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

EXECUTIVE SUMMARY

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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

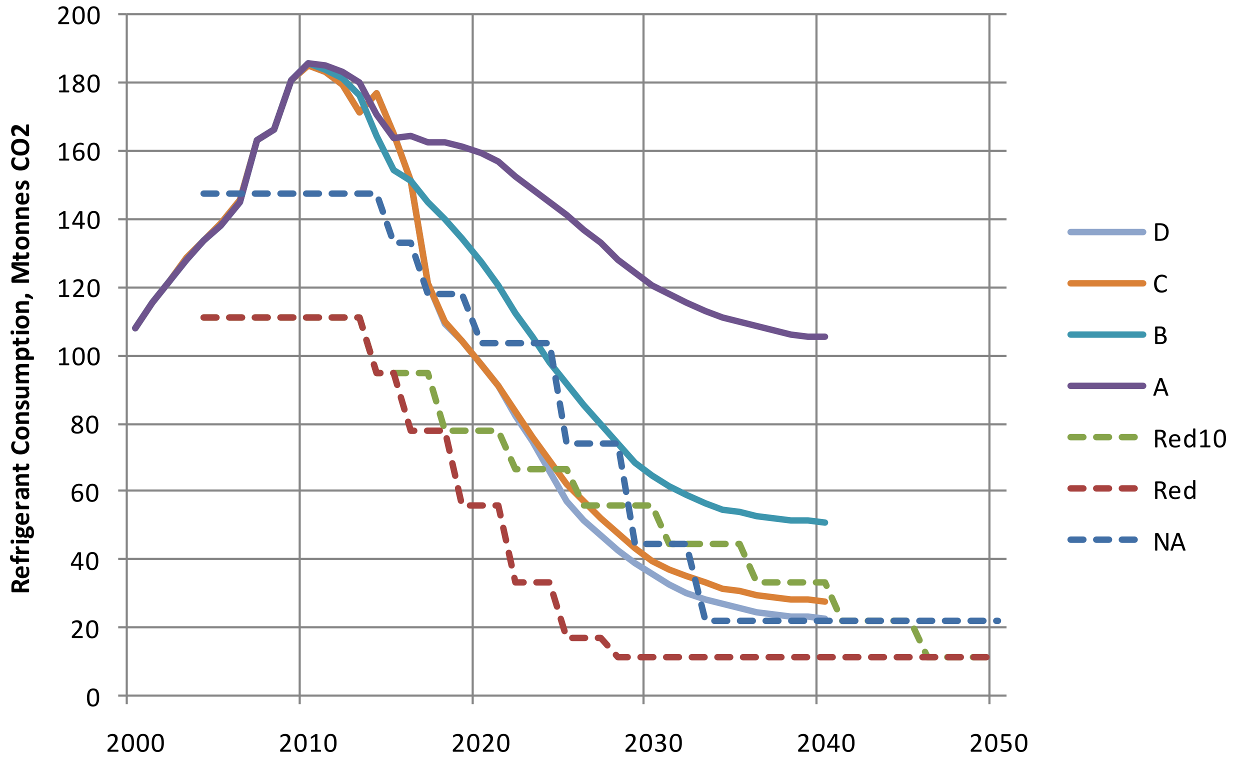


Figure ES 1 clearly shows that:

- 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.

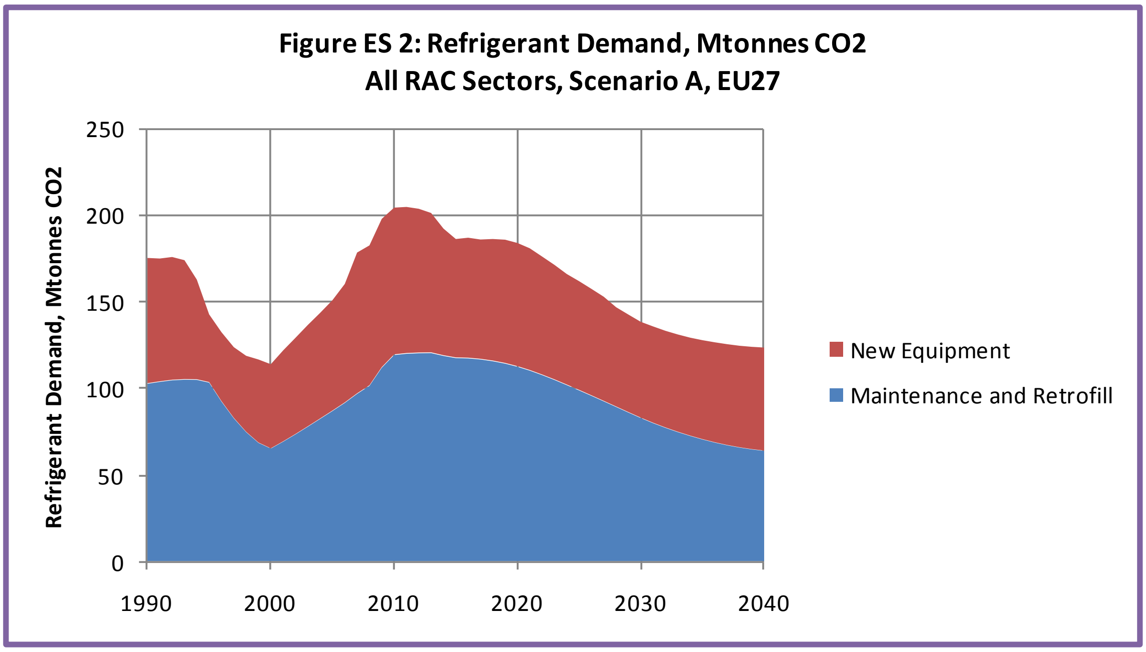
    Results of sensitivity analysis are shown in Table ES 3. These show that the uncertainty in abatement costs is in the range from around €4 to €43 per tonne CO_2.

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

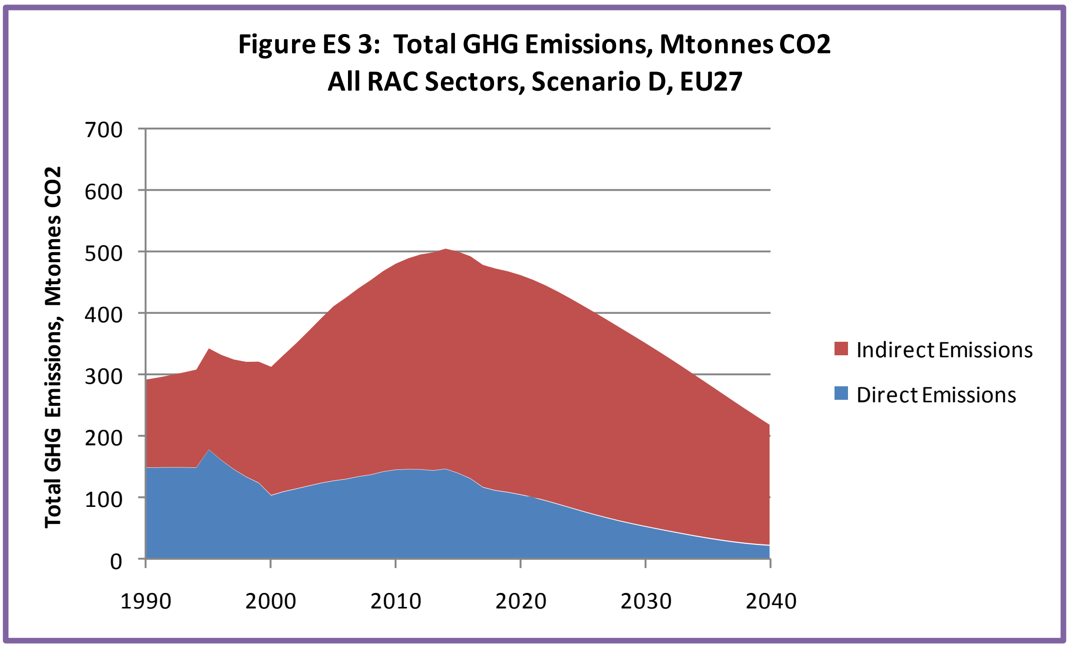
15. Abatement cost figures in Oko Recherche 2011 use optimistically high assumptions for the improved energy efficiency of alternatives such as ammonia. This study provides a more realistic assessment of energy efficiency differences between refrigerants.

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.

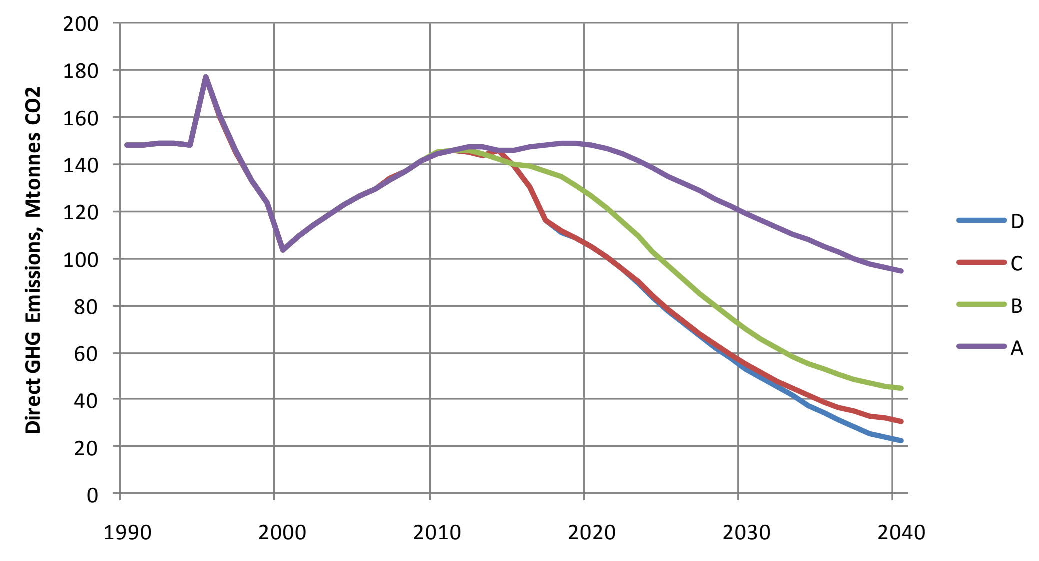


17. The modelling shows the importance of energy related "indirect" CO_2 emissions. In 2030, the energy related emissions are 85% of total emissions, as shown in Figure ES 3. To achieve maximum reduction in total emissions it is clearly essential that energy efficiency of RAC systems is further improved. 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.

Figure ES 4: Direct Greenhouse Gas Emissions, Mtonnes CO2All RAC Sectors, EU27



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

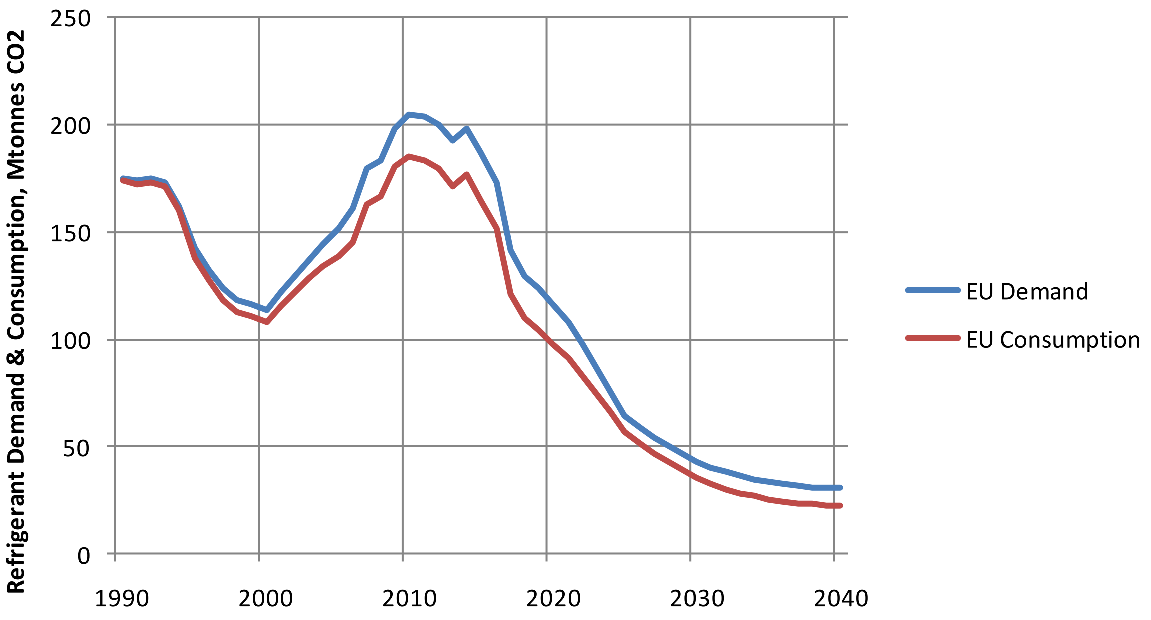
21. There is a difference between EU <u>consumption</u> of refrigerant (Montreal Protocol definition that excludes imports / exports in pre-charged equipment) and EU <u>demand</u> (which includes such imports / exports). Most of the difference is related to the small air-conditioning market, for

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

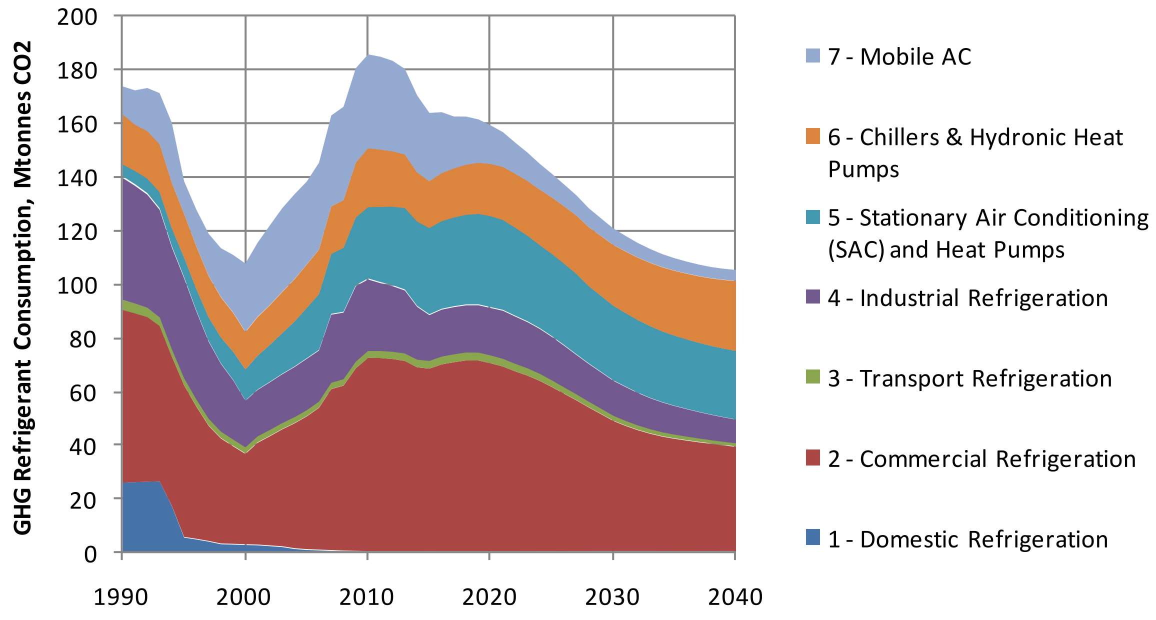
Use of Mildly Flammable Refrigerants

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.

Figure ES 6: GHG Refrigerant Consumption, Mtonnes CO2
All Refrigerants, Scenario A, EU 27



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.