and fire protection with a 100% cut in HFC demand from around 2020. Demand for medical aerosols is assumed to fall by around 50% by 2030 and 75% by 2040.

Table 6.2a: Demand Profiles in non-RAC HFC Markets – BAU Scenario

Market	**Demand kT CO_2** (for new equipment / products and aftermarket if relevant)			
	2010	2020	2030	2040
Technical aerosols	5,500	7,500	7,000	6,500
Medical aerosols	8,000	8,500	8,500	8,500
Foam	11,000	11,000	11,000	11,000
Fire protection	5,500	5,000	4,500	4,000
Total	**30,000**	**32,000**	**31,000**	**30,000**

Table 6.2b: Demand Profiles in non-RAC HFC Markets – Low impact Scenario

Market	**Demand kT CO_2** (for new equipment / products and aftermarket if relevant)			
	2010	2020	2030	2040
Technical aerosols	5,500	3,000	500	500
Medical aerosols	8,000	7,000	6,000	6,000
Foam	11,000	6,000	1,000	1,000
Fire protection	5,500	2,000	500	500
Total	**30,000**	**18,000**	**8,000**	**8,000**

Table 6.2c: Demand Profiles in non-RAC HFC Markets – High impact Scenario

Market	**Demand kT CO_2** (for new equipment / products and aftermarket if relevant)			
	2010	2020	2030	2040
Technical aerosols	5,500	Negligible[11]	Negligible	Negligible
Medical aerosols	8,000	6,000	4,000	2,000
Foam	11,000	Negligible	Negligible	Negligible
Fire protection	5,500	Negligible	Negligible	Negligible
Total	**30,000**	**6,000**	**4,000**	**2,000**

[11] Negligible because alternatives have very low GWPs (most are below 5)

7. HFC Phase Down Profiles

In this section of the report a comparison is made of HFC consumption and demand profiles, based on the SKM Refrigerants Model, and phase down proposals made by North America and scenarios developed by Oko Recherche for the EU.

7.1. Phase Down Proposals

Three different HFC phase down options have been evaluated. These are:

- the revised North American Proposal, issued in April 2010 (NA)
- EU Option RED
- EU Option RED 10

The baselines and the phase down steps in each option are slightly different.

Baseline Consumption

The baselines for each option, in tonnes CO_2 equivalent, are specified as follows:

NA proposal: HFC consumption + 85% HCFC consumption, average for 2005 to 2008

EU RED / RED 10: HFC consumption plus 25% of HCFC consumption, average for 2004 to 2006

The baseline values for each of the above have been calculated using outputs from the SKM Refrigerants Model for EU Consumption and EU Demand data for the relevant years. See Section 1.4 for a description of the difference between "Demand" (which takes into account pre-filled imported products) and "Montreal Protocol Consumption" (which only takes into account refrigerants sold in bulk). The baselines for each phase down option are given in Table 7.1. The "RAC" columns give the baseline based on RAC applications only and the "Total" columns include HFCs used in non-RAC Sectors (as discussed in Section 6).

Table 7.1: Baseline Consumption and Demand

Option	Baseline Consumption, MT CO_2		Baseline Demand, MT CO_2	
	RAC	Total	RAC	Total
NA	147	177	163	193
RED	111	141	124	154
RED 10	111	141	124	154

It is clear from Table 7.1 that the baselines for the NA and RED phase down options are significantly different. RED and RED 10 both have a baseline that is over 25% lower than NA.

Phase Down Steps

The allowable HFC consumption is defined by a series of cuts in the baseline consumption. Table 7.2 shows the phase down steps (note: phase down steps for RED A and RED B are the same – the difference between these proposals is the baseline). The RED options reach a lower level of phase down than the NA proposal (10% of baseline instead of 15%) and the rate of phase down is much faster. The final step in RED scenarios is 4 years earlier than the NA proposal (2029).

Table 7.2: Phase Down Steps

	2010	2014	2015	2016	2017	2018	2019	2020	2022	2025	2028	2029	2031	2033	2036	2041	2046
NA	100%	-	90%	-	80%	-		70%	-	50%		30%		15%			
RED	100%	85%	70%		-		50%	-	30%	15%	10%			-			
RED10	100%	85%				70%			60%				50%	40%	30%	20%	10%

A graphical comparison of the phase down options is given in Figure 7.1. This clearly shows that the NA proposal is less drastic than the EC RED option. In particular:

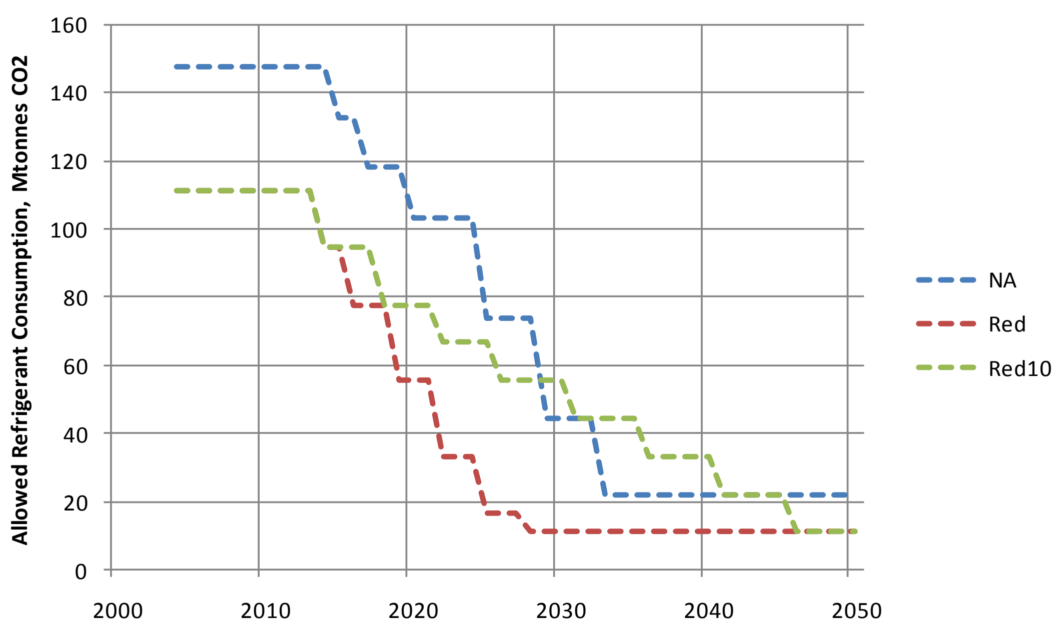
a) By 2020 the NA proposal requires a 30% cut in consumption from baseline. The RED option require faster early action with a 50% cut by 2019.

b) By 2025 the NA proposal requires a 50% cut in consumption – this level is reached 6 years later than the 50% cut under RED option. By 2025 the RED scenario requires an 85% cut – this is the level required by 2033 under NA proposals.

c) The final goal is a consumption of 15% of baseline in the NA proposals and 10% in RED.

d) The allowed baseline is more generous in the NA proposals than for RED and RED 10. Although RED 10 has a much slower series of cuts the final target is the same as RED.

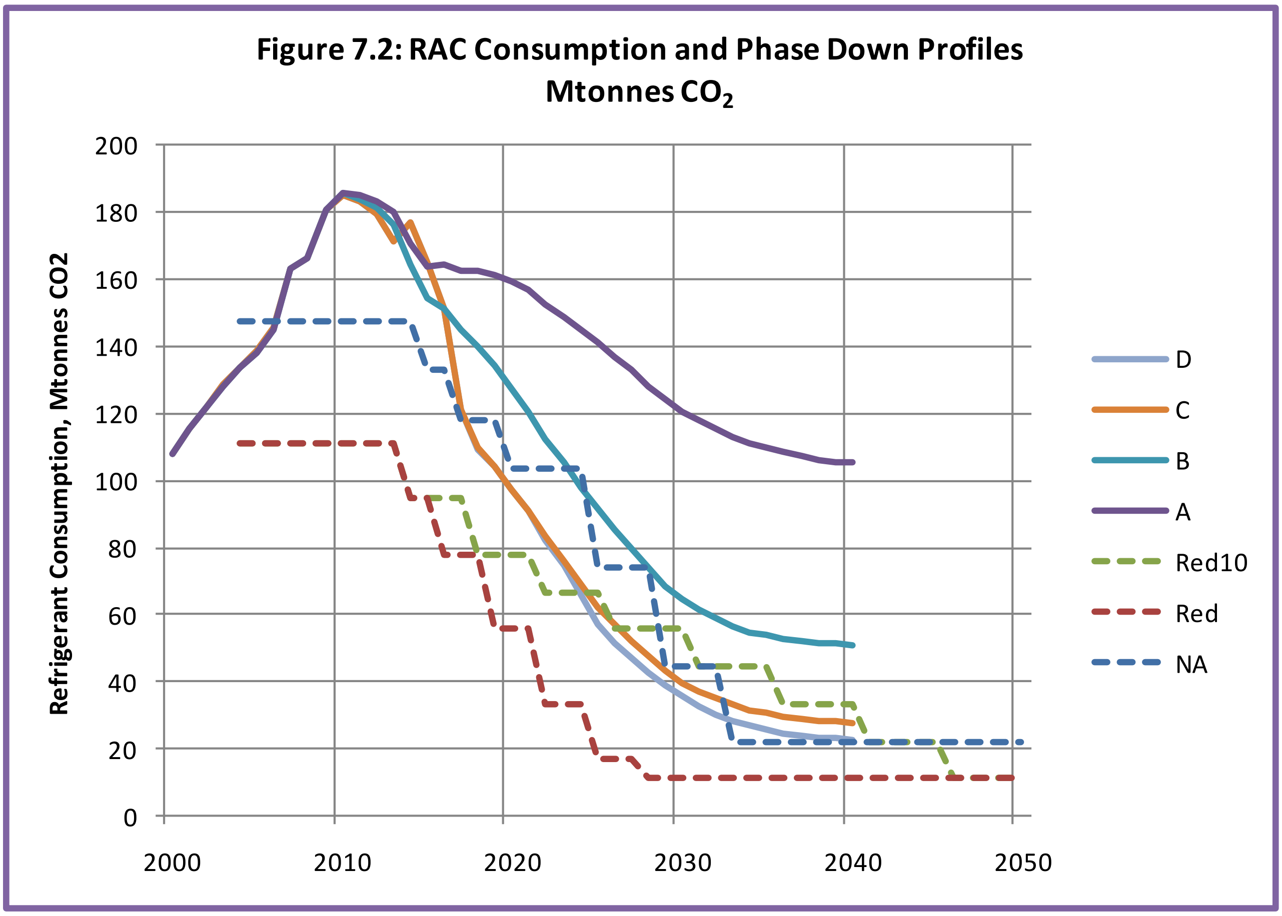
Figure 7.1: Phase Down Profile, Consumption (Mtonnes CO2)



7.2. Assessment of HFCs in RAC Sector

A comparison of the phase down steps and refrigerant consumption profiles has been made, taking the RAC market in isolation from other HFC uses (see Section 7.3 for an analysis including non-RAC sectors).

Figure 7.2 shows the consumption profile from 2000 to 2040 and the phase down steps which begin in 2014. Scenario B fails to meet any of the proposed profiles. Scenarios C and D meet the NA profile between 2018 and 2032 but does not achieve the final step. This important graph clearly shows that it will be very difficult for the RAC Sectors to achieve the phase down levels in the EU RED proposal.



It is important to note that the phase down proposals are referenced to “baselines” that are all related to consumption between 2004 and 2009. Figure 7.2 shows that consumption in the RAC sector has grown considerably since the baseline periods. This makes it difficult to achieve any of the proposed phase down profiles in the early years. A more realistic “start point” that reflects actual demand between 2010 and 2012 would help make the phase down profile achievable.

As discussed in Section 5.2.7 recovered refrigerant should be available in the market during the phase down process. Under Scenarios C and D around 28 Mtonnes CO_2 might be available in 2025 and 20 Mtonnes in 2033. Use of recovered refrigerants would help fully achieve all phase down profiles.

7.3. Overall Assessment Including Non-RAC Sectors

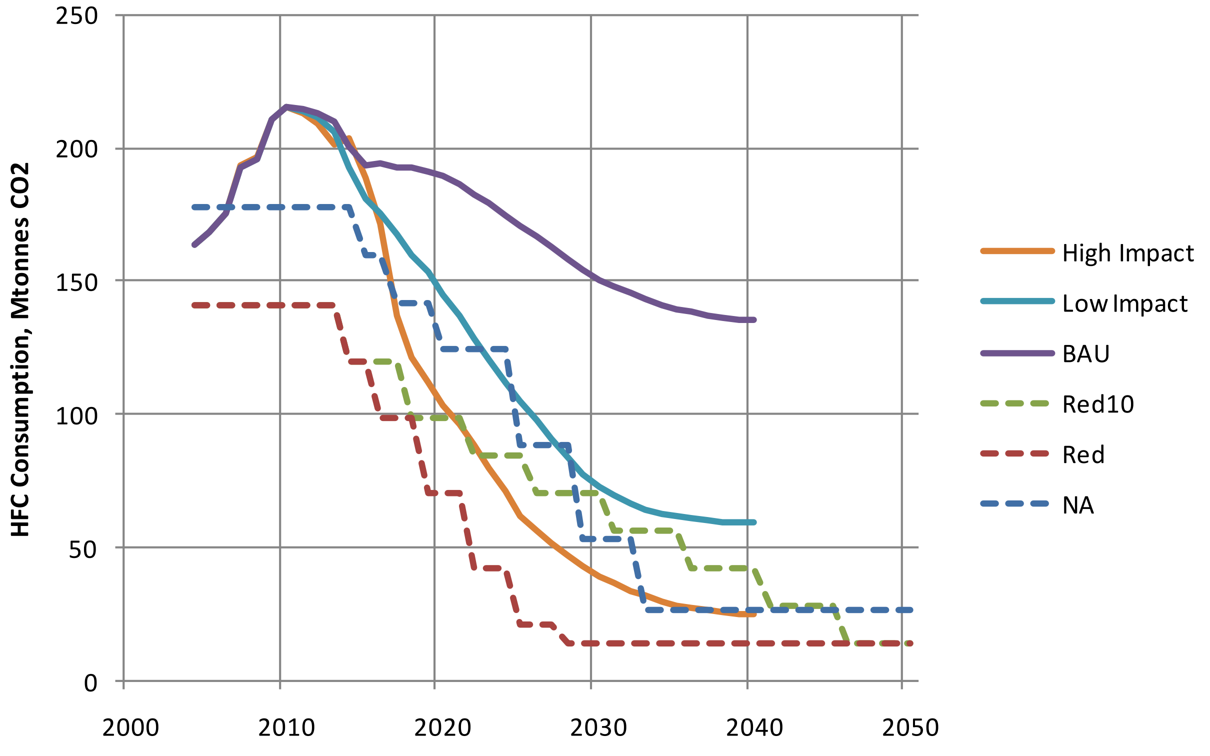
In Chapter 6 the non-RAC uses of HFCs were discussed. Table 6.2 gives BAU, low impact and high impact profiles for the future use of HFCs in these markets (foams, technical aerosols, MDIs and fire protection). These profiles have been combined with RAC scenarios to produce 3 future profiles for the whole of the HFC market.

The new profiles are:

1) BAU This is Scenario A for RAC plus BAU for non-RAC
2) Low impact This is Scenario B for RAC plus low impact for non-RAC
3) High impact This is Scenario D for RAC plus high impact for non-RAC

Figure 7.3 shows the results. As for RAC on its own, the BAU profile is well above the phase down targets. The combined high impact profile is slightly lower compared to the NA profile than Scenario D for RAC treated in isolation. This is because greater percentage cuts are forecast for non-RAC sectors. The high impact profile fails to meet the EU RED profile.

Figure 7.3: HFC Consumption and Phase Down Profiles Including non RAC sectors, Mtonnes CO2



Appendix A Acronyms and Abbreviations

BAU	Business as usual
CFC	chloro-fluoro-carbon
COP	Coefficient of Performance
F-Gas	fluorinated gas – includes HFCs, PFCs and SF6
FPS	Fire protection system
GHG	greenhouse gas
GWP	global warming potential
HCFC	hydro-chloro-fluoro-carbon
HFC	hydro-fluoro-carbon
HFO	hydro-fluoro-olefin
LT	low temperature – referring to refrigeration carried out in the -20 to -40^{o}C zone
MAC	mobile air-conditioning
MDI	metered dose inhaler
MT	medium temperature – referring to refrigeration carried out in the 2 to 5^{o}C zone
Mtonnes	million tonnes
ODP	ozone depletion potential
PFC	per-fluoro-carbon
RAC	refrigeration, air-conditioning and heat pumps – includes all mobile and stationary applications of these three technologies
SAC	Stationary air-conditioning
SF_6	sulphur hexafluoride
VRF	Variable refrigerant flow

Appendix B References

Öko-Recherche, Review of F-Gas Regulation for the European Commission, Final Report, 2011

Erie-Armines, "1990 to 2010 Refrigerant inventories for Europe, Previsions on banks and emissions from 2006 to 2030 for the European Union", 2011

F-Gas Regulation (EC 842/2006), 2006

EU Ozone Regulation (EC 1005/2009), 2009

MAC Directive (2006/40/EC), 2006

IPCC 4^{th} AR

SKM Enviros 2011 – private communication with Defra

European Commission, F-Gas Consumption Data, 2011

UNEP Technology and Economic Assessment Panel (TEAP) Progress Report, 2012

Eco Design ENTR Lot 6 – Air conditioning – Task 1, 2011

Eco Design ENTR Lot 6 – Air conditioning – Task 2, 2011

Eco Design ENTR Lot 6 – Air conditioning – Task 6, 2012

Eco Design ENER Lot 10 – Residential Air conditioning – Task 2, 2008

Eco Design ENER Lot 10 – Residential Air conditioning – Task 4, 2009

Eco Design ENER Lot 10 – Residential Air conditioning – Task 5, 2008

Eco Design ENER Lot 10 – Residential Air conditioning – Task 6, 2008

Appendix C Market Sub-Sector Profiles

The SKM Refrigerants Model uses 43 market sub-sectors to carry out the analysis required for this study. The 43 market sub-sectors are summarised in Table 2.1. A one page profile has been prepared for each market sub-sector to highlight key modelling parameters. The 43 profiles are included in this Appendix. For each sub-sector we have given:

a) A brief description of the end use markets and the type of cooling application.

b) The definition of a standard “2010 system” that is used in the model to represent new equipment being installed in the sub-sector in 2010. This is defined in terms of refrigerant type, refrigerant charge (kg), cooling duty (kW) and COP. The cooling duty is full load design duty and the COP is an average annual figure for system COP (taking into account compressor power and auxiliaries such as pumps and fans).

c) An estimate of the baseline (2010) split of refrigerants used (a) in the bank of all systems in the sub-sector and (b) in new equipment being purchased in 2010.

d) Various modelling factors. Emission factors are given for manufacturing and installation losses, annual leakage losses and refrigerant lost at end-of-life during decommissioning. Cost factors include typical capital cost for new equipment and annual running costs (mostly energy related, plus an allowance for maintenance). Operating factors (annual running hours and percentage load factor) are used to estimate total energy use.

e) Pre-filled imports and exports. This gives an estimate of the proportion of net imports (i.e. imports minus exports) of new equipment that is brought into the EU already containing all or some of the required refrigerant charge. For some imported equipment (e.g. split system air-conditioning units) it is common practice to add refrigerant during installation if pipe runs are long – a factor is estimated to reflect the amount of charge added during installation. This is always zero for factory built systems such as small hermetic systems or water chillers, but can be significant for split systems.

f) Market size, expressed in terms of the number of new systems being installed, given for 2010 and 2030.

g) A list of alternative refrigerant options that are considered applicable for the market sector. The impact of each alternative (compared to a standard “baseline” 2010 system) is specified in terms of changes to (a) capital cost and (b) running cost. Comments are given about the current and future availability of each alternative.

It should be noted that the sub-sector profiles are intended as short summary sheets giving a range of information about the sub-sector. In the SKM Refrigerants Model we use much more detailed data for each parameter, with key modelling factors (e.g. market size; leakage factors) specified annually between 1990 and 2040.

Reference: 1.1	**Domestic Refrigeration, Refrigerators**			
Description: Domestic refrigerators for storage of chilled food. Hermetically sealed factory built units always sold pre-charged with refrigerant. Note: the "standard system" for this sub-sector is shown as using HC 600a – since this is the predominant refrigerant in new units sold in Europe today. A small minority of units are sold using HFC 134a – and it is these HFC systems for which we consider the alternatives in the lower section of this table.				
Standard system 2010	HC 600a	Charge: 0.05 kg	Cooling: 0. 2 kW	COP: 3.0
Refrigerant split 2010	Bank: 69% HFC 134a; 23% HCs; 8% CFC 12			
	New Equipment: 10% HFC 134a; 90% HCs			
Emission factors 2010	Manufact. / Install: 0.5%	Annual leakage: 0.01%	End of life: 80%	
Cost factors 2010	Lifecycle: 15 years	Capital: €408	Energy: €47 per year Maintenance: €8 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 60%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 17 million units	2030: 19 million units		
Installed base	2010: 250 million units	2030: 280 million units		

Alternative Refrigerant Options (comparison with remaining R134a systems)

No.	**Refrigerant (alternative to R134a)**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HC 600a	+2%	-3.5%	+2%	**Note: shown as an alternative for the remaining R134a systems.** By 2010 already replaced HFC systems as most common in new equipment. Used for almost all small and medium sized refrigerators. Largest units still use HFC 134a
2	HFO 1234yf	+0%	0%	+0%	Not available until 2015 at earliest. Could play a useful role for very large units if HC flammability is a concern.

Reference: 1.2	Domestic Refrigeration, Freezers			
Description: Domestic freezers for storage of frozen food. Hermetically sealed factory built units always sold pre-charged with refrigerant. Note: the "standard system" for this sub-sector is shown as using HC 600a – since this is the predominant refrigerant in new units sold in Europe today. A small minority of units are sold using HFC 134a – and it is these HFC systems for which we consider the alternatives in the lower section of this table.				
Standard system 2010	HFC 134a	Charge: 0.05 kg	Cooling: 0.2 kW	COP: 2.0
Refrigerant split 2010	Bank: 66% HFC 134a; 27% HCs; 8% CFC 12			
	New Equipment: 10% HFC 134a; 90% HCs			
Emission factors 2010	Manufact. / Install: 0.5%	Annual leakage: 0.01%	End of life: 80%	
Cost factors 2010	Lifecycle: 15 years	Capital: €408	Running: €47 per year Maintenance: €8 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 60%		
Pre-filled imports	0% of new equipment	Charge added during installation: 0% of total		
Annual new systems	2010: 4.3 million units	2030: 4.8 million units		
Installed base	2010: 61 million units	2030: 70 million units		

Alternative Refrigerant Options (comparison with remaining R134a systems)

No.	Refrigerant (alternative to R134a)	Capital	Energy	Mainten-ance	Availability
1	HC 600a	+2%	-3.5%	+2%	**Note: shown as an alternative for the remaining R134a systems.** By 2010 already replaced HFC systems as most common in new equipment. Used for almost all small and medium sized freezers. Largest units still use HFC 134a
2	HFO 1234yf	+0%	0%	+0%	Not available until 2015 at earliest. Could play a useful role for very large units if HC flammability is a concern.

Reference: 2.1	**Commercial Refrigeration, Small Hermetic, MT**			
Description: Small systems used for chilled products in food retail and food service (restaurants, pubs, hotels, canteens etc.). Includes a wide variety of applications including small chilled retail display cabinets, bottle coolers, in-line drink coolers, vending machines. Hermetically sealed factory built units always sold pre-charged with refrigerant.				
Standard system 2010	HFC 134a	Charge: 0.24 kg	Cooling: 0.8 kW	COP: 2.1
Refrigerant split 2010	Bank: 84% HFC 134a; 14% HCFC 22; 2% CFC 12; <1% HCs; <1% CO2			
	New Equipment: 93% HFC 134a; 5% HCs; 2% CO_2			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 0%	Annual leakage: 1% Top-up factor: 100%	End of life: 91%	
Cost factors 2010	Lifecycle: 15 years	Capital: €1200	Energy: €330 per year Maintenance: €24 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 630,000 units	2030: 760,000 units		
Installed base	2010: 8,200,000 units	2030: 11,000,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HC 600a	+8%	-7.5%	+13%	Available for some models in 2012, but limited range. Uptake likely to grow significantly.
2	HFO 1234yf	+4%	0%	+9%	Not available in 2012. Becomes available 2015 to 2018. Could take share of market where HC flammability is a problem.
3	CO_2	+8%	-2.5%	+13%	Limited availability in 2012. Energy use higher in warm climates, lower in cold climates.
4	HFO B700	0%	0%	0%	Potential use of a non-flammable HFO blend, with properties similar to HFC 134a, GWP around 700, available from 2016.

Reference: 2.2	**Commercial Refrigeration, Small Hermetic, LT**			
Description: Small sealed systems used for frozen products in food retail and food service (restaurants, pubs, hotels, canteens etc.). Includes a variety of applications including small frozen retail display cabinets, ice makers, commercial storage cabinets. Hermetically sealed factory built units always sold pre-charged with refrigerant.				
Standard system 2010	HFC 134a	Charge: 0.24 kg	Cooling: 0.8 kW	COP: 1.2
Refrigerant split 2010	Bank: 84% HFC 134a; 13% HCFC 22; 2% CFC 502; <1% HCs; <1% CO2			
	New Equipment: 93% HFC 134a; 5% HCs; 2% CO_2			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 0%	Annual leakage: 1% Top-up factor: 100%	End of life: 91%	
Cost factors 2010	Lifecycle: 15 years	Capital: €1,800	Energy: €560 per year Maintenance: €36 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 300,000 units	2030: 360,000 units		
Installed base	2010: 3,900,000 units	2030: 5,200,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HC 600a	+8%	-8%	13%	Available for some models in 2012, but limited range. Uptake likely to grow significantly.
2	HFO 1234yf	+4%	0%	+9%	Not available in 2012. Becomes available 2015 to 2018. Could take share of market where HC flammability is a problem.
3	HFO Blend 300	0%	0%	0%	Potential use of a non-flammable HFO blend, with properties similar to HFC 134a, GWP around 700, available from 2016.
4	CO_2	+8%	-2.5%	+13%	Limited availability in 2012. Energy use higher in warm climates, lower in cold climates.

Reference: 2.3	Commercial Refrigeration, Single condensing units MT			
Description: Small split system refrigeration to cool one or more retail displays containing chilled products. Condensing unit (compressor and air cooled condenser) located remotely from evaporator that cools display case. Also used to cool storage spaces such as small chill rooms and beer cellars.				
Standard system 2010	HFC 404A	Charge: 3.6 kg	Cooling: 5 kW	COP: 2.2
Refrigerant split 2010	Bank: 53% HFC 404A; 34% HFC 134a; 13% HCFCs			
	New Equipment: 60% HFC 404A; 40% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 14% Top-up factor: 100%	End of life: 66%	
Cost factors 2010	Lifecycle: 15 years	Capital: €12,500	Energy: €2,000 per year Maintenance: €380 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 150,000 units	2030: 120,000 units		
Installed base	2010: 1,320,000 units	2030: 1,760,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+3%	-8%	+3%	Fully available in 2012. HFC 134a is better suited to MT systems than HFC 404A in terms of energy efficiency and lower GWP. Needs larger compressor.
2	HFC 407A / 407F	0%	-8%	0%	Fully available in 2012. HFCs 407A and 407F are better suited to MT systems than HFC 404A in terms of energy efficiency and lower GWP. Equal compressor size.
3	HFO Blend 700	+4%	-8%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) well suited to this application.
4	HFO Blend 300	+8%	-8%	+11%	Not available until 2015 to 2018. Should be a mildly flammable blend well suited to this application.
4	HFO 1234yf	+11%	-8%	+15%	Not available until 2015 to 2018. Lowest GWP option. Refrigerant is mildly flammable. Needs larger compressor.

Reference: 2.4	**Commercial Refrigeration, Single condensing units LT**			
Description: Small split system refrigeration to cool one or more retail displays containing frozen products. Condensing unit (compressor and air cooled condenser) located remotely from evaporator that cools display case. Also used to cool storage spaces such as small freezer rooms.				
Standard system 2010	HFC 404A	Charge: 2.7 kg	Cooling: 2 kW	COP: 1.2
Refrigerant split 2010	Bank: 86% HFC 404A; 12% HCFCs; 2% other HFCs			
	New Equipment: 100% HFC 404A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 14% Top-up factor: 100%	End of life: 66%	
Cost factors 2010	Lifecycle: 15 years	Capital: €10,000	Energy: €1,400 per year Maintenance: €300 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 150,000 units	2030: 140,000 units		
Installed base	2010: 1,550,000 units	2030: 2,070,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 407F	+0%	-3.5%	+0%	Fully available in 2012. HFC 407F is better suited to LT systems than HFC 404A in terms of energy efficiency and lower GWP. Equal compressor size.
2	HFO Blend 700	+4%	-3.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable blend suited to this application.
3	HFO Blend 300	+8%	0%	+11%	Not available until 2015 to 2018. Should be a mildly flammable blend suited to this application.

<table>
<tr><th colspan="2">Reference: 2.5</th><th colspan="4">Commercial Refrigeration, Large Multipack, MT</th></tr>
<tr><td colspan="6">Description: Large multipack centralised systems used in large food retail including supermarkets and hypermarkets. MT packs serve chilled display cases (e.g. for fresh meat, dairy products etc.). A typical system may have 4 to 6 compressors (usually semi-hermetic reciprocating or hermetic scroll) in a factory built “pack” located in a plant room, connected to external air cooled condensers and to a number of retail display cabinets and sometimes to a chilled store room.</td></tr>
<tr><td colspan="2">Standard system 2010</td><td>HFC 404A</td><td>Charge: 200 kg</td><td>Cooling: 100 kW</td><td>COP: 2.2</td></tr>
<tr><td colspan="2" rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 77% HFC 404A; 9% HFC 134a; 11% HCFCs; 2% other HFCs; 1% NH3</td></tr>
<tr><td colspan="4">New Equipment: 88% HFC 404A; 10% HFC 134a; 2% NH3</td></tr>
<tr><td colspan="2">Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 3%</td><td>Annual leakage: 21%
Top-up factor: 100%</td><td colspan="2">End of life: 20%</td></tr>
<tr><td colspan="2">Cost factors 2010</td><td>Lifecycle: 15 years</td><td>Capital: €300,000</td><td colspan="2">Energy: €39,000 per year
Maintenance: €9,000 per year</td></tr>
<tr><td colspan="2">Operating factors</td><td colspan="2">Operating hours per year: 8760</td><td colspan="2">Load factor (when in use): 70%</td></tr>
<tr><td colspan="2">Pre-filled imports</td><td>Net imports: 0%</td><td colspan="3">Charge added during installation: 100% of total</td></tr>
<tr><td colspan="2">Annual new systems</td><td colspan="2">2010: 19,000 units</td><td colspan="2">2030: 18,000 units</td></tr>
<tr><td colspan="2">Installed base</td><td colspan="2">2010: 198,000 units</td><td colspan="2">2030: 264,000 units</td></tr>
<tr><td colspan="6">Alternative Refrigerant Options (comparison with standard 2010 system)</td></tr>
</table>

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+3%	-8%	+3%	Fully available in 2012. Improved efficiency and GWP.
2	HFC 407A/F	0%	-8%	0%	Fully available in 2012. Improved efficiency and GWP.
3	CO_2	+8%	-2.5%	+15%	Good availability in 2012, although limited skills in service sector. Energy use higher in warm climates, lower in cold climates. Both transcritical systems and cascade systems are in use now and more likely in the future.
4	HC hermetics plus chiller	+11%	0%	+15%	Limited use in 2012
5	HFO Blend 700	+4%	-7.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
6	NH3	+38%	0%	+45%	A small number of ammonia systems (with secondary coolants) may continue to be used.

Reference: 2.6	**Commercial Refrigeration, Large Multipack, LT**			
Description: Large multipack centralised systems used in large food retail including supermarkets and hypermarkets. LT packs serve frozen display cases (e.g. for frozen vegetables, ice cream etc.). A typical system may have 4 to 6 compressors (usually semi-hermetic reciprocating or hermetic scroll) in a factory built "pack" located in a plant room, connected to external air cooled condensers and to a number of retail display cabinets and sometimes to a frozen store room.				
Standard system 2010	HFC 404A	Charge: 100 kg	Cooling: 50 kW	COP: 1.2
Refrigerant split 2010	Bank: 85% HFC 404A; 12% HCFCs; 2% other HFCs; 1% NH3			
	New Equipment: 98% HFC 404A; 2% NH3			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 21% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 15 years	Capital: €250,000	Energy: €35,000 per year Maintenance: €7,500 per year	
Operating factors	Operating hours per year: 8760	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 18,000 units	2030: 17,000 units		
Installed Base	2010: 186,000 units	2030: 249,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Maintenance	Availability
1	HFC 407F	+0%	-3.5%	+0%	Fully available in 2012. Improved efficiency and GWP.
2	CO_2 transcritical	+8%	-2.5%	+15%	Good availability in 2012, although limited skills in service sector. Energy use higher in warm climates, lower in cold climates. Both transcritical systems and cascade systems are in use now and more likely in the future.
4	HC hermetics plus chiller	+11%	0%	+15%	Limited availability in 2012
5	HFO Blend 700	+4%	-3.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
6	NH3	+38%	0	+45%	A small number of ammonia systems (with secondary coolants) may continue to be used.

Reference: 3.1	**Transport Refrigeration, Vans and light trucks**				
Description: Refrigeration systems used in vans and light trucks used for transport of chilled and / or frozen food. Small systems that are usually belt driven from vehicle engine.					
Standard system 2010	HFC 404A	Charge: 1.6 kg		Cooling: 3 kW	COP: 1
Refrigerant split 2010	Bank: 68% HFC 404A; 32% HFC 134a				
	New Equipment: 100% HFC 404A				
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2%	Annual leakage: 24% Top-up factor: 100%		End of life: 44%	
Cost factors 2010	Lifecycle: 9 years	Capital: €3,000		Energy: €1,300 per year Maintenance: €90 per year	
Operating factors	Operating hours per year: 4400		Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total			
Annual new systems	2010: 16,000 units			2030: 18,000 units	
Installed base	2010: 143,000 units			2030: 168,000 units	
Alternative Refrigerant Options (comparison with standard 2010 system)					
No.	**Refrigerant**	**Capital**	**Energy**	**Maintenance**	**Availability**
1	HFC 134a	+5%	-8%	+5%	Fully available in 2012, but only applicable to chilled vans.
2	HFC 407A or 407F	+0%	-3.5%	+0%	Available in 2012 but not widely used in this sector.
3	B700	+5%	-3.5%	+5%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
5	CO_2	+10%	-2.5%	+17%	Made available in 2012 for transport refrigeration.

Reference: 3.2	**Transport Refrigeration, Large Trucks and Iso-Containers**			
Description: Refrigeration systems used in large trucks and iso-containers for transport of chilled and / or frozen food. Large systems that are usually independently driven from a dedicated diesel engine.				
Standard system 2010	HFC 404A	Charge: 6 kg	Cooling: 9 kW	COP: 1.1
Refrigerant split 2010	Bank: 78% HFC 404A; 14% HFC 134a; 6% HCFCs; 1% CFCs			
	New Equipment: 91% HFC 404A; 9% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2%	Annual leakage: 20% Top-up factor: 100%	End of life: 82%	
Cost factors 2010	Lifecycle: 15 years	Capital: €9,000	Energy: €3,400 per year Maintenance: €270 per year	
Operating factors	Operating hours per year: 4400	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 29,000 units	2030: 35,000 units		
Installed base	2010: 429,000 units	2030: 503,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Maintenance**	**Availability**
1	HFC 134a	+5%	-8%	+5%	Fully available in 2012, but only applicable to chilled trucks.
2	HFC 407A or 407F	+0%	-3.5%	+0%	Available in 2012 but not widely used in this sector.
3	B700	+15%	-3.5%	+5%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	CO_2	+10%	-2.5	+17%	Made available in 2012 and may increase in popularity for transport refrigeration.

Reference: 4.1	Industrial Refrigeration, Small DX LT			
Description: Small sized direct expansion systems for low temperature industrial applications. Usually air cooled condensing unit connected to separately located evaporator cooling a room or a product. .				
Standard system 2010	HFC 404A	Charge: 30 kg	Cooling: 20 kW	COP: 1.1
Refrigerant split 2010	Bank: 83% HFC 404A; 15% HCFCs; 3% other HFCs			
	New Equipment: 100% HFC 404A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 18 years	Capital: €40,000	Energy: €9,000 per year Maintenance: €1,200 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 8,100 units	2030: 7,200 units		
Installed base	2010: 106,000 units	2030: 119,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten -ance	Availability
1	HFC 407A or 407F	+0%	-3.5%	+0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP.
2	B700	+4%	-3.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend suited to this application.
3	B300	+9%	0%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend suited to this application.

Reference: 4.2	Industrial Refrigeration, Small DX MT			
Description: Small sized direct expansion systems for medium temperature industrial applications. Usually air cooled condensing unit connected to separately located evaporator cooling a room or a product. Over the long-term, the model assumes a slight shift away from small DX systems and towards indirect systems.				
Standard system 2010	HFC 404A	Charge: 45 kg	Cooling: 30 kW	COP: 2.3
Refrigerant split 2010	Bank: 40% HFC 404A; 37% HFC 134a; 20% HCFCs; 5% other HFCs			
	New Equipment: 50% HFC 404A; 50% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 18 years	Capital: €50,000	Energy: €6,300 per year Maintenance: €1,500 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 14,000 units	2030: 10,000 units		
Installed base	2010: 222,000 units	2030: 178,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten -ance	Availability
1	HFC 134a	+4%	-7.5%	+4%	Fully available in 2012. Improved efficiency and GWP. Needs larger compressor.
2	HFC 407A or 407F	+0%	-7.5%	+0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP Equal compressor size.
3	B700	+40%	-7.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
5	B300	+9%	-7.5%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.3	**Industrial Refrigeration, Medium DX LT**			
Description: Medium sized direct expansion systems for low temperature industrial applications. Usually air cooled condensing unit connected to separately located evaporator cooling a room or a product. .				
Standard system 2010	HFC 404A	Charge: 120 kg	Cooling: 80 kW	COP: 1.2
Refrigerant split 2010	Bank: 73% HFC 404A; 21% HCFCs; 7% other HFCs			
	New Equipment: 100% HFC 404A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 24 years	Capital: €144,000	Energy: €33,000 per year Maintenance: €4,300 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 1,500 units	2030: 1,900 units		
Installed base	2010: 33,000 units	2030: 37,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 407A or 407F	+0%	-3.5%	+0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP.
2	B700	+4%	-3.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
3	B300	+9%	-3.5%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.4	Industrial Refrigeration, Medium DX MT			
Description: Medium sized direct expansion systems for medium temperature industrial applications. Usually air cooled condensing unit connected to separately located evaporator cooling a room or a product. Model includes an assumption for a shift away from DX systems to indirect systems.				
Standard system 2010	HFC 404A	Charge: 150 kg	Cooling: 100 kW	COP: 2.5
Refrigerant split 2010	Bank: 34% HFC 404A; 31% HFC 134a; 26% HCFCs; 9% other HFCs			
	New Equipment: 50% HFC 404A; 50% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 24 years	Capital: €150,000	Energy: €19,000 per year Maintenance: €4,500 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 2,000 units	2030: 2,300 units		
Annual new systems	2010: 61,000 units	2030: 48,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+4%	-7.5%	+4%	Fully available in 2012. Improved efficiency and GWP. Needs larger compressor.
2	HFC 407A or 407F	+0%	-7.5%	+0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP Equal compressor size.
3	B700	+4%	-7.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
3	B300	+9%	-7.5%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.5	**Industrial Refrigeration, Large DX LT**			
Description: Large sized direct expansion systems for low temperature industrial applications. Multi-compressor installation connected to separately located condensers (could be evaporative, water cooled or air cooled) and separately located evaporators cooling a room or a product.				
Standard system 2010	HFC 404A	Charge: 450 kg	Cooling: 300 kW	COP: 1.3
Refrigerant split 2010	Bank: 53% HFC 404A; 24% HCFCs; 15% ammonia; 8% other HFCs			
	New Equipment: 80% HFC 404A; 20% ammonia			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 30 years	Capital: €450,000	Energy: €110,000 per year Maintenance: €13,500 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 370 units	2030: 410 units		
Installed base	2010: 8,900 units	2030: 9,900 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFC 407A or F	0%	-3.5%	0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP.
2	Ammonia	+13%	-10%	+21%	Available in 2012
3	CO_2	+13%	-2.5%	+21%	Available in 2012, although limited skills in service sector. Energy use higher in warm climates, lower in cold climates.
4	B700	+4%	-3.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
5	B300	+9%	-3.5%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.6	Industrial Refrigeration, Large DX MT			
Description: Large sized direct expansion systems for medium temperature industrial applications. Multi-compressor installation connected to separately located condensers (could be evaporative, water cooled or air cooled) and separately located evaporators cooling a room or a product. Model includes an assumption for a shift away from DX systems to indirect systems.				
Standard system 2010	HFC 404A	Charge: 600 kg	Cooling: 400 kW	COP: 3.0
Refrigerant split 2010	Bank: 27% HFC404A; 22% HFC134a; 28% HCFCs; 15% NH3; 9% other HFCs			
	New Equipment: 45% HFC 404A; 35% HFC 134a; 20% ammonia			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 14% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 30 years	Capital: €480,000	Energy: €66,000 per year Maintenance: €14,000 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 550 units	2030: 500 units		
Installed base	2010: 15,300 units	2030: 11,900 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten -ance	Availability
1	HFC 134a	+4%	-7.5%	+4%	Fully available in 2012. Improved efficiency and GWP. Needs larger compressors.
2	HFC 407A or 407F	+0%	-7.5%	+0%	Available in 2012 but not widely used in this sector. Improved efficiency and GWP Equal compressor size.
3	Ammonia	+13%	-10%	+21%	Available in 2012
4	CO_2	+13%	-2.5%	+21%	Available in 2012, although limited skills in service sector. Energy use higher in warm climates, lower in cold climates.
5	B700	+4%	-7.5%	+4%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
6	B300	+9%	-7.5%	+12%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.7	**Industrial Refrigeration, Medium Chiller**			
Description: Medium sized chiller systems for glycol or chilled water for industrial applications. Includes packaged water chillers for industrial use and bespoke designs for lower temperature glycol or iced water.				
Standard system 2010	HFC 134a	Charge: 100 kg	Cooling: 200 kW	COP: 2.4
Refrigerant split 2010	Bank: 35% HFC 134a; 22% HCFCs; 15% ammonia; 12% R410A; 9% R407C; 8% other HFCs			
	New Equipment: 50% HFC 134a; 30% HFC 410A; 20% ammonia			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 9% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 24 years	Capital: €320,000	Energy: €41,000 per year Maintenance: €9,600 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 1,800 units	2030: 2,300 units		
Annual new systems	2010: 30,600 units	2030: 44,500 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	Ammonia	+18%	-7.5%	+25%	Available in 2012
2	HFO 1234 ze	+4%	0%	+8%	Available in 2012
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	B300	+4%	0%	+8%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 4.8	Industrial Refrigeration, Large Chiller		
Description: Medium sized chiller systems for glycol or chilled water for industrial applications. Includes packaged water chillers for industrial use and bespoke designs for lower temperature glycol or iced water.			
Standard system 2010	HFC 134a	Charge: 450 kg	Cooling: 1000 kW / COP: 3.0
Refrigerant split 2010	Bank: 37% HFC 134a; 25% HCFCs; 38% ammonia		
	New Equipment: 60% HFC 134a; 40% ammonia		
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 9% Top-up factor: 100%	End of life: 20%
Cost factors 2010	Lifecycle: 30 years	Capital: €1,500,000	Energy: €160,000 per year Maintenance: €45,000 per year
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%	
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total	
Annual new systems	2010: 1300 units	2030: 560 units	
Annual new systems	2010: 12,200 units	2030: 17,800 units	

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	Ammonia	+13%	-7.5%	+21%	Available in 2012
2	HFO 1234ze	+4%	0%	+8%	Available in 2012

<table>
<tr><th colspan="2">Reference: 4.9</th><th colspan="4">Industrial Refrigeration, Large Flooded LT</th></tr>
<tr><td colspan="6">Description: Large pumped circulation or natural circulation flooded systems for large process loads (e.g. blast freezers) or large cold stores. Multi-compressor installation connected to separately located condensers (usually evaporative) and separately located evaporators.
NOTE: “Alternative Refrigerant Options” described below give comparison with R22, not ammonia.</td></tr>
<tr><td colspan="2">Standard system 2010</td><td>Ammonia</td><td>Charge: 3000 kg</td><td>Cooling: 1000 kW</td><td>COP: 1.8</td></tr>
<tr><td colspan="2" rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 87% ammonia; 13% HCFC 22</td></tr>
<tr><td colspan="4">New Equipment: 100% ammonia</td></tr>
<tr><td colspan="2">Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 2.0%</td><td>Annual leakage: 5%
Top-up factor: 100%</td><td colspan="2">End of life: 20%</td></tr>
<tr><td colspan="2">Cost factors 2010</td><td>Lifecycle: 30 years</td><td>Capital: €2,000,000</td><td colspan="2">Energy: €270,000 per year
Maintenance: €64,000 per year</td></tr>
<tr><td colspan="2">Operating factors</td><td colspan="2">Operating hours per year: 5000</td><td colspan="2">Load factor (when in use): 70%</td></tr>
<tr><td colspan="2">Pre-filled imports</td><td>Net imports: 0%</td><td colspan="3">Charge added during installation: 100% of total</td></tr>
<tr><td colspan="2">Annual new systems</td><td colspan="2">2010: 370 units</td><td colspan="2">2030: 200 units</td></tr>
<tr><td colspan="2">Installed base</td><td colspan="2">2010: 5,300 units</td><td colspan="2">2030: 5,900 units</td></tr>
<tr><th colspan="6">Alternative Refrigerant Options (<u>comparison with R22 systems</u>)</th></tr>
<tr><th>No.</th><th>Refrigerant</th><th>Capital</th><th>Energy</th><th>Mainten-ance</th><th>Availability</th></tr>
<tr><td>1</td><td>NH3</td><td>+0%</td><td>-10%</td><td>+7%</td><td>Available in 2012</td></tr>
<tr><td>1</td><td>CO_2</td><td>+0%</td><td>-10%</td><td>+7%</td><td>Available in 2012</td></tr>
</table>

Reference: 4.10	**Industrial Refrigeration, Large Flooded MT**			
Description: Large pumped circulation or natural circulation flooded systems for large process loads or large chill stores. . Multi-compressor installation connected to separately located condensers (usually evaporative) and separately located evaporators. NOTE: "Alternative Refrigerant Options" described below give comparison with R22, not ammonia.				
Standard system 2010	Ammonia	Charge: 3000 kg	Cooling: 1000 kW	COP: 4.1
Refrigerant split 2010	Bank: 87% ammonia; 10% HCFC 22; 3% HFC 134a			
	New Equipment: 95% ammonia; 5% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 30 years	Capital: €2,000,000	Energy: €120,000 per year Maintenance: €64,000 per year	
Operating factors	Operating hours per year: 5000	Load factor (when in use): 70%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 100% of total		
Annual new systems	2010: 190 units	2030: 120 units		
Installed base	2010: 3,200 units	2030: 3,600 units		

Alternative Refrigerant Options (comparison with R22 systems)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFC 134a	0%	0%	0%	Available in 2012
2	NH_3	+0%	-10%	+7%	Available in 2012
3	CO_2	+0%	-10%	+7%	Available in 2012

Reference: 5.1	Stationary air-conditioning and heat pumps, Air to Air Small portable units, cooling only			
Description: Plug-in air conditioners, either in “packaged” or “split” format, which are moveable between rooms by the end user. Used for comfort cooling of rooms in buildings.				
Standard system 2010	HFC 410A	Charge: 0.5 kg	Cooling: 2.2 kW	COP: 1.7
Refrigerant split 2010	Bank: 71% HFC 410A; 24% HFC 407C; 4% HCFC 22			
	New Equipment: 100% HFC 410A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3.0%	Annual leakage: 2% Top-up factor: 0%	End of life: 85%	
Cost factors 2010	Lifecycle: 12 years	Capital: €400	Energy: €63 per year Maintenance: €12 per year	
Operating factors	Operating hours per year: 1050	Load factor (when in use): 33%		
Pre-filled imports	Net imports: 100%	Charge added during installation: 0% of total		
Annual new systems	2010: 2.1 million units	2030: 3.9 million units		
Installed base	2010: 16.5 million units	2030: 43.3 million units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HC 290	+10%	0%	+17%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012
3	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
4	B700	+0%	0%	+0%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.2	**Stationary air-conditioning and heat pumps, Air to Air** **Small split systems, cooling only**			
Description: Small sized split system stationary air conditioner with cooling only function, consisting of an outdoor unit and indoor unit linked by a refrigerant circuit connected on site by certified installer. Cooling only types are a minority of the market today compared to the heat pump types that can both cool and heat. The model assumes "cooling only" models will totally disappear from the EU market in the coming years.				
Standard system 2010	HFC 410A	Charge: 0.8 kg	Cooling: 3.5 kW	COP: 2.5
Refrigerant split 2010	Bank: 24% HFC 410A; 37% HFC 407C; 39% HCFC 22			
	New Equipment: 70% HFC 410A; 30% HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3.0%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 12 years	Capital: €700	Energy: €69 per year Maintenance: €21 per year	
Operating factors	Operating hours per year: 1050	Load factor (when in use): 33%		
Pre-filled imports	Net imports: 100%	Charge added during installation: 5% of total		
Annual new systems	2010: 53,000 units	2030: 0 units		
Installed base	2010: 8,400,000 units	2030: 400,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012
2	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	B700	+0%	0%	+0%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.3	Stationary air-conditioning and heat pumps, Air to Air Small split systems, heating and cooling			
Description: Small sized split system stationary reversible heat pump with heating and cooling only function, consisting of an outdoor unit and indoor unit linked by a refrigerant circuit connected on site by certified installer. The number of hours the unit is running in cooling mode or heating mode is different in the various EU climate zones. Ecodesign Lot 10 / EN14825 "average" climate condition used in this evaluation				
Standard system 2010	HFC 410A	Charge: 1.2 kg	Cooling: 3.5 kW Heating: 4 kW	Cooling COP: 2.6 Heating COP: 2.3
Refrigerant split 2010	Bank: 44% HFC 410A; 35% HFC 407C; 21% HCFC 22			
	New Equipment: 70% HFC 410A; 30% R407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3.0%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 12 years	Capital: €800	Energy: €410 per year Maintenance: €24 per year	
Operating factors	Operating hours/year cooling: 1050 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 90%	Charge added during installation: 5% of total		
Annual new systems	2010: 5.6 million units	2030: 7.3 million units		
Installed base	2010: 40 million units	2030: 88 million units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012
2	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	B700	0%	0%	0%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.4	**Stationary air-conditioning and heat pumps, Air to Air** **Medium split systems, cooling only**			
Description: Medium sized split system stationary air conditioner with cooling only function, consisting of an outdoor unit and indoor unit linked by a refrigerant circuit connected on site by certified installer. Some models combine 1 outdoor unit with more than 1 indoor unit (twin/triple/double twin/multi applications). Cooling only types are a minority of the market today compared to the heat pump types that can both cool and heat. The model assumes "cooling only" models will totally disappear from the EU market in the coming years.				
Standard system 2010	HFC 410A	Charge: 2 kg	Cooling: 7.1 kW	COP: 2.3
Refrigerant split 2010	Bank: 21% HFC 410A; 39% HFC 407C; 40% HCFC 22			
	New Equipment: 60% HFC 410A; 40% HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3.0%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 12 years	Capital: €1400	Energy: €151 per year Maintenance: €43 per year	
Operating factors	Operating hours/year cooling: 1050	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 70%	Charge added during installation: 10% of total		
Annual new systems	2010: 70,000 units	2030: 0 units		
Installed base	2010: 2,200,000 units	2030: 100,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012
2	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	B700	+0%	0%	+0%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.5	**Stationary air-conditioning and heat pumps, Air to Air Medium split systems, heating and cooling**			
Description: Medium sized split system stationary reversible heat pump with heating and cooling only function, consisting of an outdoor unit and indoor unit linked by a refrigerant circuit connected on site by certified installer. Some models combine 1 outdoor unit with more than 1 indoor unit (twin/triple/double twin/multi applications). The number of hours the unit is running in cooling mode or heating mode is different in the various EU climate zones. Ecodesign Lot 10 / EN14825 “average” climate condition used in this evaluation				
Standard system 2010	HFC 410A	Charge: 2.5 kg	Cooling: 7.1 kW Heating: 8 kW	Cooling COP: 2.6 Heating COP: 2.2
Refrigerant split 2010	Bank: 39% HFC 410A; 41% HFC 407C; 20% HCFC 22			
	New Equipment: 60% HFC 410A; 40% HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 3.0%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 12 years	Capital: €1500	Energy: €850 per year Maintenance: €46 per year	
Operating factors	Operating hours/year cooling: 1050 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 70%	Charge added during installation: 10% of total		
Annual new systems	2010: 1.8 million units	2030: 2.5 million units		
Installed base	2010: 14 million units	2030: 29 million units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	B700	+0%	0%	+0%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

<table>
<tr><td>Reference: 5.6</td><td colspan="4">Stationary air-conditioning and heat pumps, Air to Air
Large split systems, cooling only</td></tr>
<tr><td colspan="5">Description: Large sized split system stationary air conditioning system consisting of 1 outdoor unit and one or more indoor units.</td></tr>
<tr><td>Standard system 2010</td><td>HFC 410A</td><td>Charge: 5.6 kg</td><td>Cooling: 14 kW</td><td>COP: 4.0</td></tr>
<tr><td rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 26% HFC 410A; 42% HFC 407C; 33% HCFC 22</td></tr>
<tr><td colspan="4">New Equipment: 60% HFC 410A; 40% HFC 407C</td></tr>
<tr><td>Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 2.5%</td><td colspan="2">Annual leakage: 6%
Top-up factor: 100%</td><td>End of life: 90%</td></tr>
<tr><td>Cost factors 2010</td><td>Lifecycle: 15 years</td><td>Capital: €5500</td><td colspan="2">Energy: €300 per year
Maintenance: €170 per year</td></tr>
<tr><td>Operating factors</td><td colspan="2">Operating hours/year cooling: 1800</td><td colspan="2">Load factor (when in use) cooling: 33%</td></tr>
<tr><td>Pre-filled imports</td><td>Net imports: 70%</td><td colspan="3">Charge added during installation: 15% of total</td></tr>
<tr><td>Annual new systems</td><td colspan="2">2010: 58,000 units</td><td colspan="2">2030: 32,000 units</td></tr>
<tr><td>Installed base</td><td colspan="2">2010: 960,000 units</td><td colspan="2">2030: 470,000 units</td></tr>
<tr><td colspan="5">Alternative Refrigerant Options (comparison with standard 2010 system)</td></tr>
<tr><td colspan="5">Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.</td></tr>
</table>

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.7	Stationary air-conditioning and heat pumps, Air to Air Large split systems, heating and cooling			
Description: Large sized split system stationary reversible heat pump with heating and cooling only function, consisting of 1 outdoor unit and one or more indoor units (twin, triple, double twin, multi combinations).				
Standard system 2010	HFC 410A	Charge: 5.6 kg	Cooling: 14 kW Heating: 16 kW	Cooling COP: 4.0 Heating COP: 3.3
Refrigerant split 2010	Bank: 26% HFC 410A; 37% HFC 407C; 37% HCFC 22			
	New Equipment: 60% HFC 410A; 40% HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 15 years	Capital: €6000	Energy: €1,200 per year Maintenance: €180 per year	
Operating factors	Operating hours/year cooling: 1800 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 70%	Charge added during installation: 15% of total		
Annual new systems	2010: 170,000 units	2030: 200,000 units		
Installed base	2010: 2,200,000 units	2030: 3,000,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.8	**Stationary air-conditioning and heat pumps, Air to Air** **Packaged systems, cooling only**			
Description: Packaged stationary air-conditioning systems with cooling only capability, including roof tops and ducted splits >12 kW. The model assumes sales of cooling only systems decline compared to reversible units.				
Standard system 2010	HFC 410A	Charge: 20 kg	Cooling: 80 kW	COP: 3.9
Refrigerant split 2010	Bank: 19% HFC 410A; 33% HFC 407C; 47% HCFC 22 New Equipment: 60% HFC 410A; 40% HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 55%	
Cost factors 2010	Lifecycle: 15 years	Capital: €21,500	Energy: €1,700 per year Maintenance: €650 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 20%	Charge added during installation: 0% of total		
Annual new systems	2010: 3,900 units	2030: 2,500 units		
Installed base	2010: 67,000 units	2030: 38,000 units		
Alternative Refrigerant Options (comparison with standard 2010 system)				
Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.				

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

<table>
<tr><td>Reference: 5.9</td><td colspan="4">Stationary air-conditioning and heat pumps, Air to Air
Packaged systems, heating and cooling</td></tr>
<tr><td colspan="5">Description: Packaged stationary air-conditioning systems with cooling and heating capability, including roof tops and ducted splits >12 kW.</td></tr>
<tr><td>Standard system 2010</td><td>HFC 410A</td><td>Charge: 20 kg</td><td>Cooling: 80 kW
Heating: 80 kW</td><td>Cooling COP: 3.5
Heating COP: 3.0</td></tr>
<tr><td rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 19% HFC 410A; 29% HFC 407C; 51% HCFC 22</td></tr>
<tr><td colspan="4">New Equipment: 60% HFC 410A; 40% HFC 407C</td></tr>
<tr><td>Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 2.0%</td><td>Annual leakage: 5%
Top-up factor: 100%</td><td colspan="2">End of life: 55%</td></tr>
<tr><td>Cost factors 2010</td><td>Lifecycle: 15 years</td><td>Capital: €23,000</td><td colspan="2">Energy: €7,200 per year
Maintenance: €690 per year</td></tr>
<tr><td>Operating factors</td><td colspan="2">Operating hours/year cooling: 1800
Operating hours/year heating: 2800</td><td colspan="2">Load factor (when in use) cooling: 33%
Load factor (when in use) heating: 50%</td></tr>
<tr><td>Pre-filled imports</td><td>Net imports: 20%</td><td colspan="3">Charge added during installation: 0% of total</td></tr>
<tr><td>Annual new systems</td><td colspan="2">2010: 9,000 units</td><td colspan="2">2030: 10,500 units</td></tr>
<tr><td>Installed base</td><td colspan="2">2010: 109,000 units</td><td colspan="2">2030: 162,000 units</td></tr>
<tr><td></td><td colspan="4">Alternative Refrigerant Options (comparison with standard 2010 system)</td></tr>
<tr><td colspan="5">Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.</td></tr>
</table>

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.10	**Stationary air-conditioning and heat pumps, Air to Air VRF systems, cooling only**

Description: Cooling only VRF systems consisting of modular system of 1 or more outdoor units with multiple indoor units. The model assumes sales of cooling only systems decline compared to reversible units.

Standard system 2010	HFC 410A	Charge: 25 kg	Cooling: 50 kW	COP: 3.5
Refrigerant split 2010	Bank: 43% HFC 410A; 44% HFC 407C; 14% HCFC 22			
	New Equipment: 60% HFC 410A; 40 HFC 407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 15 years	Capital: €36,000	Energy: €2800 per year Maintenance: €1100 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 50%	Charge added during installation: 50% of total		
Annual new systems	2010: 2,600 units	2030: 0 units		
Installed base	2010: 44,000 units	2030: 19,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 5.11	**Stationary air-conditioning and heat pumps, Air to Air** **VRF systems, heating and cooling**			
Description: Reversible VRF systems providing heating or cooling, consisting of modular system of 1 or more outdoor units with multiple indoor units. Also there are heat recovery versions available that provide simultaneous heating and cooling to different parts of a building.				
Standard system 2010	HFC 410A	Charge: 25 kg	Cooling: 50 kW Heating: 55 kW	Cooling COP: 3.5 Heating COP: 3.1
Refrigerant split 2010	Bank: 42% HFC 410A; 41% HFC 407C; 17% HCFC 22			
	New Equipment: 60% HFC 410A; 40% R407C			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 6% Top-up factor: 100%	End of life: 90%	
Cost factors 2010	Lifecycle: 15 years	Capital: €36,000	Energy: €4700 per year Maintenance: €1100 per year	
Operating factors	Operating hours/year cooling: 1800 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 50%	Charge added during installation: 50% of total		
Annual new systems	2010: 49,000	2030: 130,000		
Annual new systems	2010: 320,000	2030: 1,600,000		

Alternative Refrigerant Options (comparison with standard 2010 system)

Currently there is no non-flammable alternative to HFC 410A. In systems of this size it is uncertain that mildly flammable refrigerants will be an acceptable alternative. HFC 134a is technically feasible and has a 30% lower GWP than HFC 410A but would have a lower energy efficiency and higher overall GHG emissions.

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, mildly flammable.
2	HFO B700	+5%	0%	+9%	Not currently available. Should be an HFO blend (GWP 700) suited to this application. Note: for AC applications, there is currently no non-flammable HFO blend on offer, so this may also be mildly-flammable.

Reference: 6.1	**Chillers & hydronic heat pumps, Small - cooling only, air cooled**			
Description: Small sized water chillers providing chilled water for air-conditioning. Scroll or screw compressors, air cooled.				
Standard system 2010	HFC 410A	Charge: 29 kg	Cooling: 100 kW	COP: 3.1
Refrigerant split 2010	Bank 14% HFC 410A; 37% HFC 407C; 25% HFC 134a; 20% HCFCs; 4% other HFCs			
	New Equipment: 40% HFC 410A; 30% HFC 407C; 30% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €20,000	Energy: €2,700 per year Maintenance: €600 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 48,000 units	2030: 58,000 units		
Installed base	2010: 513,000 units	2030: 932,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 134a	+5%	0%	+5%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
3	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
4	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
5	HFO 1234ze	+10%	0%	+14%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
6	HCs	+10%	0%	+17%	Available in 2012. Design and location must take into account high flammability of refrigerant.

Reference: 6.2	**Chillers & hydronic heat pumps, Medium - cooling only, air cooled**		
Description: Medium sized water chillers providing chilled water for air-conditioning. Scroll or screw compressors, air cooled.			
Standard system 2010	HFC 134a	Charge: 150 kg	Cooling: 500 kW	COP: 3.6
Refrigerant split 2010	Bank: 14% HFC 410A; 14% HFC 407C; 47% HFC 134a; 22% HCFCs; 4% other HFCs		
	New Equipment: 60% HFC 134a; 40% HFC 410A		
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%
Cost factors 2010	Lifecycle: 18 years	Capital: €75,000	Energy: €12,000 per year Maintenance: €2,300 per year
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%	
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total	
Annual new systems	2010: 10,000 units	2030: 12,000 units	
Annual new systems	2010: 103,000 units	2030: 186,000 units	

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
2	HFO B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	HFO B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	HCs	+10%	0%	+17%	Available in 2012. Design and location must take into account high flammability of refrigerant.
5	Ammonia	+20%	0%	+28%	Available in 2012
6	HFO 1234ze	+10%	0%	+14%	Available in 2012, but few components available

Reference: 6.3	**Chillers & hydronic heat pumps, Large - cooling only, air cooled**			
Description: Large sized water chillers providing chilled water for air-conditioning. Screw compressors, air cooled.				
Standard system 2010	HFC 134a	Charge: 360 kg	Cooling: 1200 kW	COP: 3.8
Refrigerant split 2010	Bank: 14% HFC 410A; 5% HFC 407C; 62% HFC 134a; 17% HCFCs; 3% other HFCs			
	New Equipment: 70% HFC 134a; 30% HFC 410A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €120,000	Energy: €26,000 per year Maintenance: €3,600 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 1,000 units	2030: 600 units		
Annual new systems	2010: 11,000 units	2030: 11,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten-ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
2	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	HCs	+10%	0%	+17%	Available in 2012. Design and location must take into account high flammability of refrigerant.
5	Ammonia	+20%	0%	+28%	Available in 2012
6	HFO 1234ze	+10%	0%	+14%	Available in 2012, but few components available

Reference: 6.4	Chillers & hydronic heat pumps, Small - cooling only, water cooled			
Description: Small sized water chillers providing chilled water for air-conditioning. Scroll or screw compressors, water cooled.				
Standard system 2010	HFC 410A	Charge: 29 kg	Cooling: 100 kW	COP: 5
Refrigerant split 2010	Bank: 15% HFC 410A; 39% HFC 407C; 26% HFC 134a; 17% HCFCs; 3% other HFCs			
	New Equipment: 40% HFC 410A; 30% HFC 407C; 30% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €25,000	Energy: €1,200 per year Maintenance: €750 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 1,400 units	2030: 1,700 units		
Annual new systems	2010: 15,000 units	2030: 27,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+5%	0%	+5%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
5	HCs	+10%	0%	+17%	Available in 2012. Design and location must take into account high flammability of refrigerant.
6	HFO 1234ze	+10%	0%	+14%	Available in 2012, but few components available

<table>
<tr><td>Reference: 6.5</td><td colspan="4">Chillers & hydronic heat pumps, Medium - cooling only, water cooled</td></tr>
<tr><td colspan="5">Description: Medium sized water chillers providing chilled water for air-conditioning. Scroll or screw compressors, water cooled.</td></tr>
<tr><td>Standard system 2010</td><td>HFC 134a</td><td>Charge: 150 kg</td><td>Cooling: 500 kW</td><td>COP: 5.5</td></tr>
<tr><td rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 15% HFC 410A; 15% HFC 407C; 49% HFC 134a; 18% HCFCs; 4% other HFCs</td></tr>
<tr><td colspan="4">New Equipment: 60% HFC 134a; 40% HFC 410A</td></tr>
<tr><td>Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 2.0%</td><td>Annual leakage: 5%
Top-up factor: 100%</td><td colspan="2">End of life: 25%</td></tr>
<tr><td>Cost factors 2010</td><td>Lifecycle: 18 years</td><td>Capital: €100,000</td><td colspan="2">Energy: €8,000 per year
Maintenance: €3,000 per year</td></tr>
<tr><td>Operating factors</td><td colspan="2">Operating hours/year cooling: 1800</td><td colspan="2">Load factor (when in use) cooling: 33%</td></tr>
<tr><td>Pre-filled imports</td><td>Net imports: 0%</td><td colspan="3">Charge added during installation: 0% of total</td></tr>
<tr><td>Annual new systems</td><td colspan="2">2010: 1,200 units</td><td colspan="2">2030: 1,500 units</td></tr>
<tr><td>Installed base</td><td colspan="2">2010: 13,000 units</td><td colspan="2">2030: 24,000 units</td></tr>
</table>

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
2	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
3	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
4	HCs	+10%	0%	+17%	Available in 2012. Design and location must take into account high flammability of refrigerant.
5	Ammonia	+20%	0%	+28%	Available in 2012
6	HFO 1234ze	+10%	0%	+14%	Available in 2012, but few components available

Reference: 6.6	**Name: Chillers & hydronic heat pumps, Large - cooling only, water cooled**			
Description: Large sized water chillers providing chilled water for air-conditioning. Centrifugal compressors, water cooled.				
Standard system 2010	HFC 134a	Charge: 750 kg	Cooling: 2,500 kW	COP: 6.4
Refrigerant split 2010	Bank: 95% HFC 134a; 4% HCFCs; 2% other HFCs			
	New Equipment: 100% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 20%	
Cost factors 2010	Lifecycle: 18 years	Capital: €325,000	Energy: €33,000 per year Maintenance: €9,800 per year	
Operating factors	Operating hours/year cooling: 1800	Load factor (when in use) cooling: 33%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 650 units	2030: 530 units		
Annual new systems	2010: 10,000 units	2030: 11,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
2	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non- flammable HFO blend (GWP 700) suited to this application.
3	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
4	HFO 1234ze	+10%	0%	+14%	Available in 2012, but few components available
5	HFO DR2/N12	+5%	-3.5%	+9%	Production not yet confirmed. Mildly flammable HFO blend.

Reference: 6.7	**Chillers & hydronic heat pumps, Domestic - heating only, air to water**			
Description: Domestic-sized air source heat pump for space heating via hot water,				
Standard system 2010	HFC 410A	Charge: 4.4 kg	Heating: 15 kW	COP: 2.9
Refrigerant split 2010	Bank: 21% HFC 410A; 45% HFC 407C; 33% HFC 134a; 1% HCFCs			
	New Equipment: 40% HFC 410A; 30% HFC 407C; 30% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €6,000	Energy: €1,000 per year Maintenance: €180 per year	
Operating factors	Operating hours/year heating: 2800	Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 240,000 units	2030: 670,000 units		
Installed base	2010: 2,200,000 units	2030: 8,600,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFC 134a	+5%	0%	+5%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 6.8	**Chillers & hydronic heat pumps, Small - heating only, air to water**			
Description: Medium sized air source heat pump for space heating via hot water,				
Standard system 2010	HFC 410A	Charge: 29 kg	Heating: 100 kW	COP: 2.9
Refrigerant split 2010	Bank: 20% HFC 410A; 18% HFC 407C; 60% HFC 134a; 1% HCFC			
	New Equipment: 40% HFC 410A; 60% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €30,000	Energy: €6,800 per year Maintenance: €900 per year	
Operating factors	Operating hours/year heating: 2800	Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 6,000 units	2030: 17,000 units		
Annual new systems	2010: 55,000 units	2030: 215,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFC 134a	+5%	0%	+5%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Reference: 6.9	Chillers & hydronic heat pumps, Small - reversible heating/cooling, air to water			
Description: Small sized reversible system providing (a) air cooled chilled water for cooling or (b) air source heat pump (heat delivered via hot water).				
Standard system 2010	HFC 410A	Charge: 29 kg	Cooling: 100 kW Heating: 100 kW	Cooling COP: 3.1 Heating COP: 2.5
Refrigerant split 2010	Bank: 17% HFC 410A; 42% HFC 407C; 29% HFC 134a; 12% HCFCs			
	New Equipment: 40% HFC 410A; 30% HFC 407C; 30% HFC 134a			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.5%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €30,000	Energy: €10,000 per year Maintenance: €900 per year	
Operating factors	Operating hours/year cooling: 1800 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 11,000 units	2030: 13,000 units		
Annual new systems	2010: 142,000 units	2030: 230,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 134a	+5%	0%	+5%	Available in 2012
2	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
3	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
4	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
5	HCs	+10%	0%	+17%	Design and location must take into account high flammability of refrigerant.

Reference: 6.10	Chillers & hydronic heat pumps, Medium - reversible heating/cooling, air to water			
Description: Medium sized reversible system providing (a) air cooled chilled water for cooling or (b) air source heat pump (heat delivered via hot water).				
Standard system 2010	HFC 134a	Charge: 150 kg	Cooling: 500 kW Heating: 500 kW	Cooling COP: 3.6 Heating COP: 2.8
Refrigerant split 2010	Bank: 17% HFC 410A; 17% HFC 407C; 54% HFC 134a; 12% HCFCs			
	New Equipment: 60% HFC 134a; 40% HFC 410A			
Emission factors 2010	Manufacturing: 0.5% On-site charging: 2.0%	Annual leakage: 5% Top-up factor: 100%	End of life: 25%	
Cost factors 2010	Lifecycle: 18 years	Capital: €115,000	Energy: €46,000 per year Maintenance: €3,500 per year	
Operating factors	Operating hours/year cooling: 1800 Operating hours/year heating: 2800	Load factor (when in use) cooling: 33% Load factor (when in use) heating: 50%		
Pre-filled imports	Net imports: 0%	Charge added during installation: 0% of total		
Annual new systems	2010: 2,100 units	2030: 2,700 units		
Annual new systems	2010: 28,000 units	2030: 46,000 units		

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFC 32	+5%	0%	+9%	Available in 2012, but not widely used
2	B700	+0%	0%	+0%	Not available until 2015 to 2018. Should be a non-flammable HFO blend (GWP 700) suited to this application.
3	B300	+5%	0%	+9%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.
4	HCs	+10%	0%	+17%	Design and location must take into account high flammability of refrigerant.

<table>
<tr><td>Reference: 7.1</td><td colspan="4">Name: Mobile air-conditioning – cars, vans, lorry cabs</td></tr>
<tr><td colspan="5">Description: Mobile air-conditioning systems in cars and other small sized systems in vans / lorries. Most systems are driven off main vehicle engine via belt connection.</td></tr>
<tr><td>Standard system 2010</td><td>HFC 134a</td><td>Charge: 0.6 kg</td><td>Cooling: 4 kW</td><td>COP: 1.5</td></tr>
<tr><td rowspan="2">Refrigerant split 2010</td><td colspan="4">Bank: 100% HFC 134a</td></tr>
<tr><td colspan="4">New Equipment: 100% HFC 134a</td></tr>
<tr><td>Emission factors 2010</td><td>Manufacturing: 0.5%
On-site charging: 2.0%</td><td colspan="2">Annual leakage: 5%
Top-up factor: 100%</td><td>End of life: 80%</td></tr>
<tr><td>Cost factors 2010</td><td>Lifecycle: 9 years</td><td>Capital: €600</td><td colspan="2">Energy: €120 per year
Maintenance: €18 per year</td></tr>
<tr><td>Operating factors</td><td colspan="2">Operating hours/year cooling: 600</td><td colspan="2">Load factor (when in use) cooling: 50%</td></tr>
<tr><td>Pre-filled imports</td><td>Net imports: -8%</td><td colspan="3">Charge added during installation: 0% of total</td></tr>
<tr><td>Annual new systems</td><td colspan="2">2010: 11 million units</td><td colspan="2">2030: 14 million units</td></tr>
<tr><td>Installed base</td><td colspan="2">2010: 95 million units</td><td colspan="2">2030: 123 million units</td></tr>
</table>

Alternative Refrigerant Options (comparison with standard 2010 system)					
No.	**Refrigerant**	**Capital**	**Energy**	**Mainten -ance**	**Availability**
1	HFO 1234yf	+5%	0%	+9%	Available in 2012, although quantities low until around 2014. Required in new vehicle types via MAC Directive

<table>
<tr><th>Reference: 7.2</th><th colspan="5">Name: Mobile air-conditioning – buses and trains</th></tr>
<tr><td colspan="6">Description: Mobile air-conditioning systems in buses and trains. Most systems are driven off independent motors or engines.</td></tr>
<tr><td>Standard system 2010</td><td>HFC 134a</td><td>Charge: 14 kg</td><td colspan="2">Cooling: 25 kW</td><td>COP: 1.5</td></tr>
<tr><td rowspan="2">Refrigerant split 2010</td><td colspan="5">Bank: 69% HFC 134a; 6% HFC 410A; 3% HFC 407C; 21% HCFCs</td></tr>
<tr><td colspan="5">New Equipment: 80% HFC 134a; 20% HFC 410A</td></tr>
<tr><td>Emission factors 2010</td><td colspan="2">Manufacturing: 0.5%
On-site charging: 2.0%</td><td colspan="2">Annual leakage: 18%
Top-up factor: 100%</td><td>End of life: 80%</td></tr>
<tr><td>Cost factors 2010</td><td colspan="2">Lifecycle: 15 years</td><td colspan="2">Capital: €3,800</td><td>Energy: €2400 per year
Maintenance: €110 per year</td></tr>
<tr><td>Operating factors</td><td colspan="3">Operating hours/year cooling: 2000</td><td colspan="2">Load factor (when in use) cooling: 50%</td></tr>
<tr><td>Pre-filled imports</td><td colspan="2">Net imports: -10%</td><td colspan="3">Charge added during installation: 0% of total</td></tr>
<tr><td>Annual new systems</td><td colspan="3">2010: 170,000 units</td><td colspan="2">2030: 230,000 units</td></tr>
<tr><td>Annual new systems</td><td colspan="3">2010: 2,700,000 units</td><td colspan="2">2030: 3,500,000 units</td></tr>
</table>

Alternative Refrigerant Options (comparison with standard 2010 system)

No.	Refrigerant	Capital	Energy	Mainten-ance	Availability
1	HFO 1234yf	+10%	0%	+14%	Not available until car market has sufficient supplies (may be around 2014)
2	B300	+10%	0%	+14%	Not available until 2015 to 2018. Should be a mildly flammable HFO blend (GWP 300) suited to this application.

Appendix D Sub-Sector Refrigerant Choices

The charts in the following section show the forecasts of refrigerant mix for new systems in each sub-sector. Each sub sector has a different refrigerant mix forecast for each Scenario A, B, C or D.