Further Assessment of Policy Options for the Management and Destruction of Banks of ODS and F-Gases in the EU

FINAL REPORT

- Revised Version 2
- March 2012

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Contents

Executive Summary

Background

1) This report provides the results of a study that has evaluated policy measures that can be introduced in the EU to reduce emissions from banks of Ozone Depleting Substances (ODS) and fluorinated greenhouse gases (F-Gases). The study was carried out for DG Clima by a consortium led by SKM Enviros during the period January 2011 to January 2012. The other members of the project team were Caleb and Quantum.

2) ODS were used in a range of products and equipment although bans brought in via the EU Ozone Regulations (EU, 2009) have significantly curtailed their use during the last 10 years. There remains a large bank of ODS in various parts of the insulating foam market, in particular CFC blown foam that is used for building insulation. There is also a very small ODS bank (around 3% of the total ODS bank) in parts of the RAC (refrigeration and air-conditioning) market.

3) F-Gases are used in various products including RAC, insulating foam, aerosols, fire protection, magnesium smelting, solvents and high voltage gas insulted switchgear (GIS). Only the RAC, foams and GIS markets create long lived banks with significant potential for F-Gas emissions.

4) Emissions of gases from the ODS bank cause damage to the ozone layer <u>and</u> make a contribution to global warming as most ODS also have a high GWP (global warming potential). Emissions of gases from the F-Gas bank have no effect on the ozone layer, but do make a contribution to global warming.

Study Methodology

5) This study follows a previous investigation into ODS and F-Gas Banks (ICF, 2010).

6) A detailed literature review was carried out, as reported in Section 2. This provided a useful input into the modelling of emissions and policy development. It also showed that there is very little data available to show the degree of compliance with current regulations that should already limit emissions from ODS and F-Gas banks.

7) A questionnaire was sent to officials in all EU Member States to collect information about policies and practices in each country. Helpful responses were received from 21 Member States, representing 95% of the EU population. A sample of 5 countries was selected for more detailed interviews and evaluation. Section 3 summarises the findings from the questionnaire and country case studies. This provides a valuable assessment of the variations in practices across the EU.

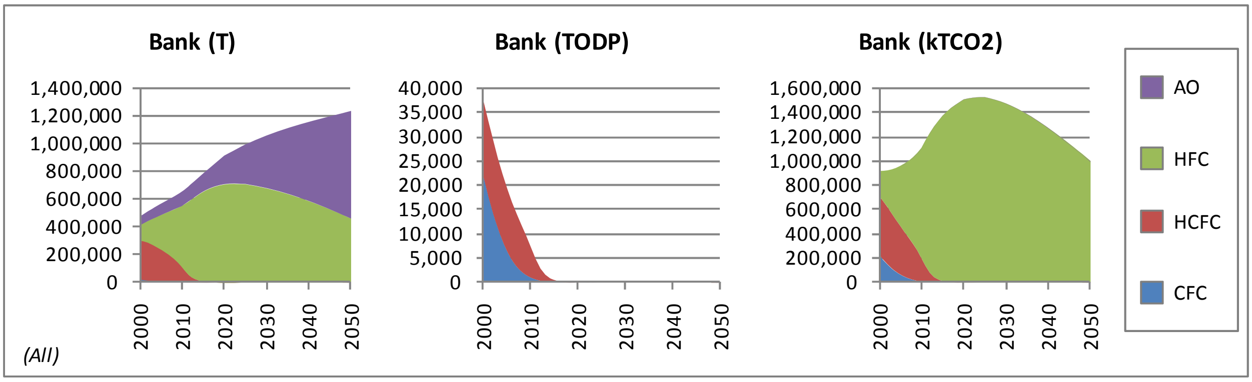
8) A previous banks model (ICF, 2010) was reviewed and various problems identified. A Revised Banks Model was developed and used as a basis to evaluate policy measures. Details of the Revised Banks Model can be found in Section 4 and Appendix B.

Levels of Emissions

9) The Revised Banks Model was developed to establish emissions from the RAC, foams and GIS markets. This modelling is complex and has required the analysis of numerous sub-sectors of each market to provide a realistic estimate of emissions across a large number of end uses that each have very different characteristics. 19 market sub-sectors were analysed including 9 for RAC, 8 for foams and 2 for GIS. The sub-sectors are summarised in Table 5-1.

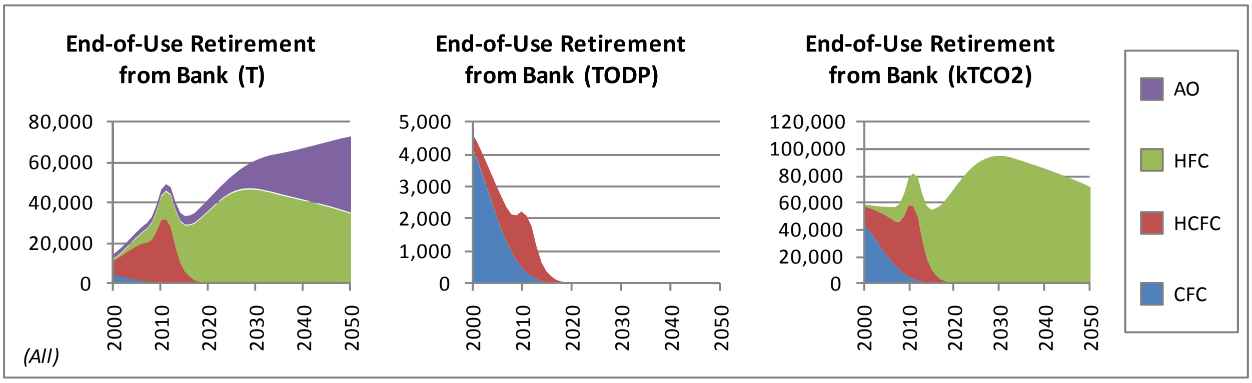
10) The Revised Banks Model delivers detailed estimates of bank size and emissions for each market sub-sector and for the main markets. Figure ES 1 illustrates an example of outputs, showing the bank development for the RAC sectors. The outputs include the actual physical tonnage in the bank (left chart) and the ODP and GWP weighted banks. This example shows how the ODP weighted bank for RAC is already tiny and will soon fall to zero. It also shows how the GWP weighted bank continues to grow till around 2020 and then falls as "All Other" (AO) refrigerants begin to take a large share of the bank.

Figure ES 2: Bank Estimate for RAC Sectors Total



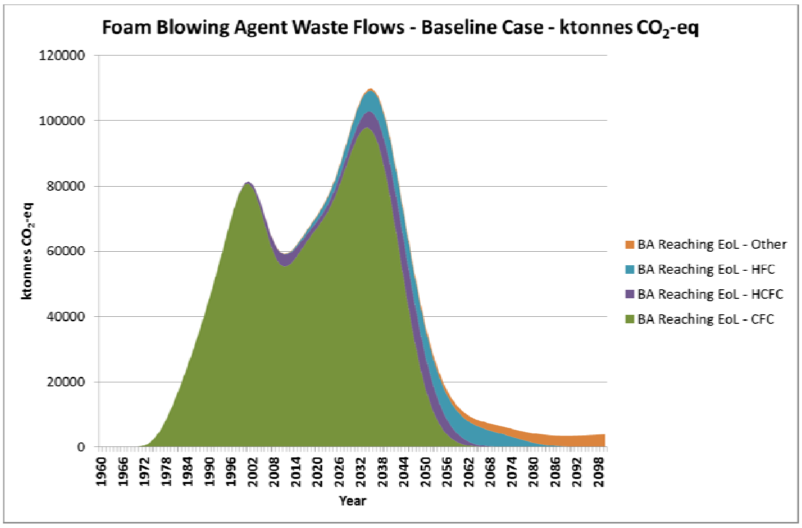
11) The rate of retirement from each bank is a crucial input into understanding emissions from banks at end-of life (EOL). Figure ES 2 illustrates the impact of the Ozone Regulation that is forcing early retirement of HCFC equipment in the period 2010 to 2015, creating a distinctive "hump" in the retirement curve.

Figure ES 2: EOL Retirement for RAC Sectors Total



12) Figure ES 3 illustrates an interesting "double hump" effect in the foam retirements, caused by the presence of both short lifecycle products (e.g. domestic appliance foam, 15 year life) and long lifecycle products (e.g. building insulation foam, 50 year life).

Figure ES 3:



13) The ODS bank is dominated by CFCs in old building insulation products. In 2015 around 97% of ODS retirements will be from the foams sector.

14) In GWP weighted terms the RAC bank becomes much more significant and annual emissions are higher from RAC than from foam because of the high level of in-life leakage losses.

15) Both the foams and RAC emission profiles change significantly between now and 2050 as a result of previous legislation (especially phase out of CFCs) and expected future changes in use of HFCs. This makes it difficult to assess the financial impact of EOL policy measures as these will vary over time as the composition of the waste stream varies.

Policy Evaluation

16) The policy evaluation was carried out in two stages. Firstly, a "long list" of 456 measures were screened by assessing 24 different policy measures for each the 19 market sub-sectors. The screening process was based on a "traffic light" grading system that quickly identified measures that were inapplicable and highlighted those with merit. The best measures were then carried forward into a "short list analysis" where a total of 20 measures were evaluated in more detail.

17) Table ES 1 shows the gradings used for each long list policy measure and Table ES 2 illustrates the gradings applied to 5 Regulatory Policy Measures in the 9 RAC market sub-sectors. Details of the long list analysis for all RAC, foams and GIS sectors are presented in Section 5.5.

Table ES 1: Traffic Light Grading System for Policy Measures

	Green1	(G1)	EOL policy worth further consideration
	Green2	(G2)	Long term EOL benefit, but main benefits are reduced "use phase" emissions
	Amber1	(A1)	May be worthwhile, but doubts over cost or regulatory effectiveness
	Amber2	(A2)	Maybe worthwhile, but doubts of technological effectiveness
	Red1	(R1)	No change required - Regulation already in place
	Red2	(R2)	Not considered effective or relevant

Table ES 2: Traffic Light Analysis for RAC Group 1 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
1) Product bans	G2	G2	A2	G2	G2	A2	G2	A2	R1
2) Recovery requirement	R1	R1	R1	R1	R1	R1	R1	G1	G1
3) Contractor recovery	R2	G1	G1	G1	G1	G1	G1	G1	G1
4) Data collection	G1	G1	A1	G1	G1	A1	A1	A1	A1
5) MS Regulation	R1	R1	R1	R1	R1	R1	R1	R2	R2

18) For the RAC market 9 polices were short listed and evaluated, as summarised in Table ES 3.

Table ES 3: RAC Short List Measures – Abatement Volume and Cost Summary Table

	RAC Proposal	Abatement, MT CO_2		Cost € per tonne CO_2	
		Low	High	Low	High
1	HCFC Emergency Measures	5	10	3	6
2	Extend EOL obligations for Mobile RAC	6	12	15	30
3	Mirror EOL obligations for Contractors	120	200	2	3
4	HFC Product Bans	2,000	2,500	15	25
5	Reduced use of R404A	700	1,100	-5	5
6	Better policing	170	280	3	6
7	GWP tax	800	1,500	15	25
8	Information initiatives	100	200	1	2
9	Data collection	75	150	10	20

19) All RAC short list measures have cost effectiveness considered as good (less than €10 per tonne CO_2 abated) or reasonable (€10 to €30 per tonne CO_2 abated). It is strongly recommended that a number of these policy measures are taken forward by the Commission. The most important measures to take forward are:

- Early implementation of measures to reduce use of HFC 404A in new and existing systems
- HFC bans in certain RAC markets for new systems
- Changes to EOL provisions of the F Gas Regulation (related to mobile RAC and contractor obligations).
- Information initiatives, building on the access to RAC contractors created by the Certificated Company Registers in each Member State
- Emergency information measures related to HCFCs
- Better Implementation and Policing of Current Regulation

20) For the foams market 8 polices were short listed and evaluated, as summarised in Table ES 4.

Table ES 4 Foams Short List Measures – Abatement Volume and Cost Summary Table

		Abatement, MT CO_2		Cost € per tonne CO_2 +	
		2012-2030	2031-2050	Low	High
1	Phase-out of HFC use in XPS / PU Spray Foams	44	18	25	45
2	Recovery, Commercial Appliances	1	2	282	2340
3	Recovery, Building Services / Industrial Sectors	4	3	286	930
4	Recovery, steel-faced panels / built-up systems	42	82	52	192
5	Improved Domestic Refrigerator EOL recovery	1	1	205*	205*
6	Industry Commitments	42	57	54	180
7	Information initiatives	21	29	54	180
8	Promotion of research into managing foam waste	Unclear	Unclear	Unclear	Unclear

+ High and low cost estimates are based on recovery costs assumptions ‘per kg’ of blowing agent as shown in Table ES-5
* Accounts for additional regulatory cost only as compliance cost already accounted for in earlier Regulatory Impact Assessment

21) Based on an analysis to 2050, the wide range of abatement cost determinations for the proposed foam measures makes it more difficult to make precise recommendations. However, the following aspects should be noted:

- No end-of-life foam measure provides an average abatement cost lower than € 50 per tonne CO_2 abated for the whole period from 2012-2050. Although ‘per kg’ recovery costs are higher and there may be technical challenges, construction foams offer the most effective options because of the volumes involved and the high average GWP of the waste stream throughout the period.

- Actions in the appliance sectors (Measures 2 & 5) deliver limited environmental benefit because most of the ozone depleting substances have already passed into the waste stream
- When taking average abatement cost determinations to 2050, the low average GWP of the waste stream for most of that period also makes these amongst the most expensive options, even when only considering the incremental regulatory costs
- Opportunities for mandatory or voluntary recovery exist for foams in the building services and industrial sectors (Measure 3), although further case studies would be useful to confirm recovery costs and logistics. As with appliances, the low average GWP of the blowing agents in the waste stream beyond 2030 might encourage early termination of a recovery programme. This would also lower the cost ranges shown in Table ES-4.
- The wide range of baseline demolition practices across European Member States makes it problematic to implement mandatory measures at EU level in the construction foam sector, even for the most accessible of product types. However, action at Member State level may be justified, at least in the early years while average GWPs warrant the recovery.
- Voluntary actions (e.g. industry commitments & information initiatives) in the construction foam sector have the potential to deliver substantial abatements even if they move recovery levels by as little as 10%, owing to the size of the banks in this sector. There are synergies with other waste management strategies already being promoted by industry.
- Although not strictly an end-of-life issue, the early phase-down of HFC use in the XPS and PU Spray Foam sectors would generate substantial emissions savings at reasonable cost effectiveness. This assessment is based on the likely future use of unsaturated molecules (HFOs) rather than HCs (assumed in the F-Gas review), since HC technologies are not appropriate for the majority of current XPS applications in Europe.

22) Recovery cost data ‘per kg’ on foam blowing agents remains largely anecdotal at this point since many foams have still to reach end-of-life. Therefore, this report has taken the anecdotal evidence available to create low and high assumptions that reflect the variation in baselines across Member States as shown in Table ES-5. These ranges are then compared with the maximum average recovery costs that could be accommodated over the period to meet typical abatement cost thresholds used in this report.. The table may therefore be helpful to those Member State officials seeking to assess whether the economics of blowing agent recovery in their country would align with the thresholds applied to their wider climate policies. Where values are shaded in grey, these are below the currently perceived minimum ‘per kg’ recovery cost and implies that measures in these sectors would be uneconomic – as might already be deduced from the abatement cost ranges shown in Table ES-4.

Table ES 5 Blowing Agent Recovery Cost Assumptions and Related Cost Thresholds

Abatement Cost Assumptions per kg of Blowing Agent and related Thresholds						
	Assumed cost € per kg		Maximum "per kg" Cost* to Meet Threshold		
	Low	High	€50/T CO_2	€100/T CO_2	€150/T CO_2
FP2 Other Appliance	10	100	0	2	4
FP3 Building Services – Pipe	30	120	4	10	17
Building Services – Slab	50	150	5	13	21
FP4 Steel-faced Panels	25	120	30	62	94
Built-up Systems	50	150	38	78	118
FP5 Domestic Refrigeration	5	25	-	-	-
FP6 Industry Commitments – Roof	50	200	55	110	166
Industry Commitments – Wall	100	300	83	165	249
Industry Commitments – Floor	200	500	138	275	415

* Grey shading denotes cost below current minimum

23) For the GIS market 8 polices were short listed and evaluated. Whilst all of these have reasonable cost effectiveness (€10 to €30 per tonne CO_2 abated) the overall abatement potential is very small compared to either the foams or RAC measures. Voluntary Agreements could be the best measure to take forward in the GIS sector.

1. Introduction

This document is the final report for the study “Further Assessment of Policy Options for the Management and Destruction of Banks of ODS and F-Gases in the EU”. The study is being carried out on behalf of DG Clima by a consortium led by SKM Enviros. The consortium includes Caleb and Quantum.

The project started in January 2011 and this report was finalised in January 2012. The report provides follow on analysis to a previous study on ODS and F-Gas banks conducted for DG Clima by ICF in 2009 / 2010 (ICF, 2010).

1.1. Structure of Report

This report is structured as follows:

Section 1, Introduction – giving background to the project including study objectives, an introduction to ODS and F-Gas banks and a summary of current legislation.

Section 2, Literature Review – providing an analysis of relevant literature.

Section 3, Member State Policies and Practices – summarising a review of relevant activities being carried out in individual EU countries. It includes results from a questionnaire sent to the 27 EU Member States and further information gathered via 5 Member State Case Studies.

Section 4, Modelling of Bank and End of Life Emissions – giving a critique of the previous banks model (ICF, 2010) and details of a Revised Banks Model developed during this study.

Section 5, Policy Options – this important section provides the analysis of a “long list” of around 400 relevant policy options and a detailed assessment of a “short list” of the 20 most promising policy interventions.

Section 6, Conclusions and Policy Recommendations – a final section giving overall conclusions and policy recommendations.

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

1.2. Study Objectives

ODS and F-Gases are widely used throughout Europe in a number of specialised applications including refrigeration, air-conditioning, insulating foam and gas insulated switchgear. At the end of the life of products and equipment in these markets there is the potential for release of ODS and F-Gases to the atmosphere, which is potentially very harmful to the environment. ODS cause damage to the ozone layer <u>and</u> they have a very high global warming potential (GWP). F-Gases have a very high GWP.

Emissions of ODS and F-Gases are covered by various pieces of legislation both at EU and Member State level. In particular, these include the EU Ozone Regulation 1005/2009 (EU, 2009), the EU F-Gas Regulation 842/2006 (EU, 2006) and EU waste regulations such as Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE) (EU, 2002). Although such legislation is already in place it is important to ensure that the end of life emissions from ODS and F-Gas banks are being minimised. Key questions include:

- Are current policies sufficient to avoid unnecessary emissions?
- Are policies being properly implemented?

The objective of this study is to provide an in-depth review of policy options for minimising emissions of ODS and F-gases from products and equipment at the end of their life, and to conduct an impact assessment supporting final policy recommendations. The steps in the project include:

Task 1: Review of relevant existing policies and Member States practices.

Task 2: Assessment and improvement of existing models and datasets on ODS and F-gas.

Task 3: Assessment of policy options for the management of ODS and F-gas banks.

Task 4: Stakeholder workshop to discuss recommended measures.

Task 5: Recommendations for policy actions at the national, regional and EU level.

All the above tasks are now complete and results of the work are in this report. The Stakeholder Workshop was held in Brussels in October 2011. 48 people attended including EC officials, Member State officials and stakeholders from the refrigeration and foam industries.

1.3. Background to ODS and F-Gas Banks

To understand the implications of end of life (EOL) emissions from ODS and F-Gas banks it is important to understand the historic and current uses of ODS and F-Gases.

ODS Uses and Banks

ODS were historically used for a variety of products and equipment. The most important were:

- Refrigerants for stationary and mobile refrigeration, air-conditioning and heat pumps (RAC)
- Propellants for aerosols
- Blowing agents for insulating foam (e.g. PU, XPS, integral skin)
- Solvents for industrial cleaning processes
- Specialist fluids for fire protection

The use of ODS for new products and equipment was banned at various dates between 2000 and 2004. The only on-going use allowed in 2012 for ODS is recycled and reclaimed HCFCs that can be used for maintenance of existing refrigeration and air-conditioning equipment.

In terms of banks of ODS, there are 2 market sectors that need to be taken into account i.e. insulating foams and RAC. Any banked ODS material used for aerosol or solvent applications will have been disposed of many years ago as these applications were banned in 2000 and do not create a long term bank. Halons used for fire protection have been subject to a phase out in the EU including that stored in historic halon banks. Some small quantities of halons are still used in certain exempted applications (e.g. military).

The **ODS foams bank** is very important in relation to this study. An ODS such as CFC 11 or CFC 12 was used as a blowing agent to create PU or XPS insulating foams. Some of the blowing agent is lost during the foam manufacturing process and some “diffuses” from the foam during its life, but a significant proportion (sometimes the majority) of the blowing agent is retained in the closed cell structure of the foam for the whole service life of the foam. At EOL this blowing agent could be emitted to atmosphere or find its way into the respective waste streams (e.g. landfill). It is important to note that in many applications, insulating foam has a very long life (e.g. >50 years in many building applications) and the EOL emission will be a long time after the foam was first manufactured. It is also worth noting that if foam goes into landfill at EOL the ODS is not necessarily emitted immediately – it can take many years for the foam to be broken down in landfill. To complicate matters further, the chemical fate of an ODS in anaerobic landfill conditions remains unclear.

The **ODS refrigerants bank** remains significant in the short term because of HCFCs still being used in various RAC applications – mostly in industrial and commercial refrigeration plants and in stationary air-conditioning applications. There are virtually no CFCs left in the refrigerants bank, as any remaining CFC equipment (e.g. domestic refrigerators or car air-conditioning) will have already reached EOL by 2012 (a few old CFC systems may still be operating but the quantities of CFCs involved are small). A key aspect of the refrigerants bank is the on-going phase out of HCFC usage in Europe. Under the EU Ozone Regulation use of virgin HCFCs was banned from January 2010 and use of reclaimed and recycled HCFCs will be banned at the end of 2014. This means that many remaining HCFC systems will be reaching EOL before 2015. Good HCFC refrigerant bank management is essential if EOL emissions are to be minimised.

F-Gas Uses and Banks

F-Gases include HFCs, PFCs and SF_6. Many of the current uses of F-Gases are as alternatives for ODS. There are also a number of other uses that go beyond traditional ODS markets. The key uses of F-Gases are:

- Refrigerants for stationary and mobile refrigeration, air-conditioning and heat pumps (RAC)
- Propellants for aerosols

- Blowing agents for insulating foam (e.g. PU, XPS, Phenolic)
- Solvents for industrial cleaning processes
- Specialist fluids for fire protection
- Insulating gas for high voltage gas insulated switchgear (GIS)
- Cover gas for magnesium smelting
- Other specialised applications e.g. electronics manufacture

As with ODS, banks created by RAC applications and foam blowing are important in relation to this study. The GIS bank is relatively small and was not previously assessed in the ICF 2010 report. However, as the GIS bank is SF_6, which has an extremely high GWP, it has been taken into account in this study.

The use of F-Gases in aerosols, solvent cleaning, magnesium smelting and electronics production does not create any long term banks and have not been considered in this study. The use of F-Gases for fire protection does create a bank, but it is relatively small and is already managed with significant care (mainly due to the requirement to have an effective fire protection system) and has not been assessed in this study.

Properties of ODS and F-Gases

It is important to understand 3 different ways in which the size of a bank can be assessed. These are as follows:

1) **Physical Bank**, tonnes. This is the actual tonnage of material contained within relevant equipment and products.
2) **Bank in GHG equivalent**, tonnes CO_2 equivalent. This is the physical bank tonnage multiplied by the GWP of each fluid. For example, HFC 134a has a GWP of 1,300; hence 1 tonne of HFC 134a has a GHG equivalent of 1,300 tonnes CO_2.
3) **Bank in ODS equivalent**, ODP tonnes. This is the physical bank tonnage multiplied by the Ozone Depletion Potential (ODP) of each fluid. For example CFC 12 has an ODP of 1; hence 1 tonne of CFC 12 has an ODS equivalent of 1 ODP tonne.

Most ODS are also very strong global warming gases, hence they make a contribution to banks in both GHG and ODS terms. All F-Gases (i.e. HFCs, PFCs and SF_6) have a zero ODP; hence they only make a contribution in GHG terms. Example properties are shown in Table 1-1 below. Note that GWP values have been updated over the last few years in the various Assessment Reports published by the UNFCCC. The table illustrates values from the 2nd, 3rd and 4th Assessment Reports. Please note that Assessment Report 3 (AR3) values are used in the 2006 F-Gas Regulation and have been used throughout the rest of this report.

Table 1-1 Example Properties of F-Gases and ODS

Substance	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)		
		AR2 (1995)	AR3 (2001)	AR4 (2007)
CFC 12	1	8,100	10,600	10,900
HCFC 22	0.05	1,500	1,700	1,810
HFC 134a	0	1,300	1,300	1,430
HFC 404A	0	3,260	3,784	3,922
SF_6	0	23,900	22,200	22,800

1.4. Bank Size and Bank Dynamics

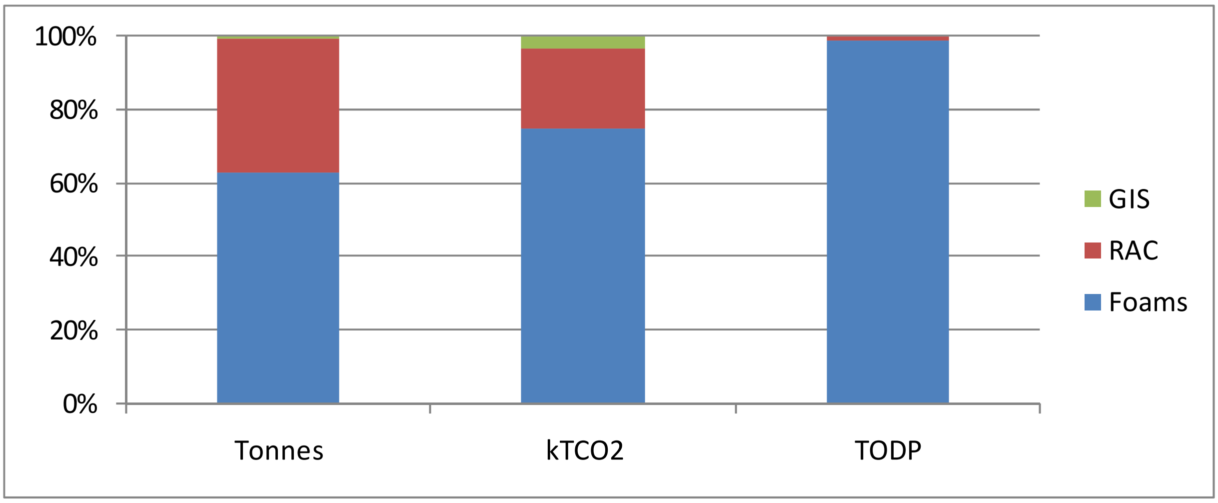
This section provides introductory information about the size of the RAC, foam and GIS banks in the EU. The data is based on the dataset for RAC and foams that is discussed in Section 4 (Revised Banks Model) and Ecofys reports (Ecofys, 2005) (Ecofys, 2010) for SF_6. In summary:

- The total **physical bank** size of ODS and F-Gases in the 27 European Union (EU) in 2010 is estimated at around 1.5 million tonnes (MT).
- This equates to a bank in **GHG** terms of 5,100 million tonnes of CO2 equivalent (MT CO_2). This is a significant bank of stored global warming gases; in the unlikely event that the whole bank was emitted it is approximately equal in magnitude to the EU's annual total greenhouse gas emissions.
- It also equates to a bank in **ODS** terms of 570,000 ODP tonnes (TODP).

The structure of the bank is illustrated in Figure 1-1. This shows the split between foams, RAC and GIS banks. It is interesting to note how the perspective taken to assess the bank changes the interpretation of the data:

- In terms of the physical bank, foams represents around 60%, RAC 40% and GIS represents a negligible quantity (0.5%).
- In GHG terms, foams and GIS both become more important due to their relatively high GWPs. Foams represent around 75% of the GHG bank, mainly due to the contribution of ODS such as CFC 11 and CFC 12.
- In ODS terms, foams dominate, representing 99% of the total. The physical bank includes some HCFC refrigerants. As illustrated in Table 1-1, HCFCs have a very low ODP, hence they make only a small contribution to the bank in ODS terms (but HCFCs also make a more significant contribution to the bank in GHG terms).

Figure 1-1 ODS and F-Gas Bank Size (EU27, 2010)

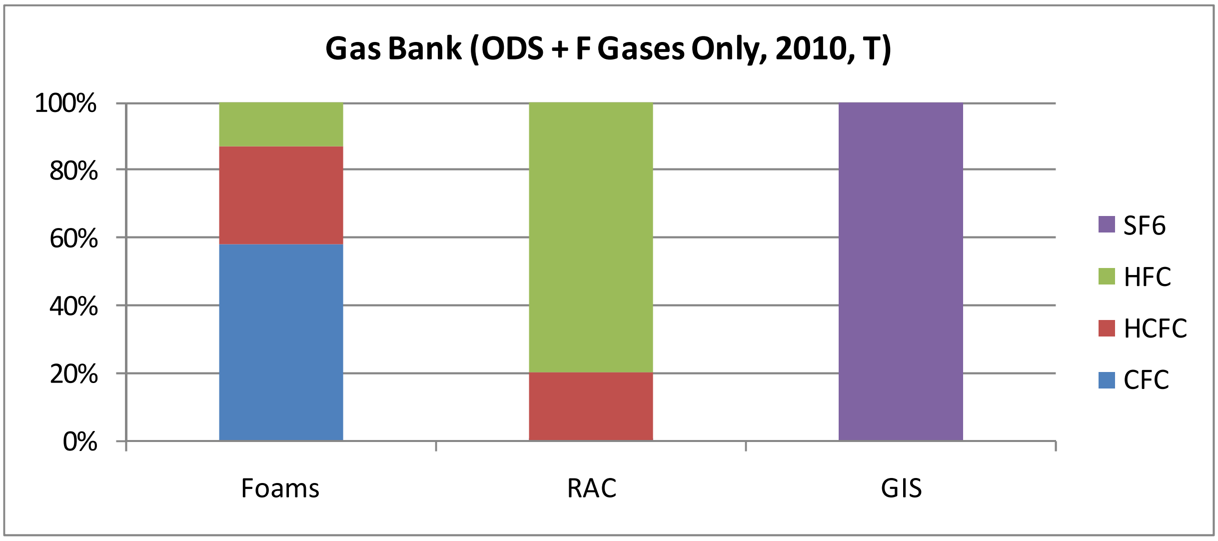


The bank can also be described with reference to the type of fluid used in relevant applications as shown in Figure 1-2. This shows that around 85% of the foams bank is made up of ODS (CFCs and HCFCs), with only a small proportion using F-Gases (HFCs). This is partly because HFCs were only introduced around 2004, but it also illustrates a significant move away from fluorocarbons in the foam blowing sector, to alternatives such as hydrocarbons. This has important implications for the long term management of the foams bank.

The RAC bank is dominated by HFCs, with a residual 20% of the bank using HCFCs (this will disappear quickly in response to phase out of HCFCs).

The GIS bank is entirely made up of SF_6.

Figure 1-2 Physical Bank Composition by Gas Type - Installed Base (2010)



Bank Dynamics and Rate of Emissions

Bank size alone does not give an effective measure of the impact of emissions of the banks of ODS and F-Gases. Each bank sector has different characteristics in terms of annual leakage rates, replacement lifetimes and ease of recovery at end-of-life (EOL). The key factors that characterise the “bank dynamics” are as follows:

Bank Composition – The composition of the bank, by different fluid type, determines their equivalent GWP and ODP and potential impact if the bank was released into the atmosphere.

Emissions during product / equipment manufacture – some emissions occur during the manufacture and installation of products and equipment. These are very low for RAC and GIS applications but can be significant for certain types of foam, especially XPS and shaped products cut from block foam.

Leak Rate in Normal Operation – RAC, GIS and foams all have some degree of leakage or diffusion during normal operation. Typically, blowing agents in insulating foams diffuse very little during their life (less than 1% per year on average), especially if impermeable facings are present. Some RAC end-use sectors also have very low leakage (e.g. hermetically sealed systems in domestic refrigerators and freezers). However, other RAC end-use sectors have historically had high leakage rates. Leak rates of around 15% per year are typical for many large commercial refrigeration systems. Leak rates of 5% to 10% per year are common in industrial refrigeration equipment and air-conditioning systems. Small GIS systems have little leakage as they are hermetically sealed, but larger systems do suffer from some on-going leakage. For RAC and GIS systems many leaks are gradual (e.g. taking place over many months before top up) but they can also be “catastrophic” when a leak causes a total loss of charge in minutes or hours. Leakage from foam is always very slow.

Top-Up Rate in Operation – It is very important to recognise the difference between applications that are “topped up” to offset the regular leakage and applications that are allowed to lose a proportion of their original charge over their life based on low emission rates. Many RAC and GIS applications are topped up to replace any leakage in operation. If this is not done the RAC or GIS equipment would no longer work correctly once a significant amount of charge was lost. Insulating foams on the other hand are never “topped up” after initial fabrication.

Lifetime – The life cycles of different applications vary considerably between less than 10 years and more than 50 years. Small RAC systems may have a life of around 10 years and will be replaced approximately 5 times within one life cycle of insulating foam for a building.

Replacement Strategy – Some sectors use very little ODS and F-Gases in new products. Modern building foams, for example, predominantly use hydrocarbon (HC) blowing agents instead of F-Gases. Most domestic refrigerators and freezers sold within the EU have used HC refrigerants for nearly 10 years. The MAC Directive will soon force the mobile air conditioning sector to use refrigerants with negligible GWP in new cars. In these sectors, the bank sizes will naturally decline as new non-ODS and non-F-Gas products predominate. For other sectors, in particular medium sized RAC, the current replacement strategy is still to use F-Gases – so these banks will persist until alternative refrigerants are more widely adopted.

EOL Recovery Effectiveness – For some sectors, recovery of ODS and F-Gases at end-of-life is already a well-established practice and the proportion of gases being released to the atmosphere may be low. However, for other sectors, in particular building foams, recovery has generally been considered not to be technically or economically feasible and so the gases are released to the atmosphere during disposal or from waste streams thereafter. Even for those sectors with an effective means of recovery, a proportion of gas may be emitted in the time between the end of operation and the start of the recovery process itself. For example, the refrigerant within a small air conditioning system can be recovered very effectively (leaving behind only a very small amount of gas as a low pressure vapour and in solution in the oil). But an unscrupulous operator may release some or all of the gas into the atmosphere to avoid the time and cost of recovery.

The effectiveness of EOL recovery depends on 4 factors as follows:

- **Quantity of charge at end of use**; the amount of charge left in a product or piece of equipment when it reaches the end of operational life. For many types of RAC and GIS this is close to 100% of the original charge as the system will have been regularly topped up during normal operating life. For foams it may be well below 100%.
- **Decommissioning and Handling Effectiveness**; proportion of end of use charge which reaches the recovery process. This effectiveness could be less than 100% for a number of reasons, including:
  - Accidental damage to equipment after decommissioning but before recovery.
  - Leakage of systems during storage before recovery.
  - Difficulty of segregation of foams during building demolition.
- **Recovery Efficiency**; the proportion of the gas that enters a recovery process which is not released to the atmosphere (i.e. it is sent for reclamation or destruction). For most RAC and GIS applications the Recovery Efficiency is high. It may be lower for foams.
- **Compliance Factor**, the percentage of a market sector that actually complies with recovery requirements (e.g. as specified in Ozone and F-Gas Regulations).

The bank dynamic characteristics of the foams, RAC and GIS sectors are summarised in Table 1-2 below.

Table 1-2 Bank Characteristics by Sector

Characteristic	Foams	RAC	GIS
Physical Bank Size 2010	940,000 tonnes[1]	550,000 tonnes[2]	8,000 tonnes
Composition	Predominantly CFCs with high GWP and high ODP	Predominantly HFCs with zero ODP, but medium GWP	Entirely SF6 with extremely high GWP (zero ODP)
Leak Rate in Operation	Very low (~1% per year)	High (5 - 15% per year is typical; lower for very small hermetic systems)	Very low for hermetic systems (<<1% per year); low for large systems (1 to 3% per year).
Top-Up requirement in use	None	Full (except for domestic refrigerators and other small hermetic systems).	Full
Lifetime	Very long for buildings (50 years average); Medium for appliances (15 years)	Long for large systems (20 to 30 years); Shorter for smaller systems (10 to 20 years)	Long, typically 30 to 50 years (Ecofys, 2010)
Current Replacement Strategy	Non F-Gas alternatives predominate in many types of new products	Depending on sub-sector, various non F-Gas alternatives exist but they may not be technically or economically suitable	Non GIS alternatives exist but may not be suitable in all environments
Future Replacement Alternatives	HFOs and other new gases could reduce F-Gas use in new foam products to zero between 2015 and 2020.	HFOs, CO_2, ammonia and other new gases have potential to significantly reduce use of HFCs in new systems.	No major changes expected in near future
Decommissioning and handling effectiveness	Depends on sub-sector: Domestic appliances: High (e.g. 80%) Other foams: Lower (e.g. PU building panel, 60%, XPS building panel, 40%)	Depends on sub-sector: Industrial: High (e.g. >90%) Domestic refrigeration and Mobile AC: Low to Medium (e.g. 0% to 50%)	High, >99% (Ecofys, 2010)
Recovery Efficiency	High	High	Very High, typically 98% (Ecofys, 2010)

Bank Size Projections

For ODS, the bank will steadily decline in size, as no new equipment containing ODS has entered the bank since around 2005. The rate of decline depends on product lifecycles.

For F-Gases, the picture is more complex, as F-Gases are still entering the bank in new products and equipment.

[1] The foams bank shown here is the bank of ODS and F-Gas blowing agent in products “in use” – it excludes gases contained within products in the waste stream.

[2] The RAC bank is the total F-Gas and ODS bank, excluding alternative refrigerants (e.g. ammonia, hydrocarbons, etc.)

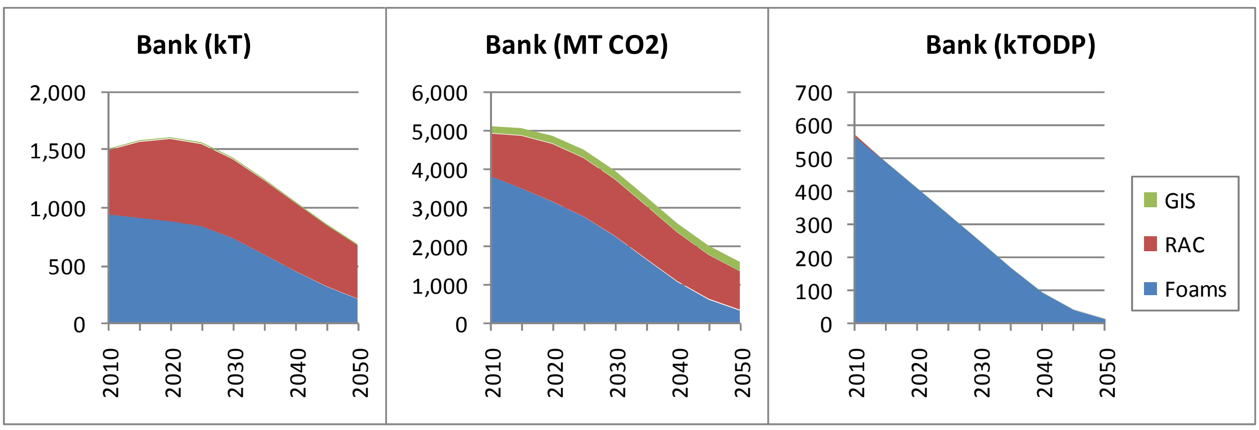
Table 1-2 above shows a brief summary of current and future F-Gas alternatives in each market. Use of such alternatives will reduce the rate at which new products or equipment using F-Gases enter the current bank.

The amount of ODS and F-Gases in the foams bank is expected to decline, as ODS and F-gas foams are replaced by non F-Gas alternatives when buildings and appliances are replaced at their end-of-life. ICF projections (ICF, 2010) do not take into account the likely use of HFOs and other new blowing agents, as these new fluids have only reached the market in 2011. It is reasonable to predict that the majority of foams currently blown with HFCs will be manufactured using HFOs or other fluids with negligible GWP by 2020, leading to a steady decline in bank size. However, because of the long lifecycle of building foam the bank of foams containing HFCs will not fall to zero for over 50 years.

The RAC bank is also likely to decline in size, although this will depend on the successful introduction of new refrigerants with negligible GWP. The mobile air-conditioning sector (MAC) is already on a path to zero F-Gas bank size, via the EU MAC Directive. HFO 1234yf is being introduced for new vehicle types in 2011 and will steadily replace use of HFC 134a in new MACs. Given a fairly short vehicle lifecycle (12 years) the MAC F-Gas bank will be close to zero between 2025 and 2030. Large industrial systems are likely to make more use of ammonia and CO_2. Very small systems will make more widespread use of HCs (following the domestic refrigerator market). However, the physical bank size for small air conditioning systems is currently forecast to grow, due to an overall growth in demand for this type of air conditioning across the EU. Currently this growth will rely on HFC refrigerants. HFO or CO_2 technologies may become suitable for more widespread application in small AC and other refrigeration end-use sectors, but the extent of this is not yet clear.

Figure 1-3 shows projections for the bank size to 2050 (for physical bank, GHG bank and ODS bank). These projections show the "Base Case" scenario, which does not fully take into account the decline that may be available through more widespread use of HFOs.

Figure 1-3 Forecast Bank Size 2010 to 2050



Emissions from Banks

The actual emissions from the banks depend on various factors including operational leakage, decommissioning and handling effectiveness, recovery efficiency and compliance factor.

Figure 1-4 shows the trends in forecast size of potential emissions for the RAC sector during operation and at end-of-life, in physical tonnes of fluid (left chart), GHG emissions (middle chart) and ODS emissions (right chart).

Figure 1-5 and Figure 1-6 show the same information for foams and GIS sectors and comparisons between all three sets of graphs shows the very significant differences in overall emission levels, emission sources and levels of abated emissions. It can be seen that the foam sector is the only one where significant 'beginning of life emissions' occur, as reflected by the blue area.

When comparing the three sets of charts (Figure 1-4, Figure 1-5 and Figure 1-6), please note that the scales and units are different.

The red areas of these charts represent in-life emissions. These are particularly important for RAC sectors which often have significant levels of leakage throughout their operating life. The grey areas indicate an estimate of the amount of gas recovered at EOL or, in the case of foams, future emissions avoided by those actions, under current practices and compliance levels. The ODS charts of Figure 1-4, Figure 1-5 and Figure 1-6 show the importance of the foams sector in accounting for nearly all the potential ODS emissions beyond 2015 (due to the large proportion of CFCs within the foams bank) and the significance of EOL emissions in particular. These ODS emissions will fall as the foams bank declines as a result of the use of non-ODS alternatives since 2004.

The GHG charts show the significance of GHG emissions from RAC equipment in normal operation (the red areas) and the importance of measures to reduce this annual leakage rate. The grey area for the RAC sector illustrates the expectation that a proportion of gas is already recovered at EOL, allowing only a relatively small amount (indicated by the purple and green areas) to be released. However, the grey area represents an amount of gas "at risk" of escape, if the assumed level of compliance is not achieved.

The size of the purple areas in the GHG charts shows the importance of potential emissions at the EOL of foams. There is currently no regulatory obligation to recover ODS and F-gases from foams outside of the domestic appliances sector. Interestingly, even measures on appliances and other shorter lifetime products alone have lasting impacts on avoided emissions through to 2050 and beyond, since the landfill bank (that would have continued to emit on an on-going basis) would be avoided. Although current alternative disposal methods (i.e. landfill) may not result in an immediate increase of the blowing agent contained within the foam, the avoidance of any purposeful recovery process makes it very likely that the blowing agent will eventually be released into the atmosphere in one form or other, even though the annual release rates will be low.

Figure 1-4 Potential Emissions from Banks (RAC Sectors)

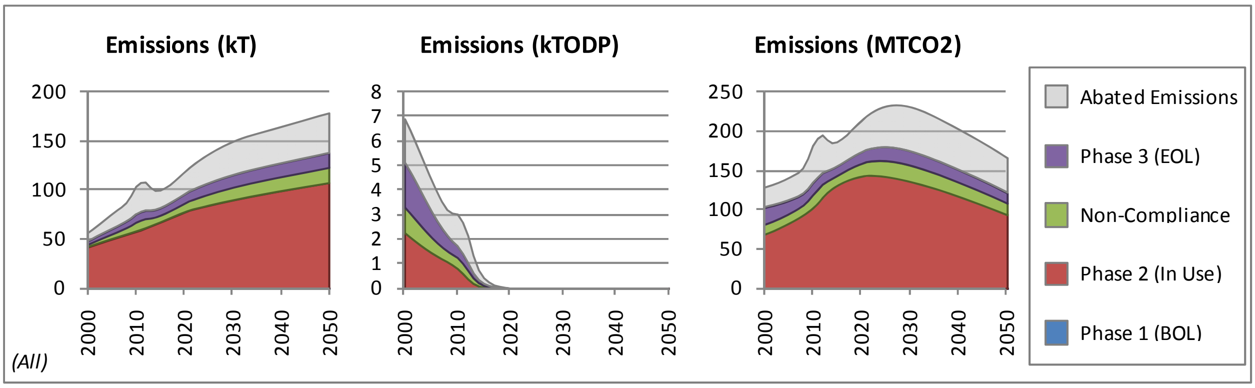


Figure 1-5 Potential Emissions from Banks (Foam Sectors)

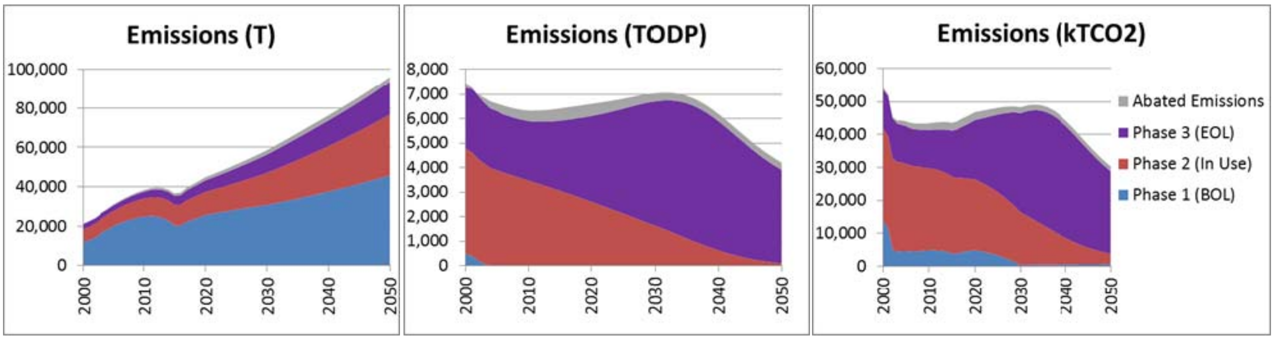
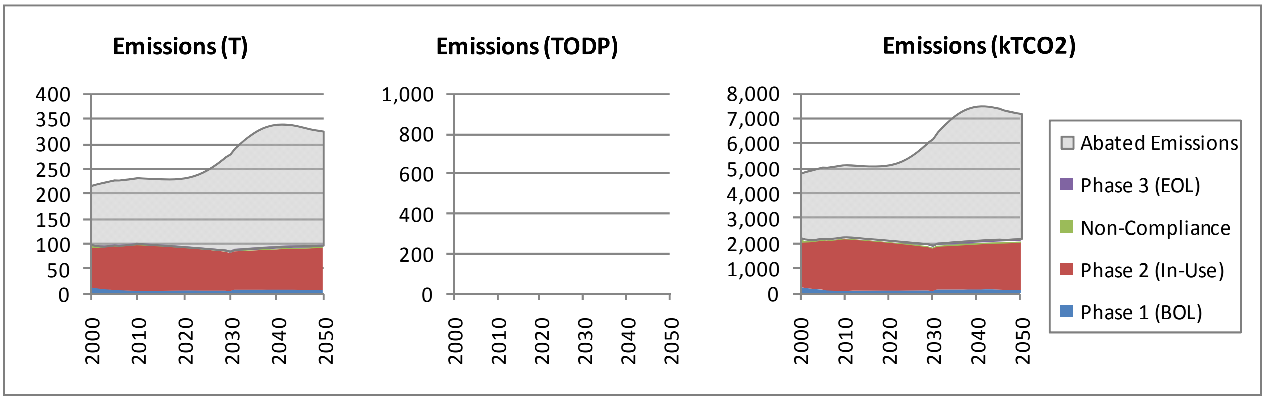


Figure 1-6 Potential Emissions from Banks (GIS Sectors)



1.5. Regulatory Overview

The current Regulations provide a strong legal requirement for EOL recovery from GIS and RAC banks, but a far weaker requirement for foams.

Stationary RAC and GIS

The Ozone Regulation (EU, 2009) and the F-Gas Regulation (EU, 2006) provide similar obligations to recover ODS and F-Gases. Article 4.1 of the F-Gas Regulation states that operators of stationary RAC equipment, GIS, fire protection systems and solvents must:

- "put in place arrangements for the proper recovery by certified personnel of fluorinated greenhouse gases to ensure their recycling, reclamation or destruction".

Article 22.1 of the Ozone Regulation states:

- "Controlled substances contained in refrigeration, air-conditioning and heat pump equipment, equipment containing solvents or fire protection systems and fire extinguishers shall, during the maintenance or servicing of equipment or before the dismantling or disposal of equipment, be recovered for destruction, recycling or reclamation."

These requirements are unconditional which means that ODS and F-Gases must be recovered from all sizes and types of stationary RAC and GIS equipment at end of life.

Any gas that is emitted at EOL from stationary RAC equipment or GIS is due to:

- Non-compliance with the F-Gas and Ozone Regulations (this is a significant risk).
- Poor decommissioning and handling effectiveness (i.e. gas is lost from the system before recovery operations start). This is a significant risk for very small equipment, but less so for larger systems.
- Poor recovery efficiency. If trained personnel carry out recovery this is a low risk.

Foams

The situation for foams is quite different. The past and current Ozone Regulations have mandated the recovery and destruction of ODS contained in insulation foams within domestic refrigerators and freezers since 1st January 2002. However, ODS contained in foams within other equipment and products are only to be recovered and destroyed if technically and economically feasible.

Article 4.3 of the F-Gas Regulation states:

- "The fluorinated greenhouse gases contained in other products and equipment, including mobile equipment unless it is serving military operations, shall, to the extent that it is technically feasible and does not entail disproportionate cost, be recovered by appropriately qualified personnel, to ensure their recycling, reclamation or destruction."

Article 22.4 of the Ozone Regulation states:

- "Controlled substances contained in products and equipment other than those mentioned in paragraph 1 shall, if technically and economically feasible, be recovered for destruction, recycling or reclamation, or shall be destroyed without prior recovery, applying the technologies referred to in paragraph 2."

The phrases:

- "technically feasible and does not entail disproportionate cost"
- "if technically and economically feasible"

are both difficult to interpret. It is believed that with the exception of domestic appliances (which are also affected by the WEEE Directive (EU, 2002)), relatively little recovery is currently taking place from foam banks to comply with the F-Gas or Ozone Regulations. In the case of F-Gases, this is largely because there are very few, if any, foams containing HFCs reaching end-of-life at this point. For ODS the lack of recovery is related more clearly to an interpretation that recovery is not technically and economically feasible.

Mobile RAC

It is important to note that mobile RAC applications including MACs and refrigerated transport are covered by Article 4.3 of the F-Gas Regulation (as above for foams). This means that the phrase "*technically feasible and does not entail disproportionate cost*" applies for mobile RAC. It is believed that compliance with refrigerant recovery obligations for mobile applications is quite widespread as it is deemed to be cost effective.

2. Literature Review

This section of the report reviews relevant literature about the RAC, foams and GIS markets.

2.1. RAC

The most relevant reports addressing policy options for the management and destruction of ODS and F-Gas banks within the refrigeration and air conditioning sectors are:

- "Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of ODS and F-Gases Banked in Products and Equipment" (ICF, 2010)
- "Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases - Interim Report (Working Document 3)" (Oko Recherche, 2011)
- "Task Force Decision XX/7 – Phase 2 Report – Environmentally Sound Management of Banks of Ozone-Depleting Substances" (TEAP, 2010)

ICF Report

The ICF report (ICF, 2010) provides detailed data about the size of the ODS and F-Gas Banks in RAC systems. A critique of the ICF modelling of bank size is given in Section 4 of this report.

The ICF report concludes that "existing EU regulations explicitly require the recovery of all ODS/F-gases from certain categories of products and equipment at end of life". Article 4 of the F-Gas Regulation (EU, 2006) applies this to stationary RAC equipment without condition, and to other equipment (including mobile RAC equipment) "to the extent that it is technically feasible and does not entail disproportionate cost". Article 22 of the Ozone Regulation (EU, 2009) applies it without condition to ODS in all RAC equipment. This confirms the comments made in Section 1.5 that as far as stationary RAC is concerned there is already the required legal framework to prevent EOL emissions. Emissions from stationary RAC are either during normal operation (outside the scope of this study) or through poor compliance with the Regulations.

The ICF report also concludes that there is a lack of data on which to assess the level of compliance with these legal requirements. It recognizes a number of potential barriers to compliance, including: "insufficient technician training, a lack of recovery equipment, high recovery /disposal costs, small quantities remaining in equipment at time of disposal, potential losses during transport and handling, and others". Within its accompanying Banks Model, it provides no estimate of the level of compliance.

Oko-Recherche Report

The report on the review of the F-Gas Regulation (Oko Recherche, 2011) comments that "only little evidence has been found so far ... for the effectiveness of containment and recovery measures". The estimates for the effectiveness of recovery measures "are based on expert estimates and are considered 'best case' assumptions". Estimates for the "disposal emission factor" (i.e. at end-of-life) of the significant RAC sectors are given in Appendix B.5, and are summarised in Table 2-1.

Table 2-1 Summary of Disposal Emission Factor and Life, from Oko Recherche 2011

Sector	End-Use	Emission Factor	Lifetime (y)
Industrial	Milk farm cooling, ice rinks and other industry	30%	20
	Other food and drink processing	30%	30
Commercial	Centralised systems	30%	12
	Condensing units	50%	15
	Hermetics	70%	15
Stationary AC	Small (<12 kW)	70%	10
	VRF & Rooftop AC	30%	10
	Chillers (centrifugal)	30%	25
	Chillers (other)	30%	12

The Oko-Recherche report (Oko Recherche, 2011) states that end-of-life emissions could arise from a number of causes, including:

- Accidental release after end-of-use but before recovery (also during transport if required)
- Accidental release during recovery (due to practical constraints of industry-standard technology)
- Wilful release at any time after end-of-use

The Oko-Recherche estimates of EOL emissions (30% to 70%) are not backed up with strong documentary evidence. For larger systems (e.g. industrial, ice rinks, centralised commercial) the Oko-Recherche figures seem unrealistically high. If they are correct it suggests that there may be significant non-compliance with the obligation to prevent release to atmosphere at end-of-life.

TEAP Report

The TEAP October 2010 report (TEAP, 2010) is based on a study of global ODS banks (i.e. not confined to the EU), but concludes positively that "there are plentiful opportunities to manage low-effort banks within the next ten years" and that "the collection, recovery and destruction of refrigerants of all types represent the most immediate and cost-effective method of mitigating climate impacts from the release of ODS Banks".

TEAP provide a useful appraisal of the ease of recovery from ODS banks, characterising the ease of access as low, medium or high effort. Low effort banks are estimated to require a "cost of carbon" of US$15 per T CO_2 to ensure their effective recovery. Medium effort banks would require up to US$35 per T CO_2. Furthermore, it is recognised that the effort required for effective management of the ODS banks depends on population density, but that most RAC sector banks fall within the Low and Medium Effort categories, as shown below (Table 3-1 of the TEAP report):

Table 3-1: Impact of Population Density on Effort Required to Manage Banks

Sector	*Low Effort*	*Medium Effort*	*High Effort*
Domestic Refrigeration – Refrigerant	DP	SP	
Domestic Refrigeration – Blowing Agent	DP	SP	
Commercial Refrigeration – Refrigerant	DP	SP	
Commercial Refrigeration – Blowing Agent	DP	SP	
Transport Refrigeration – Refrigerant	DP/SP		
Transport Refrigeration – Blowing Agent	DP/SP		
Industrial Refrigeration – Refrigerant	DP/SP		
Stationary Air Conditioning – Refrigerant	DP	SP	
Other Stationary Air Conditioning – Refrigerant	DP	SP	
Mobile Air Conditioning – Refrigerant	DP	SP	
Steel-faced Panels – Blowing Agent		DP	SP
XPS Foams – Blowing Agent			DP/SP*
PU Boardstock – Blowing Agent			DP/SP*
PU Spray – Blowing Agent			DP*/SP*
PU Block – Pipe		DP	SP
PU Block – Slab		DP	SP
Other PU Foams – Blowing Agent			DP/SP*
Halon – Fire Suppression	DP	SP	

DP = Densely Populated Areas; SP = Sparsely Populated Areas
* Still technically unproven

In addition to these key reports, other information on country policies and practices is available from

- "REAL Zero - Reducing refrigerant emissions & leakage - Feedback from the IOR Project" (Cowan, 2010)
- "Living without HFCs - The Danish Experience" (Madsen, 2009)

In summary, the key reports relevant to the RAC sectors conclude that:

- The existing EU policies provide a comprehensive framework which oblige operators to manage the recovery and destruction of ODS and F-Gas banks for stationary RAC equipment.
- There is insufficient evidence to assess the level of compliance with these obligations or to quantify the emissions of ODS and F-Gases from RAC equipment at end-of-life.
- The RAC sector probably provides the best (i.e. lowest cost) opportunities for the reduction of emissions from ODS and F-Gas banks, relative to other sectors such as building foams.

2.2. Foam

Background to Foam Literature

There are a number of literature sources addressing the development and management of foam banks, but many of them cross-reference each other, making the amount of research on which bank assessments are made rather more limited.

The UNEP Foams Technical Options Committee (FTOC) has developed and managed an historical assessment of consumption of ODS and HFCs which has led to the emergence of a banks assessment at regional level, with Europe being defined as one of those regions. The UNEP data itself has been updated periodically by industry-led consumption assessments conducted via the main industry associations such as the Isocyanate Producers Association (ISOPA) and others. Caleb has acted as custodian and coordinator of the UNEP models that support this data collection and validation.

Most other assessments, including the ICF 2010 study for the EC (ICF, 2010), have drawn from this UNEP data. For example, the UNEP assessment and the ICF assessment for Europe have been derived from a common consumption data set developed for polyurethane foam in 2001. A number of differences that exist between the consumption assessments in 2008 have occurred because of varying growth rates inferred in the intervening period.

The emission functions for foams applied to develop bank estimates are also relatively uniform globally. These have been included in the "*2006 IPCC Reporting Guidelines for National Greenhouse Gas Inventories*" (IPCC, 2006). Although this latter document did not specifically address the ODS scenario, there are minimal differences between ODS emissions functions and HFC emission functions for liquid HFCs. There are variances for some gaseous HFCs (e.g. HFC-152a) because of their specific permeability through the cell walls of foams.

The seminal work for the discussion of the significance of ODS and HFC banks was the "*IPCC/TEAP Special Report on Ozone and Climate*" *(SROC)* (IPCC/TEAP, 2005) which was published in 2005. This made estimates of global banks in all previous ODS uses, including refrigeration, air conditioning and foams. This was the first work to assess the dynamics of the banks (as discussed in Section 1.4) alongside one another at global level and highlighted the fact that, although banks in foams and refrigerants are similar in size, the emission rates from those banks are significantly different resulting in a much faster 'turnover' or 'churn' for refrigerant banks (due to high rates of annual leakage from refrigerant banks). This leaves the foam banks containing much more ODS than other banks into the future because of their slow emission rates in the use phase and the lack of significant replenishment or replacement as a result of maintenance procedures during the relatively long lifecycle.

These dynamics were transferred into the European arena through a number of studies conducted on behalf of the European Commission. As an example, Milieu conducted a series of background studies in 2007 ahead of the recast of the Ozone Regulation (1005/2009) which drew from the UNEP data included within the SROC. The major report was entitled "*Review of the Implementation of Regulation (EC) 2037/2000 on substances that deplete the ozone layer – Assessment of Potential Impact of Regulatory Options*" (Milieu, 2007). This report fundamentally took the bank data available from UNEP as the baseline against which regulatory options were assessed. Those assessments also began to address some of the specific challenges posed by the rate of emission, long life-time and diffuse distribution of the banks in the foam sector.

At European level the next significant study to be commissioned was placed with ICF. It was entitled "Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-Gases) Banked In Products and Equipment" (ICF, 2010). As a central part of its remit, this study picked up on a theme developed by Milieu to see better inventories prepared at Member State level. One of the significant outputs from the work was therefore a model which, amongst other things, provided a vehicle for improving the estimates of ODS and HFC foam banks at national level. The degree to which it was able to do so is addressed in Section 3 of this report.

A further series of studies at national level also need to be mentioned. These have either provided input to the Milieu report or have been spawned by it. An example of the former is the Austrian Study "*Final Report to the BMLFUW*" submitted by Obernosterer, Smutny and Jäger in June 2005 (Obernosterer, 2005). This evaluated the bank size in Austria and was also amongst the first studies to look at the interaction between the wider waste strategy of a country and its ability to recover and destroy ODS economically. However, the report did not generate any recommendations for submission to the wider European discussion – partially because of the specificity of the Austrian situation.

An example of a study initiated after the completion of the Milieu study was a UK Study conducted by the Building Research Establishment (BRE) in the United Kingdom, supported by Caleb. This study (Building Research Establishment, 2010), entitled "*The Assessment of Building Foams containing ozone depleting substances in the UK Building Stock*" was completed in 2010, but remains unpublished at this time. The study looked at bank size, estimated annual ODS flows into the waste stream and, through a number of interviews with demolition contractors sought to identify the likelihood of recovery through current or modified practices. The lack of current segregation of lightweight demolition waste materials such as foams was identified as a barrier that could be overcome, but costs as high as £200 per tonne CO_2 saved were assessed using standardised costing procedures.

Main Conclusions from Key Foam Publications

The summary report (Milieu, 2007) of the 2007 review of the Ozone Regulation drew up the following list of recommendations for further consideration.

4. Address the issue of ODS banks in building foams:

(a) the Regulation should requires Member States to ensure recovery of ODS in building foams when economically and technically feasible, either by establishing compulsory requirements for recovery of ODS in building foams or via voluntary mechanisms. The provision could specifically mention the possibility to integrate ODS recovery from building foams in waste management plans developed by Member States (or its regional entities) dealing with construction and demolition waste.

(b) As a complement, the Regulation could also require Member States to **prepare inventories of ODS banks in building foams** (to be developed within two years of the entry into force of the Regulation) and take adequate action as described above (ensure recovery by establishing compulsory requirements for recovery or via voluntary agreements).

(c) These measures should in any case be notified to the Commission.

(d) Finally, the Regulation should authorise on the Commission to study the issue several years after the introduction of the revised Regulation. This would allow sufficient time to assess the results of actions taken by both the voluntary carbon market and any national legislation, where this has been implemented.

In the ICF 2010 Report, there were a number of recommendations surrounding the improvement of the disaggregation of European foam banks by Member State and a number of these are being addressed within the scope of this current study. However, in addition, there were a number of other findings relating to possible policy options. These were:

1. ***Expand Regulations to Require Recovery/Destruction of ODS in Construction Foam Applications.*** Because a significant share of the remaining ODS is banked in the construction foams sector (estimated to represent 80% of the CFC/HCFC banks in 2010, on a metric tonne basis) and because the quantities potentially recoverable from construction foams at end of life will continue to be significant into the foreseeable future (representing over 8,000 $KTCO_2eq.$ of avoidable emissions in 2050), mandating ODS recovery from some or all types of construction foams for the purpose of destruction, recycling or reclamation could be added as a requirement under Regulation (EC) 1005/2009 if deemed "technically and economically feasible." Feasibility of recovery (see Table 17) could be considered in determining which construction foam subsectors should fall under this extended mandate.

2. ***Enhance Synergies with Waste Regulations.*** Additional synergies could be explored through EC waste regulations to reduce logistical and cost barriers associated with the collection and transport of waste ODS/HFC refrigerant, fire extinguishing agents, and foam for reclamation or destruction. To this end, recordkeeping and reporting requirements could be streamlined to ease the burden on stakeholders.

3. *Expand Producer Responsibility Programs.* Following on the successes of Directive 2002/96/EC, the Commission could consider extending producer responsibility schemes to other products/equipment types, including large refrigeration/AC equipment. Enhanced compliance with existing regulations is likely if regulatory responsibility is assigned to discreet stakeholders and infrastructure is systematically established.

4. *Implement Market-Based Mechanisms.* Assigning a value to unwanted ODS/HFCs, in lieu of imparting a cost burden, is another way to promote recovery at EOL. This could be achieved through a number of mechanisms. For example, a tax could be placed on the sale of reclaimed or virgin ODS and F-gas refrigerants, with the funds potentially used to subsidize collection and/or destruction. Similarly, incentives could be given for the destruction of ODS construction foams by deeming such projects eligible for carbon credits on the EU ETS (they are already eligible under voluntary carbon markets, including the Chicago Climate Exchange, the Voluntary Carbon Standard, and the Climate Action Reserve). While further analysis would be needed to assess potential market impacts, the bottom-up model provides an estimate of 16 TgCO2eq that could be eligible for credits, declining over time, compared to over 3,000 TgCO2eq traded in the EU ETS in 2008. It should be noted, however, that if regulations are in place to require the collection and destruction of ODS, the collection and destruction of that ODS may not be considered "additional" on certain carbon markets, and may therefore, not be eligible for credits (even if levels of regulatory enforcement and/or compliance are low).

Critique

The distribution of the European bank of ODS in foams creates a largely non-homogeneous backdrop against which to assess policy options. A matrix can be drawn (and, indeed, is expanded as part of Section 4) which has product differentiation along one axis and country differentiation along the other. It is already well-documented at international and regional levels that recovery of ODS varies substantially with product type. Further evaluation of the product mix at country level, coupled with the typical building methods applied, shows that it is over-simplistic to seek to adopt specific regulatory mandates at the EU level. This has been reflected in some of the Member State reactions to the ICF study (ICF, 2010) in particular. This adds to the attraction of flexible market-based mechanisms that can respond to individual country scenarios more easily. The challenge, however, remains the discernment of those strategies that can be implemented reasonably at the European level (e.g. on foam in refrigeration equipment) and those that need more localised consideration.

2.3. Gas Insulated Switchgear (GIS)

There are very few publications looking at the management of banks and emissions of SF_6 from GIS. The ICF report (ICF, 2010) does not cover GIS. However ICF published a report for the Commission in 2008 "*Analysis on the Recovery of Fluorinated Greenhouse Gases in EU-27 in the Period 2004-2007 and Determination of Options for Further Progress*" (ICF, 2008) which does includes data on switchgear.

The most recent published study and by far the most thorough is by Ecofys, titled "*Update on global SF_6 emissions trends from electrical equipment*" (Ecofys, 2010), published in July 2010 and funded by an industrial consortium of JEMA, NEMA, ABB, Alstom, Ormazabal, Schneider Electric, Solvay and Siemens.

Other recent reports on SF_6 in GIS are scarce. Ecofys themselves did an earlier report in 2005 (Ecofys, 2005) which their later report (Ecofys, 2010) builds on. The US EPA has published some work, but nothing of note on banks and emissions beyond 2005 and again this data is used within the Ecofys report. Inventory data on emissions is available for EU 27 countries via the UNFCCC reports. A joint UNIPEDE CAPIEL working group investigated this sector back in 1998 (UNIPEDE/CAPIEL, 1998). There is also an IEC standard relating to switchgear: IEC 62271 (International Electrotechnical Commission, 2003).

Main Conclusions from Key GIS Publications

The main published conclusions from the reports are summarised below. These are examined over the full lifetime of the equipment through manufacture and use to end of life disposal. There are two types of GIS to consider. High Voltage (HV) GIS is factory filled only to atmospheric pressure and then filled to operating pressure on site. Medium Voltage (MV) GIS are filled with gas at the manufacturer's premises and then hermetically sealed.

Manufacturing Phase:

- Annual emission rates of the manufacturing phase declined in Europe from 8% to 3% between 1995 and 2003
- Annual emission rates during manufacturing of MV switchgear in Europe are below 3 % and are expected to reach a minimum of 2 % in 2015.
- There is no published data on emissions rates from HV switchgear during on site filling.

Use Phase:

- Emissions during use are higher for HV than for MV GIS since the MV switchgear is hermetically sealed and generally only leaks in the usage phase if the unit is failing.
- In Europe, emissions during use (of all GIS including both HV and MV) are slightly above 1% per year, but this is expected to decrease further in the coming years
- Under the IEC standard, the leakage rate for new MV GIS should be less than 0.5%
- Reductions in emissions of 40% were achieved in EU between 1995 and 2003 through voluntary agreements but it is believed there is still scope for further low cost reduction
- There is no published data on the difference in emissions between HV and MV GIS during usage.
- In the USA, emissions during use phase are slightly above 10% of the installed bank.

- The reported growth rate of the GIS market in the EU is minimal; high growth is projected for developing countries.

Decommissioning Phase:

- The global annual BAT emission rate for decommissioning is 0.9%.
- The achieved rate is nearer 2% emissions
- The impact of decommissioned SF_6 emissions will remain low globally until 2020 when the first installed GIS reach end of life
- The Revised Banks Model provides an estimated quantity of SF_6 in equipment reaching end-of-life in 2010 of 134 tonnes, of which approximately 97% or 130 tonnes is recovered. Equipment lifetime is about 40 years making decommissioning increasingly important to 2045
- There are recycling and destruction facilities in France, Germany and the UK. SF_6 is also transported to the USA for recovery and/or destruction.

Bank

- The EU 27 bank of SF_6 in 2005 was around 7,500 tonnes
- This is around 20% of the world figure with around 50% in Japan and North America
- Non-Utility Company uses of SF_6 in GIS are not well understood. These include uses by private electricity networks where high voltage electricity is required. This includes retail, manufacturing and military uses.
- There is also a diminishing bank of SF_6 from non switchgear uses such as filler in double glazed glass insulation (prevalent in Germany and Austria) and from training shoes. These uses are largely phased out but SF_6 continues to be used in magnesium smelting, niche research and military applications and in semi conductor manufacture.

Critique

Manufacture: According to our discussions with European manufacturers, emission rates during manufacture are very well controlled. However, emissions from the largest systems which are filled at the end user site are less well controlled. One switchgear installer commented “In 25 years I have never filled a large new sub-station without experiencing one significant SF_6 leak”. An exacerbating feature of this leakage is that it does not show up on utility company greenhouse reporting as the utility does not take ownership of the plant until it is operational. There may well be further opportunities for emissions reductions across Europe in this area. This could become important as the prevalence of GIS is increasing as utilities seek to reduce their land bank and move away from air filled switchgear.

Use: The contrast between the claimed European and American figure is striking. In the UK, the National Grid (NG - the National HV transmission system) produce publicly available audited data on leakage rates and this currently stands at 2.2%, down from 2.9%. NG are incentivised financially to reduce the leakage rate so it seems possible that in other countries where a financial incentive is not present, the leakage rate could be higher. This contrasts with the published EU leakage rates of between 1-2%. Leak rates reported in the US are much higher, at 10%. The national HV transmission system tends to have a larger bank than the MV distribution system so a leakage rate of just over 1% seems a good estimate but with the proviso that there are opportunities to limit leaks at the larger sites.

Leakage rates from MV distribution systems are generally lower as these use factory sealed units. In practice they are rarely topped up and any nominal leakage will only be determined at end of life. In practice the leakage rate appears to be significantly below 1%. There is a need for a study to determine actual leakage rates from both HV and MV switchgear. It would also be very interesting to determine why the leakage rate from HV appears to be much higher in the USA than in Europe.

Decommissioning: The data here agrees well with our conversations with manufacturers and fluid suppliers.

Bank: The bank estimate of 7,500 tonnes is well researched and fits with our own data on the UK (currently a little less than 1,000 tonnes). There are lots of poorly understood applications of SF_6. Reported European leakage rates vary from 1 to 3%. With a bank of 7,500 tonnes or more, this 2% variation corresponds to 150 tonnes of SF_6 emissions per year or 3.3 M tonnes CO_2 equivalent. This is a significant controllable emission which is easily targeted as countries generally only have one HV electricity transmitter.

3. Member State Policies and Practices

This section of the report provides views obtained from officials in Member State Governments. It includes (a) the information obtained from a questionnaire sent to Member State Government officials and (b) feedback from 5 “case study interviews” carried out with selected Member States.

3.1. Member State Questionnaire

The objective of the questionnaire was to gather information about various aspects of ODS and F-Gas bank management from each Member State.

The questionnaire was sent to officials in each of the 27 EU Member States. By the time of this final report we have received replies 21 Member States, as summarised in Table 3-1. The 21 returned questionnaires represent 78% of Member States by number and 95% by population.

Table 3-1 Questionnaire responses

Questionnaire replies received from:			Not received from:
Austria	France	Netherlands	Bulgaria
Belgium	Germany	Poland	Latvia
Cyprus	Greece	Romania	Luxembourg
Czech Republic	Hungary	Slovenia	Malta
Denmark	Ireland	Spain	Portugal
Estonia	Italy	Sweden	Slovakia
Finland	Lithuania	United Kingdom	

The questionnaire was split into three parts, covering RAC, foams and GIS. In each case the questions were structured to gather information on issues related to EOL recovery from ODS and F-Gas banks. In particular:

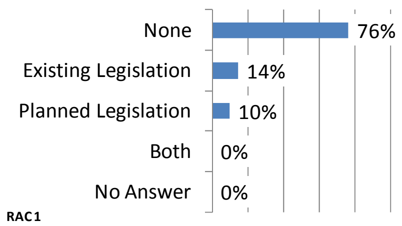
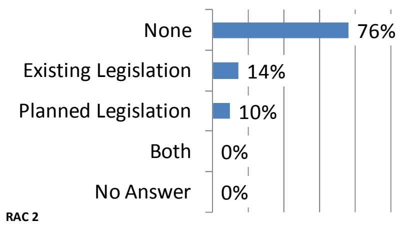
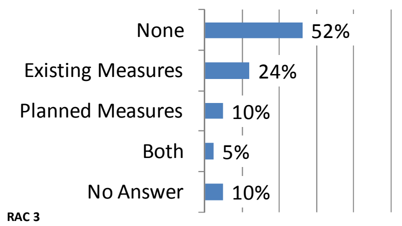
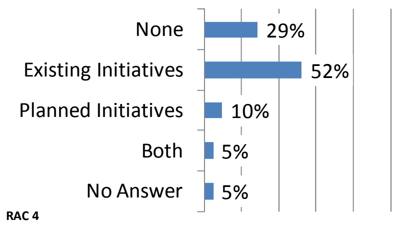
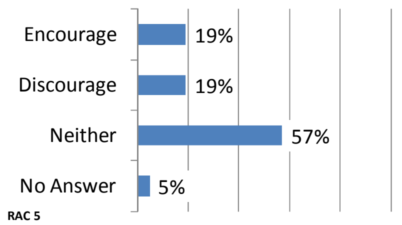
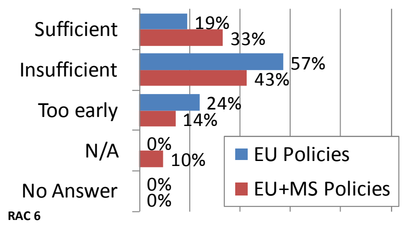
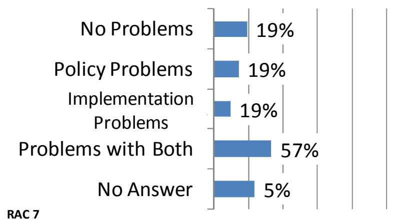
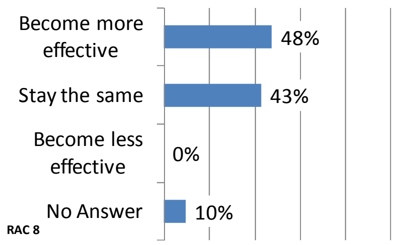
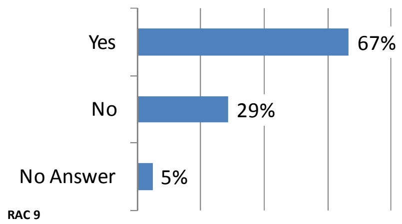
- Are there Member State policies (including regulatory and fiscal) or voluntary initiatives that go beyond the F-Gas Regulation.
- Opinions about the effectiveness of current EU and Member State policies.
- Member State suggestions for improved policies.
- Identification of key stakeholders in the Member State.
- Identification of any publications or studies that provide data about bank size.

3.2. Summary of Questionnaire Responses

3.2.1. RAC Questionnaire

Table 3-2 provides a summary of the responses to the RAC section of the questionnaire.

Table 3-2 Summary of Responses to RAC Questions

1) Does your country have existing or planned legislation that goes beyond the F-Gas Regulation by restricting the use of HFC refrigerants in **new** RAC systems? 	2) Does your country have existing or planned legislation that goes beyond the F-Gas Regulation by restricting the use of HFC refrigerants in **existing** RAC systems? 	3) Does your country have existing or planned taxation or other fiscal measures regarding the use and/or recovery of F-Gas or ODS refrigerants? 
4) Does your country have any other existing or planned initiatives to encourage the recovery and safe disposal of ODS and F-Gases from old RAC systems (e.g. voluntary initiatives or codes of practice)? 	5) Do other regulations encourage or discourage the recovery and safe disposal of ODS and F-Gas refrigerants from old RAC systems being decommissioned? 	6) In relation to the RAC sector, are the existing policies sufficient for ODS and F-Gas bank management and destruction? 
7) If the policies are not sufficient, do any problems lie with the policies themselves, or with their implementation? 	8) Will the effectiveness of existing policies change over time? 	9) In relation to refrigerants in the RAC sector, can you suggest any policy changes at EU or MS level to improve ODS and F-Gas bank management or to increase their recovery and destruction? 

The responses from Member State government experts indicated that the majority do not have national policies going beyond the existing EU F-Gas and Ozone Regulations in relation to RAC applications, with a few notable exceptions:

- Denmark – ban on new RAC systems using HFCs, except between 150 g and 10 kg in charge, together with a GWP-linked tax on the sales of ODS and F-Gases.
- Austria – ban on the use of HFCs in domestic refrigerators and freezers with refrigerant charge less than 150 g.
- Sweden – a requirement for operators to inform the local authority before installation of a new HFC system over 10 kg.
- Czech Republic – a levy was imposed on sales of ODS refrigerants (prior to 2010 ban). It is planned to use the money raised to fund a recovery incentive scheme (not yet in place).
- Slovenia – introduced a tax on sales of F-Gases in 2009. The level of tax depends on its use (e.g. it is higher for maintaining systems in use than for initial filling of new systems).
- Poland – Taxes from past sales of ODS, which is earmarked to support the recovery, collection and destruction of ODS gases and products.
- Greece – The national regulations require annual reporting of service records, with penalties for non-compliance.
- Finland – The EU regulations are extended to cover installations even when the refrigerant circuit is not interfered with. They have considered the use of taxation measures, in order to provide a financial incentive for compliance.
- France – The French respondent indicated that they are considering a tax on HFC sales.

In addition, we are also aware of national legislation in some other countries which go beyond the EU F-Gas Regulation, but these were not raised by respondents:

- Germany – a maximum leakage limit of 3% for new supermarket refrigeration systems (Cowan, 2010).
- France – controls on containment of systems above 2 kg of charge, compared to 3 kg in the (EC) 842/2006 (Oko Recherche, 2011).

A number of further issues were raised by the respondents. These are summarised below.

A majority (62%) of respondents indicated that their countries have, or are planning, other voluntary initiatives to encourage the recovery of ODS and F-Gases for safe disposal or re-use. In Sweden and Germany, it is mandatory for distributors of refrigerants to take back recovered gases free-of-charge. Many other countries (France, Ireland, UK, Poland, Italy and Romania) indicated that they offer support to industry to meet their obligations, by providing guidance and through voluntary agreements.

Regarding the level of satisfaction with existing policies, a small majority (57%) of respondents indicated that they consider current EU regulations alone to be insufficient. There was slightly more satisfaction about the combination of EU and national polices – only 43% thought these are insufficient. Slovenia and Germany raised dissatisfaction with the exclusion of mobile RAC systems from the current EU regulations[3]. Most other comments concerned the lack of measures to validate and measure compliance (e.g. data reporting). Belgium expressed dissatisfaction with the regulations on training and certification, with a preference for a requirement for regular re-assessment of competency – rather than a once-off qualification which is currently permitted.

Some correspondents raised concerns over the coordination of the Ozone and F-Gas regulations and Waste regulations. The Lithuanian respondent called for better coordination of these regulations; and suggested that the administrative burden involved in the cross-border movement of waste ODS and F-Gas for destruction is a significant additional cost and disincentive for compliance.

Many respondents (67%) provided suggestions for how to improve existing policies, including:

- Better harmonisation with waste regulations (Germany, Hungary, Spain, Lithuania).
- Introduction of an EU requirement for levies on sales of F-Gases to fund incentive schemes to encourage the recovery and disposal of used gases (Czech Republic, Sweden, Spain, Finland)
- Oblige producers and distributors to take back recovered gases and pay for destruction (Sweden, Czech Republic).
- Introduce requirements to report cross-border flows of ODS and F-Gases, to enable measurement of consumption and recovery at national levels (Germany, Cyprus).
- Minimum recovery limits (Cyprus).
- Inclusion of F-Gases in the EU Emission Trading Scheme (Slovenia).

[3] Passenger vehicle air conditioning is covered by the MAC Directive (2006/40/EC), but (EC) 842/2006 Article 3 concerning containment only applies to stationary RAC systems.

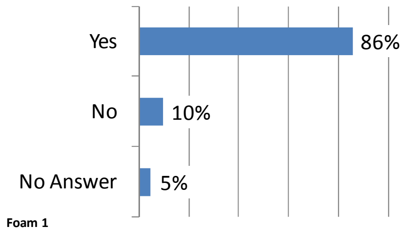
3.2.2. Foam Questionnaire

Table 3-3 provides a summary of the responses to the foams section of the questionnaire.

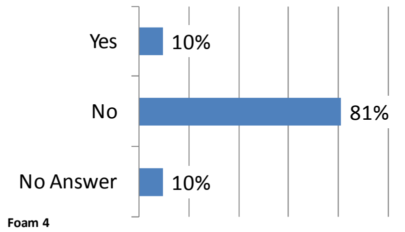
Table 3-3 Summary of Responses to Foam Questions

1) Regarding the recovery of ODS from insulating foam in domestic refrigerators:

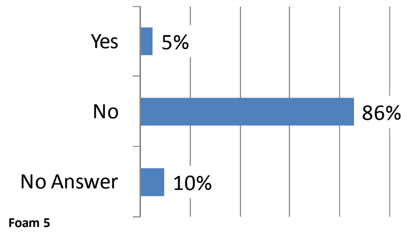
Has your country implemented the recovery of foams (as mandated in the Ozone Regulation) in domestic fridges?



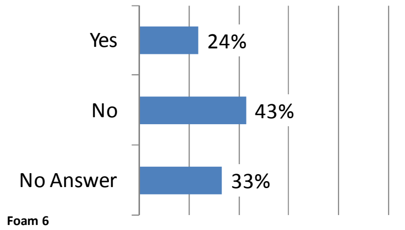
4) Have measures (regulatory or voluntary) been introduced at MS level to provide clarity about the types of foams from which ODS & F-Gases should be recovered &/or destroyed?



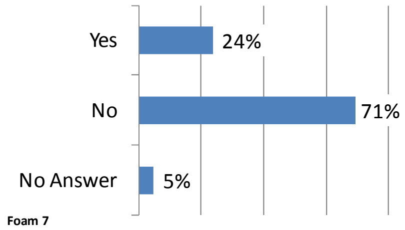
5) Do you have information on the cost-effectiveness of recovery and destruction of foams and/or the ODS or F-Gases contained within different types of foam?



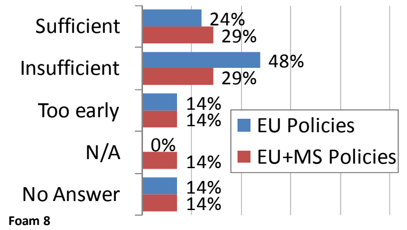
6) In your country, is the cost effectiveness of recovery influenced by the waste regulations (e.g. WEEE or Demolition Waste)?



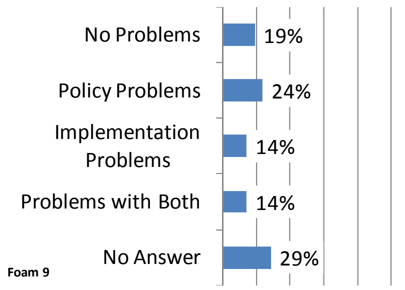
7) Do the requirements of other laws (e.g. waste regulations) conflict with those of the Ozone & F-Gas Regulations?



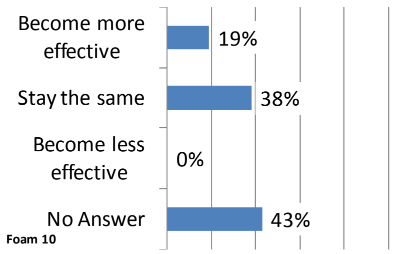
8) In relation to the foams sector, are the existing policies sufficient for ODS and F-Gas bank management and destruction?



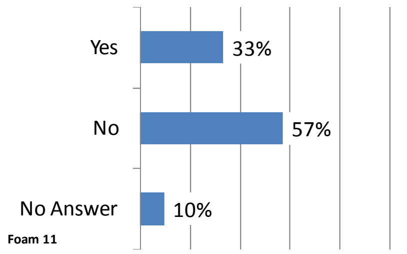
9) If the policies are not sufficient, do any problems lie with the policies themselves, or with their implementation?



10) Will the effectiveness of existing policies change over time?



11) Can you suggest policy changes at EU or MS level to improve ODS & F-Gas bank management or to increase their destruction at decommissioning?



The responses to Questions 2 and 3 in the foams section were qualitative rather than quantitative and are not shown in the charts above. The questions were:

Foams Question 2	To what extent was the recovery of ODS from foam regarded as ‘practicable’ (as worded in the repealed Regulation EC 2037/2000) in the following sub-sectors and product categories? • Commercial refrigeration • Cold Stores and other buildings
Foams Question 3	To what extent was the strategy for recovery of ODS from foam revised as a result of alternative language in the F-Gas Regulation5 (“technically feasible and does not entail excessive cost”) and the new Ozone Regulation6 (“technically and economically feasible”)?

Of the responses received to the questions on foams, the overwhelming majority indicated that action had been taken to implement the Ozone Regulations as they related to recovery of ODS from domestic refrigerators, although in a number of cases (e.g. France), it was noted that the largest driver in this area was the introduction of subsequent waste legislation in the form of the Waste Electrical & Electronic Equipment (WEEE) Regulation. This has also had a bearing on the extension of ODS recovery and destruction to commercial refrigeration equipment (e.g. vending machines and supermarket display cabinets). However, the level of impact in this product group is less well understood and is likely to be more variable across the Member States.

There was an almost unanimous response that the management of ODS in construction foams had not been tackled in earnest as yet. This was partially because products were not entering the waste stream yet (because of the long lifecycle of foam insulation in the construction sector) or because data on this aspect was unavailable.

It was confirmed that changes to the qualifying text, between the original and recast Ozone Regulations, surrounding the concept of ‘technical and economic feasibility’ of recovery had not changed practice in any country. Where anything was understood to be being done, it was primarily being driven by the classification of ODS in foams as hazardous waste. At least one Member State confirmed that they did not see recovery of ODS from foams as technically and economically feasible.

A number of individual comments on implementation aspects were made and these are summarised in Table 3-4.

Table 3-4 Comments on foam issues

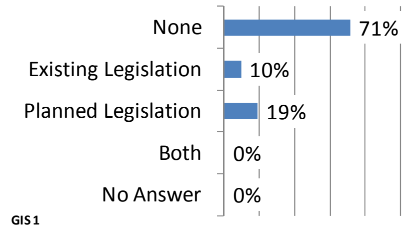
Country	Additional Comments on Implementation Issues
Austria	Hazardous waste classification relied upon to drive the correct disposal of foams containing CFCs in buildings
Cyprus	Some uncertainty about whether a stricter EU Framework would encourage more enforcement for recovery of construction foams Recognised that only other option would be fiscal incentives
Czech Republic	Foam in commercial refrigeration equipment captured well because of WEEE. Generally perceived to be cost-effective Foams from water heaters (boilers) not found to be cost-effective to recover
Greece	Hazardous waste classification relied upon to drive the correct disposal of foams containing CFCs in buildings
Italy	Highlighted the dependence of ‘practicability’ on the level of waste separation occurring
Romania	No formal implementation of the Ozone Regulation. Rely on WEEE for recovery of foams (including blowing agents)
Spain	Some concerns over residual blowing agents in construction foam at end-of-life Cost/benefit analysis based on real experiences would be necessary
Sweden	Difficulties in identifying which foams contain ODS & F-Gases at demolition (industry coalition contact provided) Possible deposit system to fund recovery in future Banks Report available in Swedish

3.2.3. GIS Questionnaire

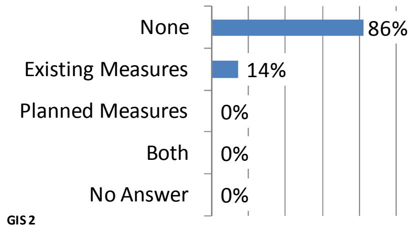
Table 3-5 provides a summary of the responses to the GIS section of the questionnaire.

Table 3-5 Summary of Responses to GIS Questions

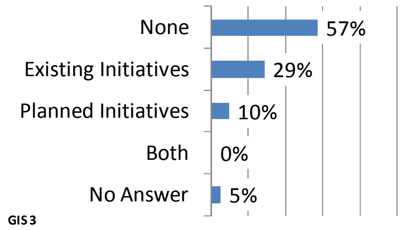
1) Does your country have existing or planned legislation related to SF6 in high voltage switchgear that goes beyond the F-Gas Regulation?



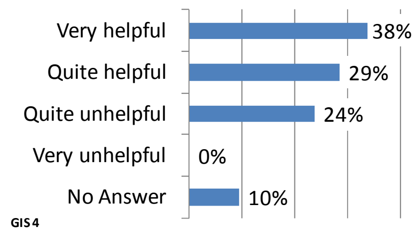
2) Does your country have existing or planned taxation or other fiscal measures regarding the use and/or recovery of SF6 from switchgear?



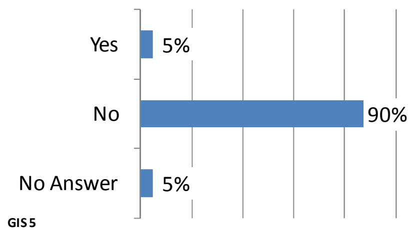
3) Does your country have any other existing or planned initiatives that help minimise SF6 emissions from switchgear (for example voluntary initiatives or recommended practices)?



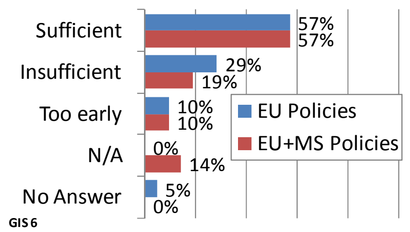
4) How helpful are the Electricity Utility Companies in the implementation of policies regarding leakage reduction and recovery of SF6 from GIS?



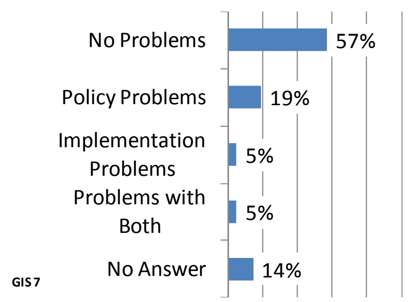
5) Are there any particular circumstances in your country which make the management of SF6 banks more difficult relative to the rest of the EU?



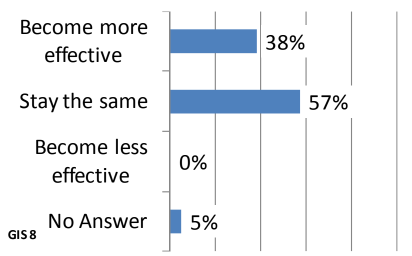
6) In relation to SF6 in switchgear, are the existing policies sufficient for ODS and F-Gas bank management and destruction?



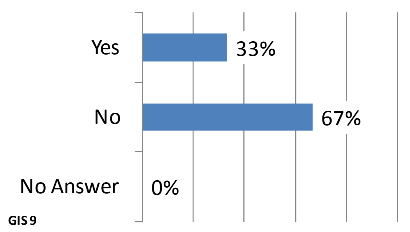
7) If the policies are not sufficient, do any problems lie with the policies themselves, or with their implementation?



8) Will the effectiveness of existing policies change over time?



9) Can you suggest any policy changes at EU or MS level to improve SF6 bank management or to increase recovery and destruction of SF6 at decommissioning of switchgear?



Nearly 60% of the countries consulted felt that the existing legislation is sufficient for the control of emissions from the GIS sector – this is much higher than the response to the equivalent question about RAC and foams sectors.

All the rest of the respondents are either taking additional action or would like to see additional action being taken. The responses are summarised further in Table 3-6.

Table 3-6 Comments on GIS issues

Country	Additional Measures
Cyprus	Believe there are policy problems with the way the F-Gas regulation covers SF_6
Denmark	F-Gas tax- €53 per kg
Estonia	Planned legislation to require record keeping
France	Planned legislation to require record keeping and management oF-Gas recovery
Germany	Voluntary Agreement in place. Also want addition EU regulation.
Hungary	Have additional existing legislation covering use of SF_6
Italy	Voluntary Agreement in place.
Netherlands	Voluntary Agreement in place.
Poland	Planned legislation to require record keeping
Romania	Voluntary Agreement in place. Planned legislation on leak reduction and recovery.
Slovenia	Existing legislation to require record keeping, Want same at EU level.
Spain	Voluntary Agreement in place.
UK	Financial incentives for emission reduction.
Finland	The use of SF6 is considered necessary due to the cold winter temperatures. The need for better training in the handling of SF6 was called for.

As can be seen in Table 3-6, there are a number of differing approaches to the management of SF_6 in switchgear being developed by the Member States. These can be summarised as follows:

- Voluntary Agreement with the electricity transmitter and other stakeholders
- Financial Incentives for emission reduction
- Increased Legislation
- Taxation of the use of SF_6

These options are reviewed in more detail below.

Voluntary Agreements

There are Voluntary Agreements 4 countries. The current round of VAs has only been in place for 1 - 2 years and little information has yet been published on how effective these are being. Ecofys report that historically VAs have been very successful in reducing emissions from GIS:

- **Spain**. A VA was signed in 2008 in Spain between AFBEL-SERCOBE (National Association of manufacturers), REE (Transmission Network Electrical Utility), UNESA (National Association of Distribution companies) and the Ministry of Environment. It covers all lifecycle phases of SF_6 and gives a reduction target of 330 kT CO2 equivalent in five years (2008-2012). As yet no data has been published on progress beyond a few notes on various good housekeeping initiatives being made by the utility.
- **Italy**. The state regulated electricity transmitter (Terna) has a stated emission rate of 0.7%. It notes that this is net of one serious emission at one isolated plant. It is targeting a leakage reduction of 0.1% over the period 2008 to 2012.
- **Germany**. There has been a VA in place in Germany since 1997. It is signed by the association of network operators (VDN), the Federation of Industrial Energy and Power Industry (VIK), the Central Association of Electrical and Electronics Industry (ZVEI) and by Solvay Fluor GmbH. No information on the current targets for reduction is available.
- **Netherlands**. The sector developed a specific monitoring system in 2007 and 2008 and exchanges information on measures to prevent emissions and experiences with alternatives. These awareness actions have contributed to decrease emissions.

Financial Incentives

The UK has a possibly unique system for financially incentivising its National Grid operators. The two operators have separately negotiated agreements to receive payments for hitting reductions in total monitored SF_6 leakage rates. This has seen leakage rates fall from 2.9% to 2.2% in England with further reductions targeted to 2012. This scheme is administered by the regulator for the energy industry in the UK.

Legislation

Hungary has existing legislation in place to increase control of use of SF_6 whilst three other countries – France, Poland and Estonia have plans to implement legislation. Areas considered for additional legislation include documentation for SF_6 management, leakage checking, recovery, collection and reclamation, documented procedures and recovery management procedures. There is some support for the extension of the F-Gas Regulation to require a similar level of record keeping to that required for the RAC sector.

Taxation

Denmark operates a tax on F-Gas which includes a rate on SF_6 of around €53 per kg.

3.3. Case Studies

Detailed country case study interviews were carried out with 5 Member States to build on the Questionnaire results (see Section 3.2), with the objectives of:

- Increasing understanding of the policies and practices at MS level
- Gathering further bank estimates data, to improve the existing Banks Model.

The 5 countries were selected to provide insights into the different situations encountered across the EU. The selection was on the following basis:

a) UK was chosen to represent one of the larger Member States.

b) Cyprus was chosen to represent the smaller countries, with significant logistical difference from the rest of the member states.

c) Czech Republic was chosen to represent the eastern European countries.

d) Spain was chosen to represent southern countries and due to its particular use of spray foam for building insulation.

e) Austria was chosen as an important example of a country with advanced waste practices.

3.3.1. UK

An interview was carried out in April 2011 with the UK government team (from the Department for the Environment, Food and Rural Affairs, DEFRA), responsible for F-Gases and ODS. Those present were: Deborah Owens, Steve Cowperthwaite, Elizabeth Chrominska, Jacob Andersen and Karen Kendrick.

Regarding the foams sector, the Defra team confirmed that the domestic appliances sector is the only one for which recovery of ODS is mandatory at EOL. It is common practice in the UK for similar appliances from the commercial sector (e.g. supermarket cabinets) to be subject to gas recovery or destruction. Defra confirmed that the recovery of ODS from building foams is not considered technically and economically feasible.

We discussed how the ICF model allocates the EU foams bank on a GDP basis, and that this may not accurately reflect the different practices at country level. This was broadly agreed by the DEFRA panel and was improved via the Revised Banks Model (see Section 4).

Defra confirmed that a report has been commissioned from BRE on ODS in building foams. The publication of this has been delayed, but is imminent.

In the refrigeration sectors, we discussed the ICF allocations made for the UK, including issues related to the air-conditioning bank and industrial refrigeration. The improvements discussed are reflected in the Revised Banks Model.

3.3.2. Cyprus

A telephone interview took place with the Cypriot government expert on ODS and F-Gases, Mr Pavlos Pavlou, in April 2011. The key points discussed during the interview were:

Domestic Appliances –waste appliances are segregated and stockpiled, prior to undergoing the necessary ODS recovery process. There is no permanent recovery equipment, but a mobile crushing unit is brought to the island when sufficient stocks have been collected.

Building Foams –there is no recovery of ODS from building foams at present. Furthermore, he thought this would be very difficult to introduce, owing to problems with technical and economic feasibility and also due to problems with ensuring compliance.

Waste refrigerants – there are no HFC or HCFC reprocessing or destruction facilities on the island. Recovered gas is collected and then sent abroad for reclamation or destruction. For commercial and industrial RAC applications, the cost of sending waste gas abroad is carried by the equipment owner, via the refrigeration contractor. For the domestic sector, the costs of recovery are paid by an industry-wide levy raised on sales of new F-Gas containing appliances.

The ICF Banks Model was discussed, and in particular the estimate for the stationary air conditioning (SAC) sector. The ICF allocation of the SAC bank is made on an equal per capita basis (as with all EU-12 countries). This underestimates the likely SAC bank in countries with a hot climate such as Cyprus. We proposed re-allocating the bank, giving Cyprus a per head bank size similar to Greece. Mr Pavlou agreed with this assessment.

ODS and F-Gas Banks in ships refrigerated transport sector – the ICF Model allocates to Cyprus 18% of the EU bank for this sector, allocated on the basis of the size of the registered shipping fleet. On a per capita basis however, this makes the total RAC bank for Cyprus very high. Malta has a similarly large allocation of shipping refrigerated transport. Furthermore, the ICF model estimates that most refrigerated ships use HCFCs (90%), compared to HFCs (10%). Mr Pavlou pointed out that EU registered ships will be subject to the end-2014 phase out for HCFC 22 – bringing about a significant move from HCFCs to an alternative non-ODS refrigerant.

Mr Pavlou was asked whether he felt the existing legal framework was sufficient to ensure effective management of the ODS and F-Gas banks. For foams, he confirmed the view that recovery from insulating foams (except domestic appliances) is NOT technically or economically feasible. For the RAC sector, he made a number of suggestions:

- The cross-border trade in F-Gases should be controlled, allowing Member States to measure the consumption of refrigerant and that sent abroad for recovery or destruction. Only this way could regulators measure the amount of gas being recovered and estimate the level of compliance
- Mr Pavlou raised concerns that training and qualifications for F-Gas technicians (as required by the F-Gas and Ozone regulations) is not be sufficient to ensure compliance. He did not

think there is sufficient incentive to ensure compliance with the containment and recovery obligations.

- The continued sale of split air conditioning systems direct to the public from DIY stores is considered a problem. These are sold pre-charged with refrigerant, usually with HFC 410A or HFC 407C. However, these are not usually installed by skilled or qualified personnel. Furthermore, any maintenance (during life) or recovery (at EOL) may not be carried out by qualified personnel.

3.3.3. Czech Republic

A telephone interview was held in April 2011 with Ms Jana Borska, the Czech Government official for ODS and F-Gas issues. The key issues discussed are summarised below:

Ms Borska confirmed that there were no studies on insulation use in buildings and no historical reporting on ODS products used in building products. She did however provide further contact details of industry stakeholders.

In order to comply with the WEEE Directive, the Czech Waste Act 2001 requires all producers of domestic appliances to be responsible for the recovery and effective disposal of all such units at the end of life.

In 2009, regulations on air pollution were amended to apply to both ODS and F-Gases and meet the recast Ozone Regulations.

The establishment of local facilities for the recovery and destruction of products containing ODS has been supported by the government's Ozone Protection Programme (funded by the State Environment Fund, which was part-financed by a levy on previous imports and production of ODS (around 16 €/kg).

The latest data on the use of refrigerants is from 2004. This suggested that R22 accounted for 48% of the fluorinated refrigerant bank (i.e. CFC + HCFC + HFC).

3.3.4. Spain

Spain was chosen for a Case Study to include a warm climate Mediterranean country. It has particular interest due to its high demand for air-conditioning and high use of PU rigid spray foam. A telephone interview was held in July 2011 with Mr Alberto Moral González of the Spanish Ministry for the Environment and Rural and Marine Affairs.

Regarding EOL emissions from the RAC sectors, it was confirmed that there is no empirical data to quantify how much is being recovered in compliance with the F-Gas Regulations.

Recovered waste refrigerant must be sent to either France or Germany for destruction, since there are no destruction facilities in Spain. Destruction costs were estimated at €5 to €7 per kg.

There is currently no incentive for end-users and contractors to recover gas, and since policing is very difficult, it is feared that only a small percentage of gas reaching EOL is recovered and sent for destruction. If an incentive could be introduced to recover the gas, then compliance should improve.

One suggestion was to limit the amount of gas available to customers based on the amount of gas recovered. It was not clear whether this should apply to gas wholesalers, contractors or end-users.

It was estimated that annual consumption of refrigerant gases (HFC and HCFC) is currently around 10,000 T per annum (bulk gas only, excludes pre-charged equipment). In 2007/08 (prior to the economic downturn), consumption was thought to be about twice current levels.

Regarding EOL emissions from the foams sectors, it was confirmed that compliance was strong in those sectors also covered by the WEEE Directive, i.e. domestic and commercial appliances. For the commercial sector, it was reported that green issues are becoming a competitive differentiator – leading to improved practices in general. But there were no obligations to recover construction foam at end-of-life.

Spain is a large user of spray foam – thought mostly to contain HCFC141b. Common practice is to apply this in 10 cm thickness. It is very difficult to recover at end-of-life and existing insulation is often over-sprayed when refurbished.

3.3.5. Austria

Austria was chosen as a Case Study owing to its reputation as an example of good, well documented, practices in its waste recycling activities, which is thought to make the recovery of ODS and F-Gases more cost-effective. An interview was held with Dr Christian Keri of Waste Management Section the Austrian Environment Ministry on 7 June 2011. The interview focused on the recovery of ODS and F-Gases from the waste stream, rather than recovery of gas from in-situ refrigeration systems.

Dr Keri confirmed the high compliance to the regulations for segregation and treatment of domestic fridges and freezers, as well as similar commercial units. He agreed that it would be possible to treat insulation panels in the same recovery plants, but that there were no reports of this being done currently. It was suggested that typical treatment costs (including collection, transport and processing) are around €100 to €130 per tonne of waste.

Regarding building insulation foam, there was a national “Ordinance” introduced in 1993 requiring the separation of building and demolition waste. The waste must be separated into 8 material streams, provided the threshold limits shown in Table 3-7 are exceeded.

Table 3-7 Austrian Regulation for Segregation of Waste Materials During Construction

Substance	Threshold (tonnes)
Excavation waste	20
Concrete waste	20
Asphalt waste	5
Wood waste	5
Metal waste	2
Plastic waste	2
Construction site waste	10
Mineral debris	40

In addition to the above, all hazardous substances (including ODS and F-Gases) must be segregated and treated accordingly.

Given that this requirement to segregate waste is already in place in Austria, the additional cost of segregation of ODS and F-Gases is reduced.

Further legislation exists which bans the landfilling of waste if the total organic content is greater than 5% - to encourage the use of power-from-waste plants. Whether this is effective for insulation foams in isolation is not clear, since the low density of most foams makes the 5% threshold difficult to exceed. Nevertheless, the calorific content may encourage some diversion to power-from-waste plants and coincidentally lead to the destruction of ODS and F-Gases in the waste stream.

Even with this legislation, it was suggested that the levels of recovered foams (received at the 3 treatment plants in Austria) are still low.

3.4. Gap Analysis

RAC

In the RAC sector, the literature review (see Section 2) and the Member State responses have shown a significant lack of empirical data to measure containment and recovery of ODS and F-Gases. One country (Estonia) is planning to introduce an on-line national database, on which all F-Gas operators will be obliged to record consumption and recovery information. This should allow regulators to monitor compliance and develop improved bank estimates. If successful, this could provide a model for other countries. This lack of information on the level of compliance represents a considerable **"Data Gap"** for the RAC sector.

Regarding the policy framework for the RAC sector, the current F-Gas Regulation (842/2006) and Ozone Regulation (1005/2009) provide comprehensive obligations for operators of stationary RAC systems to ensure F-Gases and ODS are contained during use and recovered at the end of life. Mobile systems are not covered by Article 4.1 in 842/2006, but are covered by Article 4.3, which requires recovery only if "... technically feasible and does not entail disproportionate cost". It is however, no more difficult to recover refrigerant from a mobile refrigeration system than a stationary one. The current regulations introduce a level of uncertainty for mobile RAC, which is perhaps unnecessary. We assess the **"Policy Gap"** for the refrigeration and air conditioning sector to be only small.

Of greater concern to the Member State officials was the potential for a **"Compliance Gap"**. Although the operator obligations are clear and well understood, there is considerable scope for unscrupulous operators to release gases to the environment, without significant risk of being caught. Most of the comments from the returned questionnaires were related to this compliance gap, and included suggestions for improved monitoring and/or the introduction of an incentive scheme to encourage the recovery of gases.

Foam

As with RAC, there is a considerable **"Data Gap"** in relation to the foam sectors. The research identified three key areas where information was missing. These were:

- Independent quantification of ODS contained in existing products and equipment (banks)
- Information on ODS reaching the waste stream (partly a problem of lack of mechanism of tracking waste streams and partly a problem of blowing agent identification in foams)
- Cost-effectiveness data for recovery and destruction of foams and/or the blowing agents contained within them

The latter two issues covered in these bullets also result from the fact that there is little ODS yet entering the waste stream from construction foams, making it difficult to assess whether there is a real problem with reporting or not. Experience with domestic and commercial appliances would suggest that some problems could be expected, since recovery rates in this field are believed to be less than optimal although evidence to support this conclusion is often anecdotal. A more systematic and proactive approach to monitoring would be helpful, possibly based on wider dissemination of the expected waste flows by Member State based on the Revised Banks Model.

Initially, there was also thought to be a lack of information about the type and age profile of the building stock at Member State level, but further enquiries (within the Case Studies – see Section 3.3) revealed that most Governments had departments which could assist with these questions. However, the level of detail that may be forthcoming from these departments may not be sufficient to provide a consistent picture across the EU. Nonetheless, it will be useful information to carry out bottom-up cross-checks against the information modelled from the EU-27 level. The bottom-up approach depends on knowledge of the type and age of buildings, the minimum energy efficiency requirements for each building type together with their development over time, and finally the product mix of insulation materials used at country-level over time.

The **"Policy Gap"** for the foams sector is particularly high. The majority of foam falls under the ambiguous wording in the F-Gas and Ozone Regulations that refers to "technically and economically feasible". In most Member States this means that there is a complete policy gap for foams apart from domestic refrigerators and freezers and any other equipment that is covered by the WEEE Directive.

The **"Compliance Gap"** for foams is relatively small. This is partly because of the large size of the policy gap – there is little to comply with. However, compliance in relation to domestic refrigerators and freezers appears to be relatively high.

GIS

As with both RAC and foams, there is a considerable **"Data Gap"** in relation to the GIS sector. It is interesting to note that GIS is not covered by Article 3 of the F-Gas Regulation. This would make record keeping mandatory and would go some way to reducing the data gap.

Electricity Utilities are governed by a wide range of departments across Government departments and this often leads to policies arising which are unknown to the department tasked with reporting on F-Gas policy.

Use of HV switchgear is a technically complex area and many of the Member State respondents have limited understanding of the application of switchgear. Examples of the data gap include:

- Lack of Information on banks held by the national grid operator
- Lack of information on possible growth rates in relation to GIS
- Lack of information on current leakage rates in the national grid operator
- Lack of understanding of the difference between leakage for the national grid operator and the local distribution networks
- At an EU level, little information on the variation of leakage rates between Member States, which appears to vary between 3% (UK 3 years ago) and 0.7% (Italy today).

The **"Policy Gap"** for the GIS sector is low in relation to EOL recovery – the obligations are clearly defined in Article 4.1 of the F-Gas Regulation. However, the lack of inclusion of this sector in Article 3 gives some scope for lack of action related to in-life leakage..

The **"Compliance Gap"** for GIS is relatively small. GIS is used in a heavily regulated industry and compliance is thought to be better for GIS than for either foams or RAC.

4. Modelling of Bank and End of Life Emissions

To evaluate the impact of existing and future policy measures it is vital to have accurate information about the size and chemical species in ODS and F-Gas banks in the EU and the rate at which gases in these banks reach the waste stream at end of life (EOL). This information must be established for relevant sub-sectors of the market as the potential to reduce EOL emissions varies enormously across the wide range of markets that use ODS and F-Gases.

Previous work for the Commission on ODS and F-Gas Banks (ICF, 2010) included a banks model that provided data on the size of banks in each market sector and the emissions at EOL. The ICF Banks Model has been reviewed and updated during this study. Details of this review can be found in Appendix B of this report.

There were a number of problems identified in the ICF Banks Model that are fully described in Appendix B. These problems have been addressed and a new SKM Enviros/Caleb Revised Banks Model has been developed and used for the analysis of policy measures presented in Section 5. Some of the key improvements in the Revised Banks Model include:

a) A revised life cycle assessment, based on a Poisson distribution around average product life in each market sub-sector.

b) Improvements to the assessment of the use of air-conditioning in each Member State based on better market data and the impact of Member State climate on the amount of air-conditioning required, using data for "cooling degree days".

c) More realistic assessment of phase out of RAC equipment (e.g. caused by the imminent phase out of HCFCs (especially R22) and the likely reduction in the use of very high GWP HFCs such as R404A).

d) Improvements to the split of foam usage in each Member State.

e) Improvements to the split between foam types in each Member State.

f) Improvements to the market sub-sector breakdown for foams, to reflect better the EOL differences in relation to the ease of foam recovery at EOL.

g) A facility for foam sectors to distinguish between banks in products and banks in the waste stream (to reflect the slow release of ODS and F-Gases from landfill).

h) New data added for the GIS sector.

i) New features for the analysis of policy measures were added.

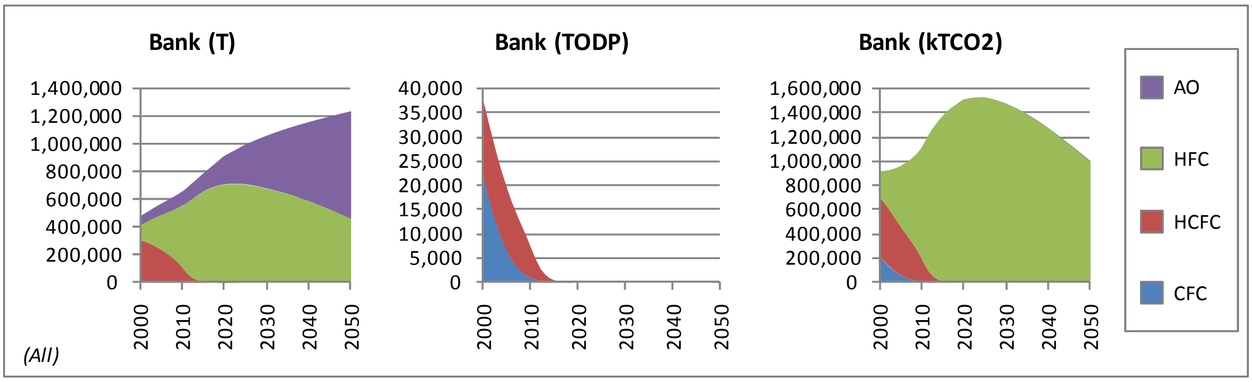
j) Other small changes to correct a number of data errors found in the ICF model.

The Revised Bank Model has been used to produce detailed data for each market sub-sector. Details of these outputs are given in Appendix C. In the paragraphs below we give some example outputs for RAC and foams.

4.1. Example Outputs from Revised Banks Model – RAC

The model provides estimates of bank size, annual retirement from the bank, and annual emissions for each RAC end use sub-sector and the RAC total. These are given in terms of tonnes of gas, or in ozone depleting tonnes (TODP), or in kilotonnes of CO_2 equivalent ($kTCO_2$). The charts in Figure 4-1 (bank size), Figure 4-2 (EOL retirements) and Figure 4-3 (overall emissions) show an example set of outputs – this is the dataset for the RAC totals. The outputs for each RAC end use sub-sector are shown in Appendix C.

Figure 4-1 Bank Estimate for RAC Sectors Total



The bank profiles shown in Figure 4-1 illustrate the rapidly declining contribution of CFC and HCFC refrigerants. They are of course the only gases which contribute in ODP terms, but this falls to zero by around 2018. In GWP terms, CFCs and HCFCs contribute 67% of the RAC total in 2000, but this has dropped to zero by 2018.

The HFC bank is projected to grow until around 2025, when it is anticipated that they will be superseded by alternative very low GWP gases – shown by the growth in the “Any Other” (AO) category (which includes “natural” refrigerants and very low GWP refrigerants such as HFOs).

Figure 4-2 EOL Retirement for RAC Sectors Total

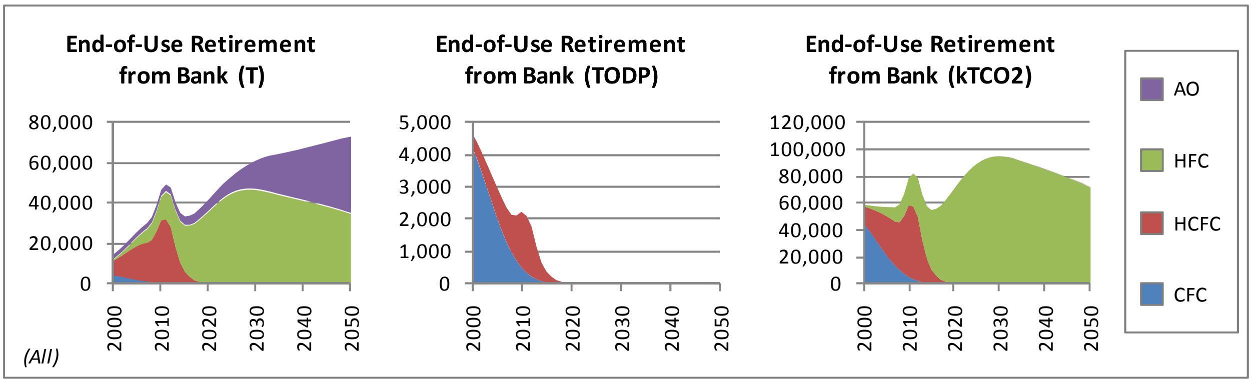


Figure 4-2 shows that until around 2012, the EOL retirement profiles are dominated by CFCs and HCFCs, because there are relatively few HFC systems reaching end of life. The HCFC phase out requirements of the Ozone Regulations cause an increase in EOL Retirement between 2010 and 2015 as HCFC systems are retired early and replaced or retrofilled by alternative gases.

In GWP terms, the effect of growing gas retirement is masked by the reduction in CFC refrigerants, many of which have particularly high GWPs. After 2020, GWP retirements rise until around 2030, when retirements fall with the increase in AO refrigerants.

Figure 4-3 Overall Emissions for RAC Sectors Total

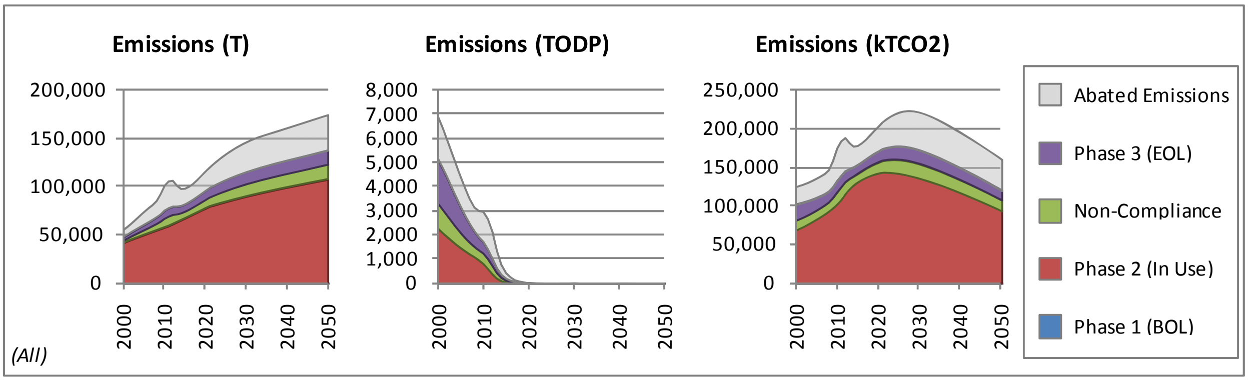


Figure 4-3 shows that overall emissions from RAC are dominated by in-use (Phase 2) emissions, illustrated by the red region in the chart.

The Phase 1 emissions (blue region), representing beginning of life emissions during manufacture and installation, are very small indeed and do not show on the scale of Figure 4-3.

The green, purple and grey regions together represent the total potential EOL emissions “at risk” if there were zero compliance and all gas reaching EOL was emitted to the atmosphere. The level of non-compliance is not known, but we provide an estimate shown by the green region.

The purple region of Figure 4-3 shows the estimated emissions resulting from current standard practices during recovery. In the domestic appliances sector, it is feared that a significant proportion of systems are damaged accidentally after removal from the property and before the final recovery process, resulting in release of the refrigerant gas. For commercial and industrial sectors, where recovery takes place in-situ, only a small residual amount of gas is likely to be emitted from the system. These emissions are not classified as “non-compliance” but could be reduced by improved practices and techniques.

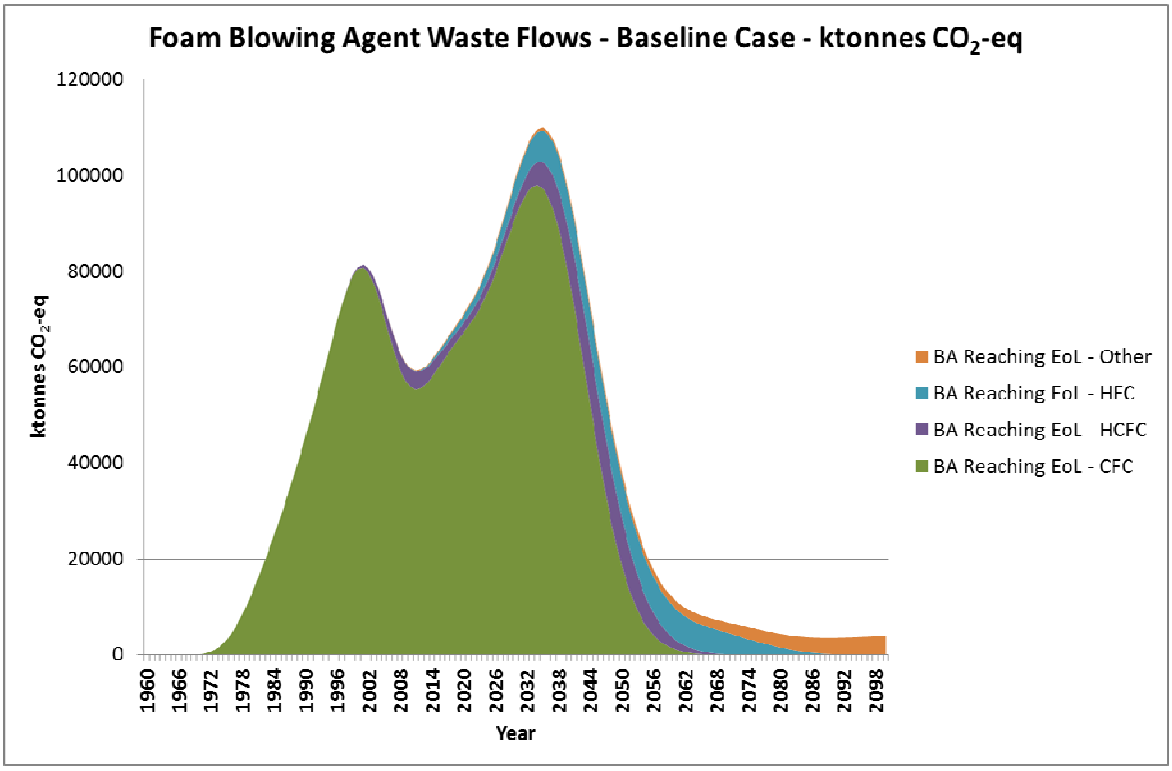
The aggregate of the blue, red, green and purple regions together represent an estimate of the current total emissions per year.

The grey region shows the “abated emissions”, representing an estimate of the emissions already avoided by current levels of compliance and recovery and destruction practices.

4.2. Example Outputs from Revised Banks Model – Foams

A key improvement to the foams modelling is illustrated in Figure 4-4. This clearly shows the "double hump" of waste arisings in the CFC blown foams market (which is not shown via the ICF model). The reason for the double hump is that the foams market has some products with a relatively short life cycle (e.g. foam in domestic refrigerators and freezers, with an average life of 15 years) and other products with a very long life cycle (e.g. laminated PU panels used for building insulation, with an average life of 50 years). CFCs were used as a blowing agent in both these markets from the 1970s until the early 1990s. The first hump in Figure 4-4 results from these short lifecycle products reaching EOL. However, even the oldest foam used for building insulation has not reached the 50 year average life. The second hump in Figure 4-4 is created by this CFC building foam reaching EOL, and it doesn't peak until the mid-2030s.

Figure 4-4



* Note: BA = blowing agent

As with the modelling for RAC sectors described in Section 4.2, the Revised Banks Model for foams can present outputs in terms of tonnes of gas, or in ozone depleting tonnes (TODP), or in kilotonnes of CO_2 equivalent ($kTCO_2$).

Figure 4-5 illustrates the overall size of foam banks split by fluid type. Note the significant growth of the "AO" (all other) part of the bank – this is due to the use of alternative fluids such as hydrocarbons following the phase out of CFCs.

Figure 4-5 Banks in Foam Products

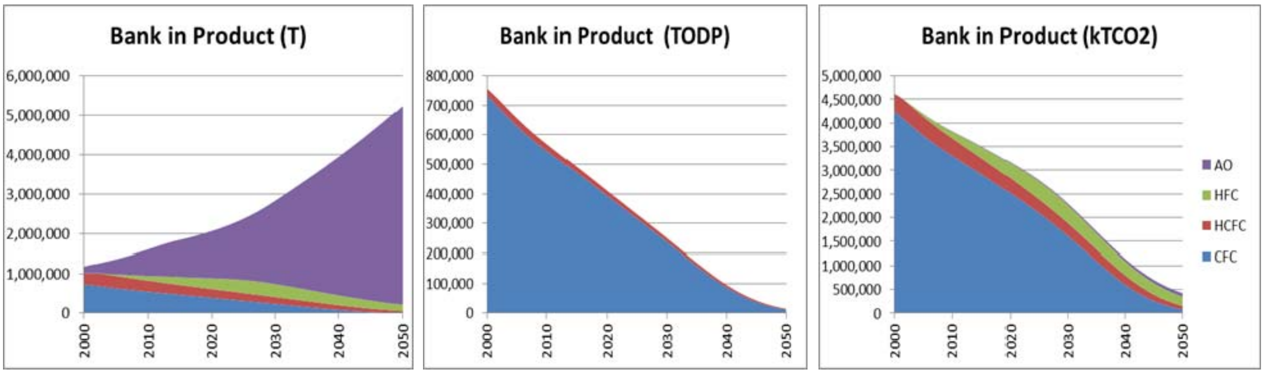


Figure 4-6 Foam Products Entering Waste Stream

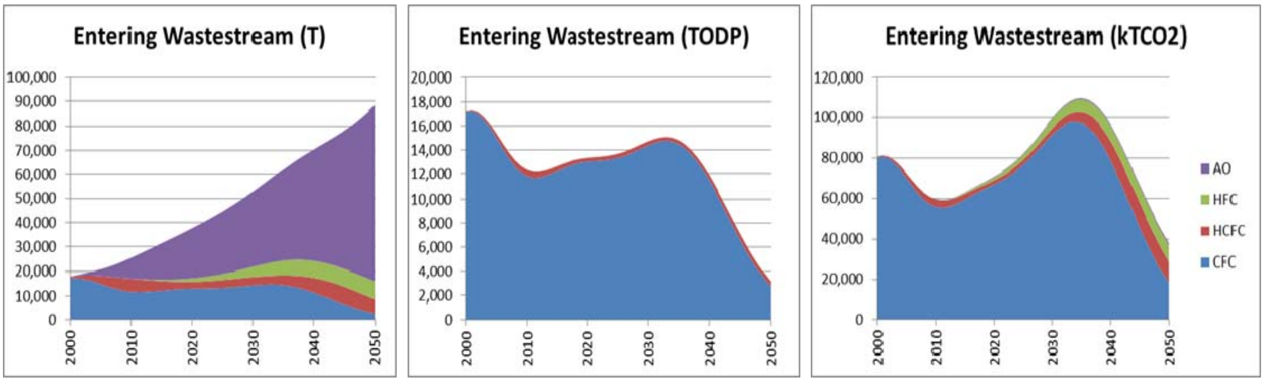


Figure 4-6 illustrates the rate of different fluid types entering the waste stream. This shows that although the total amount of foam waste in physical tonnes continues to grow, the ODP tonnes and the kT CO_2 quantities fall steadily and reach about 20% of the peak level by 2050. These graphs illustrate a difficulty that will be faced by foam recycling companies – they will need technology that can deal with hydrocarbon blowing agents as well as ODS and F-Gas blowing agents.

This effect is illustrated by the average ODP and GWP of products reaching the waste stream. Figure 4-7 shows both the ODP and GWP of "average" foam products reaching the waste stream. This falls steadily between 2000 and 2050. Figure 4-8 provides more detail for the average GWP of waste arisings in different market sub-sectors. This reflects the different product lifecycles discussed above, with foam in appliances already having a very low GWP (because most of this waste stream is hydrocarbon blown foam) whereas longer lived products fall in GWP from a much later start date.

Figure 4-7

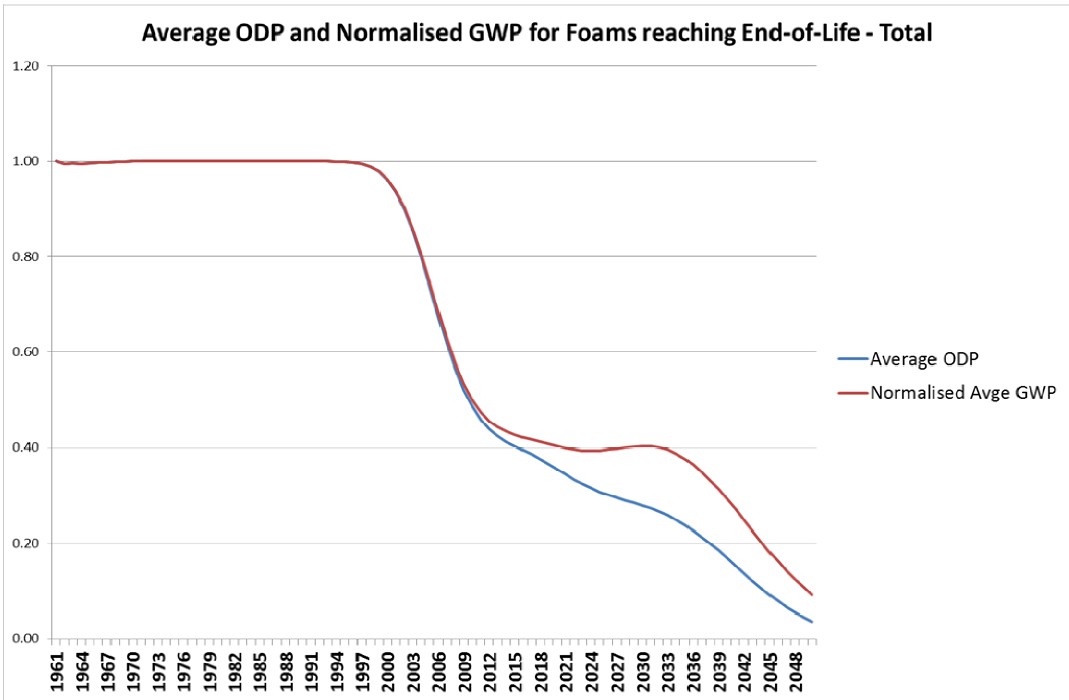
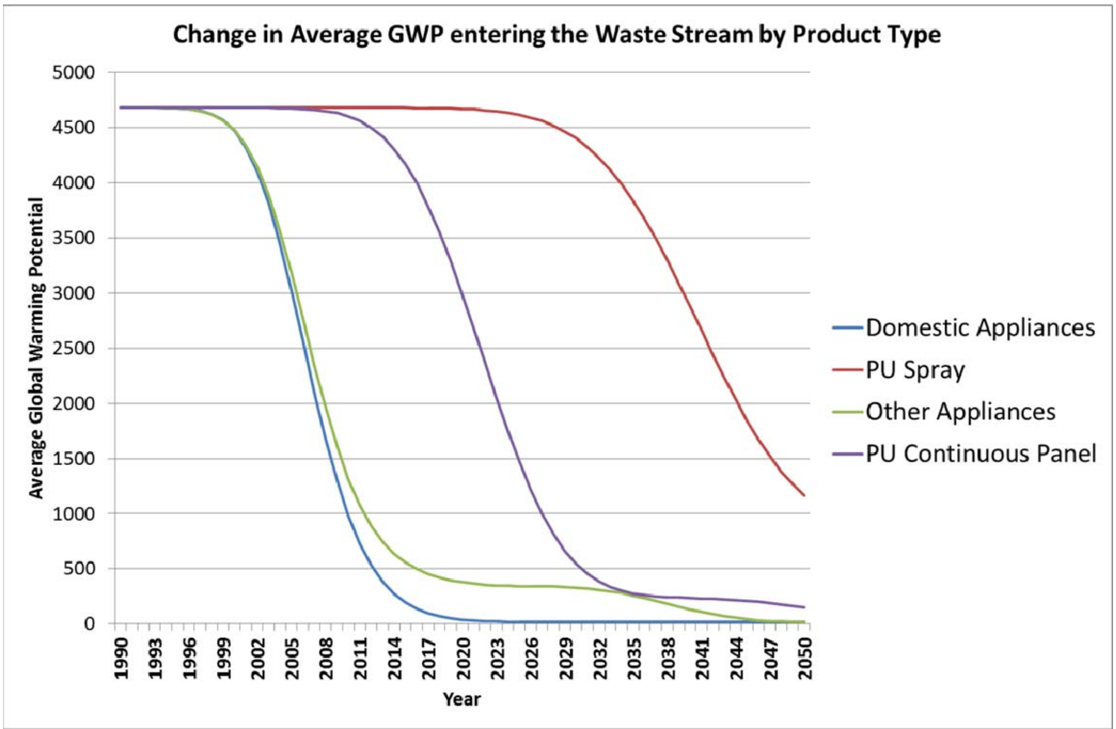


Figure 4-8



5. Policy Options

5.1. Introduction to Policy Analysis

This part of the report provides an analysis of policy options that could be adopted at EU or Member State level to reduce end of life (EOL) emissions from ODS and F-Gas banks. It is important to recognise that the opportunities to reduce EOL emissions are highly specific to the market sub-sectors in which ODS and F-Gases are used. In each market sector it is necessary to take into account:

- The size of the bank in the sub-sector and the potential impact of that bank in terms of both GHG emissions and ODS emissions.
- The rate at which products in the sub-sector are reaching EOL and how this rate is likely to vary over the next 40 years.
- The cost and practicality of recovering ODS and F-Gases from the waste stream.
- Existing regulations that apply to the market sub-sector.
- Impact of variations in end-of-life practice at Member State level

The RAC, foams and GIS markets have been split into 19 sub-sectors as described in Table 5-1. For each market sub-sector various key characteristics have been assessed and an EOL emissions profile has been established. Appendix C provides a description for each of the 19 market sub-sectors that summarises the key characteristics and the emissions profile.

Table 5-1 – Market Sub-Sectors Used for Policy Analysis

Reference	Market Sub-Sector	Description
RAC 1	Domestic Refrigerators	Domestic refrigerators and freezers
RAC 2	Commercial Hermetic Refrigeration	Small integral systems in shops, restaurants etc.
RAC 3	Small Commercial Refrigeration	Small split systems in retail, storage etc.
RAC 4	Large Commercial Refrigeration	Large retail systems (mainly supermarkets)
RAC 5	Industrial Refrigeration	Industrial cooling
RAC 6	Small air-conditioning	Small air conditioning, below 12 kW
RAC 7	Medium and Large air-conditioning	Large air conditioning, above 12 kW
RAC 8	Mobile systems	Transport refrigeration and air conditioning
RAC 9	Car / Light Van MACs	Air conditioning in cars and small vans
F1	Domestic Refrigerators/Freezer	Foam in domestic refrigerators and freezers
F2	Comm. Displays / Water Heaters	Foam in retail display cases and other appliances
F3	Block foam / pipe section	Foam for insulation of vessels and pipework
F4	Steel Faced Panels	Foam insulated panels with steel facings
F5	Laminated Boards (Built-up System)	Laminated boards used in accessible wall/roof applications
F6	Laminated Boards (Cavity Structures)	Laminated boards in less accessible wall/roof applications
F7	Laminated Boards (Floor Insulation)	Laminated boards used for floor insulation
F8	Spray foam	Foam applied in situ for wall and roof insulation
GIS 1	Hermetically sealed HV switchgear	Small factory filled hermetic switchgear, usually below 52 kV
GIS 2	Site filled HV Switchgear	Larger site filled switchgear, usually above 52 kV

5.2. Putting End of Life Emissions in Perspective, RAC and GIS

Before reviewing policy options it is important to understand the overall lifecycle of the products being considered in this study, to help put EOL emissions in perspective. This section concentrates on RAC and GIS applications. Section 5.3 discusses the slightly different circumstances for foams.

Figure 5-1 illustrates the lifecycle of RAC or GIS products containing ODS or F-Gases. It shows 3 distinct phases of the lifecycle:

Phase 1 Product manufacture and installation

Phase 2 Product Use

Phase 3 End of Life

The relative importance of each phase in terms of overall emissions varies significantly between different market sub-sectors. The optimum choice of policy measures must take such differences into account.

Phase 1: Product manufacture and installation

For the 11 RAC and GIS market sub-sectors shown in Table 5-1, the emissions during product manufacture and installation are relatively insignificant, being well under 1% of lifetime losses for most RAC and GIS applications.

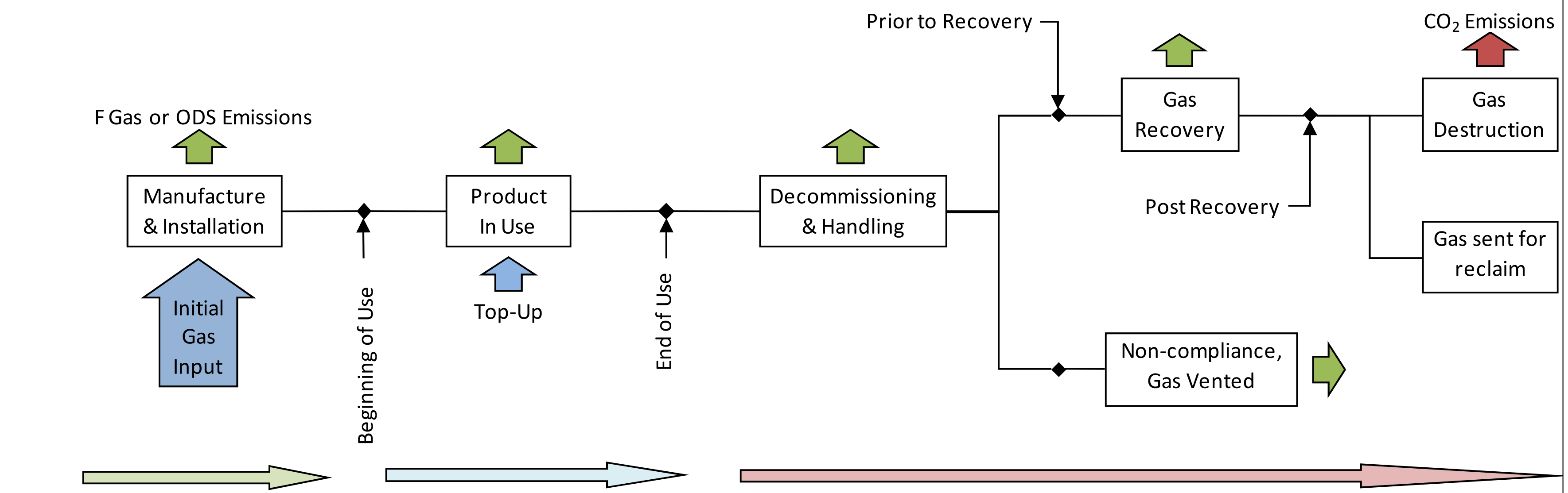
Phase 2: Product Use

For most RAC sectors the bulk of lifetime emissions occur during the product use phase. In sectors such as RAC 4 (supermarkets) and RAC 5 (industrial) well over 95% of lifecycle emissions occur during the use phase. Most RAC systems require regular refrigerant top up during the use phase to ensure that equipment performance is not affected by leakage. Because of regular top up, these types of RAC system reach the end of the product use phase with most of the original charge level still in the equipment.

Product use losses from small hermetic refrigeration systems (mainly RAC 1 and RAC 2) are much smaller because leak rates are very low. Usually there is no “in-life” top up of such systems (except the repair of accidental damage which would lead to 100% loss of refrigerant). With relatively short lifecycles (10 to 15 years) and very low annual leakage, small hermetic systems also reach the end of the product use phase with at least 90% of the original charge.

GIS systems are similar in emissions characteristics to RAC equipment. Hermetically sealed GIS leaks very little and are not topped up during life. Larger systems may be serviced during the use phase and this could involve top up.

Figure 5-1 – Life Cycle of RAC and GIS Products Containing ODS or F-Gases



Phase 1: Product Manufacture and Installation

Low emissions (around 1% of charge) for most RAC and GIS applications.

Phase 2: Product Use (<10 to >50 years)

Very low emissions (<<1% per year) and no in-life top up for hermetic refrigeration and GIS

Significant leakage emissions from many RAC systems (5% to 20% per year) – requires regular top up during product use phase.

Phase 3: End of Life

After "end of use" RAC or GIS product is decommissioned. Current Regulations require refrigerant removal. Recovered gas can be destroyed or sent for reclaim. If there is non-compliance with Regulations all or some of the gas is vented.

For all medium and large RAC systems the refrigerant should be removed in situ using a recovery machine. It can then be sent for destruction or reclaim. Handling and gas recovery losses are fairly small (<10%).

Small hermetic refrigeration systems are sent to specialist facility for refrigerant and blowing agent recovery. Handling losses often quite high (for refrigerant) and recovery losses significant (for foams).

GIS: EOL SF_6 recovery usually carried out in situ with recovery machine.

Phase 3: End of Life

Most RAC and GIS systems reach end of the use phase with between 85% and 100% of the original refrigerant charge (either because of top up during life or very low leakage during life).

At EOL there are several different ways in which refrigerants are handled, as illustrated in Figure 5-1. The potential for loss in these different stages is dependent on the market sub-sector and the way that an old product is handled at EOL.

For most RAC sectors the decommissioning / handling losses and the gas recovery losses should both be relatively low, providing plant is being decommissioned in compliance with the current F-Gas and Ozone Regulations. Almost all medium and large sized RAC equipment is decommissioned in situ by a qualified engineer using a refrigerant recovery machine to remove most of the refrigerant. When done properly the losses should be well under 5%.

Very small systems (RAC 1, RAC 2) have greater losses during handling at EOL. These types of system are taken to a specialist recovery centre, often via a local authority waste handling site. Accidental damage of the old equipment in transit is common – this will often lead to 100% loss of the refrigerant. Specialist recovery centres report that only around 50% of the refrigerant that reaches end of life is in the equipment when it reaches their recovery machines.

If gas is properly recovered it can then either be sent for destruction (usually by incineration) or to a specialist plant for gas reclaim.

During the plant decommissioning process there is some non-compliance with the F-Gas and Ozone Regulations and some systems are simply vented to atmosphere.

Based on the description above it is clear that the key opportunities to improve the rate of ODS and F-Gas recovery at EOL are:

- To ensure that in situ recovery from medium and large size RAC systems is carried out in accordance with current Regulations.
- To minimise the handling losses from small RAC systems prior to reaching specialist recovery centres.

5.3. Putting End of Life Emissions in Perspective, Foam

The lifecycle emissions and, in particular, the scope of the EOL mitigation options are somewhat different for foam. Typically, the Phase 1 emissions are driven by the product type and manufacturing / installation technique, the Phase 2 emissions are driven by product design, ambient conditions in use and foam thickness and the Phase 3 emissions are driven by market sub-sector of application. The market sub-sectors used for end-of-life scenario analysis, shown in Table 5-1, are linked to product types by the matrix shown in Table 5-2. The foams lifecycle is illustrated in Figure 5-2.

Table 5-2 – How Foam Product Types link with Market Sub-sectors

Product Type	**F1** Domestic Appliances	**F2** Commercial Appliances	**F3** Block Foam / Pipe Section	**F4** Steel-faced Panels	**F5** Laminates Built-up Systems	**F6** Laminates Cavity Structures	**F7** Laminates Floor Insulation	**F8** Spray Foam
PU Domestic Appliances	X							
PU Other Appliances		X						
PU Continuous Panel				X				
PU Discontinuous Panel				X				
PU Boardstock					X	X	X	
PU Spray								X
PU Pipe-in-Pipe			X					
PU Block – Pipe			X					
PU Block – Slab			X					
PF Boardstock					X	X	X	
PF Block – Pipe			X					
PF Block – Slab			X					
PF Discontinuous Panel				X				
XPS Board					X	X	X	
PE – Pipe			X					
PE – Slab			X					

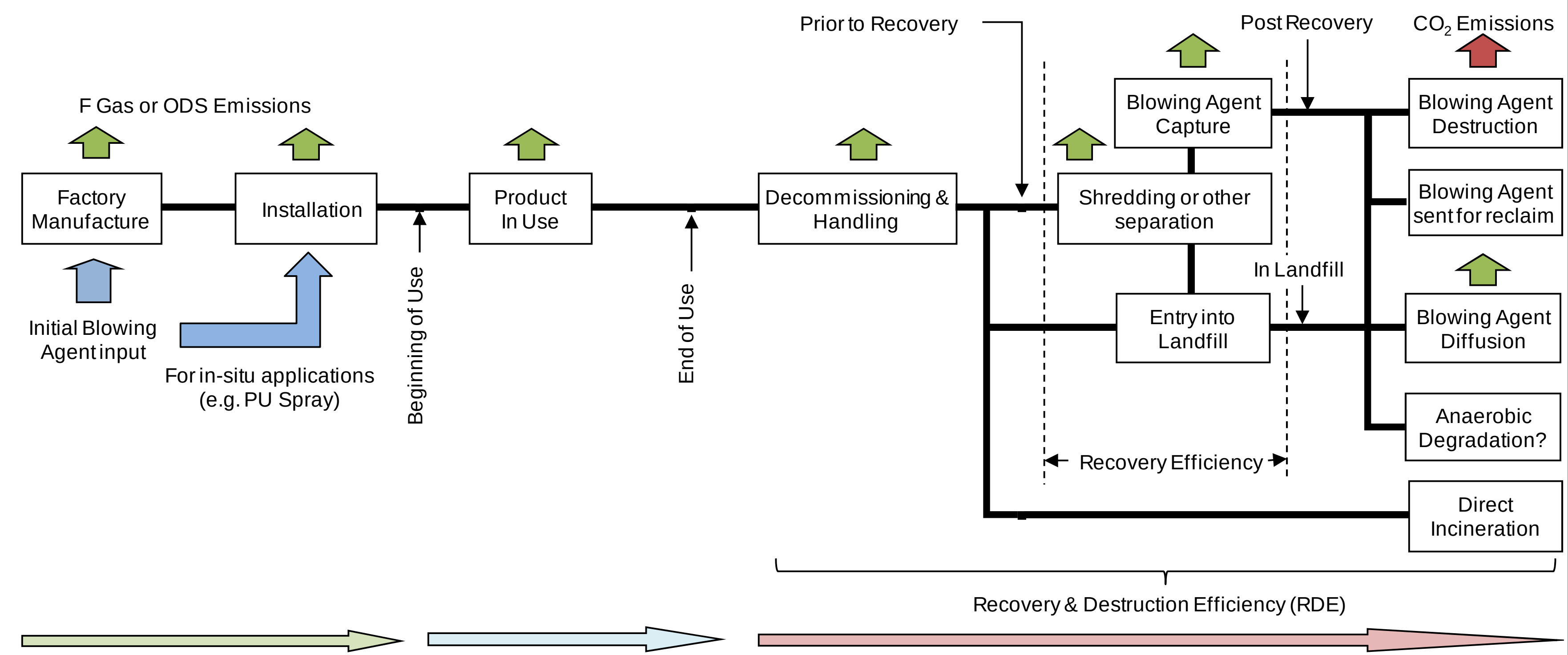
PU = Polyurethane; PF = Phenolic; XPS = Extruded Polystyrene; PE = Polyethylene

Phase 1: Product manufacture and installation

Blowing agent losses for foams during the manufacturing and installation process are typically greater than for RAC applications and vary substantially across the 16 product types shown in Table 5-2. Figure 5-2 illustrates the fact that some product types (e.g. PU Spray Foam) are actually created in-situ, leading to more significant process losses at the installation stage.

For factory manufactured products, the blowing agent losses are typically maintained at below 5%, except for extrusion processes where high processing temperatures and gaseous blowing agents lead to more substantive losses. Emissions from factory manufactured products during installation should be low provided that site practices seek to minimise additional fabrication and the waste that comes from it. The trend towards pre-fabrication off-site also assists in minimising losses at the installation stage.

Figure 5-2 – Life Cycle of Foam Products Containing ODS or F-Gases



Phase 1: Product Manufacture and Installation (first year)

Typical factory emissions will be < 5% for closed processes, although process temperature can be a factor, particularly for low boiling-point blowing agents used in extrusion processes

Installation emissions typically result from site fabrication activities but can also arise from in-situ processes such as PU Spray

Phase 2: Product Use (<10 to >50 years)

Emissions are relatively low on an annualised basis during this phase. However, emission rates vary according to product type, ambient conditions in the use phase, foam thickness and product facings used (where appropriate)

Phase 3: End of Life

There are three primary routes for disposal of foams after the decommissioning of a building, appliance or industrial installation. These are shredding (or other forms of separation), landfilling or direct incineration.

As can be seen, there can be fairly complex inter-relationships between shredding and landfill, because shredding can take place with varying levels of blowing agent capture. Shredded foams are usually landfilled thereafter, but may contain significant levels of residual blowing agent.

Depending on the nature of the landfill chosen, anaerobic degradation of certain blowing agents may be a possibility. However, this is considered with this study as a mitigation option still requiring proving rather than a baseline emission condition.

Phase 2: Product Use. The product use emissions from foams depend on both foam type and the way the foam has been installed. Losses are lowest when the foam is well "encapsulated" e.g. in a domestic refrigerator (<0.5% per year loss) or a steel faced panel (<1% per year loss). Some other foam types have up to around 2% per year loss. Losses can be exacerbated if ambient conditions in the use phase are hostile. There is no opportunity for in-life top up of foams, so all foam products reach the end of the product use phase with less foam blowing agent than at the point of installation. The amount of loss depends on the annual rate of diffusion, which in itself is dependent on the thickness of the foam, and the length of the product life cycle. Domestic refrigerators usually reach the end of the use phase with over 90% of original blowing agent. However, building foam often has a life cycle of >50 years, which can result in over 50% of the blowing agent being lost during the use phase in some foam types.

Phase 3: End of Life. Although little building insulating foam is yet reaching its EOL, most of that which is reaching the waste stream is not currently subject to a recovery process. It usually is directed along the "landfill route" shown in Figure 5-2 which will typically lead to a gradual emission decay and ultimately to total release over several decades. There is some evidence to suggest that anaerobic degradation may take place in certain managed landfills, but this has not been fully verified or quantified at the operational level. Such practices are considered as a mitigation option under this analysis.

Prior to landfill, there are some blowing agent losses when foam is being removed from a building during demolition (owing to the cutting of the foam and possible crushing during handling). In cases where there is an interest in separating out more valuable materials, such as the steel content in facings, treatment at the decommissioning stage can even accelerate the losses of blowing agent, either through the manual stripping of steel facings from panels or through shredding via car shredders without blowing agent recovery. This latter approach has even been practised in North America for domestic refrigerators, but is totally outlawed in the EU-27 via the requirements of the Ozone Regulation and the WEEE Regulation, where blowing agent recovery is mandated.

Direct incineration of insulating foams within Municipal Solid Waste Incinerators and other Waste-to-Energy facilities is a further option for some foam types – particularly those with combustible facings or no facings at all. Temperatures are typically high enough to destroy the blowing agents contained in the foams, although, without any means of tracking foam disposal via this route it is difficult to quantify the foam blowing agent being destroyed.

In contrast to production waste streams, there are few recycling options for foams at end-of-life, primarily because the composition is not fully known. The presence of ODS as blowing agents or brominated flame retardants make it inappropriate to use as feedstock for manufacture of alternative products and, even where both are absent, variability of end-of-life product is an issue. Even re-use is largely ruled out by the constraints imposed on placement of certain chemicals on the market through REACH.

5.4. Banks and End of Life Emission Profiles

Modelling of ODS and F-Gas banks during this project has led to the development of the Revised Banks Model and a set of bank and EOL emission profiles for each market sub-sector. Details are presented in Appendix C. These profiles provide an in depth understanding of the magnitude of emissions from each market sub-sector– a vital input into analysis of policy options.

5.4.1. RAC Example – Small Stationary Air-Conditioning

Figure 5-3 to Figure 5-6 provide an example of a set of bank and EOL emission profiles. The example sector is small stationary air-conditioning. Each group of profiles consists of 3 graphs with:

a) Actual tonnes (T) of gas

b) OPD tonnes of gas (i.e. actual tonnes * relevant ODP)

c) Kilotonnes (kT) CO2 equivalent (i.e. actual kT * GWP)

Bank: Figure 5-3a shows the evolution of the bank of refrigerant stored in small air-conditioning systems. In 2000 the bank consisted mainly of ODS equipment. By 2020 all the ODS in the bank are replaced by HFCs. From 2025 alternative very low GWP refrigerants begin to replace a substantial proportion of HFCs used in new systems. By 2080 the whole of the bank consists of very low GWP refrigerants. Figure 5-3b shows the bank in terms of ODP tonnes – by 2020 there are no ODS left in this market sub-sector. Figure 5-3c shows the bank in terms of kT CO_2. This peaks around 2030, when there is the maximum amount of F-Gas in the bank, and then slowly declines towards zero as HFCs are replaced by alternative low GWP refrigerants.

Quantity of Gas Reaching EOL: Figure 5-4 shows the amount of each gas type reaching EOL each year. Note that the y-axis units are 10 times less than for Figure 5-3 – reflecting the lifecycle of small air-conditioning equipment which is 10 years in the model. The gas quantities reaching EOL each year are used to calculate the effectiveness of various possible EOL policies.

Emissions in Different Phases of Lifecycle: Figure 5-5 shows emissions from different phases in the lifecycle. The large dark blue section represents leakage emissions during the use phase. The small green band represents losses that occur after end of use, during plant decommissioning and gas recovery. The large light blue section at the top represents gas that is successfully recovered and destroyed. It is important to recognise that this should be an “abated emission” i.e. it should not occur because the current F-Gas Regulation requires recovery to be carried out. However, the light blue band can also be considered to be an “at risk” amount that would be emitted if the Regulation is not being complied with.

Average GWP and ODP of Gas at EOL: Figure 5-6 shows the average GWP of refrigerants reaching end of life for small air-conditioning systems. These values change in response to the historic changes of refrigerants used for small air-conditioning systems.

The shape and magnitude of graphs equivalent to Figure 5-3 to Figure 5-6 for each market sub-sector are highly varied, as shown in Appendix C.

Figure 5-3 – Bank in Use for Small Air-conditioning

(a) (b) (c)

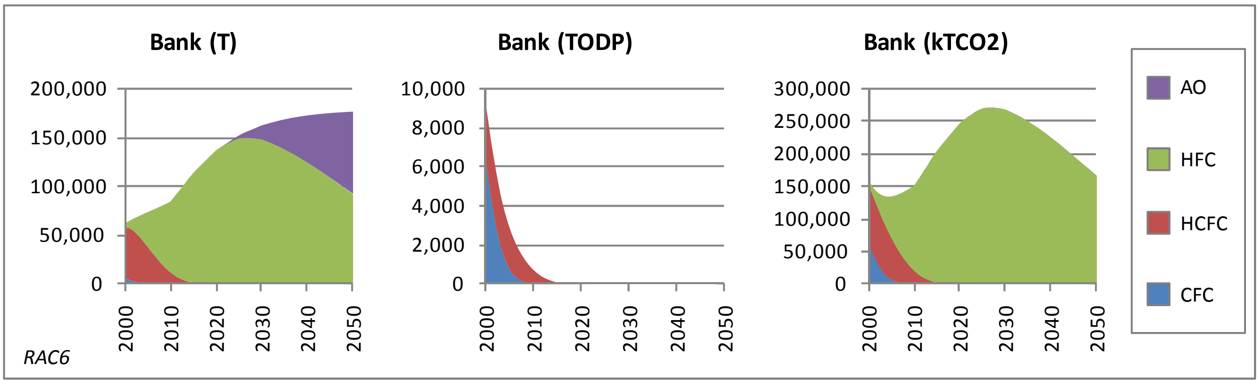


Figure 5-4 – Refrigerant Reaching EOL for Small Air-conditioning

(a) (b) (c)

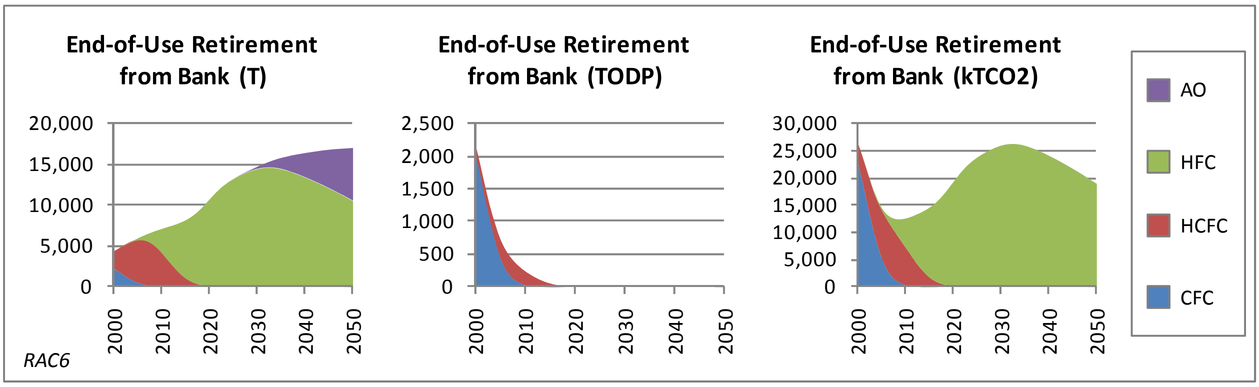


Figure 5-5 – Refrigerant Emissions by Life-Cycle Phase for Small Air-conditioning

(a) (b) (c)

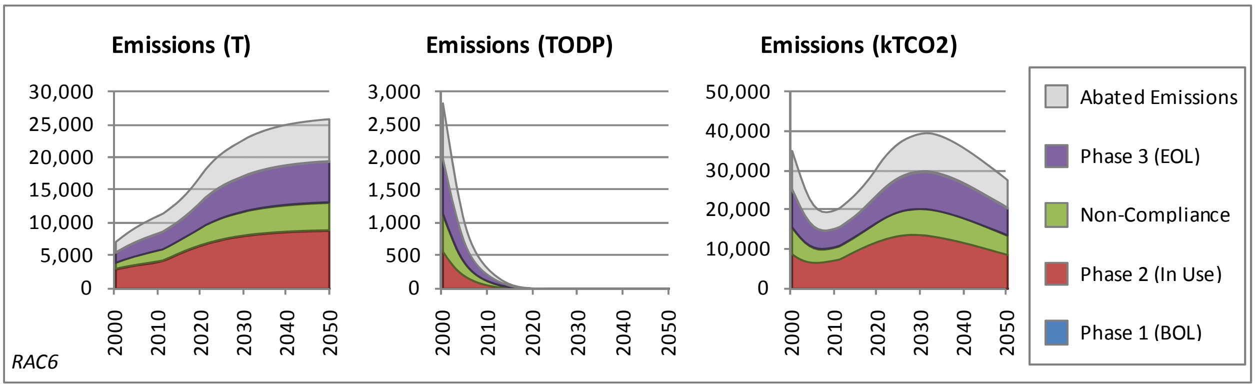
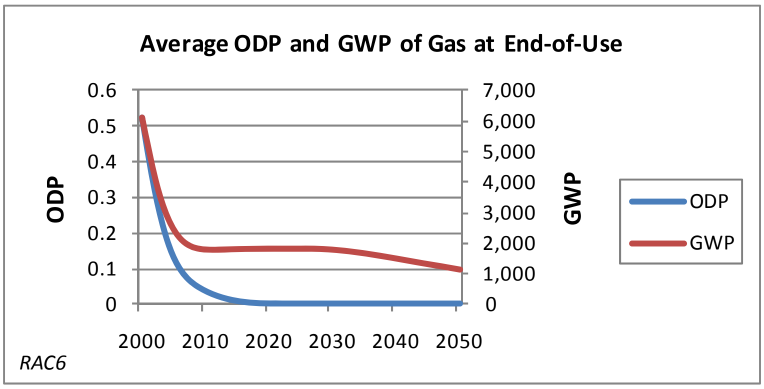


Figure 5-6 – Average GWP of Refrigerant Reaching EOL for Small Air-conditioning



5.4.2. Foams Example – PU Spray Foam

Total Banks and Banks in Product: Figure 5-7 and Figure 5-8 show the trends with time of the 'total banks' and 'banks in product' respectively. The differences between the two sets of graphs reflect the fact that considerable blowing agent is not released at decommissioning of the product and finds its way into the waste stream (typically landfill), where substantial additional banks (close to 100 million tonnes CO_2 across the EU-27) will accrue by 2050 unless active end-of-life strategies are adopted.

The banks shown in metric tonnes illustrate that lower-GWP (although unspecified) blowing agents will emerge from 2020 onwards will become the dominant component of the bank in quantitative terms. This will support a projected phase-down of high-GWP HFC use by 2030. However, the long life-times of insulation foams, both before decommissioning and afterwards, and the high-GWPs of CFCs means that they will be the most significant climate component of the total bank in 2050.

Quantity of Blowing Agent Reaching EOL: Figure 5-9 illustrates the impact of the progressive entry of different blowing agent types into the waste-stream, based on consistent average lifetimes for PU Spray Foam and the application of a Poisson distribution within the revised model. It can be seen that the annual flow is unlikely to exceed 2,000 t/yr in the period to 2050 with the peak in ozone and climate terms occurring between 2030 and 2035. Even then, this annual flow only represents about 0.6% of the bank size at that time. It is these relatively low annual flows which could present biggest challenge to efficient recovery practices, when spread across the EU-27.

Emissions by Blowing Agent Type: PU Spray Foam is one of the more emissive applications during the installation stage, because the foam is applied on site. Typical blowing agent losses are of the order of 15% at this stage. The shape of the emissions graphs in Figure 5-10 are driven more by the installation activity than by any other lifecycle phase. For example, in Figure 5-10 (b), the step down in emissions of HCFCs reflects phase-out of use of HCFC-141b in the EU in 2004. For similar reasons, the peak of the climate-based impacts occurs at around 2022, immediately before the phase-down in high-GWP HFC use is expected to commence. Again, annual emissions at their peak are not expected to exceed 2% of the total bank in climate terms.

Average GWP and ODP of Gas at EOL: Figure 5-11 shows the average ODP and GWP of blowing agents reaching end of life in the PU Spray Foam sector. In comparison with the RAC sector the drop in average values occurs much later, indicating the impact that product lifetime has on this assessment.

The shape and magnitude of graphs equivalent to Figure 5-7 to Figure 5-11 for each foam market sub-sector can vary significantly, as shown in Appendix C.

Figure 5-7 Total Bank for PU Spray Foam

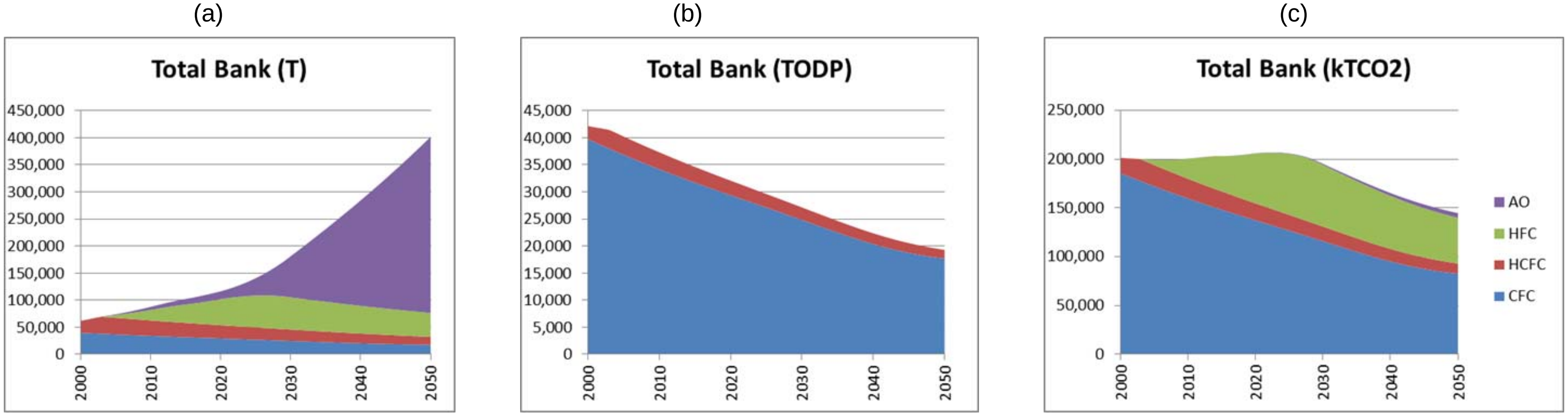


Figure 5-8 Bank in Product for PU Spray Foam

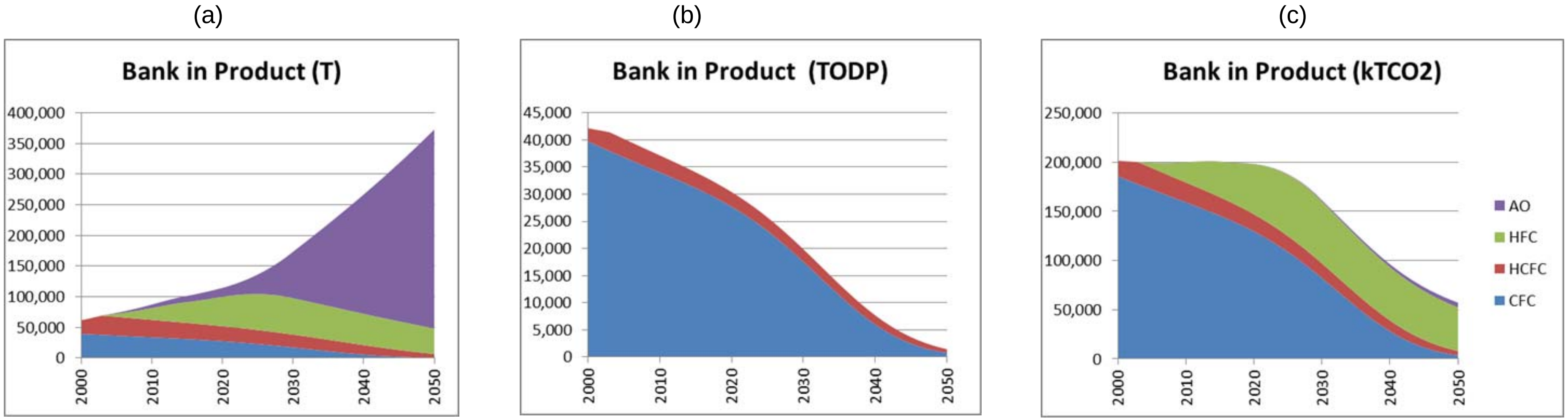


Figure 5-9 Blowing Agent Reaching EOL for PU Spray Foam

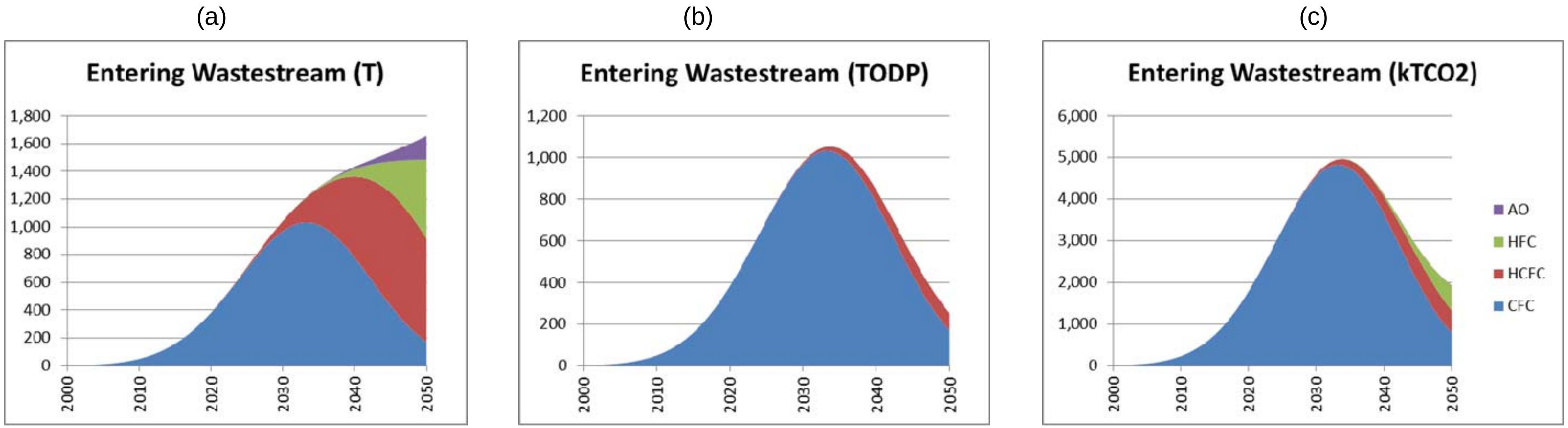


Figure 5-10 Blowing Agent Emissions by Product Type for PU Spray Foam

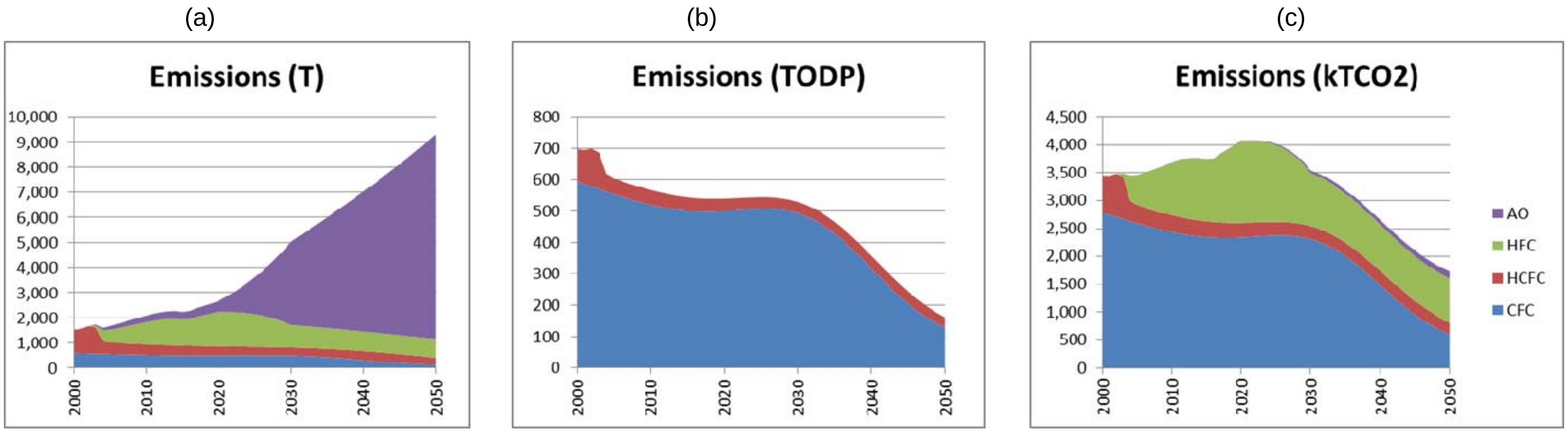
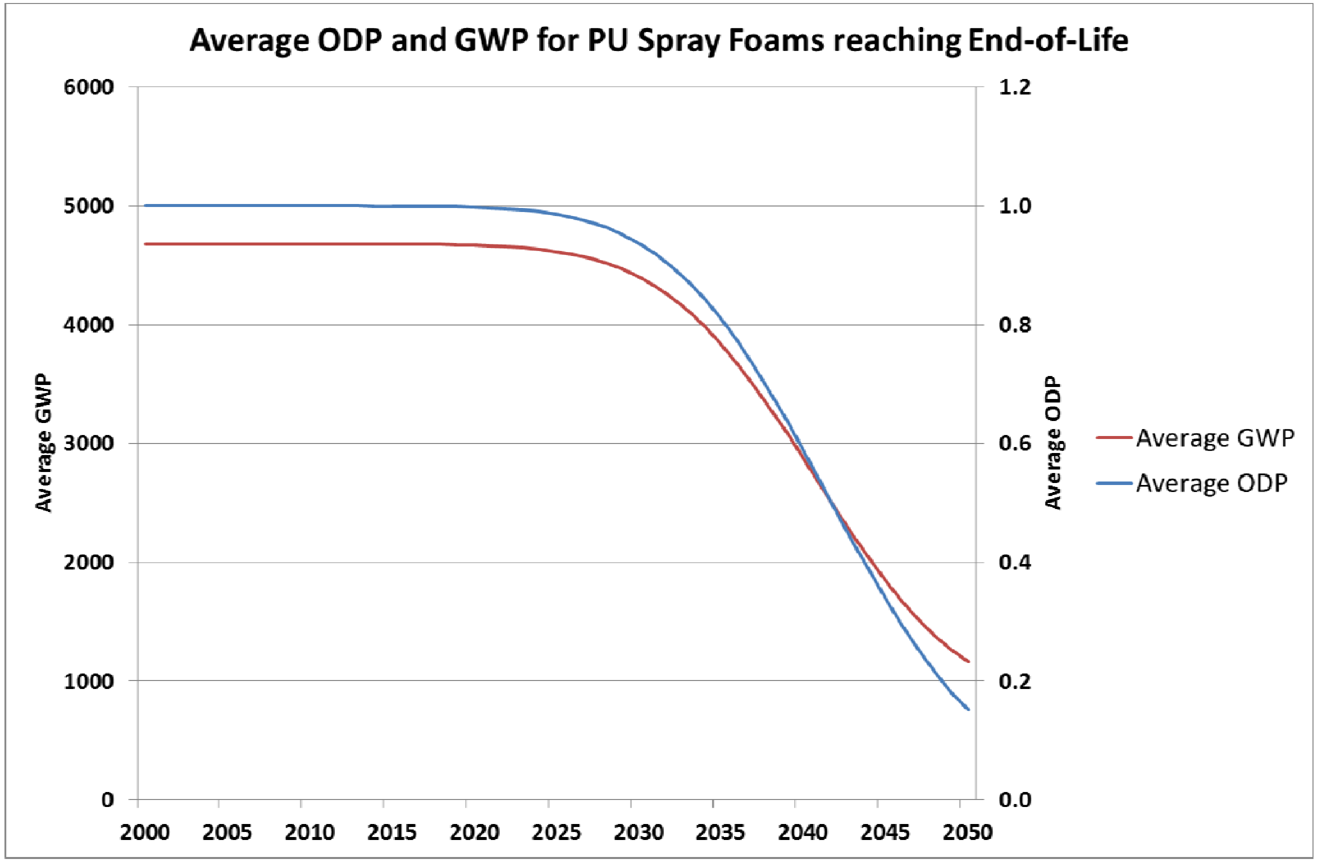


Figure 5-11 Average GWP / ODP of Blowing Agent Reaching EOL for PU Spray Foam



5.4.3. Relative Amount of Gas Reaching EOL

The relative amounts of ODS and F-Gases reaching EOL each year vary considerably between market sub-sectors. It is important to identify which are the largest sectors and hence which must be targeted with the strongest policies.

This is illustrated in Tables 5-3, 5-4 and 5-5, which show a snap shot of gas reaching EOL in 2015, 2030 and 2050 respectively. These clearly illustrate which are the largest sectors. They also show the way in which the bank evolves over time.

Comments on RAC Sectors

It is important to note that in 2015 the only ODS emissions from the RAC sectors are HCFCs. Products containing CFCs all reach end of life before 2013. Most products containing HCFCs reach end of life around 2015 (when top up of HCFC equipment with reclaimed refrigerant is banned), with a quickly reducing “tail” of emissions after that date. By 2020 RAC emissions of ODS will be close to zero.

For stationary RAC sectors, air-conditioning is the dominant source of F-Gas reaching EOL, due to a relatively short life cycle, a rapidly growing market and a lack of cost effective very low GWP alternatives. In 2015 air-conditioning (RAC 6 + RAC 7) represents 47% of the actual tonnes, 51% of the kT CO_2 and 76% of the tonnes ODP reaching EOL. By 2050 air-conditioning is even more important with 52% of the actual tonnes and 64% of the kT CO_2 reaching EOL.

Car air-conditioning (RAC 9) represents a significant proportion of actual tonnes (19% in 2015 and 17% in 2050), but the kT CO2 impact of this sector declines rapidly due to the impact of the MAC Directive from 15% in 2015 to virtually zero in 2050.

Industrial refrigeration (RAC 5) and large commercial refrigeration (RAC 4, mostly supermarkets) are both important sectors, together representing about 21% of kT CO_2 reaching EOL in 2015.

The other 4 RAC sectors RAC 1, 2, 3 and 8 only represent a small part of the total quantity of gas reaching EOL (around 13%).

Comments on Foam Sectors

The foam market sectors fit into 2 main groups based on typical lifecycle. The lifecycle of domestic and commercial appliances and some building services and industrial insulation is relatively short, typically around 15 years. The lifecycle of most other building insulation foam is very long, often in excess of 50 years. This significant difference in lifecycle affects the period over which ODS and F-Gas foams enter the waste stream. Tables 5-3, 5-4 and 5-5 clearly show that appliance foam applications have an early EOL peak whereas most building applications are only just beginning to enter the waste stream and they peak much later.

For the reasons stated above, the flow of ODS into the waste stream from appliances is already reducing rapidly and, even with statistical variations around the mean lifetime, this will result in substantial further decreases in both real tonnes and ODP tonnes by 2015. The situation is further exacerbated by the fact that the transitions of blowing agents from CFCs to HCFCs in the appliance sector were very limited – the majority of domestic appliance manufacturers moved directly from CFCs to HCs.

In the buildings sector, Tables 5-3, 5-4 and 5-5 reveal that the waste flows will grow over the next 15-20 years as foams originally installed as a result of the first energy crisis begin to reach their respective EOL. The bulk of blowing agents arriving at EOL will continue to be CFCs for the period through to 2030 based on the mean lifetime of these installations, making both the potential ozone and climate benefit of managing these banks particularly attractive. However, the technical feasibility and cost of management will be the significant factors in the building demolition waste stream.

A further general factor to consider when viewing the flow of blowing agent reaching EOL is that arrival at this lifecycle stage does not usually mean instantaneous release. If the foam remains intact, in part or in full, then the annual release rates from the waste stream will still be relatively modest. In the case of polyurethanes, the blowing agent can even be partially dissolved in the polymer matrix. This makes full recovery a significant technical challenge in all circumstances and can favour direct incineration approaches as a means of final mitigation.

One factor that is particularly clear for foams is that there will be an on-going decrease in the average GWP of the blowing agent mix in the waste stream over time. This reflects not only the overall reduction in the GWP of CFC substitutes, but the also the general de-selection of halogenated blowing agents (usually in favour of hydrocarbons) over time.

Table 5-3 – Gas Reaching EOL in 2015

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC 1, domestic refrigerators	2,400	1,800	50	7%	3%	11%
RAC 2, small commercial hermetic	600	1,400	10	2%	3%	3%
RAC 3, small commercial DX	400	1,700	0	1%	3%	0%
RAC 4, large commercial	1,700	6,700	0	5%	12%	0%
RAC 5, industrial	4,900	5,300	40	15%	9%	10%
RAC 6, small air-conditioning	8,400	15,100	60	25%	27%	14%
RAC 7, med/large ac	7,400	13,500	280	22%	24%	62%
RAC 8, transport	1,000	2,300	0	3%	4%	0%
RAC 9, car and van ac	6,500	8,500	0	19%	15%	0%
Sub-total	33,400	56,200	440	100%	100%	100%

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
F1 Domestic Refrigerators	14,000	2,700	500	45%	4%	4%
F2 Comm. Displays/Water Heaters	2,400	1,400	200	8%	2%	2%
F3 Block Foam/Pipe Section	1,600	1,400	200	5%	2%	2%
F4 Steel Faced Panels	9,600	40,400	8,600	31%	64%	68%
F5 Laminated Boards (BUS[4])	1,300	6,500	1,300	4%	10%	10%
F6 Laminated Boards (Cavity)	1,000	5,500	1,000	3%	9%	8%
F7 Laminated Boards (Floor)	700	4,000	700	2%	6%	6%
F8 Spray Foam	200	700	200	1%	1%	1%
Sub-total	30,800	62,700	12,700	100%	100%	100%

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
GIS 1	50	1,200	0	40%	40%	n/a
GIS 2	80	1,800	0	60%	60%	n/a
Sub-total	140	3,000	0	100%	100%	n/a

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC	33,400	56,200	440	51.9%	46%	3%
Foams	30,800	62,700	12,700	47.9%	51%	97%
GIS	140	3,000	0	0.2%	3%	0%
Total	64,300	121,900	13,100	100%	100%	100%

[4] BUS = Built-up systems

Table 5-4 – Gas Reaching EOL in 2030

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC 1, domestic refrigerators	2,800	200	0	5%	0%	0%
RAC 2, small commercial hermetic	800	1,800	0	1%	2%	0%
RAC 3, small commercial DX	700	2,200	0	1%	2%	0%
RAC 4, large commercial	3,000	8,600	0	5%	9%	0%
RAC 5, industrial	9,600	16,100	0	16%	17%	0%
RAC 6, small air-conditioning	15,000	26,800	0	24%	28%	0%
RAC 7, med/large ac	17,300	30,600	0	28%	32%	100%
RAC 8, transport	2,100	5,100	0	3%	5%	0%
RAC 9, car and van ac	10,300	5,300	0	17%	5%	0%
Sub-total	61,600	96,700	0	100%	100%	100%

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
F1 Domestic Refrigerators	17,700	300	0	34%	0%	0%
F2 Comm. Displays/Water Heaters	3,200	1,000	0	6%	1%	0%
F3 Block Foam/Pipe Section	3,700	5,100	900	7%	5%	6%
F4 Steel Faced Panels	13,800	9,300	1,300	27%	9%	9%
F5 Laminated Boards (BUS[5])	4,700	27,400	4,400	9%	27%	30%
F6 Laminated Boards (Cavity)	4,400	29,300	4,100	9%	29%	28%
F7 Laminated Boards (Floor)	3,300	22,800	3,100	6%	23%	21%
F8 Spray Foam	1,000	4,600	1,000	2%	5%	7%
Sub-total	51,900	99,800	14,800	100%	100%	100%

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
GIS 1	80	1,800	0	40%	40%	n/a
GIS 2	120	2,600	0	60%	60%	n/a
Sub-total	200	4,400	0	100%	100%	n/a

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC	61,600	96,700	0	54%	48%	0%
Foams	51,900	99,800	14,800	36%	50%	100%
GIS	200	4,400	0	0.2%	2%	0%
Total	113,700	200,900	14,800	100%	100%	100%

[5] BUS = Built-up systems

Table 5-5 – Gas Reaching EOL in 2050

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC 1, domestic refrigerators	3,100	300	0	4%	0.4%	0%
RAC 2, small commercial hermetic	1,000	1,500	0	1%	2%	0%
RAC 3, small commercial DX	1,000	1,100	0			0%
RAC 4, large commercial	3,800	4,500	0	7%	8%	0%
RAC 5, industrial	10,900	13,300	0	15%	18%	0%
RAC 6, small air-conditioning	17,400	19,500	0	24%	26%	0%
RAC 7, med/large ac	21,700	28,900	0	28%	38%	0%
RAC 8, transport	2,500	5,100	0	3%	7%	0%
RAC 9, car and van ac	12,800	100	0	17%	0.1%	0%
Sub-total	74,100	74,300	0	100%	100%	

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
F1 Domestic Refrigerators	23,800	400	0	27%	1%	0%
F2 Comm. Displays/Water Heaters	5,700	100	0	7%	0%	0%
F3 Block Foam/Pipe Section	8,200	1,800	300	9%	5%	10%
F4 Steel Faced Panels	29,300	5,900	0	34%	16%	0%
F5 Laminated Boards (BUS[6])	6,600	8,600	900	8%	23%	30%
F6 Laminated Boards (Cavity)	6,800	10,700	900	8%	28%	30%
F7 Laminated Boards (Floor)	5,100	8,500	700	6%	22%	23%
F8 Spray Foam	1,700	1,900	300	2%	5%	8%
Sub-total	87,200	37,900	3,100	100%	100%	100%

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
GIS 1	90	2,100	0	40%	40%	n/a
GIS 2	140	3,100	0	60%	60%	n/a
Sub-total	230	5,200	0	100%	100%	n/a

Market	Tonnes	kT CO2	ODP T	% Tonnes	% kT CO2	% ODP T
RAC	74,100	74,300	0	46%	63%	0%
Foams	87,200	37,900	3,100	54%	32%	100%
GIS	230	5,200	0	0.1%	4%	0%
Total	161,530	117,400	3,100	100%	100%	100%

[6] BUS = Built-up systems

5.5. Analysis of "Long List" of Policy Measures

Policies have been evaluated using a 2 stage process. In the first stage a "long list" of policy options was assessed to identify the most promising options. This was used to generate a short list of options for further more detailed analysis, as discussed in Section 5.6.

The long list includes 24 measures in five groups, as shown in Table 5-6. Each of these measures was evaluated for each of the 19 market sub-sectors in Table 5-1. Hence the long list evaluation included 456 individual assessments.

Table 5-6 – Long List Policy Measures

Group	Measure
1: New Regulatory Requirement	Improved regulation EU, product ban
	Improved regulation EU, recovery requirement, end users
	Improved regulation EU, recovery requirement, contractors
	Improved regulation EU, more comprehensive data collection
	Improved regulation at member state level
2: Improved Implementation of Current Regulations	Better policing
	Tougher fines
	Better data collection to support implementation
	Improved recovery of HCFCs
	Improving implementation via waste regulator
3: Voluntary Agreements (VA) or Industry Commitments (IC)	VA/IC end users
	VA/IC end user trade bodies
	VA/IC suppliers
	VA/IC supplier trade bodies
	VA/IC via supply chain
4: Fiscal Measures	Tax on new fluid
	Rebate on returned fluid
	Regulator incentive
	Carbon trading
5: Improved Information	Information to end users
	Information to designers / installers
	Information to maintenance contractors
	Information to EOL contractors
	Information to specialist recoverers

5.5.1. "Traffic Light" Evaluation

A qualitative appraisal of each of the 432 "intersections" in the policy measure / market sector matrix was carried out. It is worth noting that in many cases a policy measure was simply not applicable in a particular market (e.g. a product ban is not applicable for car air-conditioning, as a ban is already in place). In many cases the result of the appraisal of a particular policy measure applied equally across a number of market sub-sectors.

To simplify analysis of the policy matrix a "traffic light" system was used to identify the best and worst policy options. The system used is shown in Table 5-7.

Table 5-7 – Traffic Light Grading System for Policy Measures

	Green1	(G1)	EOL policy worth further consideration
	Green2	(G2)	Long term EOL benefit, but main benefits are reduced "use phase" emissions
	Amber1	(A1)	May be worthwhile, but doubts over cost or regulatory effectiveness
	Amber2	(A2)	Maybe worthwhile, but doubts of technological effectiveness
	Red1	(R1)	No change required - Regulation already in place
	Red2	(R2)	Not considered effective or relevant

5.5.2. Analysis of RAC Long List

Each measure was assessed for 9 RAC market sub-sectors. For the 216 measures assessed the overall grades in the traffic light analysis are shown in Table 5-8.

Table 5-8 – Overall Grading of all RAC Policy Measures

	Green1	(G1)	EOL policy worth further consideration	**49**
	Green2	(G2)	Long term EOL benefit, but main benefits are reduced "use phase" emissions	**19**
	Amber1	(A1)	May be worthwhile, but doubts over cost or regulatory effectiveness	**35**
	Amber2	(A2)	Maybe worthwhile, but doubts of technological effectiveness	**3**
	Red1	(R1)	No change required - Regulation already in place	**18**
	Red2	(R2)	Not considered effective or relevant	**92**

RAC Policy Measures Group 1: New Regulatory Requirement

Five policy measures related to changes to EU or Member State Regulations were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-9.

Table 5-9 – Traffic Light Analysis for RAC Group 1 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
1) Product bans	G2	G2	A2	G2	G2	A2	G2	A2	R1
2) Recovery requirement	R1	R1	R1	R1	R1	R1	R1	G1	G1
3) Contractor recovery	R2	G1	G1	G1	G1	G1	G1	G1	G1
4) Data collection	G1	G1	A1	G1	G1	A1	A1	A1	A1
5) MS Regulation	R1	R1	R1	R1	R1	R1	R1	R2	R2

1) **Improved Regulation EU, product ban.** There would be good long term impact on EOL emissions with new product bans that are likely to be cost effective in 5 RAC market sub-sectors (although most of the justification for such bans will come from leakage reduction during the use phase). For 3 RAC sectors the cost effectiveness of such bans is in doubt. 1 sector is already subject to a ban via MAC Directive.

2) **Improved Regulation EU, recovery requirement, end users.** For 7 RAC sectors there are already clear regulatory obligations in place via the F-Gas and Ozone Regulations. For 2 sectors there is a good opportunity to clarify the current Regulations.

3) **Improved Regulation EU, recovery requirement, contractors.** The current recovery requirement (and hence relevant penalties) applies to end users. It is worth considering a "mirror" requirement on personnel with an F-Gas qualification and / or companies with a Company Certificate. This could close the loophole of "end user pressure" on contractors to act illegally.

4) **Improved Regulation EU, more comprehensive data collection.** More data on recovery rates (and leakage) would help implementation. This could be collected from larger end user companies and from specialist recovery facilities (dealing with domestic and other small equipment). However, it is unlikely that this would be a cost effective policy if applied to small end users.

5) **Improved Regulation at Member State level.** This option is not considered relevant. For 7 RAC sectors there are already clear recovery requirements in place. For the other 2 sectors an improved Regulation at EU level would be preferable to individual MS action.

RAC Policy Measures Group 2: Improved Implementation of Current Regulations

Six policy measures related to improved implementation of current regulations were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-10.

Table 5-10 – Traffic Light Analysis for RAC Group 2 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
6) Better policing	G1	G1	G1	G1	G1	G1	G1	R2	R2
7) Tougher fines	A1	A1	A1	A1	A1	A1	A1	R2	R2
8) Data collection for implementation	G1	G1	A1	G1	G1	A1	A1	R2	R2
9) Improved HCFC recovery	R2	R2	G1	G1	G1	G1	G1	G1	R2
10) Implementation via Waste Regulator	G1	G1	A1	A1	A1	A1	A1	R2	R2

There are good opportunities to improve compliance with EOL recovery obligations in the F-Gas and Ozone Regulations. Unfortunately there is little data to properly quantify compliance with the recovery requirements. For most RAC sectors EOL recovery is done on site, mostly by RAC contractors. If these have latest F-Gas qualifications they should be aware of requirements and relevant techniques and should be able to achieve a high rate of gas recovery. Key compliance issues are to (a) ensure that unqualified personnel do not do EOL decommissioning and (b) that end users do not encourage contractors to "cut corners" by venting gas (e.g. because end user is not willing to pay extra for gas recovery). For domestic refrigerators and other small hermetic systems it may be possible to improve overall recovery rates considerably. It will be necessary to minimise losses during equipment handling prior to recovery and to ensure that maximum quantity of old units reach specialist facilities.

6) **Better policing**. For RAC3 to RAC7, policing of personnel qualifications and company certification is very important. This will minimise unskilled interventions at EOL. In several Member States there is currently poor compliance with the training and certification requirements. Large end users could be checked for compliance with recovery obligations. For RAC 1 and RAC 2 Member States need to check on performance of Local Authorities and specialist recovery facilities.

7) **Tougher fines**. It is considered unlikely that fines will be the most effective policy measure. They will not be effective without rigorous policing – if such policing is carried out compliance will improve without resorting to legal prosecutions and large fines.

8) **Better data collection to support implementation**. Better data collection about EOL recovery would support policing and other initiatives to improve compliance.

9) **Improved recovery of HCFCs**. This is considered very important in a number of sectors, especially RAC 5, RAC 6 and RAC 7. It is vital to recognise the small window of opportunity to prevent EOL HCFC emissions from RAC systems between 2011 and 2014 (from 2015 use of reclaimed HCFCs are banned). This timescale doesn't suit a new Regulation as

there would be insufficient time to put new legislation in place. What is required are "emergency" initiatives linked to better policing and information dissemination.

10) **Improving implementation via waste regulator**. Waste regulators could play an important role policing specialist recovery facilities (for RAC 1 and RAC 2 equipment). It is considered unlikely that waste regulators are suited to checking compliance in other RAC sectors.

RAC Policy Measures Group 3: Voluntary Agreements / Industry Commitments

Five policy measures related to voluntary agreements (VAs) were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-11.

Table 5-11 – Traffic Light Analysis for RAC Group 3 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
11) VA/IC - end users	R2	R2	R2	A1	R2	R2	R2	R2	R2
12) VA/IC - end user trade bodies	R2	R2	R2	A1	R2	R2	R2	R2	R2
13) VA/IC - suppliers & contractors	R2	R2	R2	R2	R2	R2	R2	R2	R2
14) VA/IC - supplier & contractor trade bodies	R2	R2	R2	R2	R2	R2	R2	R2	A1
15) VA/IC - via the supply chain	R2	R2	R2	R2	A1	R2	R2	A1	R2

As shown above there were no "green traffic lights" for 5 different types of VAs in the RAC sectors. It is believed that both end users and specialist maintenance contractors in most RAC markets are insufficiently "concentrated" for a VA to be effective. Across 27 Member States it would be necessary to set up hundreds of VAs – which is clearly impractical. The only exceptions to this are supermarkets and car manufacturers, both of which provide an opportunity to reach a large number of end user installations via a small number of large companies. In the sectors with biggest EOL emissions i.e. air-conditioning and industrial refrigeration there is no easy way of creating a VA that addresses a large number of end users.

RAC Policy Measures Group 4: Fiscal Measures

Four policy measures related to fiscal measures were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-12.

Table 5-12 – Traffic Light Analysis for RAC Group 4 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
16) Fiscal, tax on new fluid	R2	R2	A1	A1	A1	A1	A1	A1	R1
17) Fiscal, rebate on returned fluid	R2	R2	R2	R2	R2	R2	R2	R2	R2
18) Fiscal, Regulator incentive	R2	R2	R2	R2	R2	R2	R2	R2	R2
19) Fiscal, Carbon Trading	R2	R2	R2	R2	R2	R2	R2	R2	R2

16) **Tax on new fluid**. A high GWP weighted tax would influence design of new supermarket, industrial and large air-conditioning systems (RAC 4, 5 and 7) because of extra first cost and extra on-going costs related to leakage. This could accelerate the move away from HFCs, especially R404A, in new systems. It would also encourage (a) retrofill of R404A by lower GWP fluids such as R407F and (b) more investment to prevent leaks from existing systems. A tax could be a very flexible alternative to an outright HFC ban in this market, as it could be a powerful driver even at a relatively low carbon price (e.g. €15 to 20 per tonne CO2). A tax would have a smaller but useful influence on smaller systems in RAC 3, 6 and 8. A tax is unlikely to have much influence on very systems in RAC 1 and 2.

17) **Rebate on returned fluid**. A rebate on returned fluid would be very difficult to implement and it is unclear how the rebates would be funded.

18) **Regulator incentive**. Not relevant as there is no infrastructure for a Regulator incentive

19) **Carbon Trading**. No additionality because of existing legal requirement to recover in most RAC sectors. Also, too complex for small carbon market and widespread geography (emissions too small per installation, compared to typical EU ETS participants).

RAC Policy Measures Group 5: Improved Information

Five policy measures related to improved information were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-13.

Table 5-13 – Traffic Light Analysis for RAC Group 5 Measures

	RAC1 Domestic appliances	RAC2 Small commercial hermetic	RAC3 Small commercial DX	RAC4 Large commercial	RAC5 Industrial	RAC6 Small AC	RAC7 Large AC	RAC8 Transport	RAC9 Cars & vans
20) Information to end users	R2	A1	A1	G1	G1	A1	G1	A1	R1
21) Information to designers and installers	R2	G2	G2	G2	G2	G2	G2	G2	R1
22) Information to maintenance contractors	R2	R2	G2	G2	G2	G2	G2	G2	G2
23) Information to EOL contractors	G1	G1	G1	G1	G1	G1	G1	G1	G1
24) Information to specialist recoverers	G1	G1	R2	R2	R2	R2	R2	G1	G1

20) **Information to end users**. Information about EOL to end users could be useful, especially if targeted to larger companies (e.g. supermarkets, industrial, large building owners.

21) **Information to designers / installers**. Information about alternative refrigerants will be very useful for system designers in many RAC sectors. There are rapid changes in the availability of very low GWP refrigerants (e.g. CO_2, HFOs etc.) but little information about design standards or data about performance, in particular energy efficiency. It would also be useful to have more independent information about medium GWP replacements for R404A (e.g. R407A and R407F) and about design improvements to reduce leakage. The biggest short term impact of such information will be on reduced leakage during the use phase, but in the long term it will also deliver EOL benefits.

22) **Information to maintenance contractors**. Information to RAC contractors to help minimise in life leakage is very important (although not directly affecting the EOL issue).

23) **Information to EOL contractors**. Dissemination of information about best practice recovery techniques to EOL contractors could be an important and cost effective opportunity. All EOL contractors should have a Company Certificate – this provides an easy route to disseminate information about importance of EOL recovery and penalties for non-compliance

24) **Information to specialist recoverers**. For RAC 1 and 2, provide information to Specialist Recovery Facilities to help define ways of improving recovery rates. For RAC 8 and 9, provide information to EOL vehicle specialists.

5.5.3. Analysis of Foams Long List

Each measure was assessed for 8 foam market sub-sectors. For the 192 measures assessed the overall gradings in the traffic light analysis are shown in Table 5-14.

Table 5-14 – Overall Grading of all Foam Policy Measures

	Green1	(G1)	EOL policy worth further consideration	**51**
	Green2	(G2)	Long term EOL benefit, but main benefits are reduced "use phase" emissions	**5**
	Amber1	(A1)	May be worthwhile, but doubts over cost and regulatory effectiveness	**14**
	Amber2	(A2)	Maybe worthwhile, but doubts of technological effectiveness	**16**
	Red1	(R1)	No change required - Regulation already in place	**5**
	Red2	(R2)	Not considered effective or relevant	**101**

Foam Policy Measures Group 1: New Regulatory Requirement

Five policy measures related to changes to EU or Member State Regulations were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-15.

Table 5-15 - Traffic Light Analysis for Foams Group 1 Measures

	F1 Domestic appliances	F2 Other small appliances	F3 Building services & industrial insulation	F4 Steel Faced Panels	F5 Laminated Panels (Built-up System)	F6 Laminated Panels (Cavity Structures)	F7 Laminated Panels (Floor Insulation)	F8 Spray foam
1) Product bans	R2	G2	G2	G2	G2	G2	G1	G1
2) End-user recovery requirement	R1	G1	G1	A1	A1	A1	R2	R2
3) Contractor recovery requirement	R1	G1	G1	A1	A1	A1	R2	R2
4) Data collection	G1	G1	G1	G1	G1	G1	R2	R2
5) MS Regulation	R1	R2	R2	A1	A1	A1	R2	R2

1) **Improved Regulation EU, product ban**. The two major foam product types using HFCs are extruded polystyrene foam (XPS) and PU Spray Foam. Since these are amongst the most non-recoverable of product types, especially since XPS is used widely in floor insulation applications, the potential impact of HFC replacement is high and technically feasible alternatives are emerging. It should be noted that most of the EOL benefit will accrue after 2050. However, both product types have relatively emissive manufacturing or application techniques, which offer immediate environmental benefits from an earlier phase-down in HFC use. The on-going use of HFCs in other sectors (F2 to F6) could also be the subject of review, but the impact of measures here would be significantly less because baseline use is relatively low and limited to niche applications

2) **Improved Regulation EU, recovery requirement, end users**. The RAC sector has a clear mandatory recovery framework for nearly all of the 9 market sub-sectors. This is far from the case with foams, where the only market sub-sector with an unambiguous recovery requirement is domestic refrigerators and freezers (F1).

   There is some confusion about the scope of WEEE and RoHS for commercial appliances (F2) and an explicit statement about recovery from F2 equipment, if there are high GWP gases in foams, would provide additional clarity. This could either be via a revision of the Ozone / F-Gas Regulations or clarification of WEEE and RoHS requirements.

   Foams used for insulation in building services and industrial applications (F3) are relatively easy to separate and could be considered for mandatory recovery via a revision of the Ozone / F-Gas Regulations.

   The cost effectiveness of recovery of ODS and HFC blowing agent from steel-faced panels (F4), built-up systems (F5) and cavity structures (F6) depends greatly on the baseline practices for separation and recovery within demolition processes and varies substantially by Member State. This is symbolised by the Amber 1 ratings in Table 5-15. This makes it potentially difficult to act at EU level. Technical challenges for the recovery of floor insulation (F7) and PU Spray (F8) make it unlikely that this could be mandated.

3) **Improved Regulation EU, recovery requirement, contractors**. The provision under Measure 2 above would ensure that there is a legal obligation for end users to require contractors to implement recovery of identified market sub-sectors. It might also be appropriate to put a mirror obligation on the EOL contractors themselves, as advocated in Section 5.5.2 for the RAC sector. This again would be limited to those market sub-sectors where recovery was deemed sufficiently achievable to be mandated.

4) **Improved Regulation EU, more comprehensive data collection**. Even in the areas already mandated for recovery, there is little central and systematic information about recovery rates. Much of the information is anecdotal and from industry sources of one type or other. In other market sub-sectors, there is little activity as yet, but plotting the growth of the arrival of waste containing high GWP gases will be important for many building foams. It may not be possible to track this for some of the more non-recoverable market sub-sectors such as floor insulation and spray foam.

5) **Improved Regulation at Member State level.** This proposal picks up the themes covered in Measure 2 but focuses on those Member States where the existing practices support the economics of recovery and destruction. It suggests that commercial appliances, building services and industrial insulation are best handled at EU level but that other more marginal recovery options may be better handled at Member State level.

Foam Policy Measures Group 2: Improved Implementation of Current Regulations

Six policy measures related to improved implementation of current Regulations were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-16.

Table 5-16 – Traffic Light Analysis for Foams Group 2 Measures

	F1 Domestic appliances	F2 Other small appliances	F3 Building services & industrial insulation	F4 Steel Faced Panels	F5 Laminated Panels (Built-up System)	F6 Laminated Panels (Cavity Structures)	F7 Laminated Panels (Floor Insulation)	F8 Spray foam
6) Better policing	G1	G1	R2	R2	R2	R2	R2	R2
7) Tougher fines	A2	R2	R2	R2	R2	R2	R2	R2
8) Data collection for implementation	A2	A2	A2	A2	A2	A2	R2	R2
9) Improved HCFC recovery	R2	R2	R2	R2	R2	R2	R2	R2
10) Implementation via Waste Regulator	G1	G1	G1	G1	G1	G1	G1	G1

Cost pressures have created some undesirable outcomes for existing domestic refrigerator recovery plants (specialist recovery facilities) and there is scope for strengthening monitoring and enforcement to ensure adequate procedures are in place to minimise emissions. Although Measure 2 covers the introduction of further regulation to ensure that commercial appliances are covered, some argue that WEEE and RoHS already provide that requirement. Hence, more consistent understanding and better implementation become key. The other foam market sub-sectors have no mandatory recovery requirements and hence require primary legislation before better implementation can be considered.

6) **Better policing**. There is a recognised need for better policing of the current recovery related to domestic and commercial appliances in order to discourage the taking of short-cuts with respect to foam management.

7) **Tougher fines**. The implementation of fines at the level of National Competent Authorities, Local Authorities or the Specialist Recovery Facilities themselves could generate further focus on performance standards. However, comprehensive documentation of the expected standards would be necessary and may not always be possible.

8) **Better data collection to support implementation**. Since no current regulation exists in this area of policy, there is no immediate opportunity to act. However, it is clear that any new regulation will require a level of commitment to ensure that data is gathered and collated.

9) **Improved recovery of HCFCs**. This is a measure that is specific to the RAC sector and the provisions of this proposal, as far as they relate to foam, are captured under Measure 6.

10) **Improving implementation via waste regulator**. The role and responsibility of the waste regulator in policing and enforcement of the Ozone, WEEE and RoHS regulations, as they related to high GWP blowing agents may require further enunciation.

Foam Policy Measures Group 3: Voluntary Agreements/Industry Commitments

Five policy measures related to voluntary agreements (VAs) and industry commitments (ICs) were appraised. The traffic light analysis for these 5 measures is summarised in Table 5-17.

Table 5-17 – Traffic Light Analysis for Foams Group 3 Measures

	F1 Domestic appliances	F2 Other small appliances	F3 Building services & industrial insulation	F4 Steel Faced Panels	F5 Laminated Panels (Built-up System)	F6 Laminated Panels (Cavity Structures)	F7 Laminated Panels (Floor Insulation)	F8 Spray foam
11) VA/IC - end-users & contractors	R2	G1	R2	R2	R2	R2	R2	R2
12) VA/IC - end-user & contractor trade bodies	R2	G1	G1	G1	G1	G1	R2	R2
13) VA/IC - suppliers	R1	A2	G1	R2	R2	R2	R2	R2
14) VA/IC - supplier trade bodies	R1	A2	A2	A1	A1	A1	R2	R2
15) VA/IC - via the supply chain	R2	R2	R2	R2	R2	R2	R2	R2

11) **VA/IC End Users / Contractors**. By definition, Voluntary Agreements and statements of Industry Commitment are only required and/or valuable where there is not already a regulatory imperative, or where that imperative might be unclear. This could apply particularly to the use of commercial appliances, where individual consumer-facing companies (e.g. supermarkets) might see value in making a company-level commitment to set an example and underpin a regulatory requirement that is hitherto unclear. End-users in the buildings sector are generally likely to be too small and diverse individually to provide the required critical mass for such a commitment.

12) **VA/IC End User / Contractor Trade Bodies**. This proposal is essentially an extension of Measure 11 in that it foresees the possibility of addressing the supermarket example by way of a commitment at retail trade body level. There is also the possibility of a commitment from national federations of demolition contractors to seek to manage insulation foams in a manner consistent with their potential high GWP contents.

13) **VA/IC Suppliers**. This proposal looks at the possible option of take-back schemes by suppliers at EOL. Such a proposal is only seen to be effective for products with shorter lifetimes, since identification of specific product manufacturers over periods of greater than 25 years seems unlikely in view of the normal flux in the competitive supplier environments. Take back schemes in the domestic appliances sector already exist and can be tied to Specialist Recovery Facilities. The cost of EOL processing then has to be internalised over new sales. Similar schemes in the commercial appliances sector might be harder to set-up and maintain in view of the wide variety of equipment covered and the difficulty in finding a Specialist Recovery Facility to manage that range. There could be opportunity for a take-back approach within the building services sector, although this would need to be operated at contractor level and supported by the suppliers. There is growing interest in the possibility of a pilot project in this area.

14) **VA/IC Supplier Trade Bodies**. It is less likely that supplier trade bodies could enter into Voluntary Agreements or Industry Commitments on the management of foams in the market sub-sectors covered under Measure 13, since such commitments would normally be driven

out of the individual Corporate Social Responsibility motives of the companies themselves. In many cases, they would probably not want to cede the kudos associated with such measures to a trade body. In addition, there would be a need to manage the laggards within such bodies.

15) **VA/IC via supply chain**. Although some level of supply-chain cooperation exists in the insulation foam sector, it is believed to be very unlikely that this could extend as far as a cost-sharing arrangement for managing a legacy which could have arisen from a partially different or completely different supply chain. Therefore, this proposal is not seen as viable for foam market sub-sectors.

Foam Policy Measures Group 4: Fiscal Measures

Four policy measures related to fiscal measures were appraised. The traffic light analysis for these measures is summarised in Table 5-18.

Table 5-18 – Traffic Light Analysis for Foams Group 4 Measures

	F1 Domestic appliances	F2 Other small appliances	F3 Building services & industrial insulation	F4 Steel Faced Panels	F5 Laminated Panels (Built-up System)	F6 Laminated Panels (Cavity Structures)	F7 Laminated Panels (Floor Insulation)	F8 Spray foam
16) Fiscal, tax on new fluid	R2	R2	R2	R2	R2	R2	A1	A1
17) Fiscal, rebate on returned fluid	R2	R2	R2	R2	R2	R2	R2	R2
18) Fiscal, Regulator incentive	A2	A2	A2	A2	A2	A2	R2	R2
19) Fiscal, Carbon Trading	R2	R2	R2	R2	R2	R2	R2	R2

16) **Tax on New Fluid**. This approach is only seen as viable in applications where there is significant current use of HFCs. This would limit applicability to XPS foams and PU Spray foam. Since both of these products have unique characteristics that cannot be addressed by other product types, one possible unintended consequence of such an approach would be to discourage the use of insulation, particularly if no ready alternative blowing agent exists. In general, these product types have responded better to time-certain phase-outs in the past.

17) **Rebate on Returned Fluid**. There is no significant market for returned fluids when it comes to foam blowing agents. Re-use would be particularly limited unless it was captured from process and/or installation off-cuts. Even then, regulatory aspects such as REACH would have to be considered further.

18) **Regulator Incentive**. Not relevant as there is no infrastructure for a Regulator incentive

19) **Carbon Trading**. This possibility has been much discussed in international arenas as a way of promoting greater ODS bank management. However, the EU has already acted in a regulatory framework on appliances, which provide the most economic recovery options. Hence, there would be no additionality for any voluntary project. For schemes in other foam market sub-sectors, the cost of recovery is likely to be at such a level as to not be bridged by the value of carbon, particularly at its current price levels. In addition, the relatively modest size of individual demolition projects would make it difficult to justify the cost of project development.

Foam Policy Measures Group 5: Improved Information

Five policy measures related to improved information were appraised. The traffic light analysis for these measures is summarised in Table 5-19.

Table 5-19 – Traffic Light Analysis for Foams Group 5 Measures

	F1 Domestic appliances	F2 Other small appliances	F3 Building services & industrial insulation	F4 Steel Faced Panels	F5 Laminated Panels (Built-up System)	F6 Laminated Panels (Cavity Structures)	F7 Laminated Panels (Floor Insulation)	F8 Spray foam
20) Information to end users	R2	G1	G1	G1	G1	G1	R2	R2
21) Information to designers and installers	R2	G1	G1	G1	G1	G1	R2	R2
22) Information to maintenance contractors	R2	R2	R2	R2	R2	R2	R2	R2
23) Information to EOL contractors	G1	G1	G1	G1	G1	G1	R2	R2
24) Information to specialist recoverers	G1	G1	G1	G1	G1	G1	R2	R2

20) **Information to End Users**. There is a strong case for improving the level and consistency of information reaching the end user community about the value of managing high GWP gases in building decommissioning programmes. This could well assist in ensuring that appropriate instructions were included in demolition contracts.

21) **Information to Designers / Installers**. Although the use of high GWP blowing agents in newly installed foams continues to fall, it is important that, where use occurs, it is clearly identifiable – either through project records or through more explicit labelling. This would apply particularly to refurbishment activities. From a designer perspective it might also be useful to challenge the selection of a high GWP solution in the first place and, where made, to ensure that EOL issues have been fully considered.

22) **Information to Maintenance Contractors**. In general terms, installed foams require no maintenance during their use phase and there would be no basis for the provision of information. However, one exception to this might be the maintenance contractors in the building services and industrial insulation market sub-sectors where the maintenance of equipment can lead to the replacement of insulation.

23) **Information to EOL Contractors**. This is a particularly important area of communication and requires information tailored to the building practices of each Member State. In this context, there might be value in considering this as a Member State level initiative, although it would need to be centrally coordinated to avoid the replication of the same process 27 times. A good example of a market sub-sector trade body supplying information to the demolition contractor community was the recent Guidance Document provided on steel-faced panels by Engineered Panels in Construction (EPIC) in the UK.

24) **Information to Specialist Recovery Facilities**. Although it would normally be assumed that specialist recovery facilities will have a good working knowledge of the product types that they have processed over recent years, it will be important to keep them informed of likely changes in the waste streams and the implications of a broader set of product types to manage.

5.5.4. Analysis of GIS Long List

GIS Policy Measures Group 1: New Regulatory Requirement

The recovery requirements for SF_6 from GIS are already clearly defined in the F-Gas Regulation, so no changes are required to Article 4. The only well established technical alternative to GIS is air insulated switchgear, which has various disadvantages compared to GIS. Given the relatively low emissions from this sector (especially at EOL) a product ban is not justified.

A regulatory measure worth considering is to include GIS in Article 3, which would make the on-going requirements for leak checking and record keeping much clearer. This would not have much impact on EOL emissions, but could reduce in-life losses. Currently the detailed leak checking and record keeping requirements in Article 3 only apply to stationary RAC and to fire protection systems. It is reasonable to consider extending these to GIS.

GIS Policy Measures Group 2: Improved Implementation of Current Regulations

Compared to the RAC and foam sectors the research shows that implementation of the recovery requirements in the GIS sector is already at a reasonably high standard. More policing of the recovery obligations would make end users and specialist contractors more aware of the Regulation and may be of benefit.

GIS Policy Measures Group 3: Voluntary Agreements/Industry Commitments

The GIS sector is far better suited to a voluntary agreement (VA) approach than either foams or RAC. The main users of GIS are the national electricity transmission companies in each Member State and local electricity distribution companies. These bodies are already well regulated in most Member States (because of the importance of reliable electricity distribution and the relatively high safety risks). VAs between end user companies and the relevant regulators in each country could help ensure improved implementation of recovery requirements and also improved record keeping.

GIS Policy Measures Group 4: Fiscal Measures

Gas emissions are too low for a fluid tax to have a significant impact and a trading mechanism is unnecessarily complex for this market. A financial incentive from the regulator is an approach used in at least one Member State and could be linked to a VA approach.

GIS Policy Measures Group 5: Improved Information

More information about SF_6 bank size, in-life losses and EOL losses would be useful to confirm compliance in this market. An information initiative could be linked to a VA between end users and their regulator. Information would also improve via inclusion of GIS in Article 3.

5.6. Analysis of "Short List" of Policy Measures

The analysis of the long list of measures has been used as a basis to define a short list of measures that have been evaluated in more depth. The cost effectiveness of each measure is estimated by assessing the likely environmental benefits and the costs of implementation. Cost effectiveness data for each measure is presented in a summary table in Section 5.6.3.

5.6.1. RAC Short List

Before discussing specific policy measures it is worth noting the following:

Gases to be targeted. There are virtually no CFCs left in the RAC bank after 2011. Hence there is no new policy initiative required to target CFCs. HCFCs are important in a number of RAC sectors, and there is only a short time window available to ensure minimum EOL emissions from HCFC systems as they are being phased out via the Ozone Regulation. HFCs remain an on-going and important part of the RAC bank and will be the main target of new policies.

Existing EOL Regulations. Most RAC market sub-sectors are already covered by clear EOL recovery obligations in both the F-Gas and Ozone Regulations. Hence many of the key policy measures need to be aimed at improving compliance with existing Regulations.

RAC Proposal 1: Emergency Measures Related to HCFCs

HCFCs are used in 6 of the 9 RAC market sectors. In the industrial and air-conditioning sectors, HCFCs are still quite widely used. The Ozone Regulation will ban the use of reclaimed HCFCs for servicing existing plants by the end of 2014. During the next 3 years end users of HCFC systems will need to implement one of 3 possible actions:

a) They will retire old HCFC equipment and replace with new.

b) They will retrofill old HCFC equipment with an HFC based "drop-in" refrigerant.

c) For some very small systems they will continue to operate the plant without maintenance until it reaches EOL through equipment failure.

The majority of the current HCFC bank is in equipment that cannot be run for very long without maintenance and top up – hence most HCFC in the current bank will reach EOL via option (a) or (b) above during the next 3 years.

It is vital that end users and refrigeration contractors are not tempted to vent the old HCFC gas to atmosphere during plant decommissioning or retrofill. The existing Ozone Regulation makes it clear that gas must be recovered in these circumstances.

It is recommended that the Commission consider "emergency measures" to try and prevent such emissions. There is little time available to propose any new Regulations, so these emergency measures need to be based on dissemination of good information to end users and contractors and improved policing. See Proposals 6 and 8 for further details.

RAC Proposal 2: Clearer EOL Requirements for mobile RAC in F-Gas Regulation

7 of the 9 RAC sectors have clear mandatory requirements for EOL recovery. The requirements for mobile systems in RAC 8 (refrigerated transport and large vehicle air-conditioning) and RAC 9 (car air-conditioning) are less clear – relying on Article 4.3 of the F-Gas Regulation which states:

“The fluorinated greenhouse gases contained in other products and equipment, including mobile equipment unless it is serving military operations, shall, to the extent that it is technically feasible and does not entail disproportionate cost, be recovered by appropriately qualified personnel, to ensure their recycling, reclamation or destruction.”

It is recommended that all mobile systems are included in Article 4.1 to clarify a mandatory requirement for recovery at EOL.

RAC Proposal 3: EOL Requirement for Refrigeration Contractors

The current EOL recovery obligation for stationary RAC applications is placed on end users via Article 4.1. Placing a “mirror” legal obligation on contractors could avoid the situation where contractors are influenced by end users to vent gas during equipment decommissioning.

RAC Proposal 4: HFC Product Bans for New RAC Equipment

Bans on the use of high GWP refrigerants in new systems will provide significant short term emission reduction (through reduced leakage in the use phase) and in the longer term will reduce the risk of emissions at EOL.

The cost impact of bans will be minimised if the following points are taken into account:

a) They only apply to new systems (any existing systems using HFCs should be allowed to run to their normal EOL).

b) The timing of a ban in a specific product area is linked to the likely availability of a suitable alternative.

c) A suitable maximum GWP is adopted in each product area. For some markets it will be much easier to have an early ban if the GWP is set at “below 500” or “below 1000” rather than adopting the current “below 150” level in the MAC Directive.

d) Detailed decisions about suitable product bans must take into account the possible impact on energy related CO2 emissions to avoid the possibility of a “perverse” environmental impact where the energy related emissions go up more than the reduction in F-Gas emissions.

A detailed evaluation of product bans is being made by Oko Recherche and others in the review of the F-Gas Regulation. Some possible bans worth more detailed consideration include:

a) A ban in RAC 1 and RAC 2 from around 2015. HCs are already successfully used for most RAC 1 applications and could also be used for most RAC 2 systems. The availability of HFO 1234yf by 2015 may add to the choices available.

b) A ban for large systems in RAC 4, RAC 5 and RAC 7 from around 2015. Alternatives such as CO_2 or ammonia may be cost effective for large systems. However, it is difficult to define "large" and the best definition may be different in each market sub-sector.

c) Bans in other RAC sectors from around 2020 as new refrigerants become available. These bans may need an "elevated" maximum GWP of between 500 and 1000 as discussed above.

RAC Proposal 5: Measures to reduce use of HFC 404A in New / Existing Systems

HFC 404A is the main refrigerant used in supermarket systems across the EU and is widely used in other applications such as industrial systems and cold stores. It has by far the highest GWP of all commonly used refrigerants (3,922). It causes a significant proportion of GWP weighted emissions from all stationary RAC systems. Measures could be quickly adopted to reduce these emissions. These could include:

a) To ban use of HFC 404A in most types of new system from 2013. In some cases very low GWP refrigerants could be used in place of HFC 404A (e.g. CO_2 in some supermarkets). Where this is not appropriate (e.g. in Southern Europe where CO_2 systems may use too much energy) there are alternative "medium GWP" options that could be used instead of HFC 404A (e.g. R407A, R407F, R134a).

b) To encourage retrofill of existing systems from R404A to an alternative (probably R407A or R407F) where this is appropriate – especially for supermarket chill systems. It is believed that this saves energy as well as replacing R404A with a refrigerant with approximately half the GWP.

The ban for new systems would probably need to be part of a revised F-Gas Regulation. Encouraging retrofill of existing systems could be done via Regulation or using an information campaign (see Proposal 6).

RAC Proposal 6: Better Policing of Current Regulations

The recent Oko Recherche report (Oko Recherche, 2011) shows that some countries have made insufficient efforts to implement and police the current F-Gas Regulation. To improve EOL recovery it is important that all relevant engineers have the new F-Gas handling qualification and all companies involved in maintenance of RAC equipment are properly certificated.

The Commission should ensure that suitable programmes are in place in each Member State to police the Regulations and to ensure that training and certification are done properly.

RAC Proposal 7: Tax on F-Gases

It is worth considering whether a GWP weighted tax on F-Gases would be appropriate as a method to support other measures. A relatively low tax level (in terms of € per tonne CO_2) has a big impact on the cost of HFCs. Table 5-20 illustrates the impact of a tax on a variety of refrigerants. Two different tax levels have been chosen – the lower level of €16 per tonne CO_2 is the price of "traded CO_2" in the EU ETS. The higher price of €60 per tonne CO_2 is the amount often considered for "non-traded CO_2" and represents a possible long term price. The table shows how a tax would add a significant amount to the current cost of HFC refrigerants. The tax on very low GWP alternatives will be very low or zero.

A tax would encourage end users and contractors to make more effort to reduce emissions from existing plants and could help support a decision to use a very low GWP alternative refrigerant.

Table 5-20 – Impact of a GWP Weighted Carbon Tax on Refrigerant Prices

Refrigerant	GWP	Typical fluid price € per kg	GWP Weighted Tax, € per kg	
			At €16 per tonne CO_2	At €60 per tonne CO_2
HFC 404A	3,922	17	63	235
HFC 410A	2,088	17	33	125
HFC 134a	1,430	11	23	86
HFO 1234yf	4	55	0.06	0.24
Ammonia	0	2	0	0

RAC Proposal 8: Information Initiatives

Preparation and dissemination of good information about various aspects of the F-Gas and Ozone Regulations will support a number of other proposals and deliver emission reductions through better awareness and more widespread understanding of best practice.

It is recommended that guidance material is prepared to target the following areas:

a) End users of RAC equipment. To highlight their obligations about reducing leakage during life and ensuring recovery at EOL. Also to explain the likely changes in refrigerants over the next 10 years, to help with investment decisions for new systems.

b) Designers of RAC equipment. To highlight opportunities to design systems with low leakage and to use alternative low GWP refrigerants. A good independent appraisal of the advantages and disadvantages of alternative refrigerants in different applications is essential. It must be recognised that the availability of new refrigerants is changing rapidly – any guidance material would need to be regularly updated to take new data into account.

c) "In-life" maintenance contractors. To highlight opportunities to minimise in-life leakage.

d) EOL contractors. To highlight best practice in refrigerant recovery.

e) Specialist Recovery Facilities. To highlight ways of avoiding refrigerant loss during handling after EOL and to maximise the amount of refrigerant recovered at the facility. Also to provide guidance on how to deal with a more varied input stream in terms of (i) refrigerants and blowing agents (taking into account the increasing amount of hydrocarbon in the product mix) and (ii) equipment types (e.g. small commercial refrigeration systems and foam panels).

A crucial aspect of an information initiative is targeting the recipient organisations:

- The most important group to target are RAC contractors. These can now be targeted via the Company Certification schemes that should exist in each Member State. Using the UK as an example, it would have been very difficult to get information to contractors 5 years ago, as the majority of contractors are quite small and difficult to identify. Now the UK has a list of 4,500 companies that hold a Company Certificate – emailing information to these companies can be done easily via the relevant Certification Bodies. Better policing of such schemes will have the benefit of making information initiatives more effective.
- Specialist Recovery Facilities are easily identified (most were listed in the ICF study) and can be sent relevant information.
- End users and designers are more difficult to reach. Each Member State needs to produce lists of “top emitting” end users, both to ensure better policing and to provide a dissemination route for guidance material. Designers can be targeted via relevant Trade Bodies.

RAC Proposal 9: Improved Data Collection

As has been described in at the head of this section, most RAC sectors are already covered by regulatory obligations to prevent emissions during life and at end-of-life. However, there is very little quantitative evidence to assess the level of compliance with these obligations. Under existing regulations, end users are obliged to keep records of all leak tests, maintenance and gas additions for all systems with over 3 kg of charge (6 kg for hermetically sealed systems). Upon request, end users are obliged to provide these records for inspection by the member state regulatory body – but there is no requirement for regular (e.g. annual) submission of information on gas used and estimated emissions. Some member states are planning to introduce national requirements for collection of such information, but this goes beyond the requirements of the existing regulations.

This proposal would introduce an EU-wide obligation on end users to submit data on gas charge and annual usage on all systems over a certain size. That size limit would need to be set at a level to balance the need to gain sufficient information and the need to avoid data overload. It may be sensible to start with a level of 300 kg charge, to align with existing F-Gas and Ozone regulations, and this could be adjusted in future.

The information would be collated nationally and at an EU level, in order to build up a picture of gas use and provide evidence of the effectiveness of the regulations.

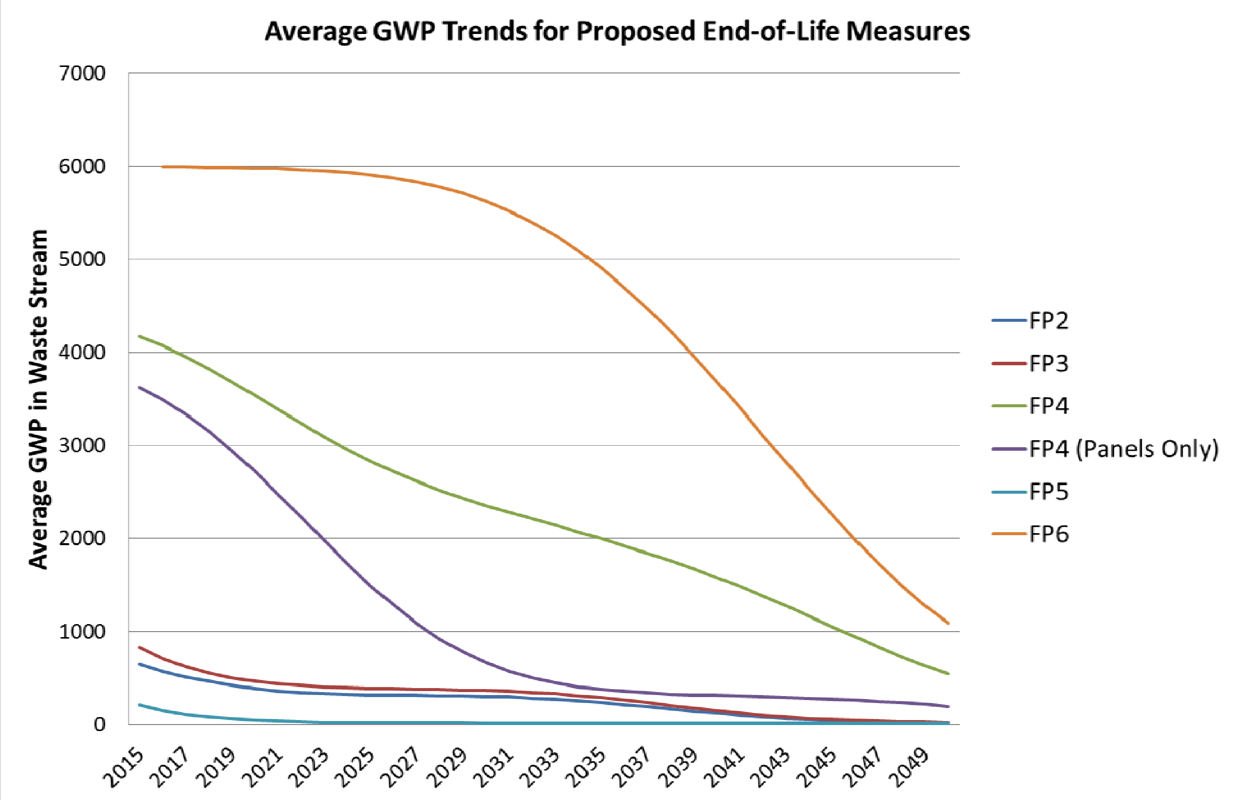
5.6.2. Foams Short List

Eight proposals have made the short list from the long list analysis. These are:

FP 1	Phase-down of the use of HFCs in the XPS and PU Spray Foams
FP 2	Mandatory recovery, Commercial Appliances
FP 3	Mandatory recovery, Building Services/ Industrial Sectors
FP 4	Mandatory recovery, Steel-faced Panels & Built-up Systems
FP 5	Improved Enforcement of Domestic Refrigerator EoL Recovery
FP 6	Engagement with stakeholders to seek Industry Commitments
FP 7	Information Initiatives
FP 8	Promotion of research into managing foam waste

Before considering individual measures, it is important to consider, as already noted in Section 5.4.2, that the average ODP and GWP of foam blowing agents will decrease with time, reflecting the fact that much of the original CFC consumption in the foam sub-sectors was directly replaced by low-GWP (typically hydrocarbon) alternatives. Where HCFCs were used as an interim measure, they have largely been replaced in a subsequent step by low-GWP alternatives, leaving only a relatively small component of high GWP gases in current blowing agent selections. Of the eight proposals made in this short list, five relate directly to interventions in the waste stream at end of life. The trends in average GWP for these measures are shown in Figure 5-12.

Figure 5-12 Average GWP for blowing agents entering the waste stream for EOL Measures



The form of these profiles is influenced by the predicted lifecycles of the product types listed in Table 5-2 and determined by the resulting gas composition of their entrained blowing agents. With long lifecycles for most building-related products, much of the CFC-containing foam will enter the waste-stream between 2025 and 2050 – so the waste streams for these products remain relatively CFC-rich (resulting in a high average GWP) for most of the study period. Conversely, the short life-cycles of some other products (e.g. appliances) mean most of the CFC foams from this sector have already entered the waste stream by 2012. This results in a low average GWP for these products and reduces the environmental impact (in terms of tonnes of CO_2) of policy measures and also increases their average abatement cost (in €/TCO_2).

However, even for construction foams where the GWP of CFCs provides the most cost-effective E-o-L recovery measures in climate terms (e.g. FP4, FP6 and FP7), it looks unlikely that many of the foam market sub-sectors will provide an economic recovery route. This is because none of the measures offer an average abatement cost for the period of less than €50/T CO_2, (see Section 5.6.4) even when the lowest assumption is taken for recovery costs 'per kg' of blowing agent. Of course, the effective abatement costs in climate terms will be lower in the early years of the period (i.e. from 2012-2025), but will be offset by higher values as the average GWP declines.

Therefore, the overriding challenge for the regulators of the foam sector is to seek to maximise the levels of recovery within these considerable constraints. This often means focusing on niches which may be at Member State level and time dependent, even though there are likely to be other opportunities apparently left unaddressed from a regulatory perspective. The comparative attractiveness of measures is also highly dependent on the timescale over which they are evaluated, since the baseline against which they are compared (normally landfill) is not a scenario in which full release occurs instantaneously. A further explanation of the complex dynamics relating to the quantification of abatement costs and climate benefits is given in Appendix B.

The other overriding factor is that further innovation in recovery and destruction techniques could create major recovery opportunities that have hitherto been either technically infeasible or economically non-viable. The important message here is that there is still time, since many of the products contained in buildings will not enter the waste stream until 2020 and beyond.

Foams Proposal 1: Phase-down of the use of HFCs in XPS and PU Spray Foams

Although the lifetime of XPS and PU Spray Foams is likely to be in excess of 30 years, even in a refurbishment application, the avoidance of HFC use in these foam market sub-sectors will ultimately deliver emissions savings at EOL. However, when Phase 1 and Phase 2 losses (see Figure 5-2) are taken into account there will already be some delivered benefits well before 2050. This is particularly the case because both product types display relatively high Phase 1 emissions.

It is estimated that it would take until 2015 to implement a significant phase-down on HFC use in the XPS sector and until 2020 to achieve the same progress in the PU Spray Foam sector based on current information available on alternatives. However, industry responses to such proposals from the XPS sector have introduced a further level of caution about reliance on very low-GWP fluorocarbons such as HFO-1234ze The industry's inputs have highlighted that only one gaseous blowing agent option in this family has so far been identified and that this is coupled with only one producer. This situation creates potential difficulties with both cost and security of supply. The level of the phase-down could be adjusted in the light of further experience with those alternatives over the coming years.

There is also a possibility of including similar HFC phase-downs in other foam sectors, but the impact is likely to be considerably less significant and, for this reason, is not included in this Proposal currently.

Foams Proposal 2: Mandatory Recovery, Commercial Appliances

Both the WEEE Regulation and the RoHS Regulation have been the recent subject of re-casts. Although it is clear to experts in the field that the scope of the WEEE Regulation still includes all commercial appliances, the re-cast has tended to become even more general in its scope and listings than in the previous version.

This proposal therefore envisages the publication of Guidance for Member States which can be cascaded to the relevant industries via trade bodies and national competent authorities confirming that commercial appliances are already covered under the WEEE Regulation and that the provision within the Ozone Regulation has been fulfilled. This could be further cemented by listing commercial appliances specifically in the Annex of the current Ozone Regulation (as provided for in Article 22 Clause 4 of Reg.EC1005/2009).

Foams Proposal 3: Mandatory Recovery, Building Services / Industrial Sectors

This proposal focuses on the potential of recovering foams when replaced as part of routine maintenance procedures on building services pipework/ductwork and on industrial process equipment and also when decommissioned at the end of life of the building or industrial plant.

The implementation of this proposal would require pipework insulation (including that used on valves and flanges) and ductwork insulation to be included in the relevant Annex of Regulation EC 1005/2009. It would also extend to process insulation used on vessels, storage tanks and other interlinking pipework. It could also require the provision of Guidance to heating/air conditioning engineers and the demolition contractors (in the case of building services) and to process companies and their contractors in the case of industrial insulation. Consideration is being given currently to a possible pilot project in the UK, which would look at the costs and benefits associated with recovery from the building services sector. It should be made clear in any adjustment to the Annex that pipe-in-pipe insulation used primarily for underground district heating pipe would not be included in this requirement.

Foams Proposal 4: Mandatory Recovery, steel-faced panels and built-up systems
(where national building practices make the measure cost-effective)

The cost-effectiveness of measures in these market sub-sectors will depend largely on the building types being managed and the underlying demolition waste segregation provisions. This proposal recognises that, even in those Member States where a high level of segregation occurs, there may be particular local factors which influence the cost-effectiveness of EOL management practices. In some instances, the dismantling, recovery and destruction of blowing agent contained in a built-up roofing system can be less expensive that the same action for a steel-faced panel because direct incineration of the separated foam may be a possibility in the case of the built-up system, whereas panels may require the intervention of a specialist recovery facility. The provisions for the lifting of panels may also be an added cost.

Individual Member States also need to assess the cost/benefit of such measures in the context of their wider policies on greenhouse gas abatement.

The proposal would require the development of a consistent cost/benefit methodology to be applied throughout the EU-27 and that Member States provide written justification to the Commission on the decision to proceed or not to proceed with a national mandate for the recovery of blowing agents from either steel-faced panels, built-up systems or both. This justification would need to be supported by validated cost estimates generated in association with the demolition contractors.

For the purposes of modelling this scenario in this study, it is assumed that Member States covering 50% of the total market will mandate the recovery of blowing agent from these sectors in 2015, with those covering the other 50% providing the relevant justification to support a decision not to proceed.

Foams Proposal 5: Improved Enforcement of Domestic Refrigerator EOL recovery

Financial pressures within the market sub-sector have caused some short-cuts to be taken in the processes to extract blowing agents from the foams contained in domestic refrigerators. These have only been recently exposed by spot audits and highlight the fact that there is no systematic process for evaluating or reporting the performance of specialist recovery facilities of this type.

This proposal is to introduce such an evaluation and reporting scheme which would be coordinated at EU-27 level but which would implemented and administered by the competent authority within each Member State, which may be the waste regulator in most cases.

Foams Proposal 6: Engagement of Stakeholders to Seek Industry Commitments

The ‘long-list’ analysis and its traffic-lighting system revealed the likelihood of being able to extract Industry Commitments from the suppliers and supplier trade bodies, as well as the end-user/contractor trade bodies in a number of foam market sub-sectors. Industry Commitments at this level are likely to take the form of commitments to raise awareness and to provide guidance on best practice for the management of foams at EOL.

For certain market sub-sectors, it might be possible to extend this level of commitment from the suppliers to encompass take-back schemes in the building services area in order to augment any effort under Proposal 3 to mandate recovery at end of life.

With respect to commercial appliances and actions put forward under Proposal 2, it could be possible to gain the commitment of a supermarket chain, for example, to showcase the correct implementation of the new Guidance emanating from the competent authorities within Member States.

In general, Industry Commitments are seen as more efficient in their deployment than the negotiation of Voluntary Agreements and are likely to be equally effective in a period of growing accountability from a Corporate Social Responsibility perspective. The insulation boards sector, covering polyurethane, XPS and phenolic products is keen to promote the incineration route for these products where appropriate incineration capacity exists. This would deal with the presence of ODS and other high GWP gases in an approved fashion (MSWI is an Approved Technology under the Montreal Protocol) as well as potentially managing the presence of brominated flame retardants in some instances. The presence of certain blowing agents and flame retardants will become an increasing barrier to re-use, particularly as REACH impinges further on the management of chemicals in the supply chain in the post-2015 period.

Foams Proposal 7: Information Initiatives

As with the RAC sector, the foam market sub-sectors are likely to benefit from authoritative and consistent information on best practice in the identification, recovery and onward management of various foam types. Guidance would be particularly helpful to the following stakeholders:

a) End-users (i.e. building owners) through national property federations and demolition waste management programmes

b) Demolition contractors via their national federations, but written at Member State level to ensure that national building and demolition practices are properly observed.

c) Industrial and building services maintenance contractors via their national federations

d) Operators of Specialist Recovery Facilities – perhaps as a periodic newsletter to update on performance, waste trends and emerging best practice.

These documents should be consistent with one another, but should be tailored to reflect the relevant aspect of the overall bank management opportunity as set out in this study. Items to be included in such information would be techniques for identifying the blowing agent type within a foam, best practice in the handling and onward transmission of foams, key advantages and disadvantages of various recovery and destruction methods and, finally, other environmental issues to be considered (e.g. transport distances).

Foams Proposal 8: Promotion of research into managing foam waste

This report has identified that the technical feasibility and cost effectiveness of foam recovery varies substantially by market sub-sector and location. There is a clear potential environmental benefit in seeking to minimise these barriers and maximise recovery and destruction as a result. This proposal therefore seeks to create a stimulus for further research into potential means of handling foam waste at EOL.

One of the other attractive elements of this proposal is that there is still time in which to conduct such research and it could be integrated into EU level Research Programmes delivering results within the 2015-2020 timeframe and still have a significant impact on potential mitigation of emissions.

As an additional area of research, this proposal would incorporate further research into the mechanisms for, and field experience of, anaerobic degradation. It would be of particular interest if it could be demonstrated that anaerobic degradation occurs to a greater level than is currently understood and leads to breakdown products that are largely benign (or at least less harmful) to the climate, the ozone layer and the wider environment.

5.6.3. GIS Short List

GIS Proposal 1: Including GIS in Article 3 (Containment Provisions)

Given the very high GWP of SF_6 it is important that efforts are made to limit leakage from GIS. Inclusion of GIS (alongside RAC and fire protection) in the provisions of Article 3 of the F-Gas Regulation to carry out regular leak checks and to maintain records will help ensure that installation and in-life emissions are reduced. As most emissions from GIS are during installation and in-life phases this could be an important measure, although it will have no EOL impact.

GIS Proposal 2: Voluntary Agreements

The Member State questionnaire showed that VAs are already common in this sector. Agreements set up between the electricity industry regulator and the main electricity supply and distribution companies in each Member State are an effective way of focussing attention on the rate of emission from GIS equipment and ensuring on-going reductions in SF_6 emissions. Six Member States already have VAs in place and others have plans for additional measures (see Section 3.2.3). Building on these current arrangements is a cost effective way to proceed. As with other GIS proposals the main benefits will be related to reduced emissions during installation and use rather than at EOL.

GIS Proposal 3: Data Collection and Information Initiatives

As with RAC and foam, there is generally a lack of consistent information about rates of SF_6 emission from GIS equipment and best practice techniques to reduce losses during installation, the in-use phase and at EOL. If Proposal 1 and / or Proposal 2 go ahead, better records will be kept and data on emissions collected by Member State electricity regulators. It would be very helpful for this data to (a) be collected in a consistent way across EU-27 and (b) be assessed at EU level to identify best practice. Lessons learned from the end users with lowest levels of emissions can be collated and disseminated to stakeholders in each Member State.

5.6.4. Cost Effectiveness of Short List Measures

The Revised Banks Model has been used to make estimates of the cost effectiveness of each short list measure described in Sections 5.6.1, 5.6.2, and 5.6.3. The results are summarised in Tables 5-21, 5-22 and 5-23.

To estimate the emission reductions from each proposed measure, changes have been made to the consumption levels and/or emissions factors relevant to the measure being evaluated. The Revised Banks Model uses 3 emissions factors:

- Decommissioning and EOL Handling Factor
- EOL Recovery Factor
- Non-compliance Factor

The adjustments made to relevant emissions factors are detailed in Appendix B.5. The Appendix also provides details of the costs related to each measure. These costs include:

a) One off costs (investment to set up a specific measure) and on-going costs (revenue costs) that will accrue over the life of the measure.

b) Costs that apply to all relevant parties include the EC, MS Governments, end users and contractors.

The cost effectiveness of measures is expressed in terms of € per tonne CO_2. The abatement potential has been aggregated over the period between when a measure first comes into effect (e.g. 2015) and 2050. The costs are calculated annually over the same time period and a Net Present Value is calculated using a 4% discount factor.

The lack of data on EOL recovery taking place in different F-Gas and ODS markets makes it very difficult to accurately model the changes to emissions factors or the costs. This leads to the potential for significant variance in the cost effectiveness in different geographies across the EU. The results in the tables below show “low” and “high” values that indicate the range of likely abatement and the range of costs.

It should be noted that some of the proposals are mutually exclusive i.e. the savings for proposals relate to the same emissions and hence it is not possible to add these measures together to estimate total abatement potential.

In addition, emission abatement in the foams sector is not likely to be uniformly spread in the period between 2012 and 2050 and this makes it inappropriate to assess savings for the whole range at once. Accordingly, rather than giving high and low abatement estimates, the foams analysis in Table 5-22 provides mean estimates for savings in the periods 2012-2030 and 2031-2050 respectively.

It is also important to note that measures in the appliance sector are considerably less significant in their impact than those in the construction sector. This is primarily as a result of the fact that most high-GWP gases have already passed into the waste stream and most blowing agents have been low-GWP since the mid-1990s.

Efforts to impact the abatement of construction foams emissions are likely to rest on initiatives at Member State level and on Industry Commitments. This is largely because of the wide range of costs associated with such measures. The benefits of such measures are expected to be particularly significant in the period between 2031 and 2050 (and beyond).

Table 5-21 RAC Short List Measures – Abatement Volume and Cost Summary Table

RAC Proposal		Abatement, MT CO_2		Cost € per tonne CO_2	
		Low	High	Low	High
1	HCFC Emergency Measures	5	10	3	6
2	Extend EOL obligations for Mobile RAC	6	12	15	30
3	Mirror EOL obligations for Contractors	120	200	2	3
4	HFC Product Bans	2,000	2,500	15	25

5	Reduced use of R404A	700	1,100	-5	5
6	Better policing	170	280	3	6
7	GWP tax	800	1,500	15	25
8	Information initiatives	100	200	1	2
9	Data collection	75	150	10	20

For an explanation of the methods used to calculate the parameters shown in Table 5-21 (above), Table 5-22 and Table 5-23, please see Appendix B.6.

Table 5-21 shows that all proposed measures to reduce RAC emissions have a cost of less than €30 per tonne CO_2 saved and that many of the measures are below €10 per tonne CO_2 saved.

The table also shows that the measures that influence the choice of refrigerant in new systems (Proposal 4 HFC product bans, Proposal 5 Reduced use of R404A and Proposal 7 GWP tax) lead to the greatest abatement potential, mainly because of the in-life leakage reductions that will be achieved.

Proposal 8, Information Initiatives is a potentially effective and very low cost measure (€1 to €2 per tonne CO_2 saved) that will build on the network of certificated RAC contractors that was established via Article 5 of the F-Gas Regulation.

Table 5-22 Foams Short List Measures – Abatement Volume and Cost Summary Table

		Abatement, MT CO_2		Cost € per tonne CO_2+	
		2012-2030	2031-2050	Low	High
1	Phase-out of HFC use in XPS / PU Spray Foams	44	18	25	45
2	Recovery, Commercial Appliances	1	2	282	2340
3	Recovery, Building Services / Industrial Sectors	4	3	286	930
4	Recovery, steel-faced panels / built-up systems	42	82	52	192
5	Improved Domestic Refrigerator EOL recovery	1	1	205*	205*
6	Industry Commitments	42	57	54	180
7	Information initiatives	21	29	54	180
8	Promotion of research into managing foam waste	Unclear	Unclear	Unclear	Unclear

\+ Low and high cost estimates are based on recovery cost assumptions 'per kg' of blowing agent as shown in Table ES-5

* Accounts for additional regulatory cost only, as compliance costs are already accounted for in earlier Regulatory Impact Assessment

Table 5-22 illustrates the wide range of abatement that can be achieved in differing sectors and over different timescales. The early phase-down of HFCs in the XPS and PU Spray Foam sectors deliver the most significant and cost effective reduction in emissions in the 2012-2030 period. However, it should be noted that the cost-effectiveness associated with XPS foam is not as attractive as that presented by Öko Recherche on the F-Gas Regulation review. This relates to the fact that the Öko Recherche approach and related costings were based on a hydrocarbon technology solution which is being assessed for China. It is clear from industry feedback, that such an approach would be inappropriate for the European market for a number of performance and regulatory reasons. The situation is only further exacerbated by the regulatory pressure currently being placed on some existing flame retardants. The costs assessed in Table 5-22 have therefore been based on the adoption of very low-GWP fluorocarbons.

Some of the ranges of abatement cost (€/T CO_2) estimates shown in Table 5-22 are particularly large. The reasons for this have already been alluded to in Section 5.6.2 and arise from a number of factors, but in particular:

- Variability between countries (due to different waste practices)
- Variability over time (due to the anticipated change in composition of products reaching the waste stream, and associated reduction in average GWP)
- The effect of current landfilling practices in delaying the release of gases to the atmosphere (in the baseline or “business as usual” case) – which spreads the associated abatement benefits of policy measures over many years in the future (extending well beyond 2050 in some cases).

The methods of assessment and cost dynamics are discussed further in Appendix B.

It is also important to note that measures in the appliance sector are considerably less significant in their impact than those in the construction sector. This is primarily as a result of the fact that most high-GWP gases have already passed into the waste stream and most blowing agents have been low-GWP since the mid-1990s.

Efforts to impact the abatement of construction foams emissions are likely to rest on initiatives at Member State level and on Industry Commitments. This is largely because of the wide range of costs associated with such measures. The benefits of these measures are expected to be particularly significant in the period between 2031 and 2050 (and beyond).

Table 5-23 GIS Short List Measures – Abatement Volume and Cost Summary Table

	Abatement, MT CO2		Cost € per tonne CO2	
	Low	High	Low	High
1 Article 3 Containment Provisions for GIS	5	10	15	30
2 Voluntary Agreements	10	16	6	12
3 Data collection and information initiatives	5	10	15	30

Table 5-23 shows there is only a small amount of abatement potential from GIS measures, due to (a) the relatively small bank, (b) the low level of emissions and (c) relatively good compliance and recovery efficiency of current practices making further improvements more difficult.

GIS Measure 1 (the extension of Article 3 to include GIS) would safeguard against any drop in compliance standards in the future. The regulation could be written to treat small hermetically sealed systems differently from larger non-hermetically sealed systems, and use charge thresholds appropriate for GIS systems rather than RAC systems.

GIS Measure 2 (voluntary agreements) would build on existing agreements in some Member States and should be relatively cost effective.

6. Conclusions and Policy Recommendations

In this study the level of emissions from ODS and F-Gas usage in RAC, foams and GIS sectors have been appraised and a wide range of policy measures to reduce emissions have been evaluated. In this final section conclusions are presented together with recommendations for the policy measures that should be considered further by the Commission.

Level of Emissions

An in depth modelling exercise was carried out to establish emissions from the RAC, foams and GIS markets. This modelling is complex and has required the analysis of numerous sub-sectors of each market to provide a realistic estimate of emissions across a large number of end uses that each have very different characteristics. 19 market sub-sectors were analysed, as summarised in Table 5-1.

For each market sector it was necessary to establish a profile of emissions between 2012 and 2050. As a key focus of this study is on End of Life (EOL) emissions this also required looking back to the date when products in current use may have entered the market – this extends back to the 1970s for some long lived applications such as building insulation foam. The annual emissions profile can distinguish between:

a) The size of the bank, the amount of product reaching EOL and the level of emissions.

b) The physical tonnage of gas, together with GWP and ODP weighted tonnages.

c) The split of emissions between lifecycle phases i.e. (i) product manufacturing / installation emissions, (ii) in-life leakage or diffusion and (iii) EOL emissions.

The modelling methodology is detailed in Appendix B and the sub-sector emissions profiles are presented in Appendix C. Section 4 of this report summarises key outputs from the modelling. Many interesting facts arise from this very detailed modelling. Some key conclusions that have helped in the policy evaluation include:

1) Virtually the whole of the ODS bank and future ODS emissions relate to foam markets, in particular the long-lived building insulation markets. In 2015 97% of ODS reaching EOL is from foams and by 2030 this has risen to 100%. The remaining 3% of the ODS bank in 2015 is for RAC applications – mainly the “tail end” of HCFC usage. The majority of this small bank will be gone by 2020 and all of it by 2030.

2) The ODS bank falls steadily as no new ODS products entered the market after 2003. By around 2050 the ODS bank in foam products in the EU will have fallen to virtually zero.

3) In terms of the GWP weighted bank, both RAC and GIS become more significant, although foams still represents the largest part of the bank in 2015 (65%), because of the very high GWP of CFC blowing agents that are still in the bank. The 2020 foams bank is about 3 million tonnes CO_2, of which 80% is CFCs. By 2050 the foams bank has fallen to only 0.5 million tonnes CO_2, the majority of which is HFCs. The RAC bank peaks at about 1.5 million tonnes CO_2 in 2020 and falls to about 1 million tonnes by 2050.

4) In terms of overall emissions RAC is much more important than might be implied by the bank size. This is because in-life emissions from many RAC sub-sectors are relatively high. In 2020 RAC emissions will be around 160 kilotonnes CO_2 of which nearly 90% is in-life emissions and only around 10% is the EOL emissions.

5) Even though the foam GWP weighted bank in 2020 is over twice the size of the RAC bank, the 2020 emissions from foam are lower, at around 44 kilotonnes CO_2. However, the EOL component of this is much more significant for foams, being 40% of the total.

6) Both the foams and RAC emission profiles change significantly between now and 2050 as a result of previous legislation (especially phase out of CFCs) and expected future changes in use of HFCs. This makes it difficult to assess the financial impact of EOL policy measures as these will vary over time as the composition of the waste stream varies. The foams profile for product entering the waste stream has a characteristic “double hump” (e.g. see Figure 4-6) caused by the distinctly different life cycles of short lived products (e.g. domestic appliance foam) and long lived products (e.g. building insulation boards).

7) The GIS market is the smallest, representing around 3% of the GWP weighted bank in 2010. It is also the most stable in terms of both bank size and emissions. A small growth in bank size is predicted between now and 2050 with more widespread use of GIS, although emissions will probably fall as the technology improves and leak levels fall.

Policy Evaluation

Section 5 of this report provides an in depth review of policy options. The policy evaluation was carried out in two stages. A “long list” of 456 measures were screened by assessing 24 different policy measures for each the 19 market sub-sectors. The 24 policy measures were in 5 main groups as listed in Table 5-6. The 5 policy measure groups were:

a) New Regulatory Requirement

b) Improved Implementation of Current Regulations

c) Voluntary Agreements (VA) or Industry Commitments (IC)

d) Fiscal Measures

e) Improved Information

The screening process was based on a “traffic light” grading system that quickly identified measures that were inapplicable and highlighted those with merit. The best measures were then carried forward into a “short list analysis” where a total of 20 measures were evaluated in more detail. In each case estimates were made of the impact of the policy measure (in terms of abated emissions) and the cost effectiveness of the measure (in terms of € per tonne CO_2 abated).

Policy Recommendations Related to RAC Sectors

Nine measures were shortlisted (see Table 5-21) and all have cost effectiveness considered as good (less than €10 per tonne CO_2 abated) or reasonable (€10 to €30 per tonne CO_2 abated). It is strongly recommended that a number of these policy measures are taken forward by the Commission. The most important opportunities include:

1) **Early implementation of measures to reduce use of HFC 404A in both new and existing systems**. This measure has high abatement potential and very good cost effectiveness. HFC 404A has a particularly high GWP (3,784) and is the most commonly used HFC refrigerant in many types of commercial and industrial refrigeration system. For **new** systems there are alternative refrigerants with a GWP less than 50% of this value that could readily be used. For many types of **existing** HFC 404A system there is good potential for cost effective retrofill with an alternative refrigerant.

2) **HFC bans in other RAC markets for new systems**. Between now and 2020 it is likely that a range of alternative refrigerants can cost effectively be used in a wide range of RAC markets. In some markets (e.g. very small hermetically sealed systems) an HFC ban is already effective in some EU countries and could be implemented by around 2015 across the EU. In other markets (e.g. small HFC air-conditioning systems containing 1 to 10 kg of refrigerant) there is not yet a “mature” and cost effective alternative although one can be envisaged for new equipment by 2020. Product bans brought in at appropriate times between now and 2020 will provide a cost effective abatement option when applied to new equipment entering the market.

3) **Changes to EOL Provisions of the F Gas Regulation**. Two changes to the F-Gas Regulation will improve EOL recovery. These are: (a) inclusion of mobile RAC systems in the provisions of Article 4.1 and (b) an obligation on RAC contractors to carry out recovery EOL activities (to mirror current obligation that applies to operators of equipment).

4) **Information Initiatives.** One of the most cost effective opportunities is for the Commission to provide better information about reducing both in-life and EOL emissions from RAC systems. This could easily be disseminated via the network of certificated RAC contractors that has been set up in the current F-Gas Regulation.

5) **Emergency information measures related to HCFCs.** There is a 3 year window of opportunity to minimise EOL emissions from HCFC equipment (before the ban on use of reclaimed HCFCs at the beginning of 2015). Providing good information to RAC contractors via the network of certificated RAC contractors will assist this process.

6) **Better Implementation and Policing of Current Regulation.** For most RAC sub-sectors the current F-Gas Regulation already has very clear requirements for EOL recovery. Some countries have implemented these very well but in many EU Member States there has been insufficient effort to get the best emission reductions from the current regulatory framework.

Policy Recommendations Related to Foam Sectors

Eight measures were shortlisted for detailed cost-benefit analysis (see Table 5-22). The range of cost-effectiveness varies significantly both between the measures themselves and also with time, as average GWPs decrease. In table 5-22, average abatement costs are shown for the period between 2012 and 2050. Using this approach, even improved Domestic Refrigerator EOL recovery struggles to be classed as anything but 'poor' '', even though the cost of compliance has already been factored into earlier regulatory assessments. The reason for this is purely related to very low average GWP of the waste stream after 2020. In short, climate will not be the driver for future blowing agent recovery beyond this date. Phase-down of HFC use in the XPS / PU Spray sectors may just fit into the 'reasonable' category, while most other measures have ranges that spread well into the region of poor cost-effectiveness. If it is assumed that any cost effectiveness assessment above €150 per tonne CO_2 saved is unaffordable, then it would appear difficult to take any mandatory action in the built environment even for the building services/industrial sector. Even though the 'per kg' recovery costs are lower than for most other building foams, the shorter lifecycle, and its impact on average GWPs more than offsets the easier access. As with other areas, the cost assumptions used will require further work to confirm costs in reality.

Another factor to consider in the assessment of mandatory options is the variability of cost effectiveness across the Member States based on the wide range of baseline waste strategies. Accordingly, mandatory recovery of some insulation foam types in the built environment may be justifiable at this level within some Member States but not others. However, the most likely option for construction foams is voluntary action through industry commitments or information initiatives. One clear factor in both cases is that relatively small levels of success (e.g. moving the recovery level by 10%) generates very substantial savings through to 2050. The encouragement of such measures is therefore strongly recommended. The value of voluntary action is that it will naturally gravitate towards the lower end of the cost abatement curve (i.e. < €100 per tonne CO_2-eq), giving it a versatility which mandatory solutions cannot offer.

The following section considers each measure individually:

1) **Phase-down of HFC use in XPS / PU Spray Foams** – This measure offers substantial abatement potential and can be delivered at reasonable cost effectiveness provided that the industry concerns about reliable and economic supply can be met. The cost effectiveness determined in this assessment is based on the new generation of unsaturated molecules (HFOs) rather than on hydrocarbons (as evaluated by Öko Recherche). Although hydrocarbons may offer an option in China and elsewhere, the technology will certainly not be able to meet the rigours of the European market.

2) **Mandatory Recovery, Commercial Appliances** – The abatement potential of this measure is relatively limited because the bulk of ozone depleting substances used in this application have already reached the waste stream. There is still some debate about whether this is a compliance issue or an extension of regulatory scope, thus making it hard to determine meaningful abatement costs. However, further clarification of the regulatory status may still be a very helpful in the short term if the matter can be addressed quickly.

3) **Mandatory Recovery, Building Services / Industrial Sectors** – As noted at several points in this report, this sector has the potential to deliver some moderate short-term abatement. Recovery costs 'per kg' of blowing agent still need to be further researched, as do the logistics of recovering materials that may have been used in challenging environments. Nonetheless, further case study experience is warranted in support of a possible regulatory or voluntary action.

4) **Mandatory Recovery, Steel-faced Panels / Built-up Systems** – Although there are substantial operational costs associated with managing construction foams at end-of-life, the overall abatement cost is relatively attractive at €52-192 per tonne CO_2 saved. However, if panels were taken in isolation, this would increase to €82-380 per tonne CO_2 saved, reflecting the impact of the shorter lifecycle of these products in the period to 2050 and the significant transition to hydrocarbons in the last ten years. Even though 'per kg' costs of recovering blowing agent are assumed to be higher for built-up systems, the higher CFC component more than offsets this factor.

5) **Improved Domestic Refrigerator EOL recovery** – As noted in the earlier paragraphs of this section, improving the levels of compliance with the recovery standards expected in this sector could be justified in the very short term, although the environmental benefit is likely to be modest now that most ozone depleting substances have already reached the waste stream. Addressing compliance issues with Specialist Recovery Facilities might also have benefits for any extension into the handling of construction foams as the flow of these increases.

6) **Industry Commitments** – In the construction foam sector, these measures represent some of the most potent options for making inroads into the large bank of blowing agents contained in these foams. The technical feasibility and range of cost-effectiveness is too wide to allow for the mandating of action, but the industry is already keen to manage end-of-life issues for its products, bearing in mind the environmental contributions that they make during their lifetimes. In particular, the wider promotion of direct incineration creates opportunities to co-manage the blowing agent issue, where incineration capacity exists.

7) **Information Initiatives** – These are likely to act in a similar fashion to the Industry Commitments. The main purpose of this measure would be to ensure that the government agencies are providing similar advice to the various stakeholders, including building owners and waste stream practitioners.

8) **Promotion of Research into Managing Foam Waste** – This is clearly a concept which, by its very nature, is not possible to quantify in such an assessment. However, the slope of the cost abatement curve in the end-of-life management of the construction foam sector, makes it that any technology that shifts the cost effectiveness of recovery of these foams will deliver substantial environmental and commercial benefits. The Commission should consider this fact when developing its research funding strategies.

Policy Recommendations Related to GIS Sectors

Three measures were shortlisted (see Table 5-23). Whilst all of these have reasonable cost effectiveness (€10 to €30 per tonne CO_2 abated) the overall abatement potential is very small compared to either the foams or RAC measures already discussed above.

The best measure for this market is likely to be a Voluntary Agreement mechanism that encourages the electricity regulator in each Member State to set up VAs with the main electricity supply and distribution companies. This can build from a number of existing VAs that are already in place for the GIS market. It would be very helpful if VAs were established in a similar format in each country and, in particular, that data collection and reporting requirements are the same across the EU. This would allow analysis of progress towards reducing emissions in this specialised sector.

Linking Some End Use Policies to an HFC Phase Down

Some of the most important measures discussed above for both RAC and foams are those that limit the use of HFCs in new equipment or products (e.g. restricting use of high GWP HFCs in certain RAC sub-sectors or for XPS / spray foam). If bans are set at dates that coincide with the availability of cost effective alternative fluids then such bans should be an effective policy measure.

A problem with an approach based on product bans is that the F-Gas Regulation would have to be very precise in the way bans are described and would need to (a) set GWP limits for the alternatives allowed in each market and (b) set size bands in which a ban may apply. Setting such limits and size bands can be problematic given the complexity of the markets and the different approaches used in different Member States. For example ammonia is cost effective alternative refrigerant in “large” RAC systems, but it is very difficult to define a specific size level that could be considered “large”.

A process based on bans involves some difficulties and risks that would be avoided if one of two alternative policy approaches was adopted. These are:

a) **A GWP weighted tax on F-Gases**. As already illustrated in Table 5-20 a GWP tax on refrigerants would have a significant impact on the selling price of high GWP refrigerants. This could force the market to adopt alternative refrigerants and/or to reduce in-life leakage. Whilst this could be a practical approach it may be difficult to implement in the EU because of the way tax laws are dealt with mainly at a Member State level.

b) **A phase down of F-Gas consumption**. A phase down of the amount of F-Gas (or HFCs) sold in a given year would have a similar effect to bans or a tax. It would force certain parts of the market to adopt alternatives as these become available. The key to the success of a phase down approach would be to (i) ensure that the phase down schedule matches the most realistic assessment of the entry dates of cost effective F-Gas alternatives in each market sub-sector and (ii) that the phase down schedule works in parallel with other policy measures to reduce in-life and EOL emissions.

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Appendix B Details of Revised Banks Model

A detailed assessment has been carried out of the banks model provided by ICF in their previous study (ICF, 2010). This had a number of shortcomings and the ICF model required revision before it could be used as a basis for the policy analysis. During this project the ICF model has been developed in a number of key areas. The improvements made in the SKM Enviros / Caleb Revised Banks Model (hereinafter referred to as the Revised Banks Model) are described in Sections B.1 to B.3 below.

The objectives of the modelling are:

1) To quantify the environmental impacts (in ODP & GWP terms) of emissions from different sectors of ODS and F-Gas use.
2) To provide further clarity on the geographic distribution of banks and emissions within the 27 EU Member States.
3) To support the policy evaluation in this study (see Section 5) by providing a basis for analysing costs and benefits.

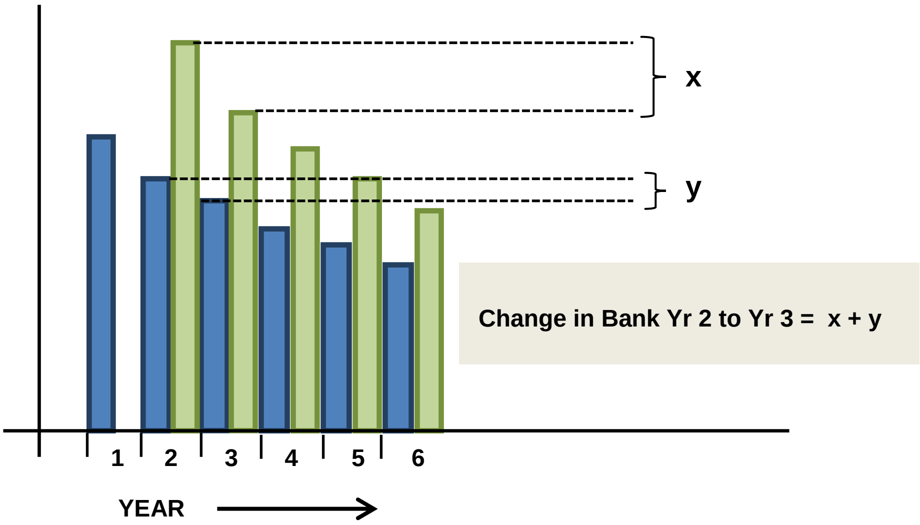
In the following sections, this Appendix provides descriptions of developments made to the ICF model. First, Section B.1 describes a fundamental revision which applies to both RAC and foams sectors. Then Sections B.2 and B.3 describe developments specific to the RAC and foams sectors respectively.

B.1 Fundamental Development of Banks Model

The ICF model uses slightly different methods for estimating the amount of gas reaching end of life (EOL) from the RAC sectors and foams sectors respectively.

For the foams sectors, the amount of blowing agent reaching EOL in a given year within the ICF model is assessed by aggregating the change in bank sizes relating to each year of historic consumption. These changes are derived by applying an exponential decay function to annual consumption starting the year after that consumption has occurred (see ICF, 2010 page 9). The application of an exponential function suggests that more units reach EOL in their first year of use than in any other year, which is counter to the reality, where newly installed products are the least likely to be lost from the bank. This dynamic is illustrated by an example shown below in Figure B-1. This approach not only has consequences for the determination of overall bank size but also impacts predictions about the mix of blowing agents reaching the waste stream in any given year. It should also be stressed that the reduction in bank size created by the time series of exponential decay for each successive year's consumption is totally separate from the losses arising from diffusion of blowing agents from installed products during the use phase.

Figure B-1 – The ICF approach to Bank Changes (Foams sector)



For the RAC sectors in the ICF model, the amount reaching end of life in each year was estimated as a proportion (1 / Average Life) of the bank size. The input to the RAC model was a time series of bank size estimates. This method is reasonable for stable, homogenous banks, but becomes inconsistent when applied to rapidly-changing, heterogeneous banks (e.g. subject to phase-outs or bans).

To overcome these issues, the Revised Banks Model as redeveloped by SKM Enviros and Caleb uses a consistent method based on a time-series estimate of consumption which is tracked throughout its lifecycle in the bank. This means that decommissioning at end-of-life, and hence contribution to the waste flows, only occurs once the product lifetime is reached[7].

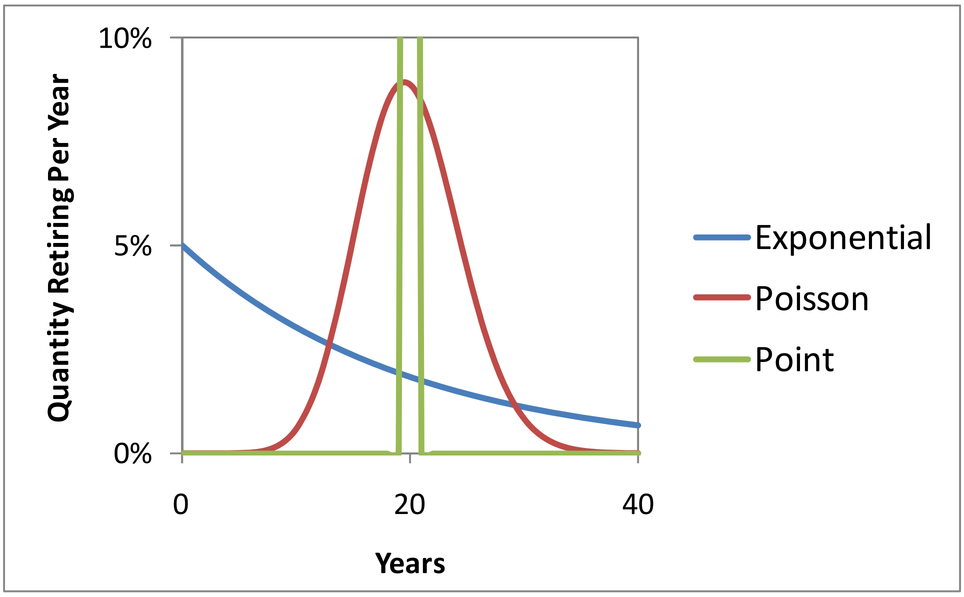
For the foams sectors, the time series of historic consumption used within the ICF and SKM-Enviros/Caleb models are very similar because both feed from the same data sources relating to 2001 estimates. However, the SKM-Enviros/Caleb model adopts the historic time series previously used by TEAP rather than a linear growth approach used by ICF, since the impact of the energy crisis in the 1970s is an important perturbing factor in the growth of insulation foam during that period. Similarly, the rapid changes in Building Regulations across Europe in the period from 2001-2008 have led to the SKM-Enviros/Caleb model having greater growth in consumption over that period, albeit adjusted for reductions in blowing agent made possible by the use of more efficient blowing agents.

As an enhancement to earlier models of this type (e.g. the point distribution used by TEAP and the exponential distribution used by ICF), a Poisson distribution is used for the predicted life in use. The advantage of the Poisson distribution is that it offers a more intuitive model of expected life for the units in the bank. This is illustrated in Figure B-2, which shows the

[7] In the RAC sectors, the product lifetime may be foreshortened due to regulatory phase-out or phase-down by, for example, retrofilling or early replacement.

probability distribution of the expected life using three different models (exponential, Poisson and a point distribution) for an assumed expected life of 20 years.

Figure B-2 – Alternative Life Expectancy Models



Note: The "Point" distribution is difficult to illustrate graphically, since it extends to 100% at the singular value of the expected life (i.e. 20 years in the above example).

B.2 Revised Banks Model – RAC Sectors

B.2.1 Description of Bank Dynamics – RAC Sectors

The Revised Banks Model for the RAC sectors takes into account the following characteristics.

In-Use Leakage

During its working life, most RAC systems leak gas to the atmosphere. Some leak very little (e.g. hermetically sealed refrigeration systems in domestic appliances) except for rare catastrophic failures. Some refrigeration systems leak by a significant amount – e.g. commercial supermarket systems may leak by around 15% per year.

In-Use Top-Up

For most RAC sectors, it is normal practice to top-up the systems after maintenance or a leak. If the charge drops below a critical level, the system's cooling capacity and energy efficiency will be adversely affected. The Revised Banks Model assumes most RAC systems are topped up to their full original level each year (apart from their last year of use, when they are not topped up). The only exceptions to this are assumed to be:-

- The domestic appliances sector – zero top-up
- Car air-conditioning – full top-up for first 75% of life, but zero top-up for last 25% of life.

Phase-Out and Retrofilling

In RAC sectors, the Ozone Regulations have imposed a number of phase-outs of different refrigerant types. First, in the early 1990's, there was a ban on the use of CFCs in new systems and on the supply of gas for maintenance. This meant that most existing CFC systems had to be replaced or retrofilled. The exceptions were systems which did not leak or require maintenance (e.g. domestic fridges). Secondly, by 2015, the use of HCFCs will be banned for maintenance or topping up – requiring a second round of replacement or retrofilling.

In addition, the Revised Banks Model allows for a third round of retrofilling (between around 2015 and 2020), where high GWP HFC gases (e.g. R404A) might be substituted by medium GWP HFC gases (e.g. R407A and R407F). This third round of phase-out is not included in the Base Case scenario, but is used in some alternative scenarios for particular End Use sectors.

The new model addresses these dynamics by including an "gas phase out algorithm", which imposes "early retirement" on systems with the gas being phased out, which are then substituted either by new systems (i.e. replacement) or by retrofilling the old systems with a new gas.

Bank and EOL Emission Calculations in Revised Banks Model

In summary, for each particular end use sector and gas type, the bank size and annual EOL retirements are defined by the following relationships.

Current_Bank in Year T (X_T) = Previous_Bank (X_{T-1})

– Leakage_Losses	
+ Top_Up_Consumption	(for most RAC sectors, Top_Up = Leakage)
+ New_Installs_Consumption (U_T)	(e.g. replacement + market growth)
– Natural_Retirements	
– Early_Retirements	(e.g. for R22 Phase Out)
– Retrofill_Outs	(e.g. for R22 Phase Out)
+ Retrofill_Ins_Consumption	(e.g. R422D as a replacement for R22)

Where the quantity of gas reaching "natural" EOL is defined as:

$$\text{Natural\_Retirements} = \sum_{t=0}^{t=T} p(U'_t, L, t)$$

$p(\cdot)$ is the Poisson distribution function

U'_t is New_Installs in Year t, after accounting for Early_Retirements & Retrofills

L is mean in-use lifetime for the sector

And the total quantity of gas reaching EOL (i.e. "retirement" from the bank) in each year is defined as:

Total_EOL_Retirements (Y_T) = Natural_Retirements + Early_Retirements + Retrofill_Outs

B.2.2 Emission Factors – RAC Sectors

For the RAC sectors, the model takes the EOL retirement quantities and applies a number of additional factors to estimate the emissions to atmosphere at the different stages of the product life cycle (see Figure 5.1). These are defined below.

Total_CO_2_Emissions (Z_T) =

Manufacture_Installation_Emissions	$a\rho U_T$
+ In-Use_Leakage_Emissions	$b\rho X_T$
+ EOL_Non-Compliance_Emissions	$c\rho Y_T$
+ Decommissioning_Emissions (including handling)	$d(1-c)\rho Y_T$
+ Recovery_Emissions	$e(1-d)(1-c)\rho Y_T$
+ Destruction_Emissions	$f(1-e)(1-d)(1-c)Y_T$

Where

ρ is the GWP of the gas

a is the Installation Emissions Factor

b is the In-Use Leakage Factor

c is the EOL Non-Compliance Factor

d is the Decommissioning Emissions Factor

e is the Recovery Emissions Factor (= 1 / Recovery Efficiency)

f is the Destruction Emissions Factor

For details of the estimates used for these factors, by sector and gas type, please see Section B.5 of this Appendix.

B.2.3 Other Changes in Revised Banks Model – RAC Sectors

In addition to the points described above, the earlier model provided by ICF has been revised in the following ways.

Stationary Air Conditioning Sectors

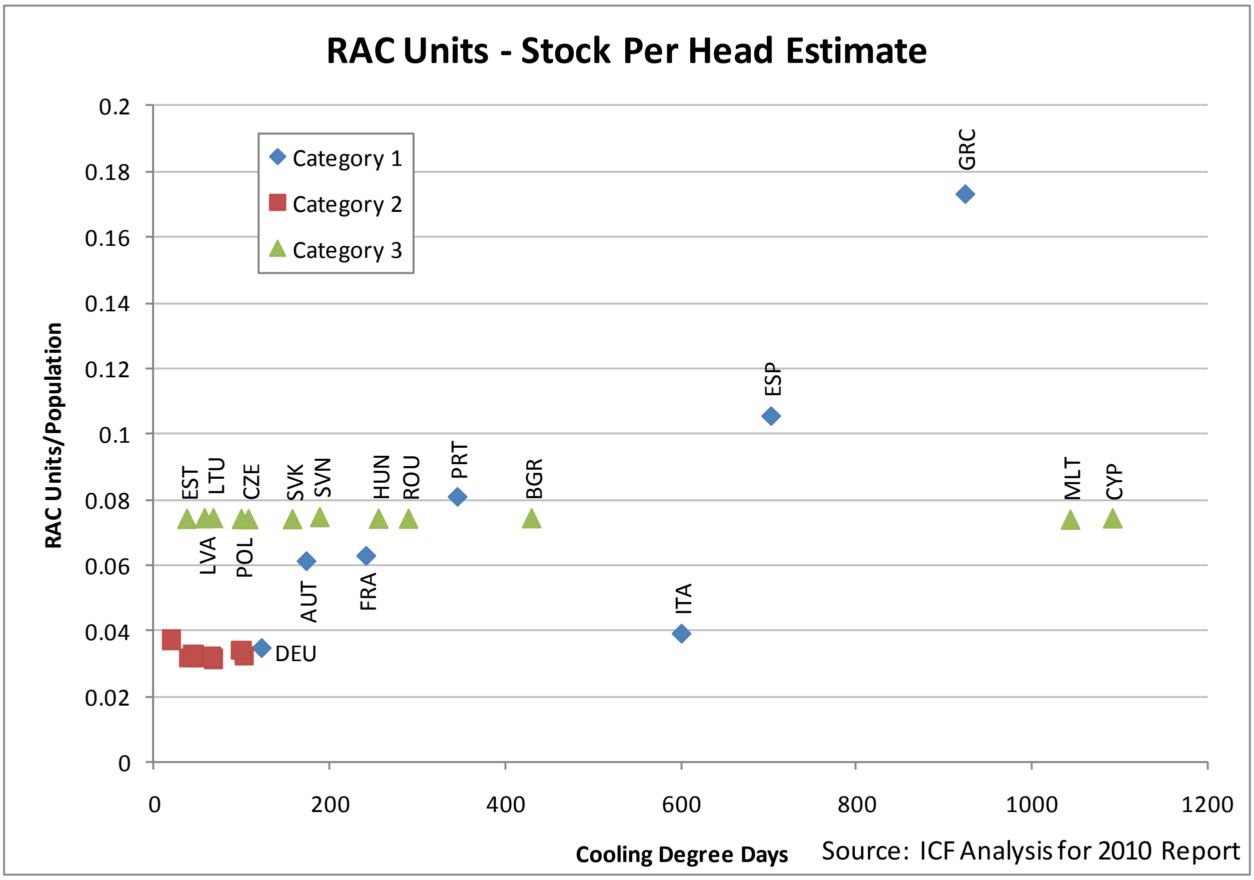
The ICF Model uses two end-use sub-sectors within the stationary air conditioning sector: (i) small / medium and (ii) large stationary air conditioning, defined as being below / above 75 kW cooling capacity respectively.

These are significant sectors due to their original size (in 2010) and the forecast growth to 2050, when they are forecast to account for 54% of the total RAC bank in GWP terms.

The underlying data indicates that the small / medium stationary air conditioning end-use sector includes small room air conditioning systems (<12 kW cooling capacity, in line with the EcoDesign Lot 10 definition) and medium-sized central air conditioning systems between 12 and 75 kW cooling capacity. The source information for the room air conditioning estimate is the "Energy Efficiency of Room Air-Conditioners" Report (CEECAP, 1999), which is based on a survey of sales data from 7 countries (Austria, France, Germany, Greece, Italy, Spain, and Portugal) from 1990 to 1996. This was then extrapolated to the EU12 member states based on population (ignoring any differences in climate or GDP). Figure B-3 shows the resulting installed base in terms of units per head against cooling degree days (a standard measure of annual air-conditioning load) for each Member State. The Member States are grouped by category as shown below.

Category 1	Country in original CEECAP 1999 report survey
Category 2	Other EU15 countries (BEL, DNK, FIN, IRL, LUX, NLD, SWE, GBR)
Category 3	EU12 countries

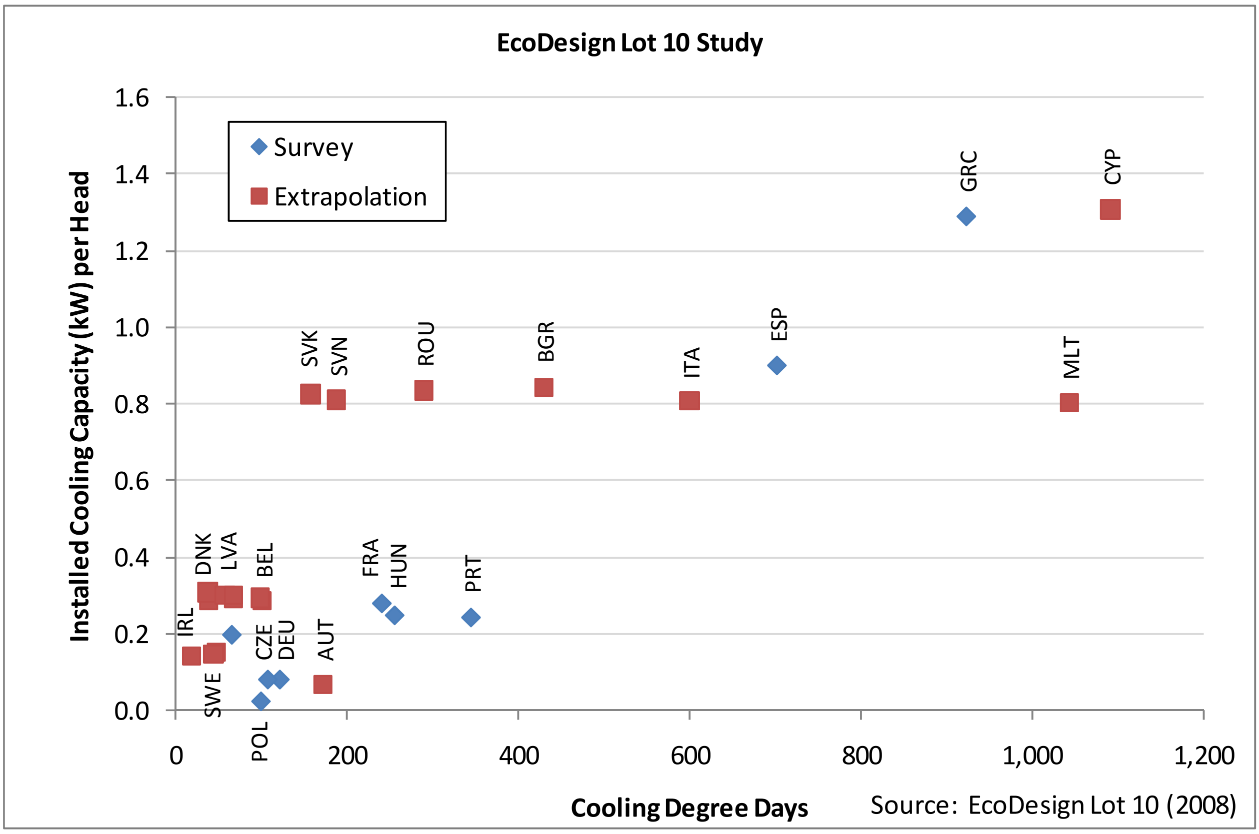
Figure B-3 – Room Air Conditioning Stock (Units per Head) from ICF Model



The graph shows a surprisingly low estimate for Italy, and the simplistic allocation method for the EU12 countries.

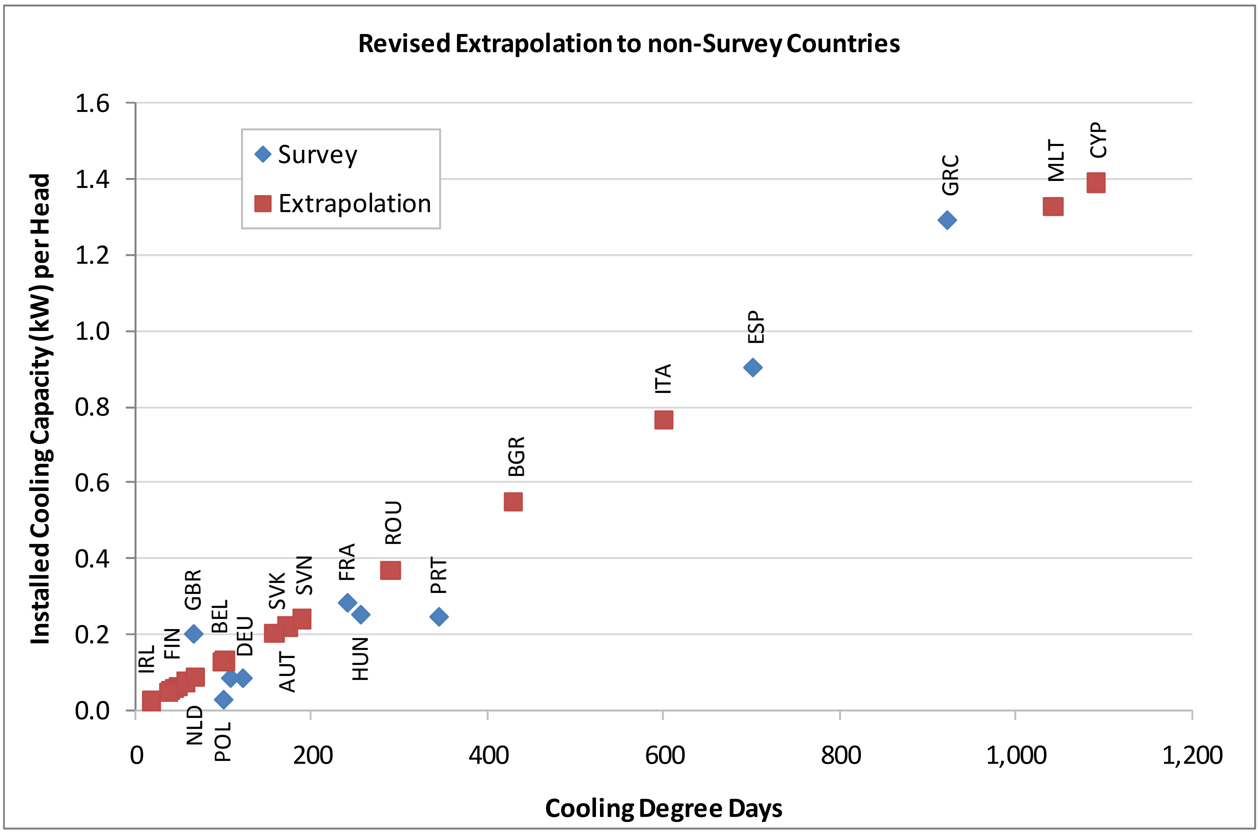
Due to the significance of this sector to the overall RAC bank, the project team has investigated a more recent bank estimate from the EcoDesign Lot 10 study, which itself uses 2002 and 2005 sales market data from BSRIA for 9 countries (FRA, DEU, GRC, PRT, ESP, GBR, HUN, CZE, POL). The EcoDesign study extrapolated this data to the other countries using Installed Cooling Capacity per Head and identifying "similar" countries. For example, Cyprus was given the same cooling per head as Greece (other pairings include Austria and Germany, Belgium and France). In addition, a group of EU12 countries were allocated a similar cooling per head as Italy. The chart in Figure B-4a shows this allocation of cooling per head to non-surveyed countries, in a comparison with Cooling Degree Days.

Figure B-4a – EcoDesign Lot 10 Allocation of Room AC Cooling Capacity



The EcoDesign Lot 10 allocation appears to give an unreasonable estimate for many EU12 countries (e.g. Slovakia and Roumania). As a result, the project team have used a revised extrapolation, based on Cooling Degree Days and Cooling per Head to estimate the cooling installed base in the non-surveyed countries – as illustrated in chart in Figure B-4b. This allocation (together with an estimated gas charge per kW cooling) is used in the Revised Banks Model for the small stationary air conditioning end-use sector (less than 12 kW cooling capacity).

Figure B-4b – Revised Bank Model Allocation of Room AC Cooling Capacity



[Note: The labels for a small number of data points in Figures B-4 a and b have been omitted, in order to maintain legibility.]

For the medium (12 to 75 kW cooling capacity) and large (above 75 kW) stationary air conditioning end-use sectors, the Revised Banks Model uses the 2009 installed base estimates from the ICF Model, but then uses the EcoDesign Lot 10 growth estimates to project this across the study period to 2050.

UK Industrial Sector

A data input error in the ICF model had allocated the UK a zero HFC bank for the industrial refrigeration sector. This has been corrected by making an allocation based on GDP, in line with the method applied to other countries.

R404A GWP

The ICF model had used a GWP of 3,138 for R404A. This was due to an error in an underlying spreadsheet. This has been corrected to the AR3 value of 3,784.

B.2.4 Outputs from Revised Banks Model – RAC Sectors

The model provides estimates of bank size, annual retirement from the bank, and annual emissions for each RAC end use sub-sector and the RAC total. These are given in terms of tonnes of gas, or in ozone depleting tonnes (TODP), or in kilotonnes of CO_2 equivalent ($kTCO_2$).

The charts in already presented in the main report show an example set of outputs for bank size (Figure 4-1), EOL retirements (Figure 4-2) and overall emissions (Figure 4-3). A comprehensive set of outputs for each RAC end use sub-sector are shown in Appendix C.

B.3 Revised Banks Model – Foam Sector

B.3.1 Description of Bank Dynamics – Foam Sector

Consistent with other internationally constructed models of foam banks, the SKM Enviros/Caleb Revised Banks Model is based on emission factors applied to the following phases of the lifecycle of insulating foam

- Manufacturing
- Installation
- Use phase
- Decommissioning
- Waste Stream

The manufacturing and installation emissions are often combined into a single loss estimate, frequently described as ‘first year losses’. This approach also allows for the consistent handling of those foam types which are generated on site (e.g. PU Spray Foams). Figure 5.2 illustrates the typical lifecycle of foam and highlights the significant emission points throughout.

In comparison with the RAC sector, the annual emission rates from foams during the use phase are significantly lower and, even though there is no top-up option, the products can reach end-of-life with significant residual blowing agent content. Indeed, it is important that foams retain their blowing agents since their low gaseous thermal conductivity delivers much of the energy saving properties of the foam. Owing to the long lifecycle of most construction foams, the overall quantity of blowing agent banked in products is of a similar order of magnitude to refrigerant in the RAC sector, although the mix of blowing agents is likely to contain a much higher proportion of ODS from older products still installed and in use.

Once the end-of-life phase is reached, the method of decommissioning and handling can influence the rate of blowing agent release significantly. Ironically, the processes that disturb the foam the least (e.g. landfill) can be the most environmentally beneficial in the short-term, although they only delay the ultimate release in the waste stream. Accordingly, if the method of decommissioning is chosen and managed carefully, the overall emissions can be greatly reduced even when anaerobic degradation of blowing agents is factored into the baseline.

The Revised Banks Model has considerable versatility in this end-of-life phase and models a mixture of up to four different decommissioning routes. These are:

- **Landfill**
- **Shredding without recovery** (sometimes used to access other resources)
- **Recovery** (including both mechanical recovery/destruction and direct incineration)
- **Re-use**

Emission rates from the bank in the waste stream vary depending on the decommissioning route chosen as shown in Table B-1 below:

Table B-1 Emission Factors in the waste stream

Route	*First Year (Initial) Loss*	*Annual Loss Rate*
Landfill	10-20%	0.5-1%
Shredding Without Recovery	20-25%	2%
Recovery	5%	Not applicable
Re-use	Not applicable	0.25-0.5%

There is also a facility to adjust for different assumptions about the level of anaerobic degradation that may take place in landfill. This facility, coupled with the adoption of a genuine time series methodology (as already described in Section B.1) provides a significantly more versatile approach. Within the Revised Banks Model, it is possible to set differing assumptions for each Member State, although this facility has not been applied in practice because the level of knowledge of current practices at end-of-life are not sufficiently quantified at Member State level to make the analysis reliable at this point. However, some of the data collection proposals reviewed in Section 5 could be helpful in informing future analyses at Member State level.

B.3.2 Geographic Distribution of Foam Banks in the EU

Insulating foams compete with a number of other forms of insulation material, with the most notable competitor being mineral fibre (both glass and rock). Choices depend heavily on building type, methods of construction, the prevailing climate and energy saving regulations – all of which vary by Member State. It is therefore expected that the distribution of insulation foam across Europe is not uniform. The consultancy company IAL produces an assessment of the European Insulation markets at country level on a regular basis and the project team has used these studies (latest in 2008) to characterise the following geographic differences:

- Variation in the use of thermal insulation by country
- Variation in the choice of foam versus fibre by country
- Variation in the use of foam technologies previously dependent on ODS by country

Figure B-5

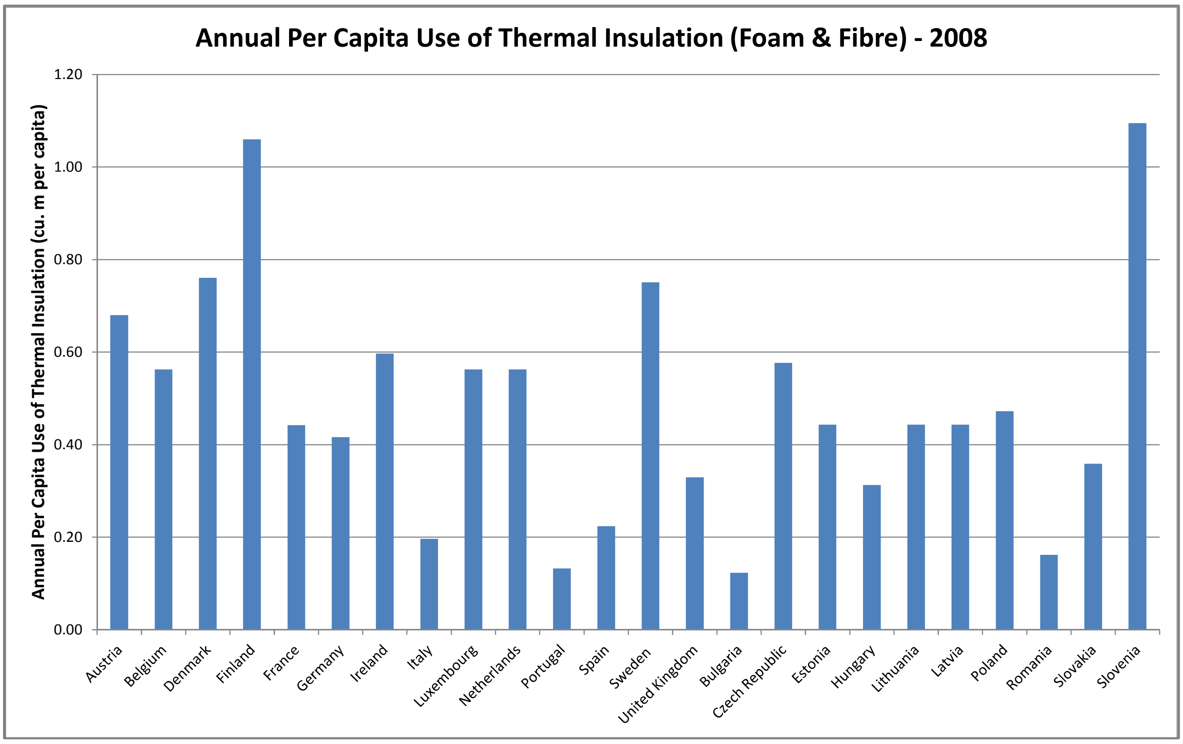


Figure B-5 shows that the Scandinavian countries tend to use the most insulation per capita, although Slovenia seems to provide an exception to the general trends observed. The choice of foam insulation as a percentage of the total is shown below:

Figure B-6

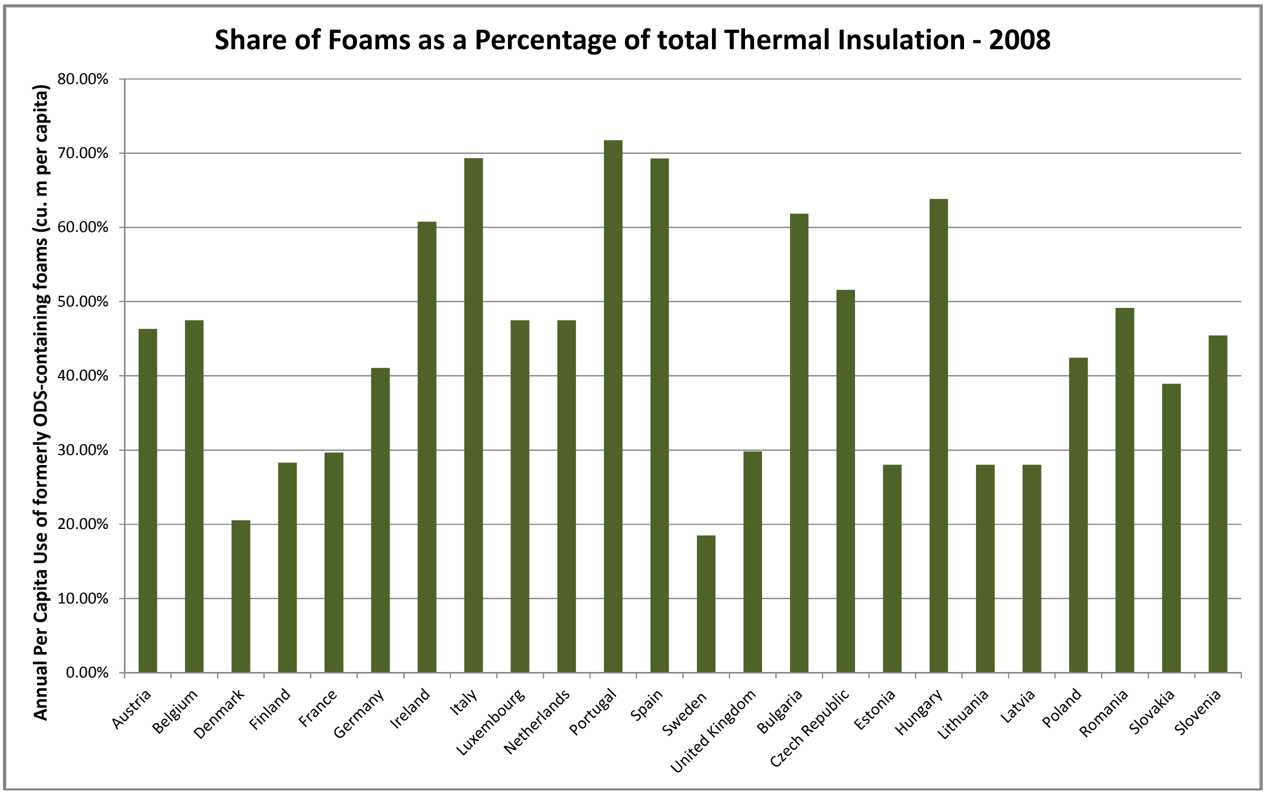
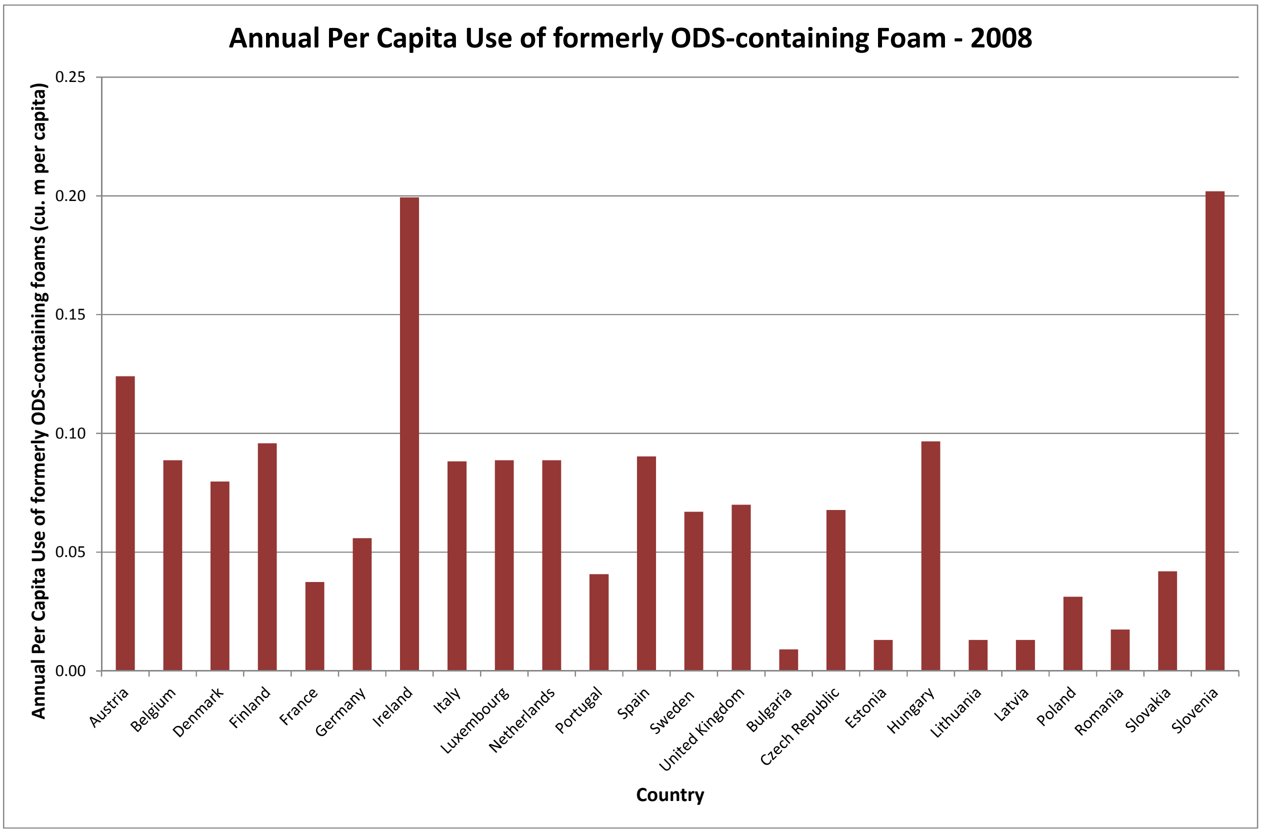


Figure B-6 shows that the Scandinavian countries tend to use the lowest proportion of foams, based largely on the fact that most residential construction is timber-framed and does not have constrained cavity sizes. By contrast, the use of foams is at its greatest where temperatures are higher and moisture levels can be more of an issue. Although the percentage of foams in Germany is in excess of 40%, the actual proportion of the overall thermal insulation market that was previously based on ODS was less than 14%, illustrating the fact that expanded polystyrene (EPS) continues to be a major part of the product mix in Germany. This is not consistent across all Member States as perspectives on the use of EPS in buildings vary considerably depending on the test methods used to define fire standards and regulations. As the EU-27 slowly proceeds towards harmonisation of fire standards, this variation may diminish. However, it will certainly have been an incremental factor in the distribution of ODS-containing foams over the period when the banks were developing.

Figure B-7 illustrates the actual thermal insulation sales in 2008 which are based on formerly ODS-dependent product types:

Figure B-7

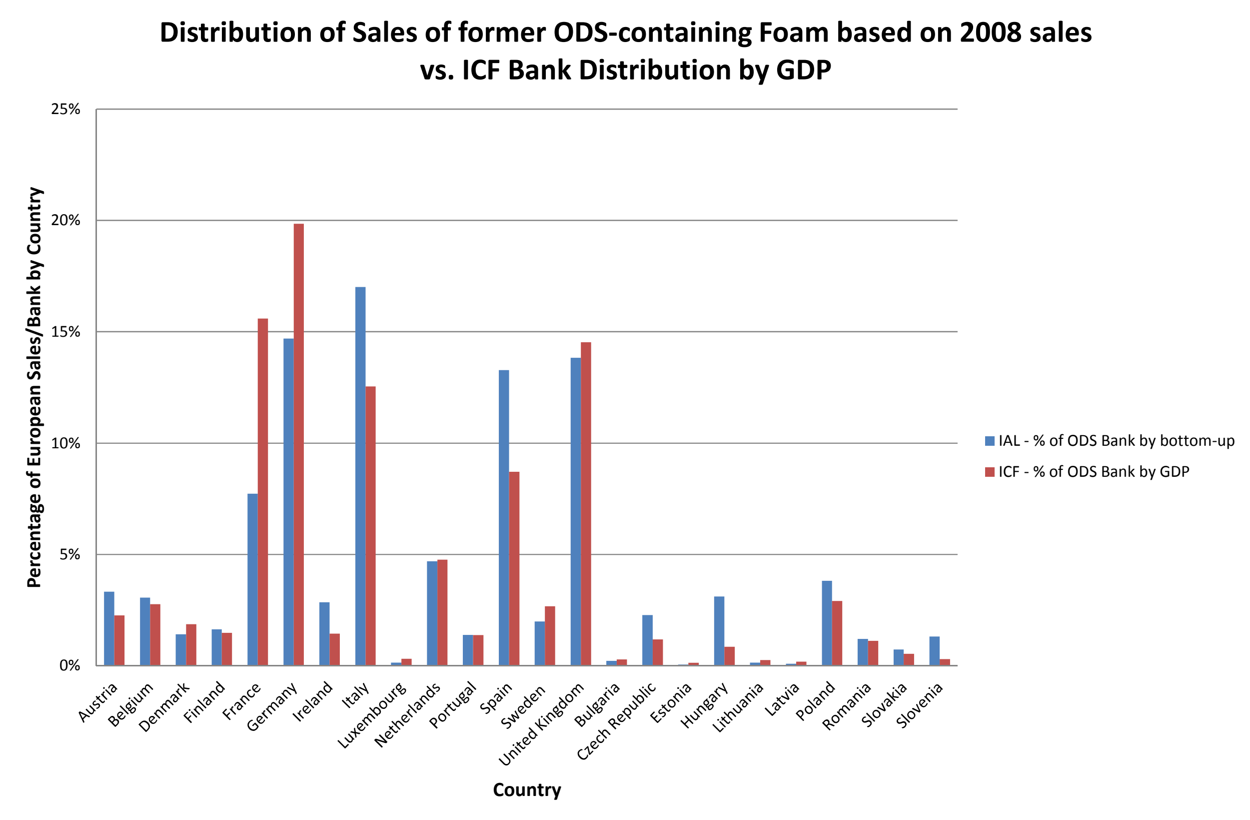


The Irish figure in Figure B-7 reflects the tail end of the property boom in the country and this may also explain the Slovenian figure. However, a more significant reason why Ireland stands out in this particular graph is the prevalence of use of polyurethane and polyisocyanurate, driven in turn by the influence of major polyurethane manufacturers in Ireland such as Kingspan.

It is also interesting to note that most Eastern European countries tend to have relatively little demand for these foams, with much of the limited insulation used coming from fibrous insulation suppliers, largely because of cost.

With these sources of variation in mind, it might be expected that the correlation between the ICF method of distribution of ODS banks based on GDP and the bottom-up assessment based on thermal insulation usage patterns and product mix, might be limited. However, Figure B-8 illustrates that some of the factors probably counter-act one another:

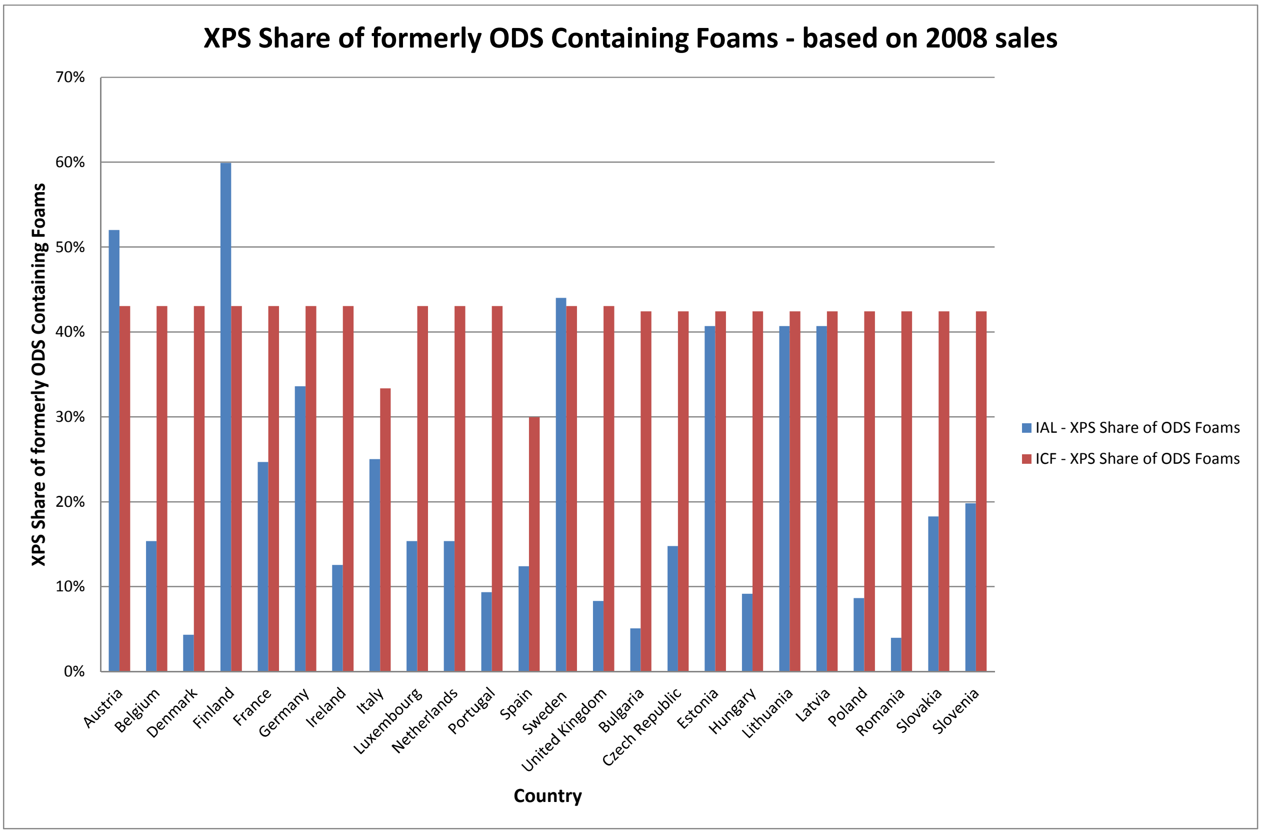
Figure B-8



Although real caution must be exercised in comparing 2008 sales distributions with distributions based on historic bank development, the comparison also reveals that the ICF approach has under-estimated the size of the ODS banks in Southern Europe (e.g. Italy and Spain) and, most notably, over-estimated them in France and Germany. The United Kingdom figure is interesting in that the correlation seems, at first glance to be reasonably good. However, the growth in former-ODS using foams between 2001 and 2008 was dramatic because of switches from fibre to foam during that period, as insulation requirements in cavities became too great to be met by fibre alone. Had the graph above been plotted against 2001 data for the United Kingdom, its share of the ODS bank would have been less than 5% based on that figure, amounting only to 41,750 tonnes in total. Again, this highlights the care that needs to be exercised in using 2008 data to assess bank historic ODS bank sizes.

The final part of this analysis is the effective level of competition between formerly ODS-containing foam types (e.g. polyurethane versus extruded polystyrene versus phenolic). As noted in an earlier paragraph, a significant factor in this trend at Member State level can be the attitude of the authorities to the fire risk presented by these material types. Figure B-9 illustrates the specific impact that these attitudes have on the selection of XPS, which in most other respects is an efficient and cost-effective thermal insulation option.

Figure B-9



This represents the most significant development from the ICF model, since ICF assumed that the split of foam banks between ODS using product types was consistent for each Member State in the EU15 and, based on a slightly different ratio, for each Member State in the EU12. The only exception to this fixed approach was for Italy and Spain because of the known reliance on PU Spray Foam in those countries.

As it can be seen from the graph, with the exception of Austria, Finland and Sweden, the XPS share of the market demonstrated by the IAL data is considerably lower than that predicted by ICF, which reinforces the belief that the XPS bank has been over-estimated in the ICF work. The most likely cause of this is that the split was extrapolated from a country in which XPS was more accepted than is reflected by the actual European average.

In summary, the Revised Banks Model has tried to take these factors into account by offering a geographic assessment based on the IAL distribution, but this remains subject to further refinement as new country-level information comes to light.

B.3.3 Emissions Factors – Foam Sector

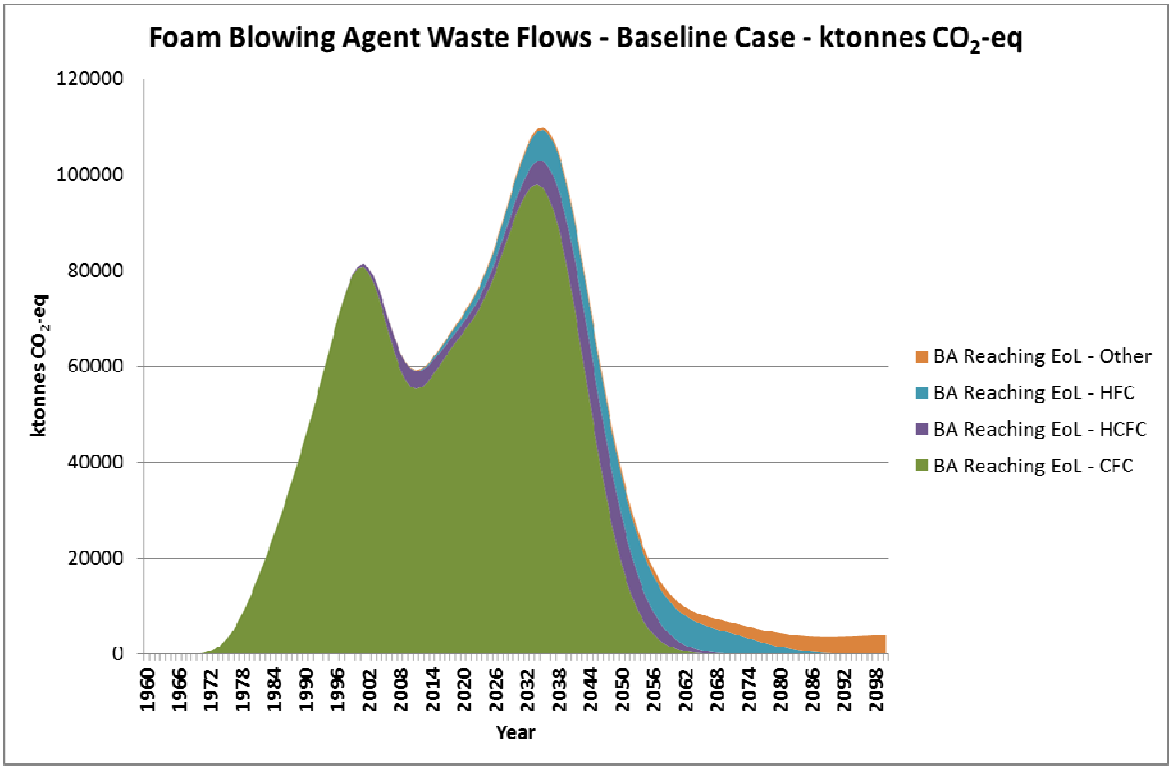
Both the ICF Report and the Revised Banks Model use the 2006 IPCC National Greenhouse Gas Inventory Guidelines as their primary source of emission factors for ‘first year’ and annual use phase losses, leading to a similar prediction for the amount of blowing agent remaining in a foam at the point of decommissioning.

At that point, ICF introduces a generic ‘technically recoverable’ factor for each of the five primary foam product types that it considers (see table 15 on page 39 of ICF,2010). This scales down the available blowing agent for recovery for each product type. Since this is applied by product type rather than application area (e.g. walls, roofs or floors), it must necessarily take an average based on which applications are most prevalent for a product type. However, this is an implicit adjustment in the ICF approach rather than an explicit one.

By contrast, the Revised Banks Model has sub-divided a number of product types (e.g. PU Continuous Laminate, XPS Board and PF Continuous Laminate) into application sub-sectors in order to allow a more focused approach to assessing the ability to technically recover blowing agent. Understandably, there is not sufficient bottom-up information at European or Member State level to fully populate such a model with referenced assumptions. Therefore, the project team used a detailed assessment of the UK market (Construction Markets, 2008) as an initial proxy for the EU-27. The details of the resulting assumptions used for sub-dividing the product groups are shown in Section B.5 of this Appendix along with the more general emission factors adopted from the 2006 IPCC Guidelines.

The over-riding influence on the application of emission factors remains the impact of a fully consistent time series throughout the model, as detailed in Section B.1. For the foam sector, this is particularly important because it leads to the so-called double-hump in the rate of gas entering the waste stream, as shown in Figure B-10. The graph plots the quantity of blowing agent arising annually in the waste stream following decommissioning by blowing agent type. Such a phenomenon was not evident from the ICF modelling work because of the sequential exponential decay approach shown in Figures B-1 and B-2.

Figure B-10

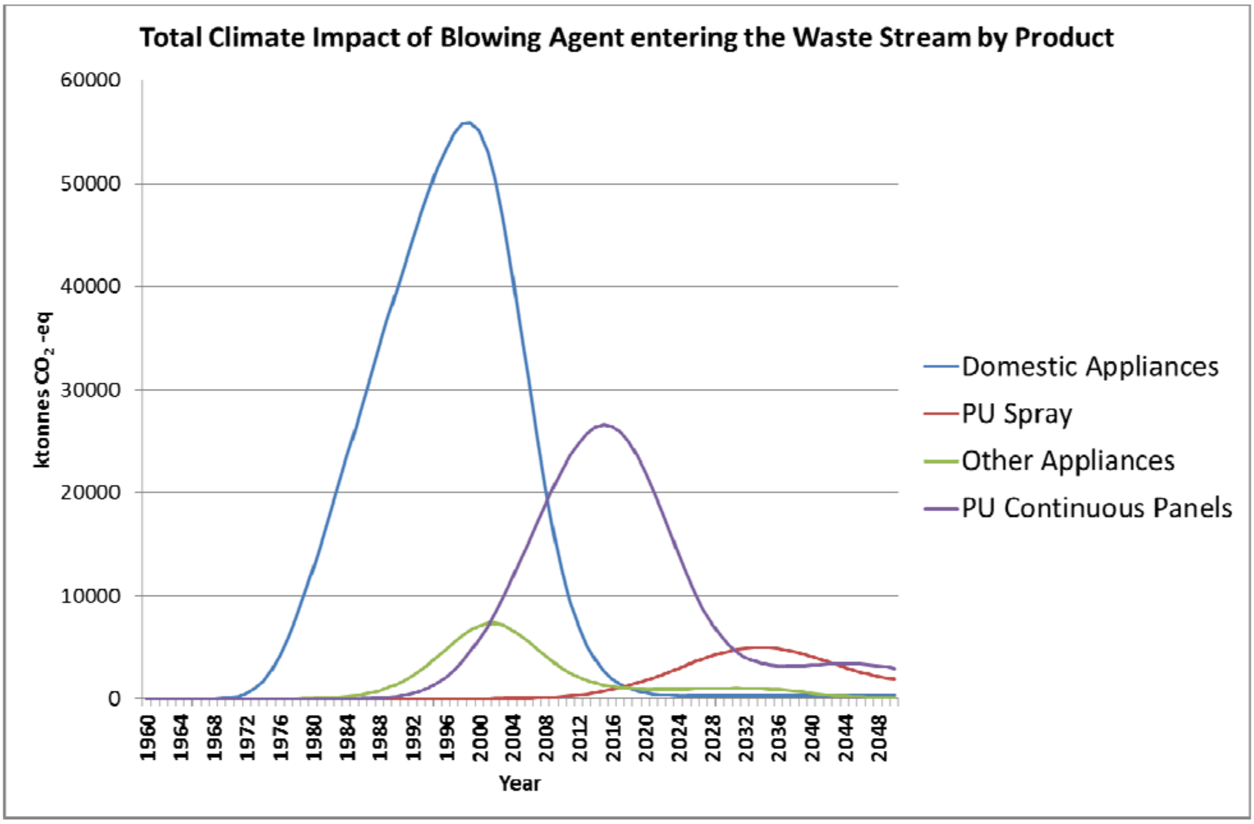


B.3.4 Other Changes to ICF model – Foam Sector

Comparing Figure B-10 with versions of the 'double-hump graph' shown in TEAP's response to Decision XX/7 and elsewhere, it can be seen that the two humps are rather closer together than was previously the case, meaning that the depth of the 'valley' occurring in the period between 2008 and 2015 is less pronounced. The reasons for this are two-fold:

- Firstly, the decision to adopt a Poisson distribution around the lifecycles of all product types means that there is an impact on the assumed period of use of insulation foams in appliances and in the construction sector, thereby essentially extending the shorter lifecycle (at least in part) and reducing the longer lifecycle (at least in part).
- An additional factor, however, was a decision to reduce the average lifecycles of metal-faced panel products from 50 years to 30 years. This was agreed on the basis of anecdotal evidence that has been continuing to emerge from this product sector over the last five years and which seems to be fairly consistent across Europe, where these panels are typically used in steel-framed buildings which can be re-clad periodically through their lifecycles. Figure B-11 illustrates both the Poisson distribution assumption and the change in assumed average lifecycle for selected product types.

Figure B-11


Total Climate Impact of Blowing Agent entering the Waste Stream by Product
ktonnes CO_2 -eq
60000
50000
40000
30000
20000
10000
0
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
2024
2028
2032
2036
2040
2044
2048
Year
Domestic Appliances
PU Spray
Other Appliances
PU Continuous Panels

B.3.5 Outputs from the Revised Banks Model – Foam Sector

Figure B-10 already indicates that the blowing agent entering the waste stream has an ODS content throughout the study period (i.e. to beyond 2050) based on the average lifetime of construction foam products. Even then, it should be noted that much of the blowing agent will pass through the decommissioning phase and will enter the waste stream 'intact' – thereby creating a new bank in the waste stream. Therefore, when speaking about the overall blowing agent bank in foams, it is important to be precise about whether only banks in use-phase products are being addressed (i.e. those that are still recoverable) or whether there is a reference to the total blowing agent consumed, but yet to be released (the formal definition of a bank). Figure B-12 illustrates the difference between the trends in the two parameters in the period 2000-2050 and illustrates that over 3 billion tonnes CO_2-eq of blowing agent may be in the waste stream, but not released, by 2050 based on a business as usual scenario. This baseline assessment does not take into account any blowing agent which might subsequently decompose through anaerobic degradation.

Figure B-12 Total Bank versus Bank in Product (kT CO_2)

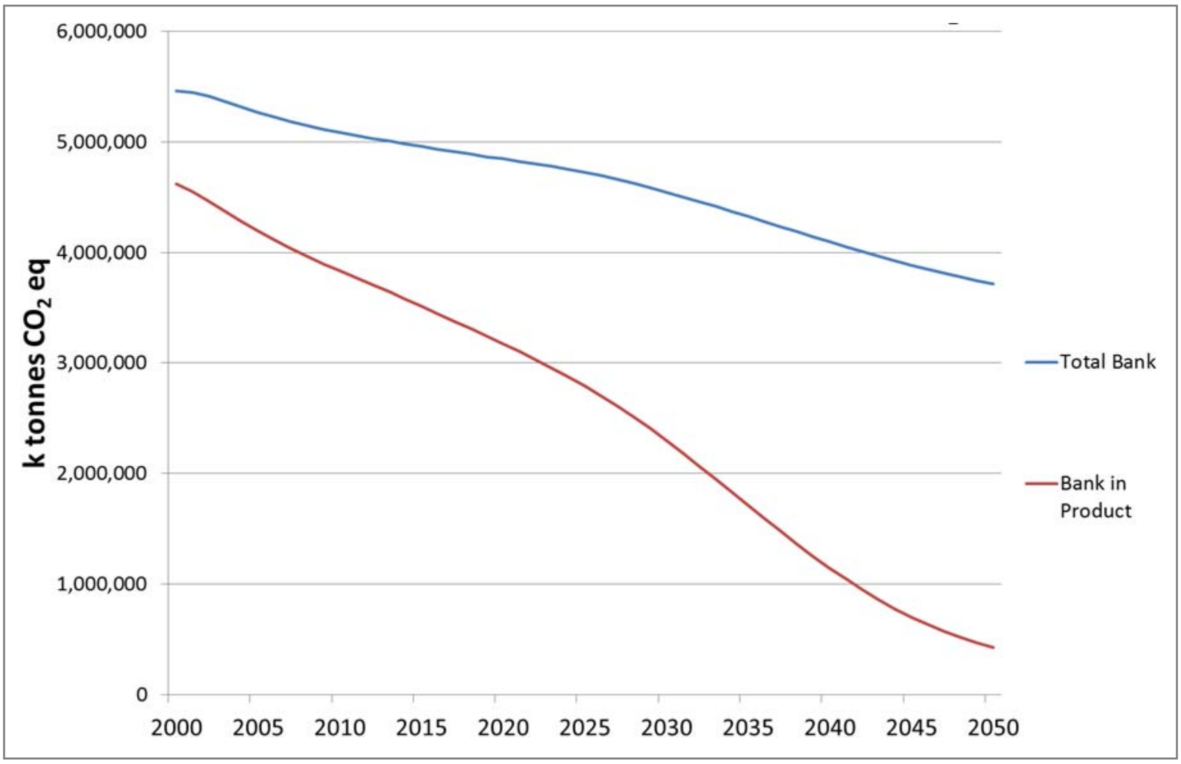


Figure B-12 also illustrates that most of the high GWP blowing agents will be out of the product bank by 2050 with the exception of some HFC-containing construction foams, as also illustrated in Figure B-10.

Consistent with the dataset provided for refrigerants, the following graphs (Figures B-13, B-14 and B-15) illustrate the trends in banks (both total bank and bank in product), waste stream flows and emissions in tonnes, ODP tonnes and k tonnes CO_2 .

Figure B-13 Total Bank (foams)

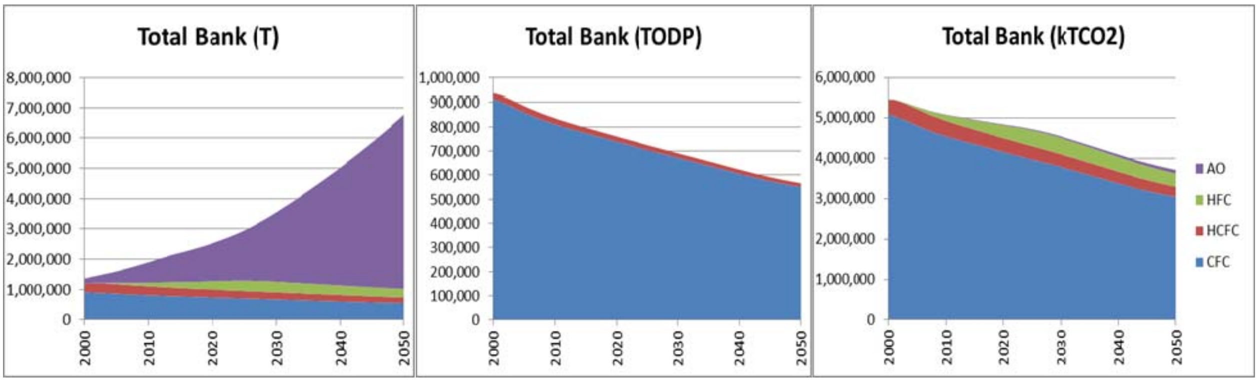
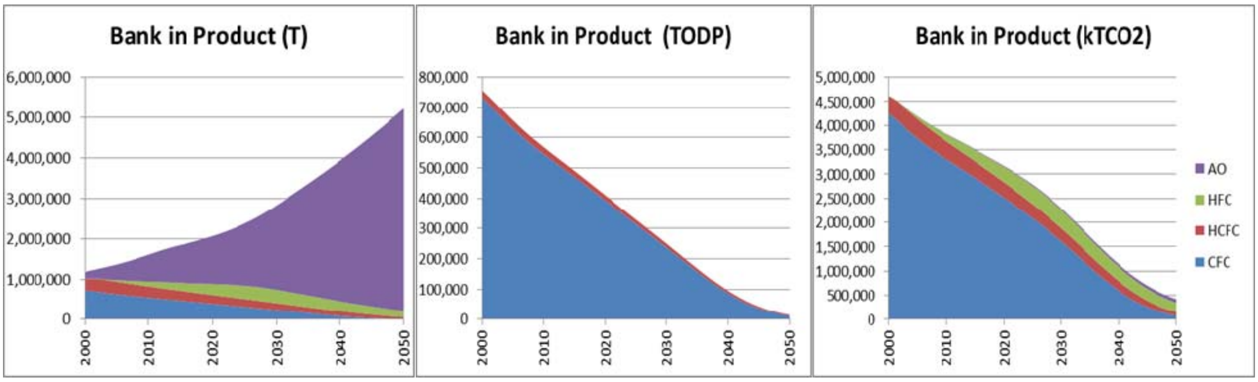
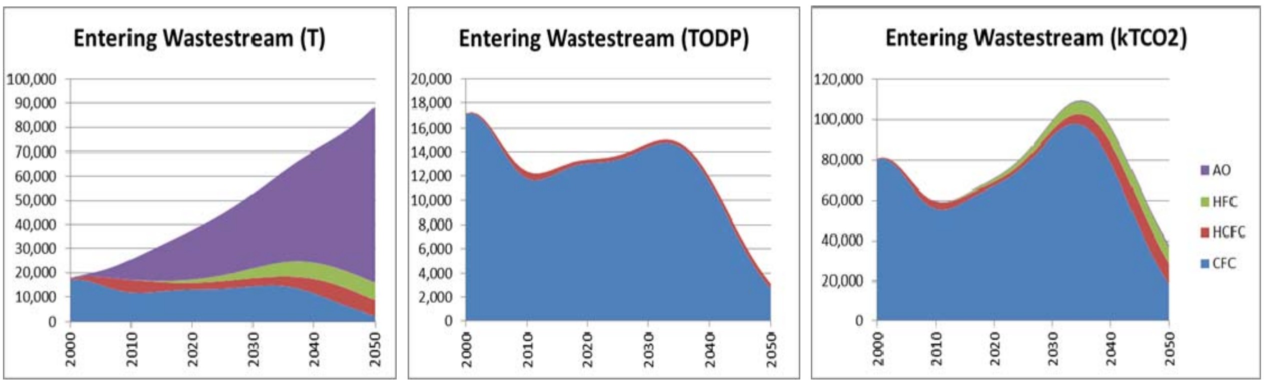


Figure B-14 Bank in Product Use-Phase (foams)



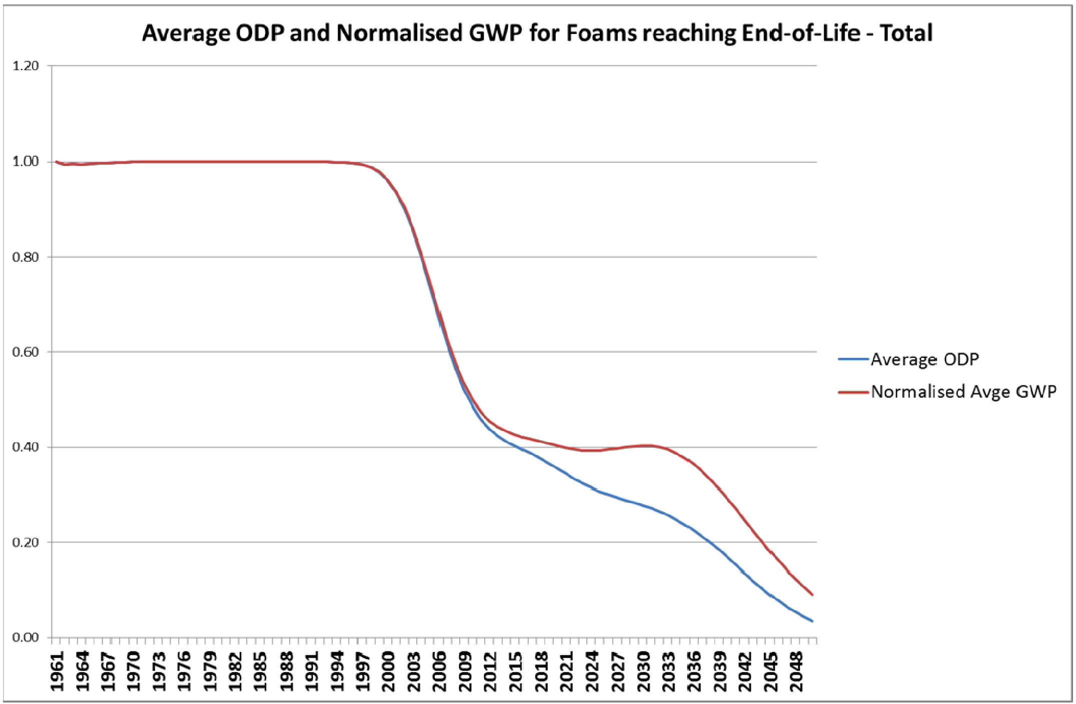
These two sets of graphs largely mirror the trends shown in Figure B-12 but provide more information on the mix of blowing agents making up the banks and the absolute tonnages of high GWP blowing agents in the banks in product. This figure is now believed to be below 1 million tonnes, although representing some 4.5 billion tonnes CO_2 based on the high proportion of CFCs still contained in the bank currently.

Figure B-15 Gas Entering Waste Stream (foams)



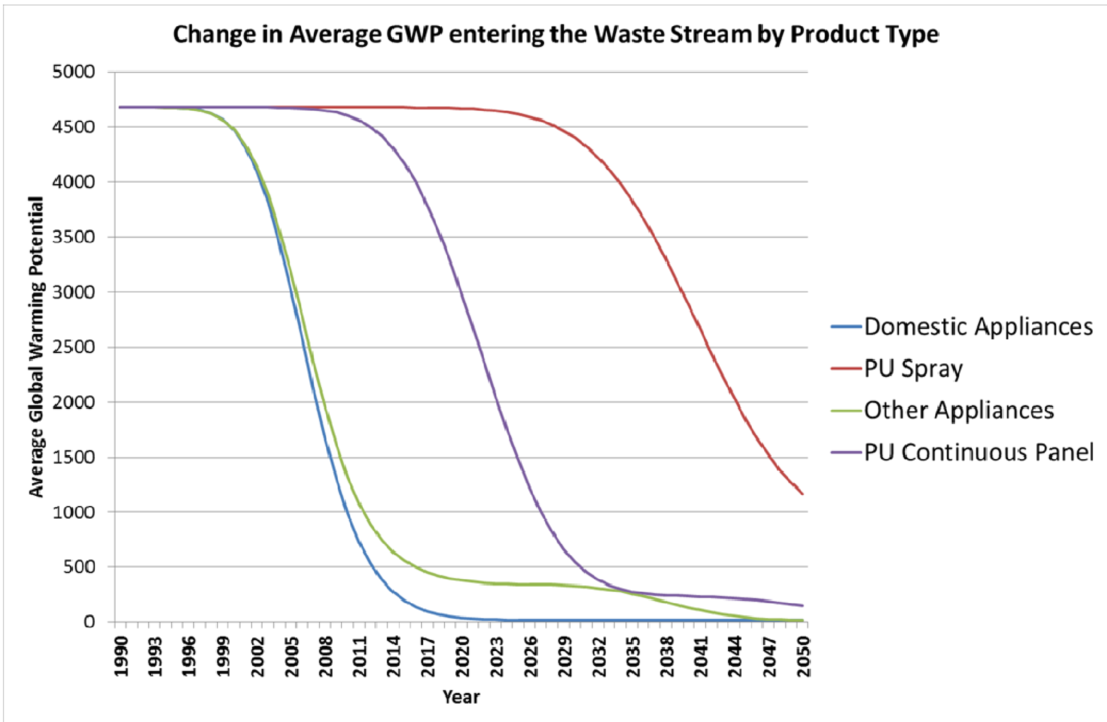
As expected, these graphs illustrate the source of the 'double-hump' in Figure B-10 well. However, the primary point to note is the growth in 'All Other' blowing agents (notably hydrocarbons) entering the waste stream from 2000 onwards. Since most decommissioning facilities at end-of-life will not be able to determine blowing agent type easily, it should be expected that all construction foams will be processed simultaneously. Accordingly, the average ODP and GWP will decline over time, as illustrated in Figure B-15.

Figure B-15



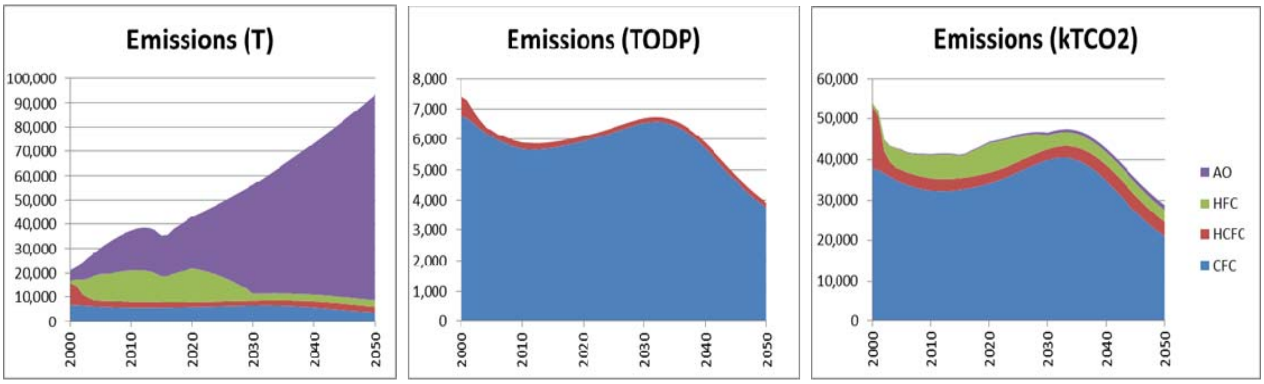
This decline will vary in timing and magnitude depending on the product type and alternative blowing agent selected, as shown in Figure B-16.

Figure B-16



The resulting baseline emissions from the Revised Banks Model are shown in Figure B-17

Figure B-17 Emissions to Atmosphere (foams)



It is worth noting that emissions remaining largely constant in the period from 2000 to 2040 being between 40 and 50 million tonnes CO_2 annually for all foams across the EU-27, even though the make-up of the sources (e.g. manufacturing losses for HFCs changes with time. To bring this into perspective, the annual refrigerant losses for the same period are shown to be between 100 million and 200 million tonnes CO_2. – i.e. between a factor of 2 and 4 larger.

B.3.6 Mitigation Scenarios and the determination of cost effectiveness

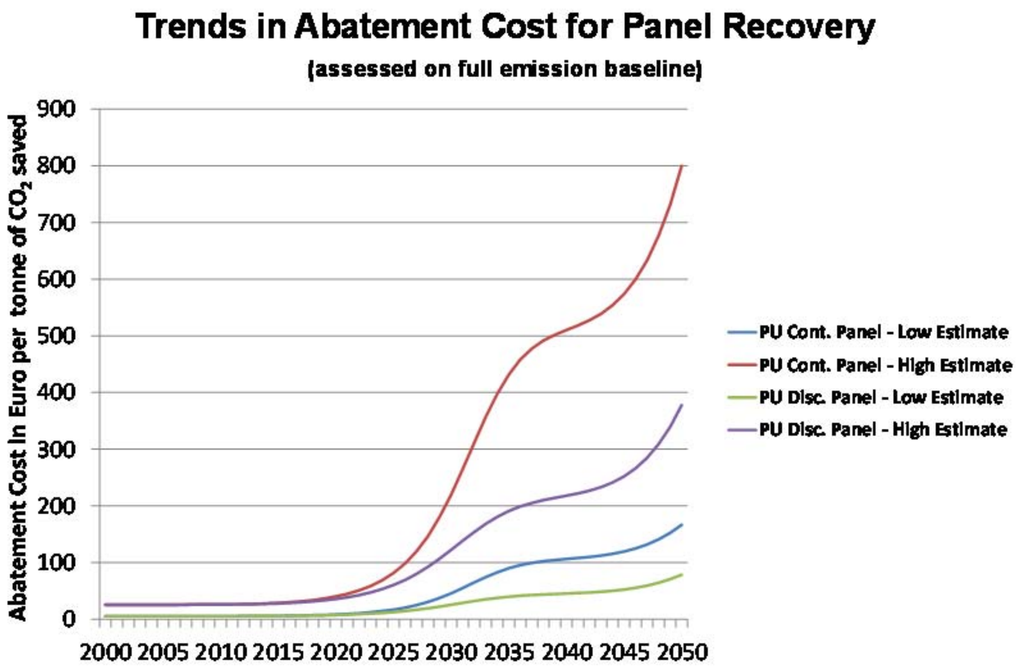
Section 5 of this Report provides an assessment of eight policy options in the foams sector which offer potential emissions savings over the period to 2050. Five of these relate to direct end-of-life measures. However, in contrast to emissions savings made in the RAC sectors, these savings are not instantaneous, since the baseline emissions against which they are assessed are spread over an extended period (owing to the slow release of gas from waste foam in landfill sites). Consequently, the calculation of the average abatement cost has to take into account the following:

- The blowing agent from most foam types will not be emitted in total within the period to 2050 in the baseline case
- Actions to mitigate emissions taken in one period will deliver abatement in subsequent periods. Therefore assessments will understate environmental benefits and over-state environmental costs in the earlier phases while over-stating benefits and understating costs in later periods.
- As a further influence on average abatement cost, the average GWP of waste streams will almost invariably decrease with time

When approaching an assessment of cost abatement, it is therefore vitally important to define the criteria by which it is determined. To be consistent with the terms of reference of this project, the approach taken has been to derive average abatement cost values using NPV values based on 4% depreciation for both costs and savings. However, this approach can hide some trends which may be important in a policy setting. In the following paragraphs, the example of steel-faced panels is used to illustrate these factors.

Adopting the RAC approach of total loss in the year of decommissioning as the baseline, Figure B-18 shows that a very wide range of abatement costs can be achieved depending on the specific blowing agent selections made. The graph reflects the differences between continuous and discontinuous panels as well as the range of 'per kg' recovery costs identified for panels.

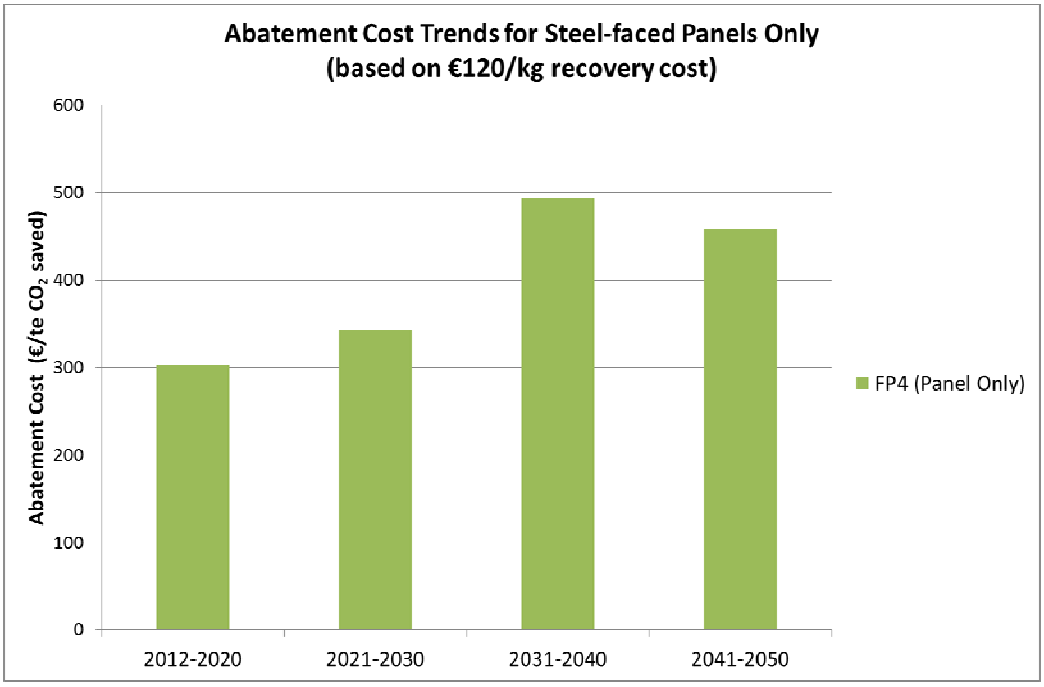
Figure B-18 – Trends in Abatement Costs for Panels



KEY:
"Cont." = "Continuous; "Disc." = "Discontinuous"
Low and High Cost Estimates are based on recovery costs of €25 and €120 per kg of blowing agent respectively

However, once weighted averages are applied for the mix of blowing agents arriving in the waste stream the trends are less intuitive. Figure B-19 shows the outputs for steel-faced panels with average abatement costs assessed in ten year periods.

Figure B-19 – Trends in Abatement Costs for Panels



In this instance, it can be seen that cost effectiveness is at its best in the early part of the period (2012-2020) as would be expected when the CFC content is at its most significant. Average abatement costs then drift up through the following decades because of changes in the blowing agent mix and a lowering of the average GWP, even though savings are still being made in baseline emissions in these subsequent periods from measures taken in the 2012-2020 period.

When the average GWP finally begins to plateau in the 2041-2050 period, the savings still accumulating from the earlier measures related to CFC emissions begin to dominate and the average abatement cost for 2041-2050 is lower because of these cumulative effects, despite the fact that the current waste stream has an even lower average GWP than previously.

B.4 GIS

The original ICF bottom-up model did not include GIS. We have now added country estimates for GIS installed banks using the 2007 EU-wide estimate from the Ecofys report on SF_6 emissions (increased by 3% p.a. to 2010). The bank has been apportioned according to electrical consumption data (Eurostat). The current forecast is for this bank to increase in line with forecast growth in electricity generating capacity throughout the forecasting period.

Figure B-20 Bank Size (GIS)

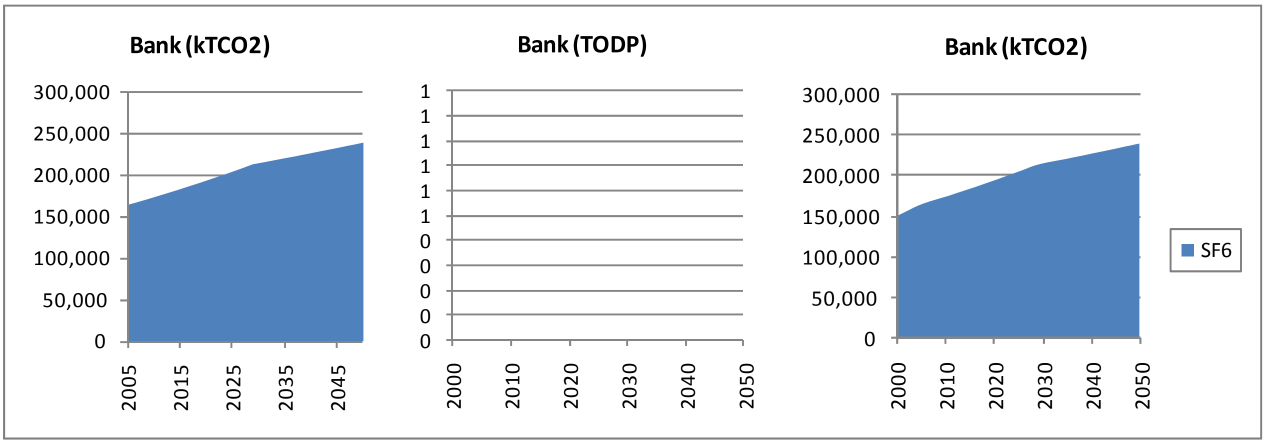
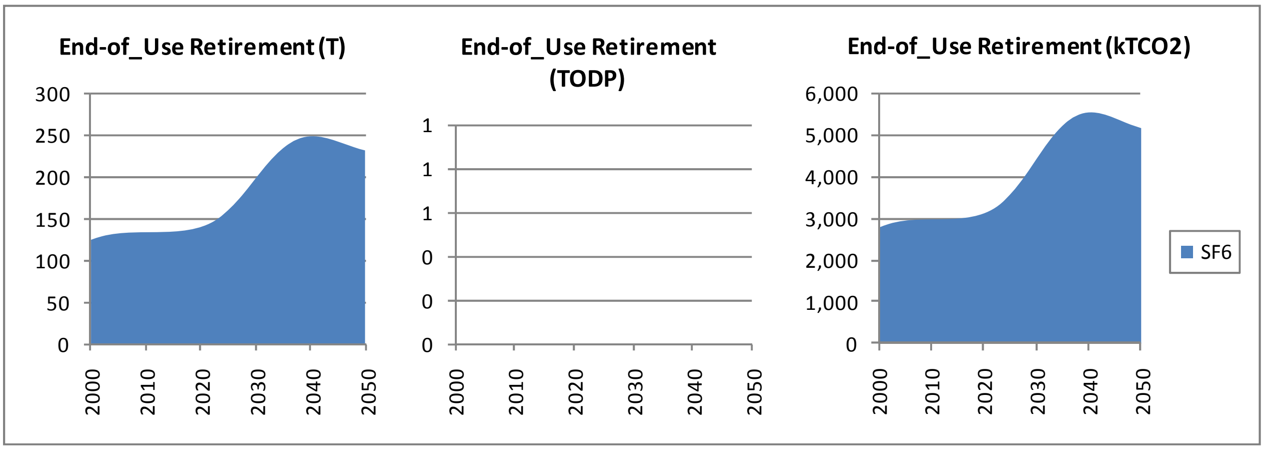
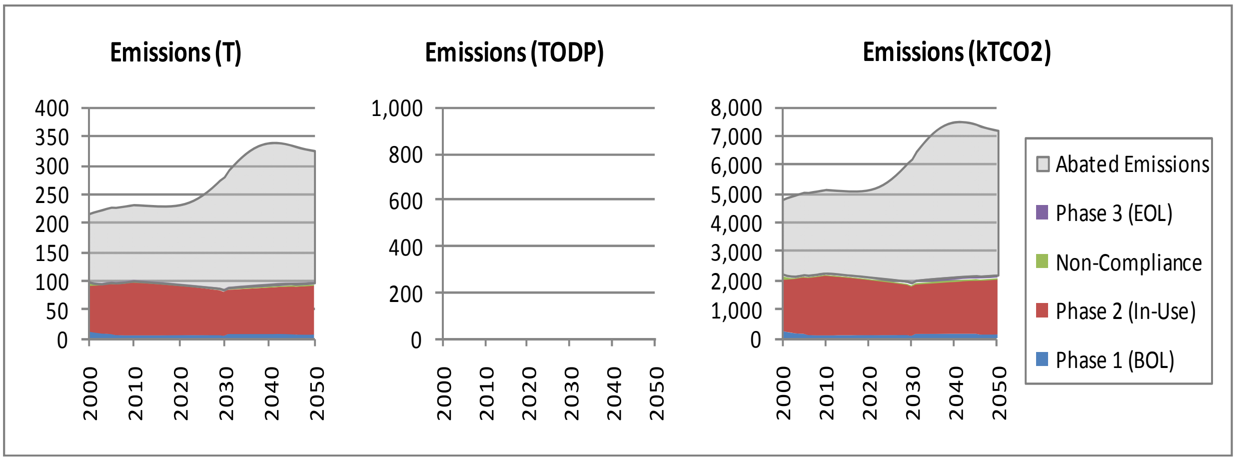


Figure B-21 Gas Reaching EOL Retirement from the Bank (GIS)



The increase in SF6 reaching EOL retirement from the GIS bank after 2020 is a function of the average life of the GIS products (40 years) and the start of significant use (in the 1970s and 80s).

Figure B-22 Potential Emissions from Bank (GIS)



B.5 Assumptions and Factors Used in Cost Benefit Analyses

The following sections show the estimated emission factors and implementation costs used in carrying out the cost benefit analysis of the shortlist policy options. For each policy option, the following information is given:

- Policy title
- Brief description
- Cost factors – One-off costs, ongoing costs and an aggregate measure (in 2012 net present value terms) are shown for different market agents: e.g. the European Commission (including other EU bodies), member state governments, end-users, service providers and manufacturers.
- Annual quantities of gas retired from the bank and emission factors – These are shown where the “With Measures” case differs from the “Without Measures” case. The factors are not shown if the two cases are the same.
- Resulting change in aggregate emissions – This is shown in both graphical and tabular form.

B.5.1 RAC Measure 1: HCFC Phase-Out Emergency Measures

Title

1) HCFC Phase-Out Emergency Measures

Brief Description

Measures to minimise additional emissions which may arise due to deadline (end of December 2014) for use of HCFC refrigerants, such as:

- Awareness initiative – targeting end-users and contractors, to raise awareness of legal obligations and best practices
- Increased enforcement – policy measures are already in place, but policing could be improved to increase compliance

Costs

	One-off Costs (€M)	On-going Costs (€M/y)				NPV (€M)
Party	2012	2012	2013	2014	2015	2012
EU Commission	1.0	0.5	0.5	0.5	0.3	2
MS Governments	5.4	2.7	5.4	5.4	2.7	20.7

Assumptions

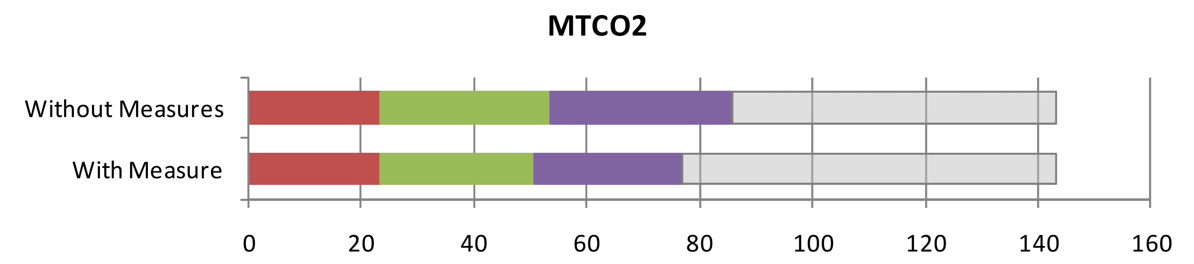
Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors							
	Without Measures				With Measure (1)			
End-Use Sector	2012	2013	2014	2015	2012	2013	2014	2015
Passenger Vehicle MAC	40%	40%	40%	30%	38%	34%	31%	30%
Buses MAC	27%	27%	27%	20%	25%	23%	20%	20%
Small AC	33%	33%	33%	25%	32%	28%	26%	25%
Medium AC	27%	27%	27%	20%	25%	23%	20%	20%
Large AC	20%	20%	20%	15%	19%	17%	15%	15%
Domestic Appliances	27%	27%	27%	20%	25%	23%	20%	20%
Small Commercial	33%	33%	33%	25%	32%	28%	26%	25%
Med/Large Commercial								
Medium Commercial (DX)	27%	27%	27%	20%	25%	23%	20%	20%
Large Commercial	27%	27%	27%	20%	25%	23%	20%	20%
Road Transport	27%	27%	27%	20%	25%	23%	20%	20%
Shipping	27%	27%	27%	20%	25%	23%	20%	20%
Industrial	27%	27%	27%	20%	25%	23%	20%	20%

	Decommissioning Emissions Factor							
	Without Measures				With Measure (1)			
End-Use Sector	2012	2013	2014	2015	2012	2013	2014	2015
Passenger Vehicle MAC	33%	33%	33%	25%	32%	28%	26%	25%
Buses MAC	20%	20%	20%	15%	19%	17%	15%	15%
Small AC	53%	53%	53%	40%	51%	45%	41%	40%
Medium AC	7%	7%	7%	5%	6%	6%	5%	5%
Large AC	7%	7%	7%	5%	6%	6%	5%	5%
Domestic Appliances	67%	67%	67%	50%	63%	57%	51%	50%
Small Commercial	67%	67%	67%	50%	63%	57%	51%	50%
Med/Large Commercial								
Medium Commercial (DX)	7%	7%	7%	5%	6%	6%	5%	5%
Large Commercial	7%	7%	7%	5%	6%	6%	5%	5%
Road Transport	20%	20%	20%	15%	19%	17%	15%	15%
Shipping	13%	13%	13%	10%	13%	11%	10%	10%
Industrial	7%	7%	7%	5%	6%	6%	5%	5%

	EOL Recovery Factor							
	Without Measures				With Measure (1)			
End-Use Sector	**2012**	**2013**	**2014**	**2015**	**2012**	**2013**	**2014**	**2015**
Passenger Vehicle MAC	64%	64%	64%	85%	67%	75%	83%	85%
Buses MAC	68%	68%	68%	90%	71%	79%	88%	90%
Small AC	64%	64%	64%	85%	67%	75%	83%	85%
Medium AC	68%	68%	68%	90%	71%	79%	88%	90%
Large AC	71%	71%	71%	95%	75%	84%	93%	95%
Domestic Appliances	64%	64%	64%	85%	67%	75%	83%	85%
Small Commercial	64%	64%	64%	85%	67%	75%	83%	85%
Med/Large Commercial								
Medium Commercial (DX)	71%	71%	71%	95%	75%	84%	93%	95%
Large Commercial	71%	71%	71%	95%	75%	84%	93%	95%
Road Transport	68%	68%	68%	90%	71%	79%	88%	90%
Shipping	71%	71%	71%	95%	75%	84%	93%	95%
Industrial	71%	71%	71%	95%	75%	84%	93%	95%

HCFC Only Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	23	23
Non-Compliance	27	30
Phase 3 (EOL)	26	32
Abated Emissions	66	58

B.5.2 RAC Measure 2: Extend EOL Obligations to Mobile Refrigeration Systems

Title

2) Extend EOL Obligations to Mobile Refrigeration Systems

Brief Description

- All stationary RAC has clear EOL requirements in current regulations
- Mobile applications have ambiguous requirement
  - recovery "technically feasible and does not entail disproportionate cost"
  - no doubts over technical feasibility – but could be doubts over cost effectiveness
- Recommendation for regulatory change
  - include all mobile RAC systems in Article 4.1
  - or provide clear guidance that recovery from these systems considered cost effective

Costs

	One-off Costs	On-going Costs			NPV
Party	**2012 - 2014**				**2012**
EU Commission	€ 3.5M	€ 0.5M/y			€ 3.3M
MS Governments	€ 6.8M	€ 2.7M/y			€ 6.4M
End Users (labour)	€ 0.0M	€ 2.5M/y			€ 60.3M
End Users (gas destruction) (€3/kg)		**2015** € 0.04M/y	Growing to	**2035** € 0.75M/y	€ 12.4M
Contractors (equipment)	€ 1.6M				€ 1.5M
Contractors (training)	€ 5.4M	**2015 to 17** € 0.5M/y	**2018 →** € 0.5M/y		€ 12.0M

Assumptions

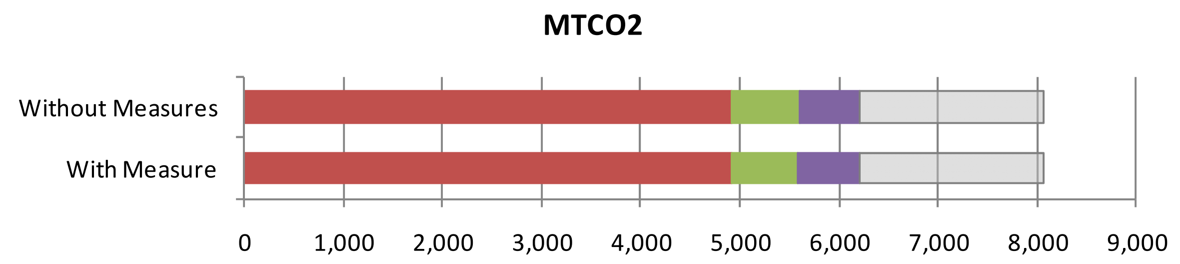
Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors							
	Without Measures				With Measure (2)			
End-Use Sector	**2015**	**2016**	**2017**	**2018→**	**2015**	**2016**	**2017**	**2018→**
Passenger Vehicle MAC	30%	30%	30%	30%	30%	30%	30%	30%
Buses MAC	20%	20%	20%	20%	16%	13%	10%	8%
Road Transport	20%	20%	20%	20%	18%	16%	15%	13%
Shipping	20%	20%	20%	20%	18%	16%	15%	13%

	Decommissioning Emissions Factor							
	Without Measures				With Measure (2)			
End-Use Sector	**2015**	**2016**	**2017**	**2018→**	**2015**	**2016**	**2017**	**2018→**
Passenger Vehicle MAC	25%	25%	25%	25%	25%	25%	25%	25%
Buses MAC	15%	15%	15%	15%	15%	15%	15%	15%
Road Transport	15%	15%	15%	15%	15%	15%	15%	15%
Shipping	10%	10%	10%	10%	10%	10%	10%	10%

	EOL Recovery Factor							
	Without Measures				With Measure (2)			
End-Use Sector	**2015**	**2016**	**2017**	**2018→**	**2015**	**2016**	**2017**	**2018→**
Passenger Vehicle MAC	85%	85%	85%	85%	85%	85%	85%	85%
Buses MAC	90%	90%	90%	90%	90%	90%	90%	90%
Road Transport	90%	90%	90%	90%	90%	90%	90%	90%
Shipping	95%	95%	95%	95%	95%	95%	95%	95%

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	4,921	4,921
Non-Compliance	673	685
Phase 3 (EOL)	611	609
Abated Emissions	1,867	1,857

B.5.3 RAC Measure 3: Mirror EOL Obligations for Contractors

Title

3) Mirror EOL Obligations for Contractors

Brief Description

- Current EOL recovery obligation for stationary RAC applications is placed on end users via Article 4.1
- Recommendation:
  - Place a “mirror” legal obligation on contractors
  - Could avoid the situation where contractors are influenced by end users to vent gas during equipment decommissioning
  - In many RAC markets, easier to police contractors than end users

Costs

	One-off Costs	On-going Costs				NPV (€M)
Party	**2012 to 2014**	**2015**	**2016**	**2017**	**2018→**	**2012**
EU Commission	€ 10.1M					9.7
MS Governments (set-up)	€ 54.0M					67.1
MS Governments (enforcement)	€ 0.0M	€ 5.4M/y	€ 5.4M/y	€ 5.4M/y	€ 2.7M/y	51.9

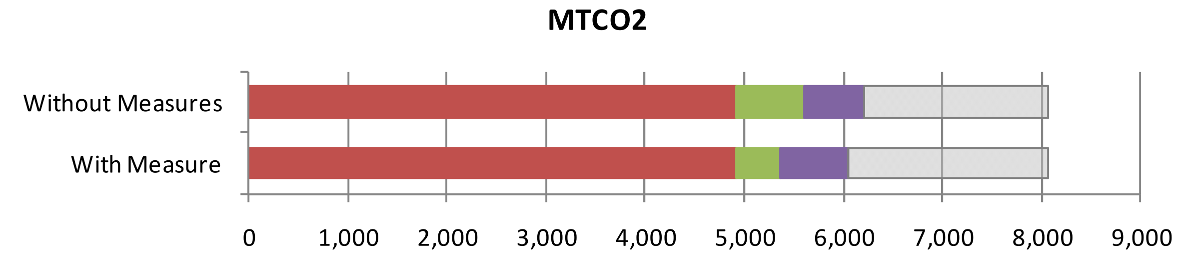
Assumptions

Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors						
	Without Measures	With Measure (3)					
End-Use Sector	**2012→**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020→**
Passenger Vehicle MAC	30%	28%	25%	23%	21%	20%	18%
Buses MAC	20%	18%	17%	16%	14%	13%	12%
Small AC	25%	23%	21%	19%	18%	16%	15%
Medium AC	20%	18%	17%	16%	14%	13%	12%
Large AC	15%	14%	13%	12%	11%	10%	9%
Domestic Appliances	20%	18%	17%	16%	14%	13%	12%
Small Commercial	25%	23%	21%	19%	18%	16%	15%
Med. Commercial (DX)	20%	18%	17%	16%	14%	13%	12%
Large Commercial	20%	18%	17%	16%	14%	13%	12%
Road Transport	20%	18%	17%	16%	14%	13%	12%
Shipping	20%	18%	17%	16%	14%	13%	12%
Industrial	20%	18%	17%	16%	14%	13%	12%

NB: Decommissioning Emissions Factor and EOL Recovery Factor are assumed to remain unchanged by this measure.

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	4,921	4,921
Non-Compliance	445	685
Phase 3 (EOL)	675	609
Abated Emissions	2,032	1,857

B.5.4 RAC Measure 4: HFC Product Bans for new HFC Equipment

Title

4) HFC Product Bans for new RAC Equipment

Brief Description

- HFC alternatives available in some RAC markets
  - and new alternatives rapidly developing
  - e.g. CO2, HFOs, HFO blends
- Well timed bans can be very cost effective
  - short term benefit – reduced leakage emissions
  - long term benefit – reduced EOL emissions
- Bans will mainly be justified on short term benefit and be considered via F Gas Regulation review
- Should only apply to new equipment
- Must take into account risk of increased energy use
- Must be sub-sector specific in terms of
  - timing – when will a cost effective solution be commercially available?
  - GWP limit – some markets could have a very low GWP limit (e.g. <1 kg systems can use HCs or 1234yf)
  - other markets may require higher GWP e.g. split system air-conditioning needs non-flammable refrigerant e.g. HFO blend with GWP between 500 and 1000)
- RAC1, RAC2: early ban (? from 2016) and GWP < 50
  - small hermetic systems using HCs or 1234yf
- Large systems: early ban (? from 2016) and GWP < 50
  - supermarkets using CO2 (or CO2 cascading to HC or HFO)
  - industrial systems using ammonia
  - large chillers using HFO
  - BUT, what is definition of large?!
- Medium sized systems: later ban (? from 2020) and higher GWP limit e.g. <800
  - with provision for early review if lower GWP solution available

Costs

	One-off Costs (€M)	On-going Costs (€M/y)		NPV (€M)
Party	**2012 to 2014**	**←2019**	**2020→**	**2012**
EU Commission	€ 9.6M	€ 0 M/y	€ 0.5M/y	€ 9.6M
MS Governments	€ 51.9M	€ 0 M/y	€ 5.4 M/y	€ 51.9M
End Users	€ 0.0M	€ 0 M/y	€ 1,125M/y	€ 20,445.4M

Assumptions

Measures will ban use of certain gases in certain sectors from a certain date, after which the quantity of gas reaching end-of-life will gradually be reduced relative to the WOM case.

Table of Gas Retiring from the Bank (T/y)

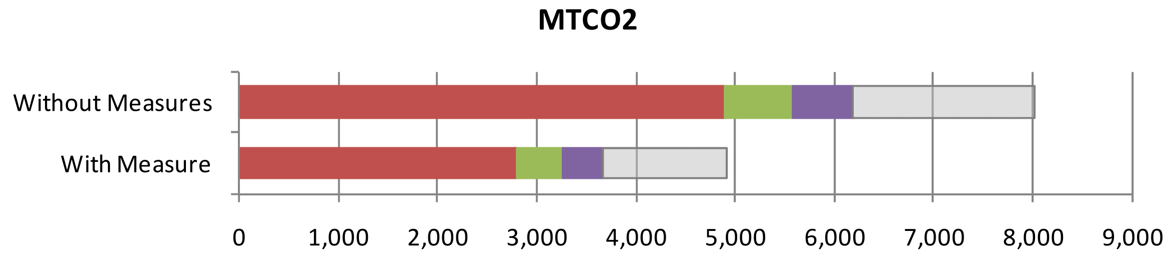
		ScenarioA = 1 (Base Case)				ScenarioA = 2 (HFC Use Bans)				
End Use	Year	CFC	HCFC	HFC	AO	CFC	HCFC	HFC	AO	HFOB
10	2010			-5,031				-5,031		
	2015			-6,506	-1			-6,442	-1	
	2020			-8,195	-108			-8,113	-107	
	2025			-7,701	-1,628			-7,619	-1,609	
	2030			-4,036	-6,268			-3,991	-6,195	
	2035			-892	-9,964			-881	-9,847	
	2040			-76	-11,221			-75	-11,085	
	2045			-3	-12,082			-3	-11,931	
	2050			0	-12,762			0	-12,598	
20	2010			-150				-151		
	2015			-194				-196		
	2020			-244				-246		0
	2025			-259	0			-259	0	-2
	2030			-274	-1			-224	-1	-52
	2035			-281	-12			-94	-12	-189
	2040			-266	-38			-14	-38	-254
	2045			-249	-72			-1	-72	-250
	2050			-229	-109			0	-110	-230

31	2010	-29	-4,041	-3,018		-29	-4,041	-3,018		
	2015	-1	-1,015	-7,130		-1	-1,015	-7,130		
	2020	0	-82	-10,621		0	-82	-10,621		0
	2025		-2	-13,174	-4		-2	-12,174	-4	-1,000
	2030		0	-14,360	-249		0	-5,737	-249	-8,623
	2035			-14,332	-1,339			-683	-1,339	-13,649
	2040			-13,319	-2,950			-22	-2,950	-13,296
	2045			-11,986	-4,679			0	-4,679	-11,986
	2050			-10,468	-6,427				-6,427	-10,468
32	2010		-9,745	-330			-9,745	-330		
	2015		-2,973	-2,468			-2,973	-2,468		
	2020			-6,815				-6,815		0
	2025			-11,117	0			-11,080	0	-37
	2030			-12,636	-20			-11,065	-20	-1,572
	2035			-13,086	-323			-5,400	-323	-7,686
	2040			-13,374	-1,328			-1,032	-1,328	-12,342
	2045			-12,464	-2,757			-77	-2,757	-12,387
	2050			-11,051	-4,316			-2	-4,316	-11,049
40	2010		-3,311	-83			-3,311	-83		
	2015		-1,088	-667			-1,088	-667		
	2020			-1,539	0			-1,539	0	
	2025			-2,556	0			-2,548	-8	
	2030			-3,803	-5			-3,555	-253	
	2035			-4,261	-36			-2,811	-1,486	
	2040			-4,060	-126			-1,001	-3,185	
	2045			-4,048	-316			-160	-4,204	
	2050			-4,074	-651			-12	-4,712	
50	2010	-403		-1,432	-328	-403		-1,432	-328	
	2015	-49		-964	-1,379	-49		-964	-1,379	
	2020	-2		-321	-2,299	-2		-320	-2,299	
	2025	0		-153	-2,573	0		-147	-2,579	
	2030			-141	-2,669			-87	-2,723	
	2035			-145	-2,758			-24	-2,878	
	2040			-148	-2,807			-3	-2,952	
	2045			-152	-2,880			0	-3,032	
	2050			-156	-2,960				-3,116	
60	2010	-88	-343	-168		-90	-348	-169		
	2015	-7	-116	-445	0	-8	-118	-450	0	
	2020	0	-12	-594	-6	0	-12	-601	-7	
	2025		0	-669	-36		0	-565	-150	
	2030		0	-694	-90		0	-221	-573	
	2035			-675	-152			-26	-812	
	2040			-668	-228			-1	-907	
	2045			-640	-305			0	-958	
	2050			-588	-381				-982	
71	2010		-312	-216	0		-312	-216	0	
	2015			-436	0			-436	0	
	2020			-584	-8			-584	-8	0
	2025			-616	-64			-601	-79	0
	2030			-567	-182			-393	-304	-19
	2035			-507	-307			-137	-550	-91
	2040			-435	-429			-20	-652	-152
	2045			-369	-559			-1	-701	-174
	2050			-294	-666			0	-726	-181

72	2010	-1,249	-865	0	-1,249	-865	0	
	2015		-1,745	0		-1,745	0	
	2020		-2,336	-32		-2,336	-32	0
	2025		-2,464	-257		-2,403	-316	-2
	2030		-2,269	-727		-1,570	-1,216	-76
	2035		-2,027	-1,227		-546	-2,201	-362
	2040		-1,739	-1,715		-82	-2,610	-608
	2045		-1,474	-2,235		-5	-2,803	-697
	2050		-1,176	-2,663		0	-2,903	-725
80	2010	-246	-102		-249	-104		
	2015		-230			-233		
	2020		-317			-322		0
	2025		-389	0		-392	0	-3
	2030		-447	-2		-368	-2	-86
	2035		-473	-15		-158	-15	-323
	2040		-487	-48		-24	-49	-470
	2045		-495	-92		-1	-93	-501
	2050		-470	-136		0	-139	-478
90	2010	-5,314	-32	-87	-5,314	-32	-87	
	2015		-476	-93		-476	-93	
	2020		-840	-93		-840	-93	0
	2025		-994	-99		-994	-99	0
	2030		-1,218	-112		-1,217	-112	-1
	2035		-1,438	-122		-1,410	-122	-28
	2040		-1,402	-140		-1,173	-140	-229
	2045		-1,275	-200		-611	-200	-665
	2050		-1,204	-331		-181	-331	-1,022
100	2010	-6,446	-199	-2,562	-6,446	-199	-2,562	
	2015		-1,466	-2,680		-1,466	-2,680	
	2020		-3,105	-2,999		-3,105	-2,999	0
	2025		-4,655	-3,435		-4,648	-3,441	0
	2030		-5,926	-3,643		-5,710	-3,839	-19
	2035		-5,669	-3,724		-4,251	-4,862	-281
	2040		-5,017	-4,146		-1,637	-6,482	-1,044
	2045		-4,932	-5,039		-321	-7,851	-1,799
	2050		-4,886	-6,041		-33	-8,733	-2,162

NB: In this case, it is assumed that the emission factors are not changed – only the quantity of gases reaching retirement each year is changed (as shown in the table immediately above).

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	2,810	4,903
Non-Compliance	460	677
Phase 3 (EOL)	398	597
Abated Emissions	1,242	1,844

B.5.5 RAC Measure 5: Measures to reduce use of R404A in new and existing systems

Title

5) Measures to reduce use of R404A in new and existing systems

Brief Description

- HFC 404A in widespread use in EU
  - majority of supermarkets use 404A for chill and frozen
  - many industrial and cold storage applications
  - recent UK study (of food chain refrigeration): R404A = 48% of HFC related emissions from RAC systems
- HFC 404A has highest GWP of common refrigerants
  - R404A = 3,784 (AR3)
  - R134a = 1,300   R410A = 1,975   R407F = 1,705
- HFC 404A not most efficient choice for some applications – especially at medium temperatures, such as chill storage
- Significant environmental benefits in less R404A use
- For new systems:
  - select alternative with low or medium GWP
  - should be little extra capital cost and could be lower running cost e.g. R134a or R407A/F in chill systems
- For existing systems:
  - consider retrofill with R407A or R407F
  - 50% reduction in GWP; could be 7% to 12% decrease in energy use for chill applications
  - retrofit needs care: to avoid extra leakage
- Should we legislate to achieve reduced R404A use?
  - but how quickly could this happen?
- Is it better (and lower cost) to:
  - provide good case study material to prove benefits
  - get major end users (e.g. supermarkets) to make commitments to stop using R404A quickly (some are already doing this)
  - promote via major contractors, designers etc.

Costs

	One-off Costs	On-going Costs	NPV
Party	**2012 to 2014**		**2012**
EU Commission	€ 10M	0	€ 9.6 M
MS Governments	€ 54M	0	€ 51.9M

Assumptions

Measures will ban use of certain gases in certain sectors from a certain date, after which the quantity of gas reaching end-of-life will gradually be reduced relative to the WOM case.

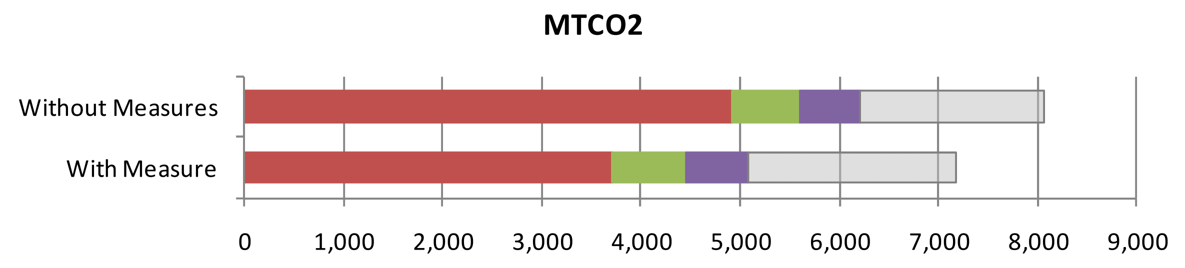
Table of Gas Retirement from Bank (T/y)

		ScenarioA = 1 (Base Case)				ScenarioA = 3 (Reduced R404A)					
EndUse	Year	CFC	HCFC	HFC	AO	CFC	HCFC	HFC	AO	HFOB	HFC2
10	2010			-5,031			-18	-4,941	-7		
	2015			-6,506	-1			-6,392	-8		
	2020			-8,195	-108			-8,056	-115	0	
	2025			-7,701	-1,628			-7,577	-1,609	0	
	2030			-4,036	-6,268			-3,980	-6,168	0	
	2035			-892	-9,964			-887	-9,800	-1	
	2040			-76	-11,221			-79	-11,041	-3	
	2045			-3	-12,082			-3	-11,892	-5	
	2050			0	-12,762			0	-12,563	-5	
20	2010			-150				-150			
	2015			-194				-194			0
	2020			-244				-243			-1
	2025			-259	0			-211	0		-48
	2030			-274	-1			-82	-1		-192
	2035			-281	-12			-12	-12		-270
	2040			-266	-38			-1	-38		-266
	2045			-249	-72			0	-72		-249
	2050			-229	-109				-109		-229

31	2010	-29	-4,041	-3,018		-29	-4,041	-3,018		
	2015	-1	-1,015	-7,130		-1	-1,015	-7,130		0
	2020	0	-82	-10,621		0	-82	-9,713		-909
	2025		-2	-13,174	-4		-2	-5,145	-4	-8,029
	2030		0	-14,360	-249		0	-633	-249	-13,727
	2035			-14,332	-1,339			-21	-1,339	-14,311
	2040			-13,319	-2,950			0	-2,950	-13,318
	2045			-11,986	-4,679				-4,679	-11,986
	2050			-10,468	-6,427				-6,427	-10,468
32	2010		-9,745	-330			-9,632	-325		
	2015		-2,973	-2,468			-2,945	-14,464		0
	2020			-6,815						-6,516
	2025			-11,117	0				0	-10,916
	2030			-12,636	-20				-19	-12,224
	2035			-13,086	-323				-315	-12,795
	2040			-13,374	-1,328				-1,286	-13,042
	2045			-12,464	-2,757				-2,671	-12,081
	2050			-11,051	-4,316				-4,195	-10,731
40	2010		-3,311	-83			-3,311	-83		
	2015		-1,088	-667			-1,088	-5,756		0
	2020			-1,539	0				0	-1,509
	2025			-2,556	0				0	-2,579
	2030			-3,803	-5				-5	-3,770
	2035			-4,261	-36				-37	-4,225
	2040			-4,060	-126				-127	-4,083
	2045			-4,048	-316				-316	-4,069
	2050			-4,074	-651				-647	-4,064
50	2010	-403		-1,432	-328	-403		-1,432	-328	
	2015	-49		-964	-1,379	-49		-964	-1,379	0
	2020	-2		-321	-2,299	-2		-320	-2,299	0
	2025	0		-153	-2,573	0		-136	-2,573	-17
	2030			-141	-2,669			-58	-2,669	-83
	2035			-145	-2,758			-11	-2,758	-134
	2040			-148	-2,807			-1	-2,807	-147
	2045			-152	-2,880			0	-2,880	-152
	2050			-156	-2,960				-2,960	-156
60	2010	-88	-343	-168		-88	-343	-168		
	2015	-7	-116	-445	0	-7	-116	-445	0	0
	2020	0	-12	-594	-6	0	-12	-580	-6	-14
	2025		0	-669	-36		0	-423	-36	-245
	2030		0	-694	-90		0	-104	-90	-590
	2035			-675	-152			-8	-152	-667
	2040			-668	-228			0	-228	-668
	2045			-640	-305				-305	-640
	2050			-588	-381				-381	-588
71	2010		-312	-216	0		-312	-216	0	
	2015			-436	0			-1,253	0	0
	2020			-584	-8				-8	-526
	2025			-616	-64				-64	-616
	2030			-567	-182				-182	-567
	2035			-507	-307				-307	-507
	2040			-435	-429				-429	-435
	2045			-369	-559				-559	-368
	2050			-294	-666				-666	-294

72	2010	-1,249	-865	0	-1,249	-865	0	
	2015		-1,745	0		-5,013	0	0
	2020		-2,336	-32			-32	-2,104
	2025		-2,464	-257			-257	-2,463
	2030		-2,269	-727			-727	-2,268
	2035		-2,027	-1,227			-1,227	-2,027
	2040		-1,739	-1,715			-1,715	-1,739
	2045		-1,474	-2,235			-2,235	-1,474
	2050		-1,176	-2,663			-2,664	-1,176
80	2010	-246	-102		-246	-102		
	2015		-230			-669		0
	2020		-317					-286
	2025		-389	0			0	-389
	2030		-447	-2			-2	-447
	2035		-473	-15			-15	-473
	2040		-487	-48			-48	-487
	2045		-495	-92			-92	-495
	2050		-470	-136			-136	-470
90	2010	-5,314	-32	-87	-5,314	-32	-87	
	2015		-476	-93		-3,205	-93	0
	2020		-840	-93			-93	-756
	2025		-994	-99			-99	-994
	2030		-1,218	-112			-112	-1,218
	2035		-1,438	-122			-122	-1,438
	2040		-1,402	-140			-140	-1,402
	2045		-1,275	-200			-200	-1,275
	2050		-1,204	-331			-331	-1,204
100	2010	-6,446	-199	-2,562	-6,446	-199	-2,562	
	2015		-1,466	-2,680		-10,281	-2,680	0
	2020		-3,105	-2,999			-2,999	-2,854
	2025		-4,655	-3,435			-3,435	-4,663
	2030		-5,926	-3,643			-3,648	-5,901
	2035		-5,669	-3,724			-3,742	-5,636
	2040		-5,017	-4,146			-4,166	-5,013
	2045		-4,932	-5,039			-5,045	-4,935
	2050		-4,886	-6,041			-6,036	-4,882

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	3,709	4,921
Non-Compliance	743	685
Phase 3 (EOL)	636	609
Abated Emissions	2,087	1,857

B.5.6 RAC Measure 6: Better Policing of Current Regulations

Title

6) Better Policing of Current Regulations

Brief Description

- No EOL Regulatory gap for RAC
  - the problem is poor implementation
- Level of policing varies considerably across EU
  - little data to show the success of F Gas / Ozone Regulations
- Member States have obligation to properly implement the Regulations
  - would be beneficial to provide support to MSs to achieve better policing
  - learning lessons from some good MS initiatives
  - using material from Information Initiative (Proposal 8)

Costs

	One-off Costs	On-going Costs	NPV
Party	**2012 to 2015**	**2016→**	**2012**
EU Commission	€ 8M	0	€ 8M
MS Governments	€ 108M	€ 27M/y	€703M

Assumptions

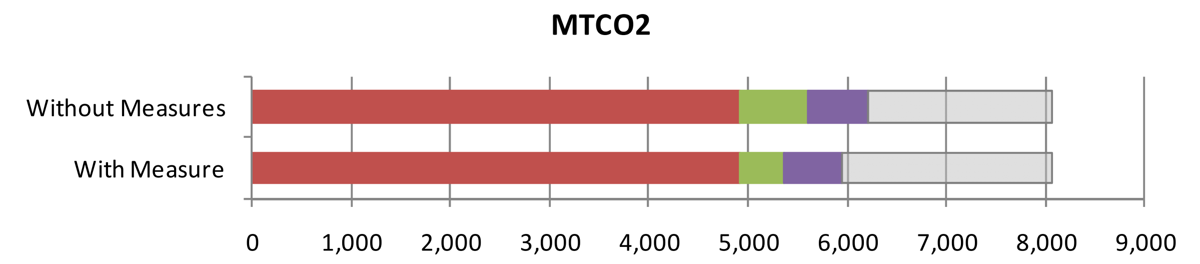
Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors										
	Without Measures	With Measure									
End-Use Sector	**2012→**	**2013**	**2014**	**2015**	**2016**	**2017**	**208**	**2019**	**2020**	**2021**	**2022→**
Passenger Vehicle MAC	30%	29%	27%	26%	24%	23%	22%	21%	20%	19%	18%
Buses MAC	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Small AC	25%	24%	23%	21%	20%	19%	18%	17%	17%	16%	15%
Medium AC	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Large AC	15%	14%	14%	13%	12%	12%	11%	10%	10%	9%	9%
Domestic Appliances	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Small Commercial	25%	24%	23%	21%	20%	19%	18%	17%	17%	16%	15%
Med/Large Commercial											
Medium Commercial (DX)	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Large Commercial	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Road Transport	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Shipping	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%
Industrial	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%

	Decommissioning Emissions Factor										
	Without Measures	With Measure									
End-Use Sector	**2012→**	**2013**	**2014**	**2015**	**2016**	**2017**	**208**	**2019**	**2020**	**2021**	**2022→**
Passenger Vehicle MAC	25%	24%	24%	23%	22%	21%	21%	20%	20%	19%	18%
Buses MAC	15%	15%	14%	14%	13%	13%	12%	12%	12%	11%	11%
Small AC	40%	39%	38%	37%	35%	34%	33%	32%	31%	30%	29%
Medium AC	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%	4%
Large AC	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%	4%
Domestic Appliances	50%	49%	47%	46%	44%	43%	42%	40%	39%	38%	37%
Small Commercial	50%	49%	47%	46%	44%	43%	42%	40%	39%	38%	37%
Med/Large Commercial											
Medium Commercial (DX)	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%	4%
Large Commercial	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%	4%
Road Transport	15%	15%	14%	14%	13%	13%	12%	12%	12%	11%	11%
Shipping	10%	10%	9%	9%	9%	9%	8%	8%	8%	8%	7%
Industrial	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%	4%

EOL Recovery Factor is not affected by this measure.

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	4,921	4,921
Non-Compliance	440	685
Phase 3 (EOL)	582	609
Abated Emissions	2,130	1,857

B.5.7 RAC Measure 7: Tax on F Gases

Title

7) Tax on F Gases

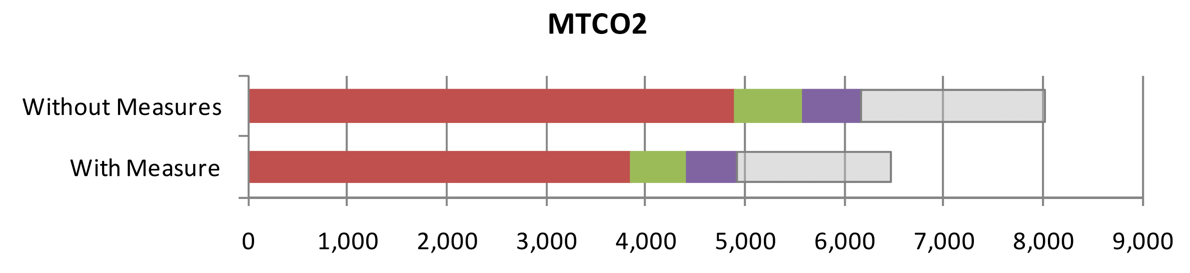
Brief Description

- Alternative to product bans: a GWP weighted tax on HFCs
- Key advantages:
  - allows more flexibility of response
  - affects new and existing systems
  - encourages development of very low GWP designs
- Disadvantages:
  - less certainty over effectiveness
  - doesn't suit all RAC markets (e.g. small hermetic systems have very small charge, so tax adds little to total cost of new equipment and in-life leakage is not an issue)

Costs

Assumption: €/tCO2 same as for Measure 4 HFC Product Bans, but abatement potential only around half M4.

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	3,856	4,903
Non-Compliance	569	677
Phase 3 (EOL)	497	597
Abated Emissions	1,543	1,844

B.5.8 RAC Measure 8: Information Initiatives

Title

8) Information Initiatives

Brief Description

- Good information initiative has excellent potential
  - especially if linked to MS policing (Proposal 6)
- EC could coordinate preparation of useful information:
  - for **end users** – highlighting obligations and explaining benefits of alternative technologies / techniques
  - for **designers** – promoting low leakage techniques and use of alternative low GWP refrigerants
  - for **contractors** – encouraging best practice to reduce leakage and for EOL recovery
  - for **specialist recovery facilities** – guidance on achieving best rates of recovery
- Builds on current regulations
- Key group to target – RAC contractors
  - they are responsible for most EOL recovery
- Current Regulation requires Company Certification
  - this provides a way to get good information to all EU contractors
  - assuming this obligation is well implemented!
- Specialist Recovery Facilities also easy to target
- Harder to reach end users and designers
  - MSs should be targeting their 'high risk' emitters

Costs

	One-off Costs	On-going Costs	NPV
Party	**2012 to 2014**	**2012→**	**2012**
EU Commission	€ 7.0M	€ 0.2M/y	€ 12M
MS Governments	€ 8.1M	€ 5.4M/y	€ 144M

Assumptions

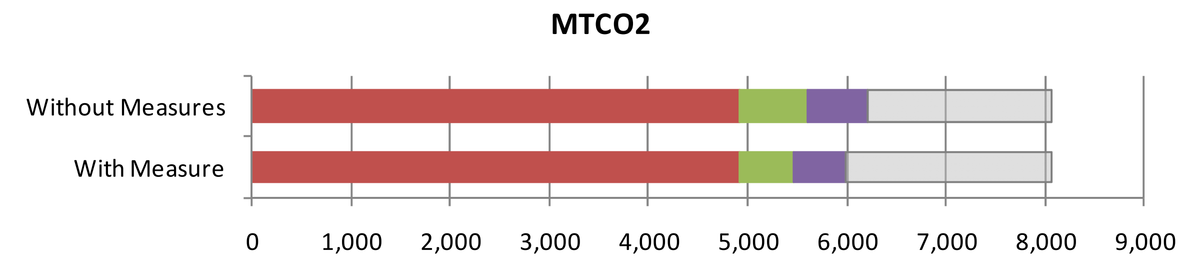
Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors									
	Without Measures	With Measure								
End-Use Sector	**2012→**	**2013**	**2014**	**2015**	**2016**	**2017**	**208**	**2019**	**2020**	**2021→**
Passenger Vehicle MAC	30%	29%	28%	27%	27%	26%	25%	24%	24%	23%
Buses MAC	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Small AC	25%	24%	24%	23%	22%	21%	21%	20%	20%	19%
Medium AC	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Large AC	15%	15%	14%	14%	13%	13%	12%	12%	12%	11%
Domestic Appliances	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Small Commercial	25%	24%	24%	23%	22%	21%	21%	20%	20%	19%
Med/Large Commercial										
Medium Commercial (DX)	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Large Commercial	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Road Transport	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Shipping	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%
Industrial	20%	19%	19%	18%	18%	17%	17%	16%	16%	15%

	Decommissioning Emissions Factor									
	Without Measures	With Measure								
End-Use Sector	**2012→**	**2013**	**2014**	**2015**	**2016**	**2017**	**208**	**2019**	**2020**	**2021→**
Passenger Vehicle MAC	25%	24%	24%	23%	22%	21%	21%	20%	20%	19%
Buses MAC	15%	15%	14%	14%	13%	13%	12%	12%	12%	11%
Small AC	40%	38%	36%	34%	33%	31%	29%	28%	27%	25%
Medium AC	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Large AC	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Domestic Appliances	50%	49%	47%	46%	44%	43%	42%	40%	39%	38%
Small Commercial	50%	49%	47%	46%	44%	43%	42%	40%	39%	38%
Med/Large Commercial										
Medium Commercial (DX)	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Large Commercial	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Road Transport	15%	15%	14%	14%	13%	13%	12%	12%	12%	11%
Shipping	10%	10%	9%	9%	9%	9%	8%	8%	8%	8%
Industrial	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%

EOL Recovery Factor is not affected by this measure.

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	4,921	4,921
Non-Compliance	538	685
Phase 3 (EOL)	537	609
Abated Emissions	2,077	1,857

B.5.9 RAC Measure 9: Improved Data Collection

Title

9) Improved Data Collection

Brief Description

- Little quantitative evidence to assess the level of compliance with EOL obligations
- Already an obligation to keep records
  - for all F Gas equipment over 3 kg
  - but no coordinated use of such data
- Could modify record keeping obligations to include mandatory reporting of data
  - about F Gas 'bank', top up and recovery
- Only for large systems (and/or large companies) to minimise costs
  - e.g. >30 kg or >100 kg or >300 kg
  - collate data nationally and at EU level to improve compliance

Costs

	One-off Costs	On-going Costs (€M/y)	NPV (€M)
Party	**2012 to 2014**	**2015→**	**2012**
EU Commission	€ 9M	€ 1M	€ 31M
MS Governments	€ 17M	€ 1M	€38M
End Users	€ 0M	€ 30M	€669M

Assumptions

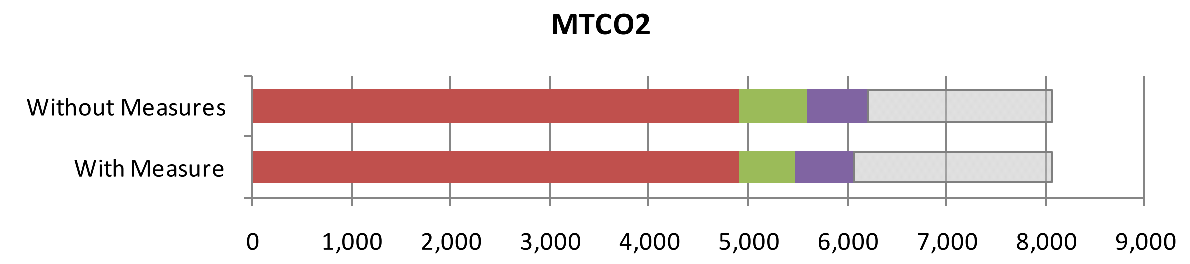
Measures are assumed to reduce emission factors as shown below:

	Non-Compliance Factors											
	Without Measures	With Measure										
End-Use Sector	**2012→**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025→**
Passenger Vehicle MAC	30%	29%	29%	28%	28%	27%	27%	26%	26%	25%	25%	24%
Buses MAC	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Small AC	25%	25%	24%	24%	23%	23%	22%	22%	21%	21%	20%	20%
Medium AC	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Large AC	15%	15%	14%	14%	14%	14%	13%	13%	13%	13%	12%	12%
Domestic Appliances	20%	19%	18%	17%	16%	15%	15%	14%	13%	13%	12%	11%
Small Commercial	25%	24%	23%	21%	20%	19%	18%	17%	17%	16%	15%	14%
Med/Large Commercial												
Med. Commercial (DX)	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Large Commercial	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Road Transport	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Shipping	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%
Industrial	20%	20%	19%	19%	18%	18%	18%	17%	17%	17%	16%	16%

	Decommissioning Emissions Factor											
	Without Measures	With Measure										
End-Use Sector	**2012→**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025→**
Passenger Vehicle MAC	25%	25%	24%	24%	23%	23%	22%	22%	21%	21%	20%	20%
Buses MAC	15%	15%	14%	14%	14%	14%	13%	13%	13%	13%	12%	12%
Small AC	40%	39%	38%	38%	37%	36%	35%	35%	34%	33%	33%	32%
Medium AC	5%	5%	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Large AC	5%	5%	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Domestic Appliances	50%	48%	45%	43%	41%	39%	37%	35%	33%	32%	30%	28%
Small Commercial	50%	48%	45%	43%	41%	39%	37%	35%	33%	32%	30%	28%
Med/Large Commercial												
Med. Commercial (DX)	5%	5%	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Large Commercial	5%	5%	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%
Road Transport	15%	15%	14%	14%	14%	14%	13%	13%	13%	13%	12%	12%
Shipping	10%	10%	10%	9%	9%	9%	9%	9%	9%	8%	8%	8%
Industrial	5%	5%	5%	5%	5%	5%	4%	4%	4%	4%	4%	4%

EOL Recovery Factor is not affected by this measure.

Total Aggregate Emissions over Study Period (2012 to 2050)



	With Measure	Without Measures
Phase 1 (BOL)	0	0
Phase 2 (In life)	4,921	4,921
Non-Compliance	568	685
Phase 3 (EOL)	573	609
Abated Emissions	2,010	1,857

B.5.10 Foams Measure 1: Phase-down of HFC use in XPS / PU Spray Foams

Title

F1) Phase-down of HFC use in XPS & PU Spray Foams

Brief Description

Although the baseline forecast is that both sectors will have phased out their use of HFCs by 2030 as new technology improvements emerge, the acceleration of the phase-down will attract the use of more expensive blowing agents such as unsaturated fluorocarbons (HFOs). These are estimated to be between three and five times more expensive than the HFCs they will replace:

- No one-off costs are envisaged because transitions were anticipated in any event and requalification of products would have resulted in either case. The NPV difference created by the timing is viewed as negligible in this instance
- XPS phase-down is brought forward by eight years and occurs between 2013 and 2022
- PU Spray Foam phase-down is brought forward by five years and occurs between 2016 and 2025

Costs

	Unit BA Costs (€/kg)		On-going Costs (€M per period)				NPV (€M)
Company Cost	**Current**	**Future**	**2010-2015**	**2016-2020**	**2021-2025**	**2025-2030**	**2012**
PU Spray – Low	5.0	15.0	50	104	116	38	246
PU Spray – High	5.0	25.0	100	209	231	76	493
XPS – Low	5.0	15.0	323	635	729	260	1339
XPS – High	5.0	25.0	490	1079	1288	461	2282

Assumptions

Measures are assumed to reduce emission factors as shown below:

	Market Share of Fluorinated and Other Blowing Agents							
	Without Measures				With Measures			
End-Use Sector	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
PU Spray – HFCs	85%	85%	85%	41.5%	85%	85%	41.5%	0%
PU Spray – HFOs	0%	0%	0%	0%	0%	0%	41%	80%
PU Spray - Other	15%	15%	15%	58.5%	15%	15%	17.5%	20%
XPS – HFCs	55%	55%	55%	27.6%	55%	38.5%	11%	0%
XPS – HFOs	0%	0%	0%	0%	0%	16.5%	44%	55%
XPS – CO_2/Other	45%	45%	45%	72.4%	45%	45%	45%	45%

B.5.11 Foams Measure 2: Mandatory Recovery, Commercial Appliances

Title

F2) Mandatory Recovery of Commercial Appliances

Brief Description

With the re-cast of WEEE and RoHS not offering improved clarification of treatment of commercial appliances, there is potential to include commercial appliances Including water heaters) within the Annex of Ozone Regulation EC Reg. 1005/2009 :

- The measure could be implemented as early as 2013
- Awareness-raising of the change of regulation would be required at Commission and Member State level
- Primary costs would be with end-users being required to process units for foam recovery

Costs

	One-off Costs	On-going Costs (€M per period)				NPV (€M)
Company Cost	**(€M)**	**2013-2020**	**2021-2030**	**2031-2040**	**2041-2050**	**2012**
EU Commission	3.5	4.0	5.0	5.0	5.0	13.2
MS Governments	6.8	21.6	27.0	27.0	27.0	59.1
End-Users	0.0	355.9	513.6	675.4	912.4	1113.4
Contractors	0.0	39.5	57.1	75.0	101.4	123.7

Assumptions

Measures are assumed to increase recovery levels of commercial appliances from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	**2012**	**2013**	**2014**	**2015→**	**2012**	**2013**	**2014**	**2015→**
Commercial Appliances	35%	35%	35%	35%	35%	85%	85%	85%

B.5.12 Foams Measure 3: Mandatory Recovery, Building Services / Industrial Sectors

Title

F3) Mandatory Recovery of Insulation Foams used in Building Services and Industrial Applications

Brief Description

The opportunity exists to recover foams from the building services and industrial sectors because routine maintenance programmes may result in the replacement of the insulation when the pipework is serviced :

- The measure could be implemented as early as 2014
- Awareness-raising of the change of regulation would be required at Commission and Member State level
- PU Pipe-in-Pipe insulation used for district heating services is not included in this proposal

Costs

	One-off Costs	On-going Costs (€M per period)				NPV (€M)
Company Cost	(€M)	2014-2020	2021-2030	2031-2040	2041-2050	2012
EU Commission	3.5	3.5	5.0	5.0	5.0	13.2
MS Governments	6.8	18.9	27.0	27.0	27.0	56.5
Maintenance Contractors	0.0	23.6	46.6	50.0	71.5	85.6
End-Users	0.0	212.4	419.2	450.4	643.2	770.1

Assumptions

Measures are assumed to increase recovery levels of commercial appliances from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	2012	2013	2014	2015→	2012	2013	2014	2015→
PU Pipe Insulation	15%	15%	15%	15%	15%	15%	100%	100%
PU Slab	15%	15%	15%	15%	15%	15%	70%	70%
PF Pipe Insulation	15%	15%	15%	15%	15%	15%	100%	100%
PF Slab	15%	15%	15%	15%	15%	15%	70%	70%
PE Pipe Insulation	0%	0%	0%	0%	0%	0%	100%	100%
PE Slab	0%	0%	0%	0%	0%	0%	100%	100%

B.5.13 Foams Measure 4: Mandatory Recovery, Steel-faced Panels / Built-up Systems

Title

F4) Mandatory Recovery of Insulation Foams used in Steel-Faced Panels and Built-up Systems

Brief Description

Although the opportunity exists to recover foams from steel-faced panels and built-up systems, the ability to do so cost-effectively depends on the baseline demolition waste practices and, in particular, segregation of waste. These practices vary substantially by Member State and also depending on historic construction practices within the country. For these reasons, mandatory recovery is not expected to be required across the whole of the EU-27, but could occur at Member State level. The following assumptions have been made:

- Individual Member States will implement mandatory recovery such that 50% of the market within the EU-27 is covered by 2015
- An unambiguous definition of built-up systems can be reached whereby easily demountable systems are captured by any mandatory requirement (for modelling purposes, built-up systems are assumed to be primarily roofs)

Costs

	One-off Costs	On-going Costs (€M per period)				NPV (€M)
Company Cost	**(€M)**	**2014-2020**	**2021-2030**	**2031-2040**	**2041-2050**	**2012**
EU Commission	3.5	3.5	5.0	5.0	5.0	12.7
MS Governments	6.8	18.9	27.0	27.0	27.0	56.5
Maintenance Contractors	0.0	178.4	439.7	616.0	653.5	821.8
End-Users	0.0	1605.4	3957.2	5544.0	5881.3	7396.1

Assumptions

Measures are assumed to increase recovery levels of commercial appliances from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	**2012**	**2013**	**2014**	**2015→**	**2012**	**2013**	**2014**	**2015→**
PU Continuous Panels	15%	15%	15%	15%	15%	15%	15%	35%
PU Discontinuous Panels	15%	15%	15%	15%	15%	15%	15%	35%
PF Discontinuous Panels	15%	15%	15%	15%	15%	15%	15%	35%
PU Boardstock – Roofs	0%	0%	0%	0%	0%	0%	0%	50%
PF Boardstock – Roofs	0%	0%	0%	0%	0%	0%	0%	50%
XPS Board – Roofs	0%	0%	0%	0%	0%	0%	0%	50%

B.5.14 Foams Measure 5: Improved Domestic Refrigerator EOL Recovery

Title

F5) Improved Domestic Refrigerator E-o-L Recovery through better measurement and enforcement

Brief Description

There are some issues concerning the recycling of domestic refrigerators which need addressing. These include:

- The incomplete implementation of mandatory recovery of blowing agents from domestic refrigerators
- Adoption of more rigorous extraction techniques to address levels of residual blowing agent in polyurethane matrices
- Poor data availability across the EU in the effectiveness of current practices

Costs

Company Cost	One-off Costs (€M)	On-going Costs (€M per period) 2014-2020	2021-2030	2031-2040	2041-2050	NPV (€M) 2012
EU Commission	1.5	1.6	2.0	2.0	2.0	6.2
MS Governments	15.0	86.4	108.0	108.0	108.0	318.8
Special recovery Facilities*	0.0	44.3	64.0	74.3	86.0	127.6
End Users*	0.0	398.9	575.7	668.3	774.2	1148.7

Assumptions

Measures are assumed to increase recovery levels of commercial appliances from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	2012	2013	2014	2015→	2012	2013	2014	2015→
PU Domestic refrigerators	60%	60%	60%	60%	60%	95%	95%	95%

*The costs associated with increased processing levels at Special Recovery Facilities are not included the Table 5-22 assessment because they are already considered to have been accounted for within the Regulatory Impact Assessment conducted for EC Reg 1005/2009. Although a similar argument could be applied for EU Commission and Member State costs, these are considered in Table 5-22 to reflect the factual situation.

B.5.15 Foams Measure 6: Industry Commitments

Title

F6) Industry Commitments to promote recovery of blowing agents from Boardstock products

Brief Description

Industry trade associations are keen to promote best practice in end-of-life management of their products as part of their product stewardship obligations and also to be consistent with the environmentally beneficial profile that thermal insulation products seek to engender. Such commitments could involve the following:

- PU Europe, EXIBA and EPFA developing and promoting best practice guidance for the management of board products at end-of-life, dealing with foam matrices as well as blowing agent issues. Mechanical recovery and direct incineration would both be covered.
- The use of board product is so widespread that even an improvement of 10% in recovery levels would make a substantial contribution
- Poor data availability across the EU in the effectiveness of current practices

Costs

	One-off Costs	On-going Costs (€M per period)				NPV (€M)
Company Cost	(€M)	2014-2020	2021-2030	2031-2040	2041-2050	2012
EU Commission	0.5	0.6	0.8	0.8	0.8	2.4
MS Governments	0.0	0.2	0.2	0.2	0.2	0.4
Trade Association Costs	0.5	1.1	1.6	1.6	1.6	5.0
Contractors	0.0	21.4	178.7	301.9	351.3	334.5
End Users	0.0	192.6	1608.0	2716.9	3161.5	3010.8

Assumptions

Measures are assumed to increase recovery levels of laminated boards from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	2015	2017	2019	2021→	2015	2017	2019	2021→
PU Boardstock – Roof	0%	0%	0%	0%	0%	5%	5%	10%
PU Boardstock – Wall	0%	0%	0%	0%	0%	5%	5%	10%
PU Boardstock – Floor	0%	0%	0%	0%	0%	5%	5%	10%
PF Boardstock – Roof	0%	0%	0%	0%	0%	5%	5%	10%
PF Boardstock – Wall	0%	0%	0%	0%	0%	5%	5%	10%
PF Boardstock – Floor	0%	0%	0%	0%	0%	5%	5%	10%
XPS Board – Roof	0%	0%	0%	0%	0%	5%	5%	10%
XPS Board – Wall	0%	0%	0%	0%	0%	5%	5%	10%
XPS Board – Floor	0%	0%	0%	0%	0%	5%	5%	10%

B.5.16 Foams Measure 7: Information Initiatives

Title

F7) Information Initiatives by the European Commission and Member State Governments

Brief Description

There is a strong overlap between Measure 6 (Industry Commitments) and Measure 7 (Information Initiatives) depending on the levels of engagement under each measure. For the purposes of assessment in Table 5-22, it is assumed that these Information Initiatives deliver half of the savings envisaged under Measure 6. Costs are expected to be similar to those projected for other information initiatives (e.g. Measure 2)

Costs

	One-off Costs	On-going Costs (€M per period)				NPV (€M)
Company Cost	(€M)	2014-2020	2021-2030	2031-2040	2041-2050	2012
EU Commission	3.5	4.0	5.0	5.0	5.0	13.0
MS Governments	6.8	21.6	27.0	27.0	27.0	67.6
Contractors	0.0	15.0	106.4	169.5	177.2	217.3
End Users	0.0	134.7	957.0	1525.3	1594.2	1955.6

Assumptions

Measures are assumed to increase recovery levels of laminated boards from the waste stream as shown below:

	Increased Recovery from Waste Stream							
	Without Measures				With Measure			
End-Use Sector	2015	2017	2019	2021→	2015	2017	2019	2021→
PU Boardstock – Roof	0%	0%	0%	0%	0%	2.5%	2.5%	5%
PU Boardstock – Wall	0%	0%	0%	0%	0%	2.5%	2.5%	5%
PU Boardstock – Floor	0%	0%	0%	0%	0%	2.5%	2.5%	5%
PF Boardstock – Roof	0%	0%	0%	0%	0%	2.5%	2.5%	5%
PF Boardstock – Wall	0%	0%	0%	0%	0%	2.5%	2.5%	5%
PF Boardstock – Floor	0%	0%	0%	0%	0%	2.5%	2.5%	5%
XPS Board – Roof	0%	0%	0%	0%	0%	2.5%	2.5%	5%
XPS Board – Wall	0%	0%	0%	0%	0%	2.5%	2.5%	5%
XPS Board – Floor	0%	0%	0%	0%	0%	2.5%	2.5%	5%

B.5.17 Foams Measure 8: Promotion of Research into Managing Foam Waste

Title F8) Promotion of Research into Managing Foam Waste
Brief Description There are no meaningful cost effectiveness criteria when it comes to assessing the targeting/efficiency of research into this type of subject. However, the following areas may be of relevance: • Further assessment into the likelihood of anaerobic degradation in current managed landfills • Investigation into means of promoting greater levels of anaerobic degradation in managed landfills • Further investigation into the costs and environmental benefits of a wider range of direct incineration methods • Development of more efficient recovery methods in efforts to minimise costs of recovery • Development and promotion of transformation technologies (as opposed to destruction technologies) to increase the 'value added' in end-of-life management

B.5.18 GIS Measure 1: Including GIS in Article 3 (Containment Provisions)

Title

GIS Measure 1) Including GIS in Article 3 (Containment Provisions)

Brief Description

- GIS currently not included in GIS
- Inclusion will oblige end-users to carry out regular leak checks and maintain records, which should help to ensure that installation and in-lige emissions are reduced
- This will only affect in-use emissions, not EOL emissions

Costs

	One-off Costs	On-going Costs (€M/y)	NPV (€M)
Party	**2012 to 2014**	**2015→**	**2012**
EU Commission	€ 3.5M	€ 0M	€ 3.3M
MS Governments	€ 6.8M	€ 0M	€ 6.4M
End Users	€ 0M	€ 3.1M	€ 268M

Assumptions

Measures are assumed to reduce emission factors as shown below:

Estimated Leakage Rate in Use (% per year)

	Without Measures	With Measure
2010	1.2%	1.2%
2011	1.18%	1.18%
2012	1.16%	1.16%
2013	1.14%	1.14%
2014	1.12%	1.12%
2015	1.10%	1.10%
2016	1.08%	1.06%
2017	1.06%	1.02%
2018	1.04%	0.98%
2019	1.02%	0.94%
2020	1.00%	0.90%
2021	0.98%	0.86%
2022	0.96%	0.82%
2023	0.94%	0.78%
2024	0.92%	0.74%
2025	0.90%	0.70%
2026	0.88%	0.70%
2027	0.86%	0.70%
2028	0.84%	0.70%
2029	0.82%	0.70%
2030	0.80%	0.70%

EOL Recovery Factor is not affected by this measure.

B.5.19 GIS Measure 2: Voluntary Agreements

Title

GIS Measure 2) Voluntary Agreements

Brief Description

- Industry wide voluntary agreements are already in place in some member states
- Develop best practice in design, operation and EOL recovery
- These should be adopted EU wide

Costs

	One-off Costs	On-going Costs (€M/y)	NPV (€M)
Party	**2012 to 2014**	**2015→**	**2012**
EU Commission	€ 0.3M	€ 0.0M	€ 0.3M
MS Governments	€ 4.1M	€ 0.0M	€ 3.9M
End Users	€ 4.1M	€ 0.0M	€ 3.9M
Contractors		€ 1.0M	€ 22.3M
Manufacturers	€ 1.5M	€ 1.0M	€ 23.7M

Assumptions

Measures are assumed to reduce emission factors as shown below:

Estimated Leakage Rate in Use (% per year)

	Without Measures	With Measure
2010	1.2%	1.2%
2011	1.18%	1.18%
2012	1.16%	1.16%
2013	1.14%	1.14%
2014	1.12%	1.12%
2015	1.10%	1.10%
2016	1.08%	1.04%
2017	1.06%	0.98%
2018	1.04%	0.92%
2019	1.02%	0.86%
2020	1.00%	0.80%
2021	0.98%	0.74%
2022	0.96%	0.68%
2023	0.94%	0.62%
2024	0.92%	0.60%
2025	0.90%	0.60%
2026	0.88%	0.60%
2027	0.86%	0.60%
2028	0.84%	0.60%
2029	0.82%	0.60%
2030	0.80%	0.60%

EOL Recovery Factor is not affected by this measure.

B.5.20 GIS Measure 3: Data Collection and Information Initiatives

Title

GIS Measure 3) Data Collection and Information Initiatives

Brief Description

- It would be very helpful for gas consumption and emissions data to be:
  - collected in a consistent way across EU-27
  - assessed at EU level to identify best practice.
- Lessons learned from the end users with lowest levels of emissions can be collated and disseminated to stakeholders in each Member State.

Costs

	One-off Costs	On-going Costs (€M/y)	NPV (€M)
Party	**2012 to 2014**	**2015→**	**2012**
EU Commission	€ 1.8M	€ 0.2M	€ 6.2M
MS Governments	€ 3.4M	€ 0.3M	€ 9.2M
End Users	€ 0M	€ 2.8M	€ 62M

Assumptions

Measures are assumed to reduce emission factors as shown below:

Estimated Leakage Rate in Use (% per year)

	Without Measures	With Measure
2010	1.2%	1.2%
2011	1.18%	1.18%
2012	1.16%	1.16%
2013	1.14%	1.14%
2014	1.12%	1.12%
2015	1.10%	1.10%
2016	1.08%	1.06%
2017	1.06%	1.02%
2018	1.04%	0.98%
2019	1.02%	0.94%
2020	1.00%	0.90%
2021	0.98%	0.86%
2022	0.96%	0.82%
2023	0.94%	0.78%
2024	0.92%	0.74%
2025	0.90%	0.70%
2026	0.88%	0.70%
2027	0.86%	0.70%
2028	0.84%	0.70%
2029	0.82%	0.70%
2030	0.80%	0.70%

EOL Recovery Factor is not affected by this measure.

B.6 Methodology for Calculating Marginal Abatement Cost

For each shortlisted policy option, Tables Table 5-21, Table 5-22 and Table 5-23 show the total aggregated abatement potential (in T CO_2) and the abatement cost (in €/T CO_2) over the study period (2012 to 2050). These parameters have been calculated for each policy option as follows:

Total Aggregate Abatement Potential – This is the simple aggregate total over the study period of the annual differences between the forecast emissions with the policy and the forecast emissions without the policy. There is no discount factor applied to future abatement potentials.

Marginal Abatement Cost (€) per Tonne CO_2 – This is a fixed rate X (in € per T CO_2), which if multiplied by each year's forecast emissions abatement potential, would give an annual abatement cost for each year. The rate X is chosen so that the net present value (NPV) of these future annual abatement costs is the same as the NPV of the upfront and ongoing costs of implementing the policy.

This methodology for calculating the marginal abatement cost (MAC, in €/T CO_2) over a period is consistent with the standard method of calculating the MAC for a given year, as is used for example when generating MAC curves (McKinsey & Company, 2009). That standard method involves taking the total annualised costs (i.e. annuitized capital costs + operating costs, in €/y) and dividing this by the annual abatement potential (in T CO_2 per year); and is also equivalent to that described in the "World Energy Model – Methodology and Assumptions" report of the World Energy Outlook 2011 (IEA, 2011). The methodology used in this report applies the same principles and gives equivalent values, by calculating a MAC for a given policy option with varying annual costs and varying annual abatement quantities over a period spanning several years.

Appendix C End Use Sector Characteristics

A summary of each End-Of-Life Market Sector is provided in the sub-sections overleaf.

The structure for each subsector is as follows:

- Charts of forecast bank size (in T, TODP and kT CO2)
- Charts of forecast annual “retirement from bank” (in T, TODP and kT CO2)
- Charts of forecast emissions by life-cycle phase (in T, TODP and kT CO2)
- Chart of forecast average ODP and GWP of gas on retirement from the bank
- Table of sector characteristics, giving key features of the sector and the gases used.

C.1 RAC1 – Domestic Appliances

Figure C-1-1 Bank Forecast

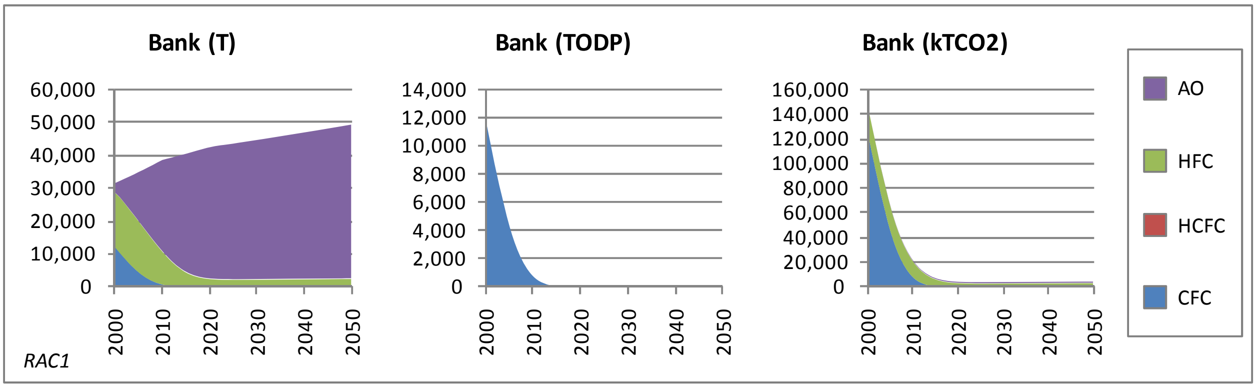


Figure C-1-2 End-Of-Use Retirement from Bank

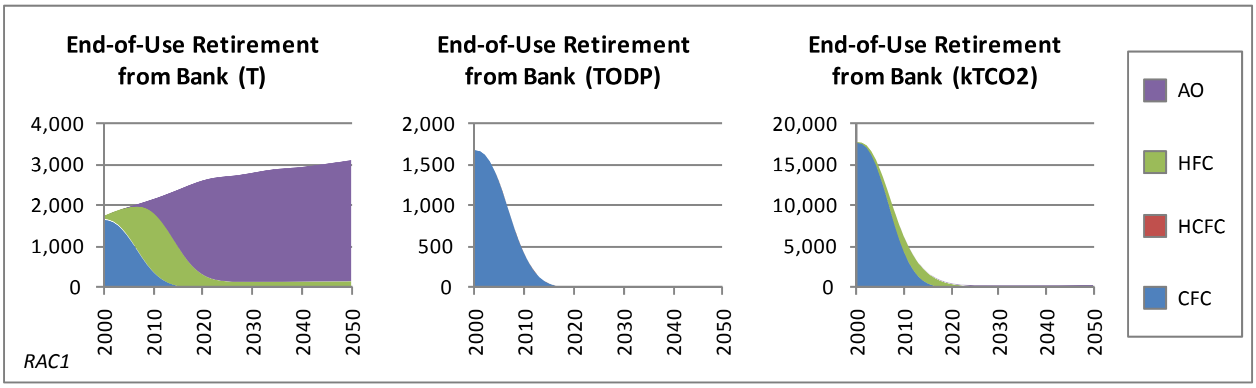


Figure C-1-3 Emissions by Lifecycle Phase

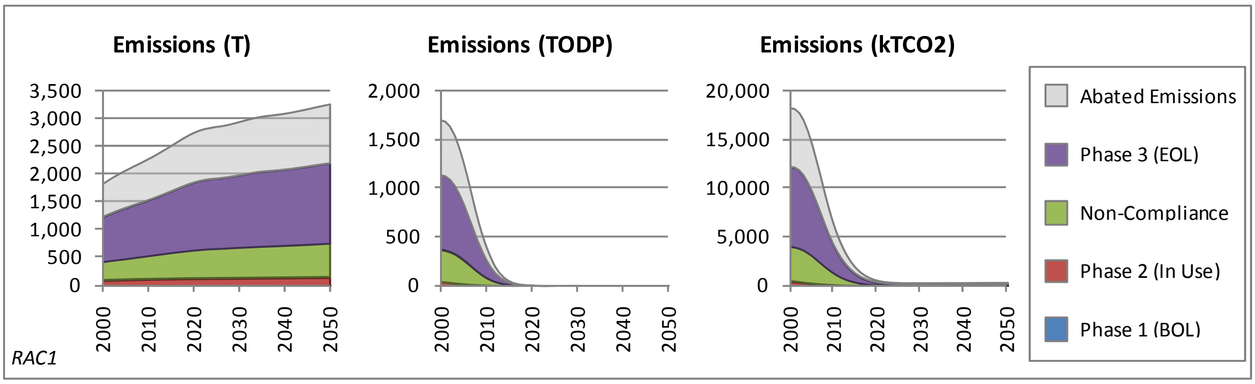


Figure C-1-4 Average ODP and GWP at End-Of-Use Retirement from Bank

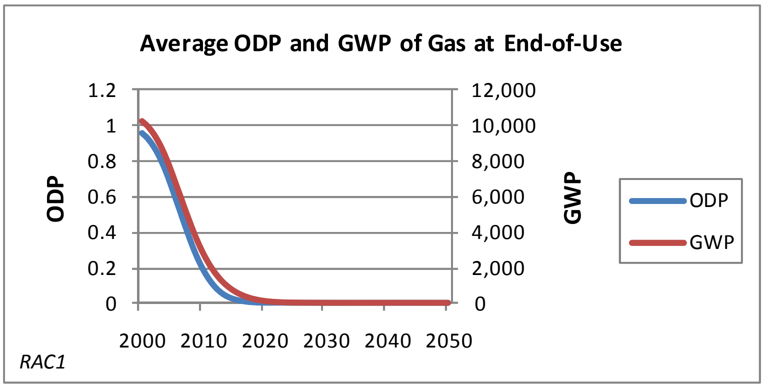


Table C-1-1 RAC1 Sector Characteristics

Main Refrigeration System Type/s	Small hermetic	
Typical refrigerant charge	0.05 to 0.15 kg	
Timeline for main refrigerants (in new systems)	Before 1993	CFC 12
	1994 to 2002	HFC 134a
	2003 to 2011	HCs (iso-butane) for most refrigerators; "US style" large refrigerators still use HFC 134a
	Possible future	HCs + HFOs
Typical Lifecycle (years)	12	
Lifetime leakage rate	Very low (< 1% per year)	
EOU Retirement from Bank 2015	CFCs	Very little - most of CFC bank gone by 2010
	HCFCs	None
	HFCs	Small amount as older HFC systems reach EOL and on-going for large US style refrigerators
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	Depends on future new product policies / practices. Very little EOL HFCs if HFC 134a banned on all domestic systems by 2015
Current legislation	Recovery required via F Gas Regulation, Ozone Regulation and WEEE Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Refrigerators sent to specialist recovery facility (SRF). Refrigerant removed with recovery machine prior to dismantling of refrigeration circuit.	
Infrastructure available	Yes, via network of Domestic refrigerator SRFs	

C.2 RAC2 – Small Commercial Hermetic

Figure C-2-1 Bank Forecast

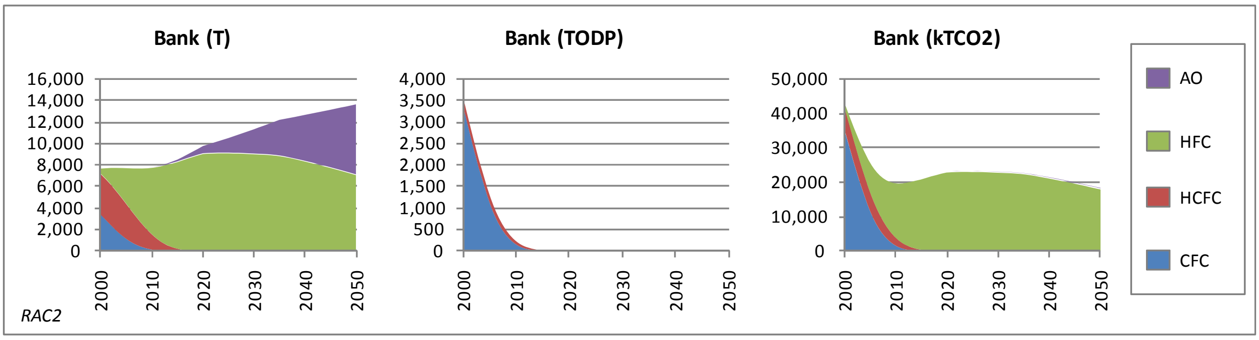


Figure C-2-2 End-Of-Use Retirement from Bank

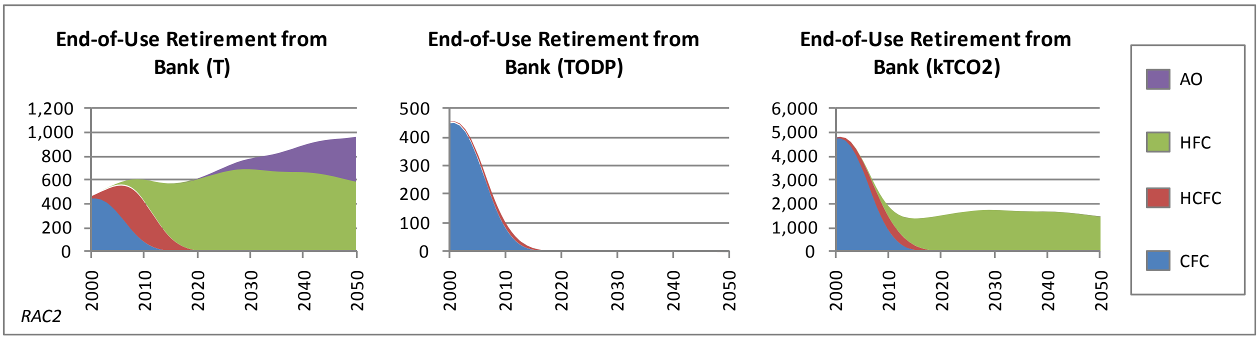


Figure C-2-3 Emissions by Lifecycle Phase

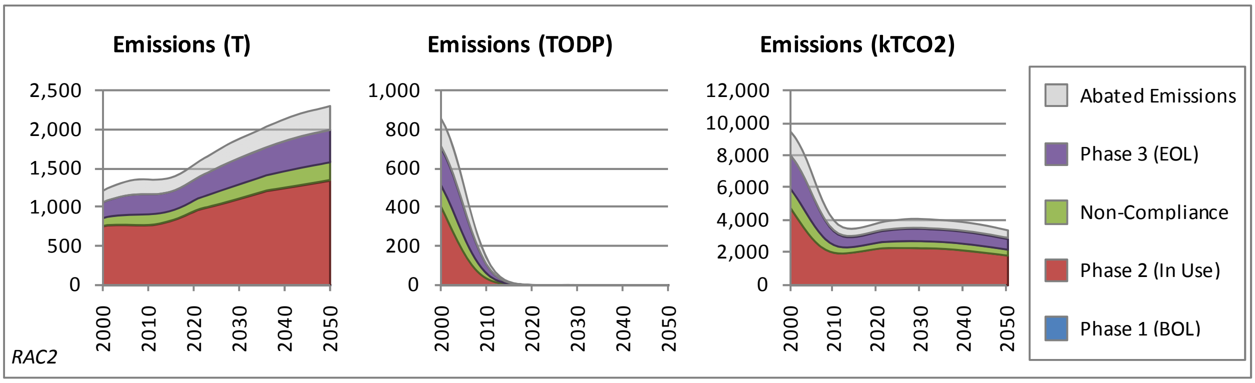


Figure C-2-4 Average ODP and GWP at End-Of-Use Retirement from Bank

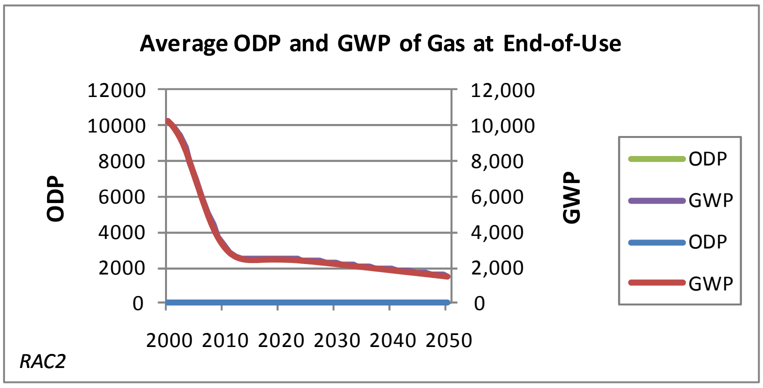


Table C-2-1 RAC2 Sector Characteristics

Main Refrigeration System Type/s	Small hermetic	
Typical refrigerant charge	0.1 to 0.5 kg	
Timeline for main refrigerants (in new systems)	Before 1993	CFC 12
	1994 to 2008	HFC 134a
	2009 to 2011	HFC 134a plus some HCs
	Possible future	HCs + HFOs
Typical Lifecycle (years)	12	
Lifetime leakage rate	Very low (< 1% per year)	
EOU Retirement from Bank 2015	CFCs	Very little - most of CFC bank gone by 2010
	HCFCs	None
	HFCs	"Normal" annual retirement as systems installed to 2008 reach EOL
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	Depends on future new product policies / practices. Very little EOL HFCs if HCs / HFOs dominate new systems by 2015
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation.	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Can be treated in similar way to domestic systems (see RAC 1) or EOL contractor can recover on site with standard recovery machine	
Infrastructure available	Potentially, via network of domestic refrigerator SRFs	

C.3 RAC3 – Small Commercial DX

Figure C-3-1 Bank Forecast

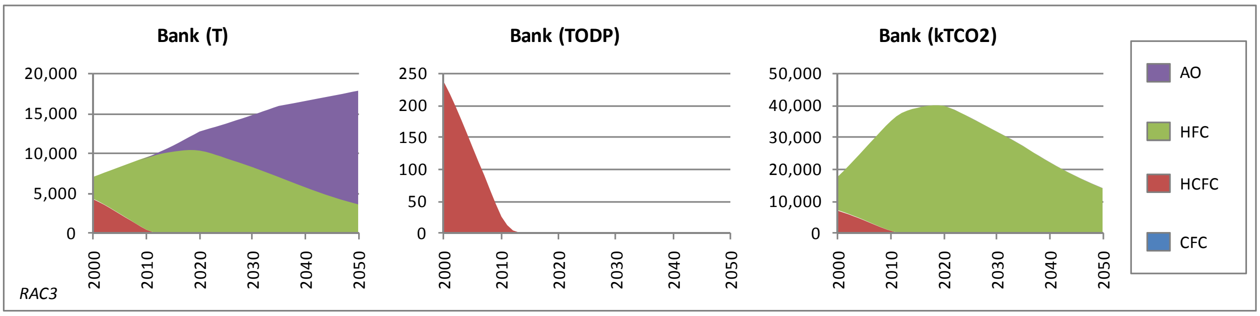


Figure C-3-2 End-Of-Use Retirement from Bank

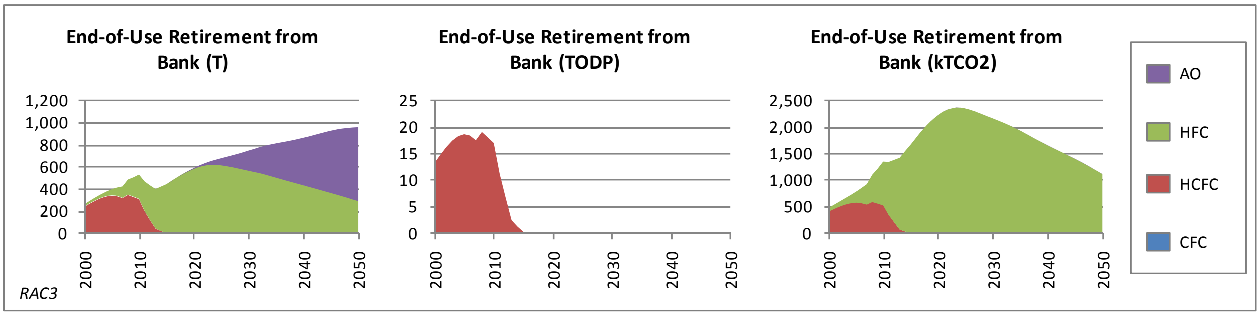


Figure C-3-3 Emissions by Lifecycle Phase

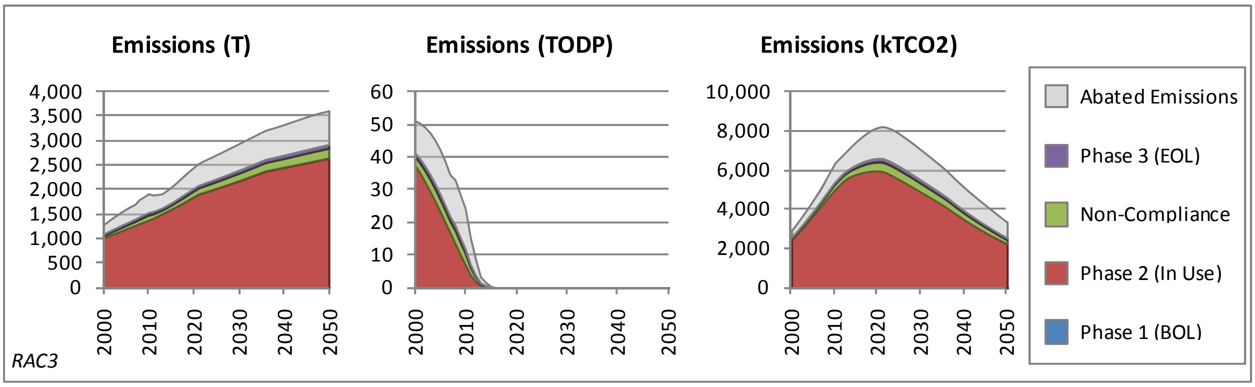


Figure C-3-4 Average ODP and GWP at End-Of-Use Retirement from Bank

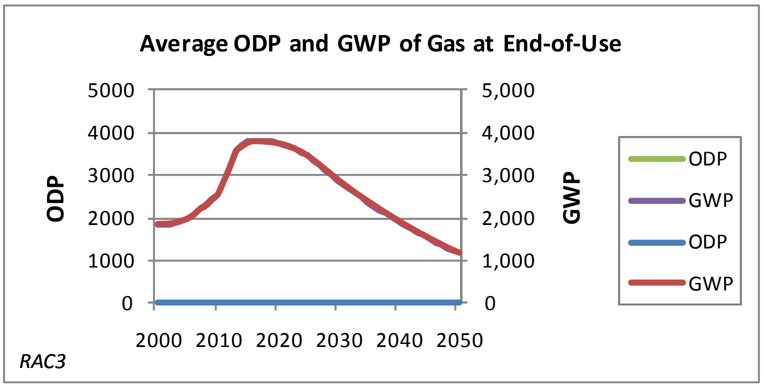


Table C-3-1 RAC3 Sector Characteristics

Main Refrigeration System Type/s	Small DX split systems	
Typical refrigerant charge	2 to 20 kg	
Timeline for main refrigerants (in new systems)	Before 1994	CFC 12, CFC 502, HCFC 22
	1995 to 2001	HCFC 22, HFCs 404A, 134a, + other HFCs
	2002 to 2011	HFCs 404A, 134a + other HFCs
	Possible future	HFCs + HFOs + CO2
Typical Lifecycle (years)	15	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	Small amount as older HCFC systems reach EOL
	HCFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	Depends on future new product policies / practices. Very little EOL HFCs if CO2 / HFOs dominate new systems by 2015
	HFCs	Small amount as older HCFC systems reach EOL
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery on site by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.4 RAC4 – Large Commercial

Figure C-4-1 Bank Forecast

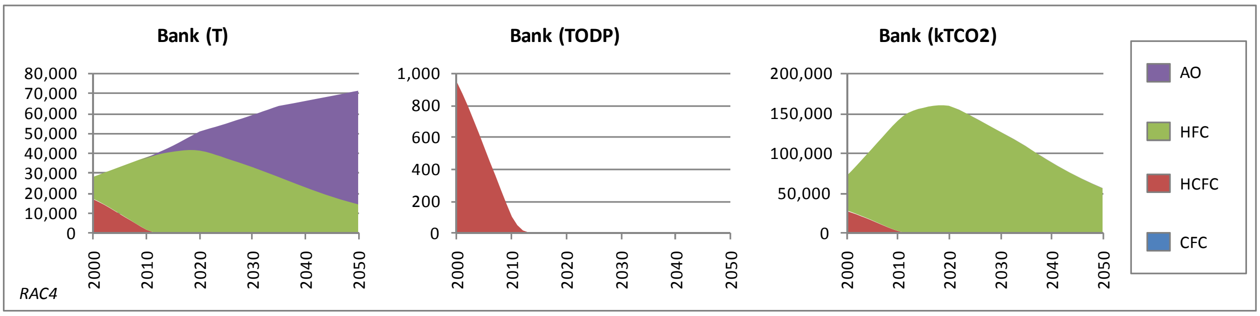


Figure C-4-2 End-Of-Use Retirement from Bank

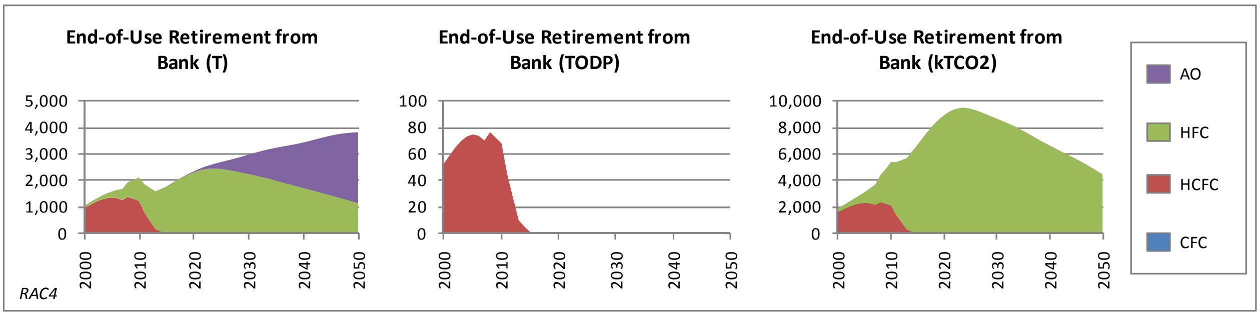


Figure C-4-3 Emissions by Lifecycle Phase

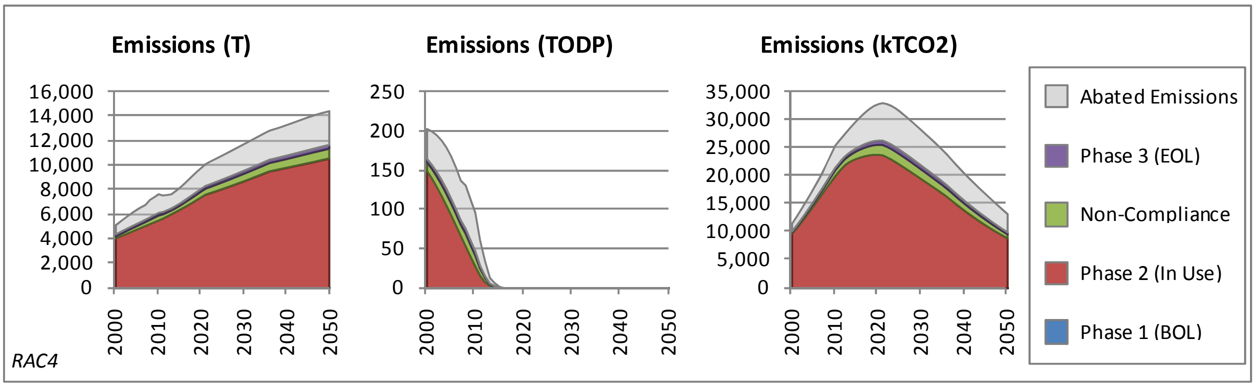


Figure C-4-4 Average ODP and GWP at End-Of-Use Retirement from Bank

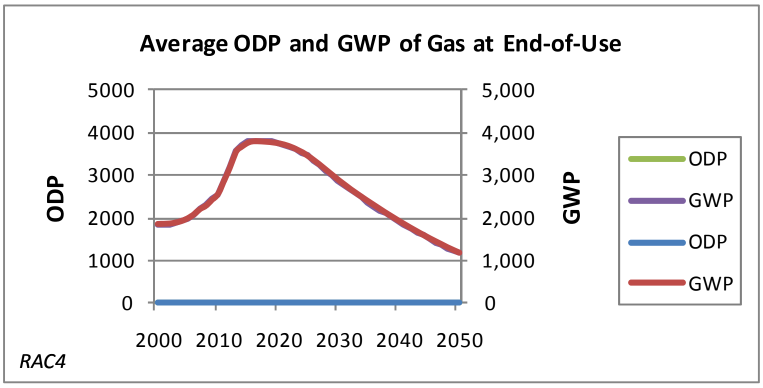


Table C-4-1 RAC4 Sector Characteristics

Main Refrigeration System Type/s	Large DX distributed systems	
Typical refrigerant charge	20 to 200 kg	
Timeline for main refrigerants (in new systems)	Before 1994	CFC 12, CFC 502, HCFC 22
	1995 to 2001	HCFC 22, HFCs 404A, 134a, + other HFCs
	2002 to 2011	HFCs 404A, 134a + other HFCs
	Possible future	HFCs + HFOs + CO2
Typical Lifecycle (years)	20	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	Final decommissioning of HCFC large systems
	HCFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	Depends on future new product policies / practices. Little EOL HFCs if CO2 / HFOs dominate new systems by 2015
	HFCs	Final decommissioning of HCFC large systems
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery on site by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.5 RAC5 – Industrial

Figure C-5-1 Bank Forecast

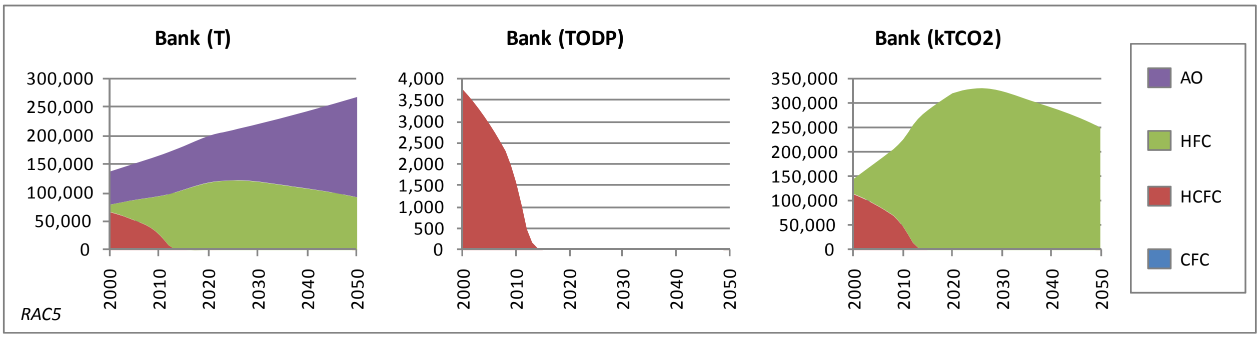


Figure C-5-2 End-Of-Use Retirement from Bank

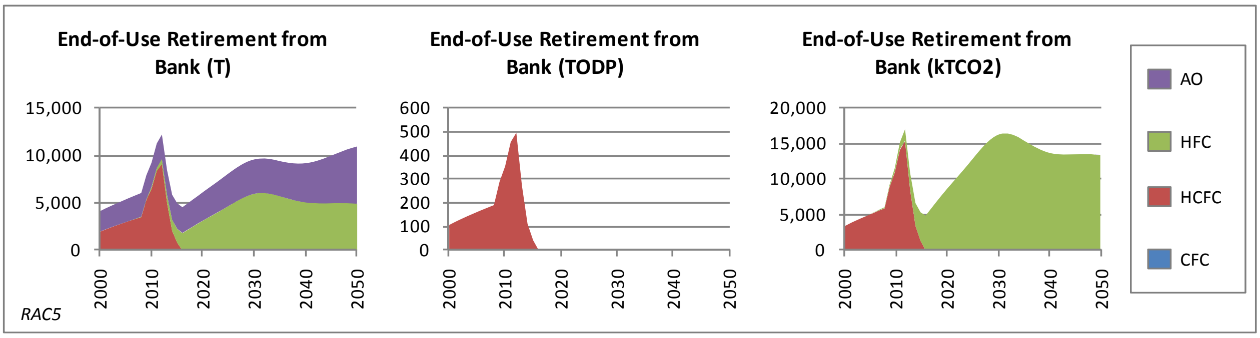


Figure C-5-3 Emissions by Lifecycle Phase

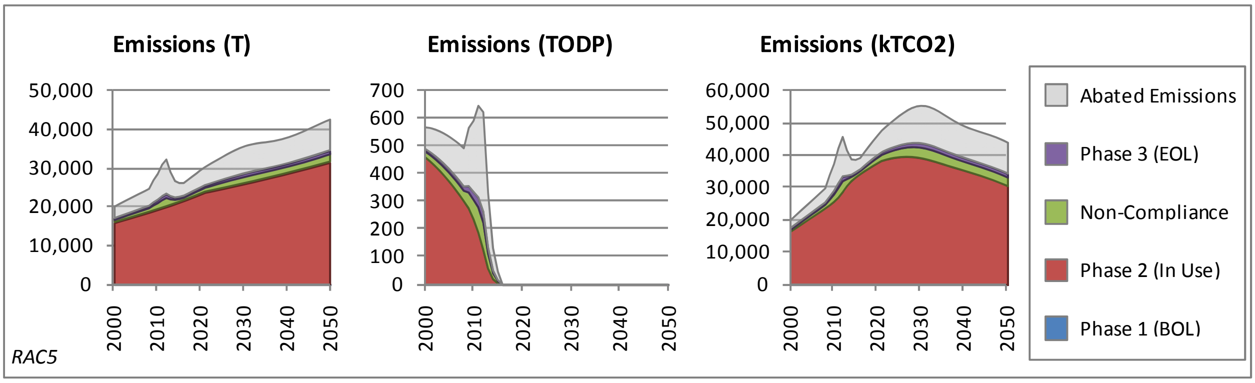


Figure C-5-4 Average ODP and GWP at End-Of-Use Retirement from Bank

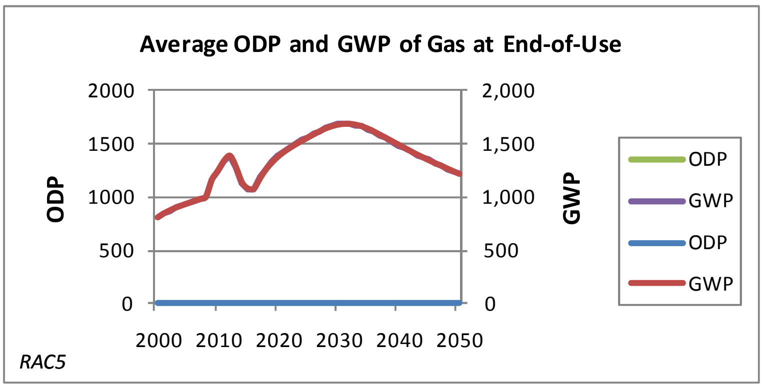


Table C-5-1 RAC5 Sector Characteristics

Main Refrigeration System Type/s	Various including DX, pumped circulation and chillers	
Typical refrigerant charge	20 to 2,000 kg	
Timeline for main refrigerants (in new systems)	Before 1994	CFC 12, CFC 502, HCFC 22, ammonia
	1995 to 2001	HCFC 22, HFCs 404A, 134a, + other HFCs + ammonia
	2002 to 2011	HFCs 404A, 134a + other HFCs + ammonia + CO2
	Possible future	HFCs + HFOs + ammonia + CO2
Typical Lifecycle (years)	25	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	None
	HCFCs	Final decommisioning of HCFC large systems
	HFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	Depends on future new product policies / practices. Little EOL HFCs if ammonia CO2 / HFOs dominate new systems by 2015
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery on site by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.6 RAC6 – Small AC

Figure C-6-1 Bank Forecast

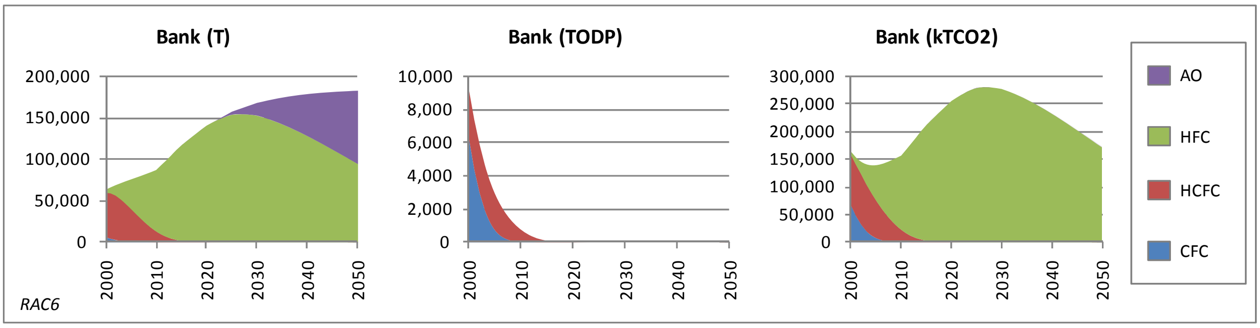


Figure C-6-2 End-Of-Use Retirement from Bank

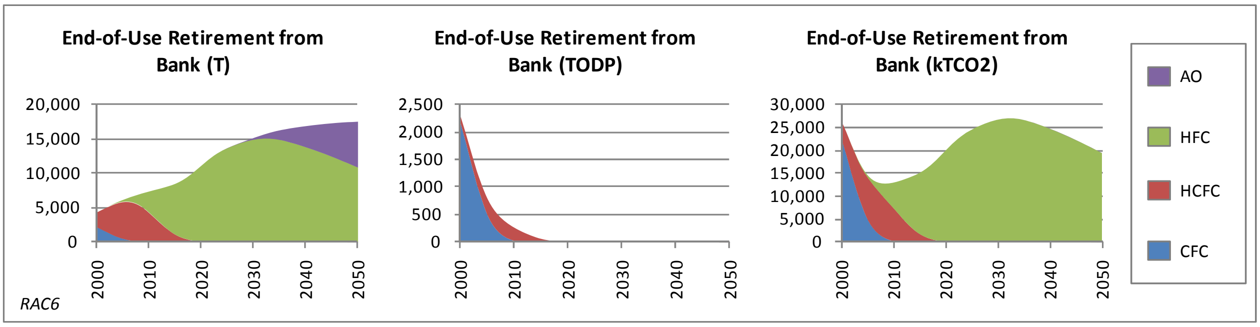


Figure C-6-3 Emissions by Lifecycle Phase

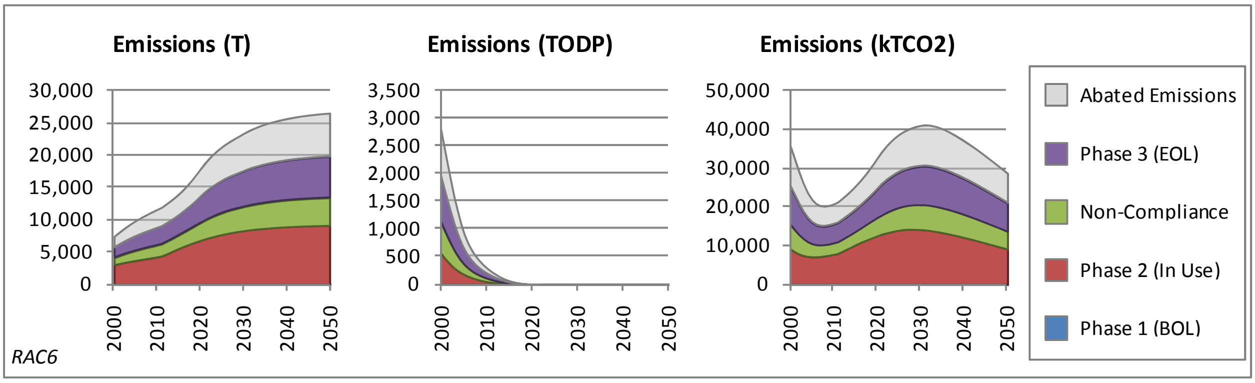


Figure C-6-4 Average ODP and GWP at End-Of-Use Retirement from Bank

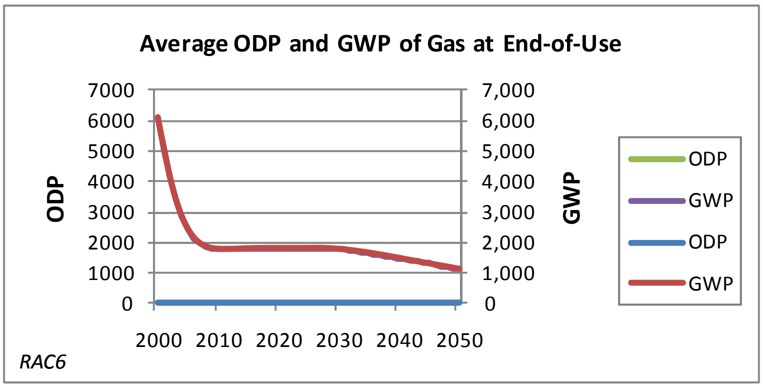


Table C-6-1 RAC6 Sector Characteristics

Main Refrigeration System Type/s	Small split systems, small VRV etc.	
Typical refrigerant charge	2 to 50 kg	
Timeline for main refrigerants (in new systems)	Before 1994	Small split systems, small VRV etc.
	1995 to 2001	2 to 50 kg
	2002 to 2011	Small split systems, small VRV etc.
	Possible future	2 to 50 kg
Typical Lifecycle (years)	12	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	Small amount as older HCFC systems reach EOL
	HCFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	Depends on future new product policies / practices. Little EOL HFCs if HFOs dominate new systems by 2020
	HFCs	Small amount as older HCFC systems reach EOL
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery on site by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.7 RAC7 – Large AC

Figure C-7-1 Bank Forecast

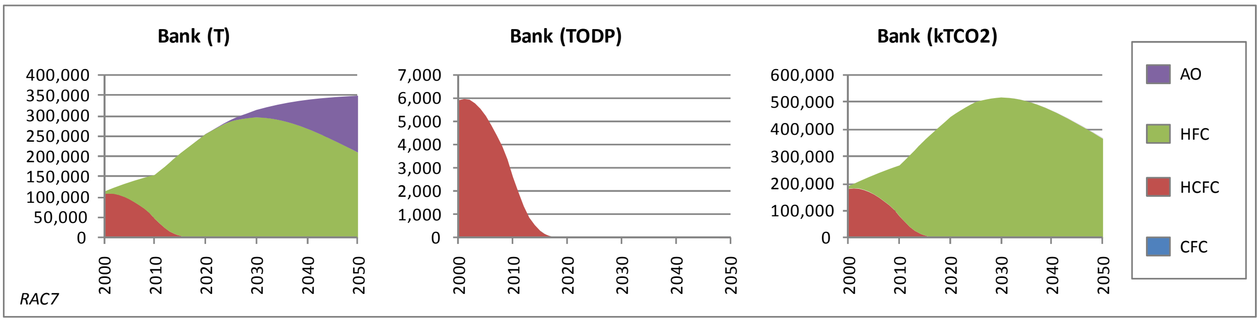


Figure C-7-2 End-Of-Use Retirement from Bank

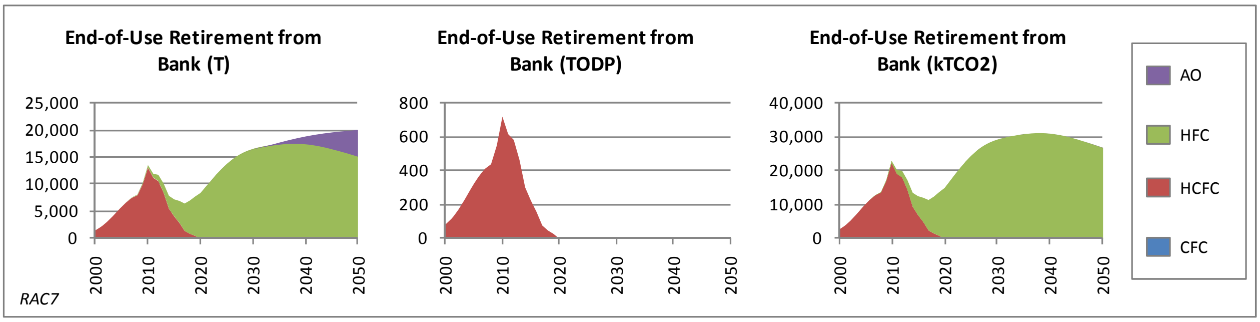


Figure C-7-3 Emissions by Lifecycle Phase

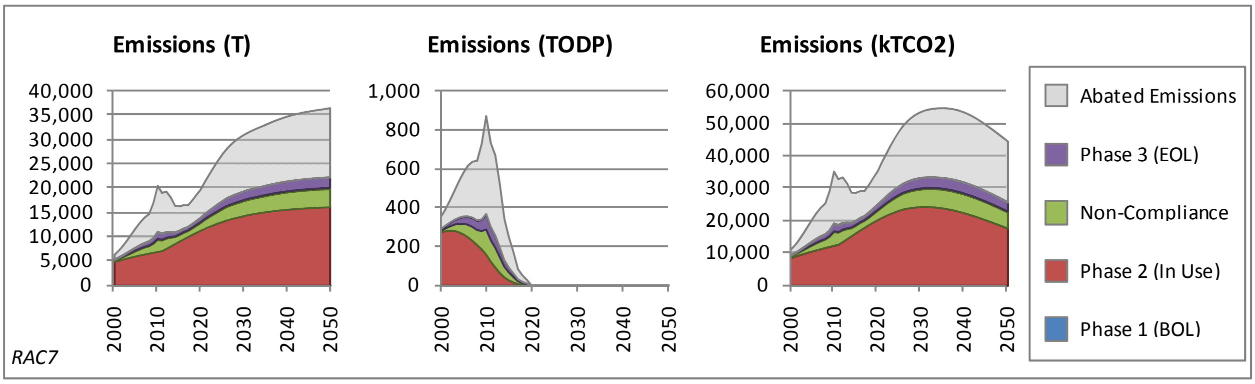


Figure C-7-4 Average ODP and GWP at End-Of-Use Retirement from Bank

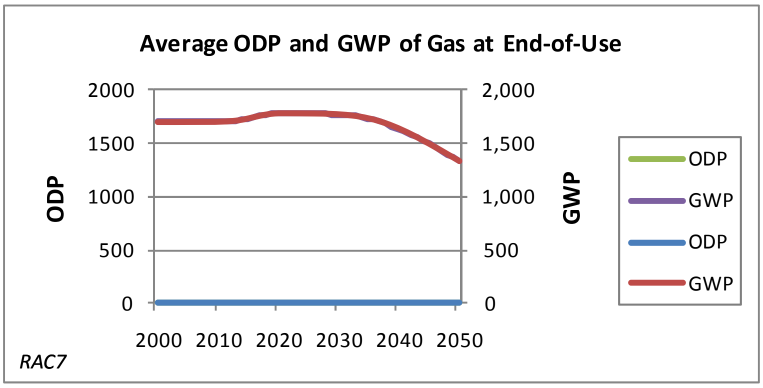


Table C-7-1 RAC7 Sector Characteristics

Main Refrigeration System Type/s	Chillers and large DX systems	
Typical refrigerant charge	50 to 500 kg	
Timeline for main refrigerants (in new systems)	Before 1994	CFC 11, CFC 12, HCFC 22
	1995 to 2001	HCFC 22, HFC 134a
	2002 to 2011	HFC 134a + ammonia + HCs
	Possible future	HFCs + HFOs + ammonia + HCs
Typical Lifecycle (years)	20	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	Final decommisioning of HCFC large systems
	HCFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	Depends on future new product policies / practices. Little EOL HFCs if ammonia / HCs / HFOs dominate new systems by 2015
	HFCs	Final decommisioning of HCFC large systems
Current legislation	Recovery required via F Gas Regulation and Ozone Regulation	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery on site by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.8 RAC8 – Transport

Figure C-8-1 Bank Forecast

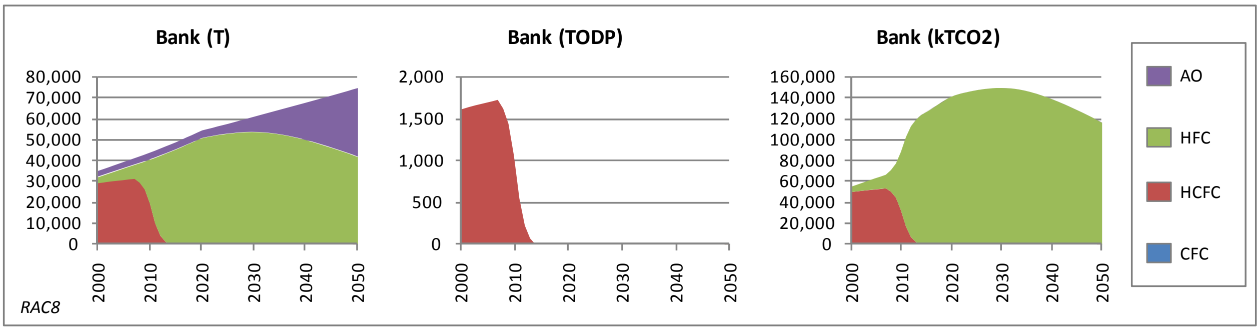


Figure C-8-2 End-Of-Use Retirement from Bank

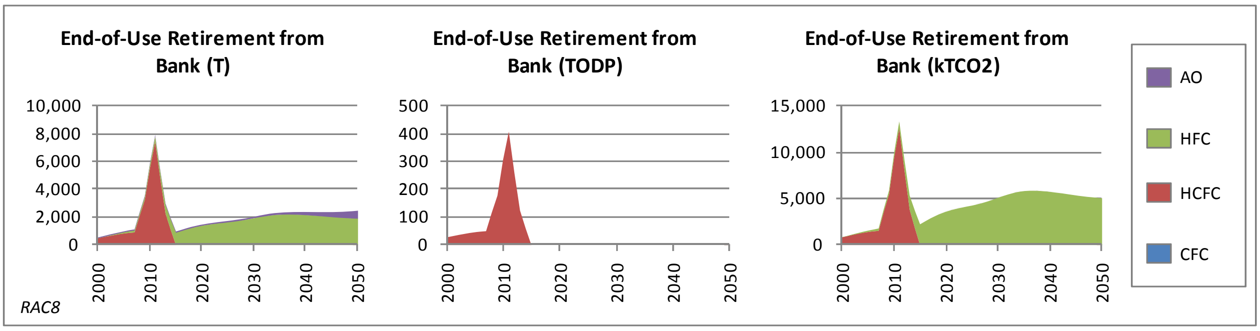


Figure C-8-3 Emissions by Lifecycle Phase

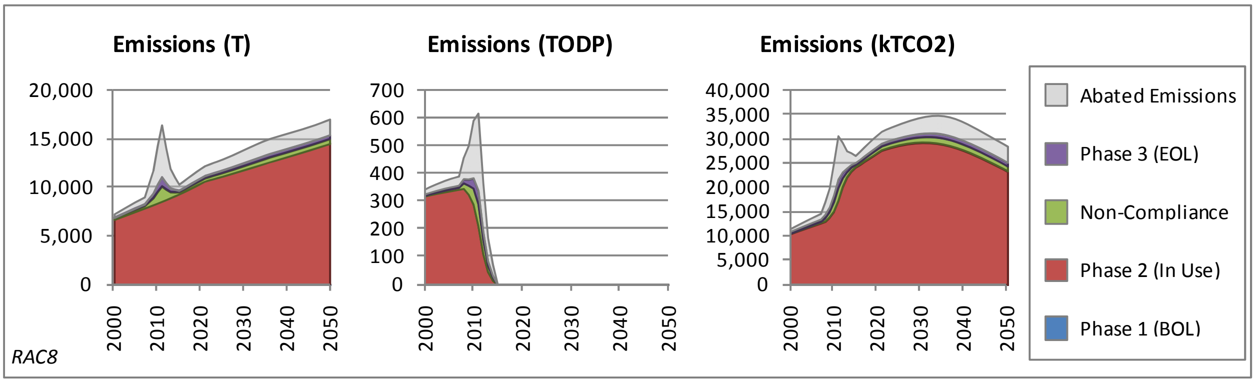


Figure C-8-4 Average ODP and GWP at End-Of-Use Retirement from Bank

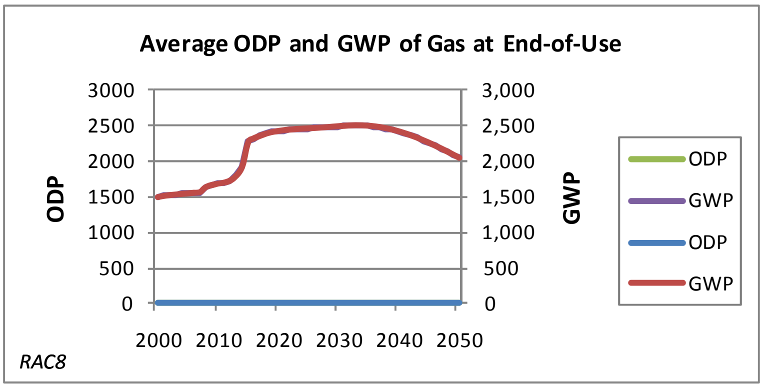


Table C-8-1 RAC8 Sector Characteristics

Main Refrigeration System Type/s	Non-car air-conditioning (e.g. lorries, buses, trains), Refrigerated transport (lorries, containers, ships)	
Typical refrigerant charge	1 to 100 kg	
Timeline for main refrigerants (in new systems)	Before 1993	CFC 12, CFC 502, HCFC 22
	1994 to 2002	HFC 134a, HCFC 22, HFC 404A
	2003 to 2011	HFC 134a, HFC 404A
	Possible future	HFCs + HFOs
Typical Lifecycle (years)	10	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	Small amount as older HCFC systems reach EOL
	HCFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	Depends on future new product policies / practices. Very little EOL HFCs if HFOs dominate new systems by 2020
	HFCs	Small amount as older HCFC systems reach EOL
Current legislation	No clear obligation - recovery required if "technically feasible and does not entail disproportionate cost". This is presumed to apply for mobile RAC, but this is not completely clear!	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery at end of vehicle life by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.9 RAC9 – Cars and Vans

Figure C-9-1 Bank Forecast

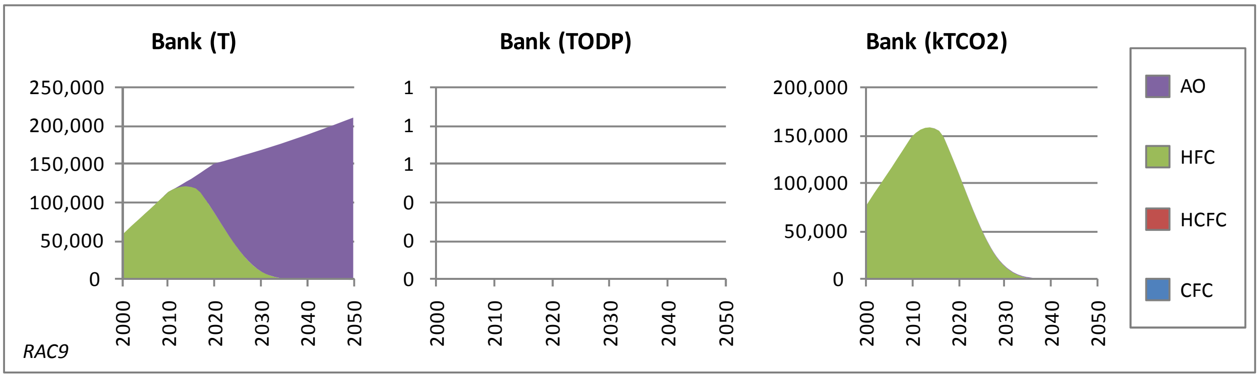


Figure C-9-2 End-Of-Use Retirement from Bank

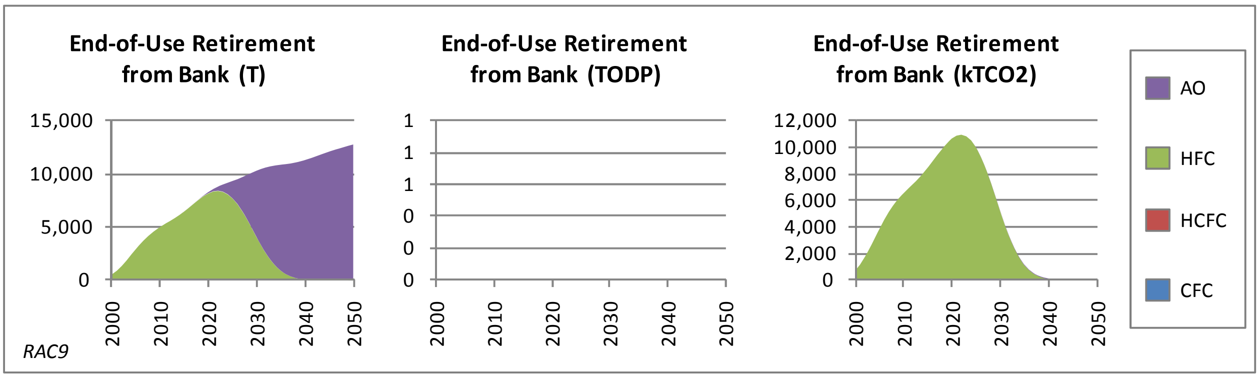


Figure C-9-3 Emissions by Lifecycle Phase

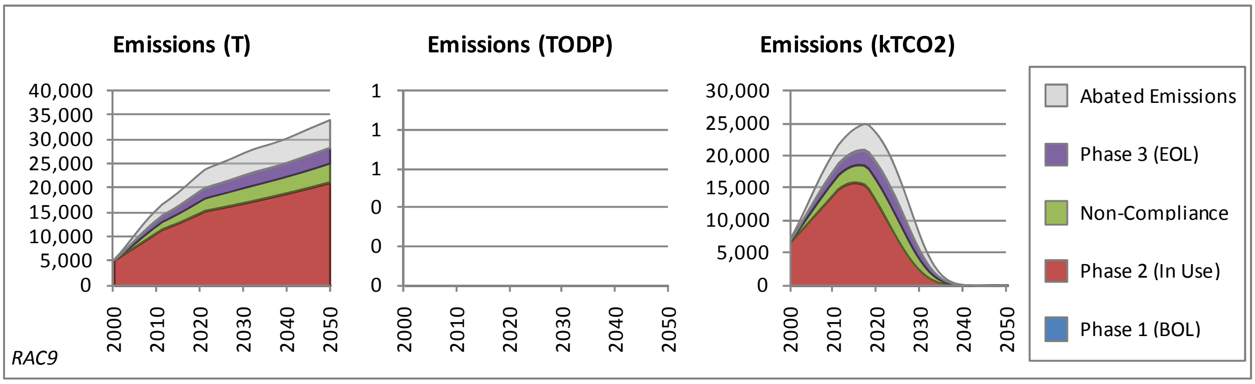


Figure C-9-4 Average ODP and GWP at End-Of-Use Retirement from Bank

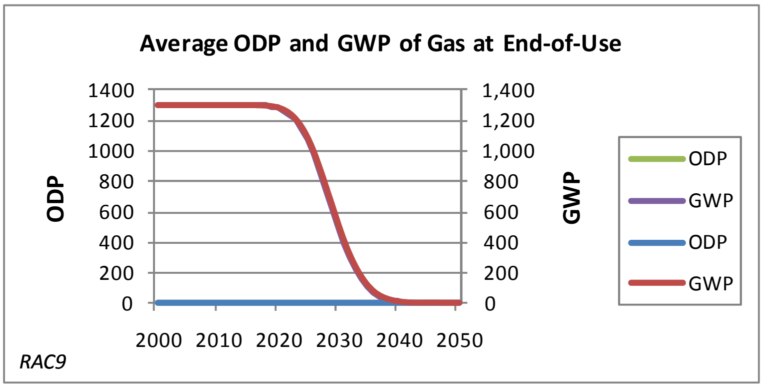


Table C-9-1 RAC9 Sector Characteristics

Main Refrigeration System Type/s	Vehicles covered by MAC Directive	
Typical refrigerant charge	0.5 to 1 kg	
Timeline for main refrigerants (in new systems)	Before 1993	CFC 12
	1994 to 2011	HFC 134a
	2011 onwards	HFC 134a, HFO 1234yf
	After 2017	HFO 1234yf
Typical Lifecycle (years)	10	
Lifetime leakage rate	None	
EOU Retirement from Bank 2015	CFCs	None
	HCFCs	None
	HFCs	"Normal" annual retirement as systems installed to 2011 reach EOL
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	Very little - most HFC systems retired by 2030
Current legislation	No clear obligation - recovery required if "technically feasible and does not entail disproportionate cost". This is presumed to apply for mobile RAC, but this is not completely clear!	
Current implementation	Not certain. Reasonable compliance is likely as majority of workforce are qualified and are aware of recovery rules.	
Technical options	Recovery at end of vehicle life by EOL contractor using standard recovery machine	
Infrastructure available	Yes, via F Gas qualified RAC contractors	

C.10 Foam 1 – Domestic Refrigerators

Figure C-10-1 Bank in Product Forecast

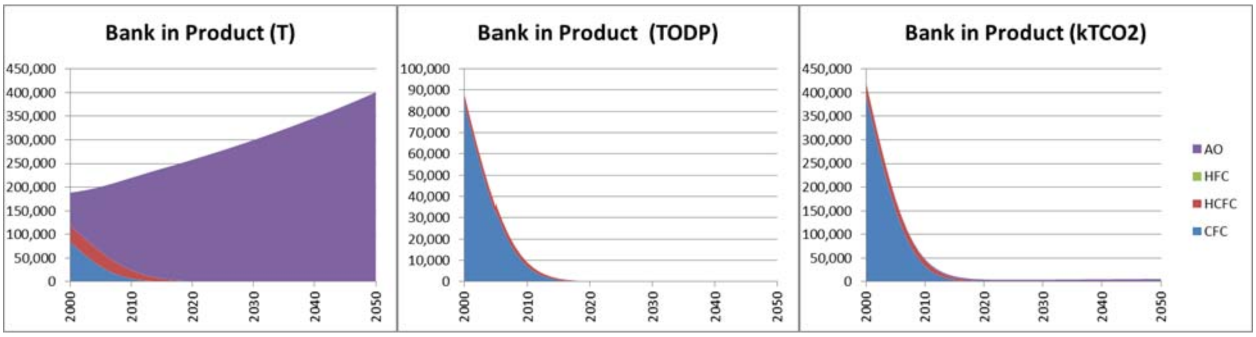


Figure C-10-2 End-Of-Use Retirement from Bank

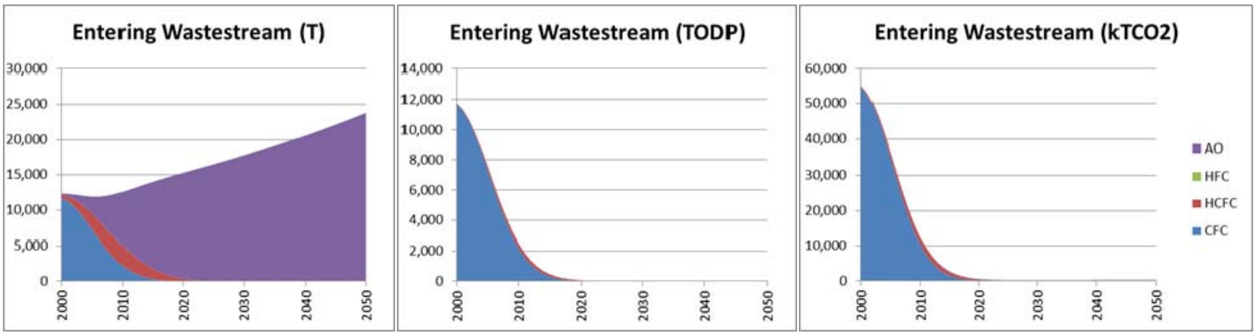


Figure C-10-3 Emissions by Lifecycle Phase

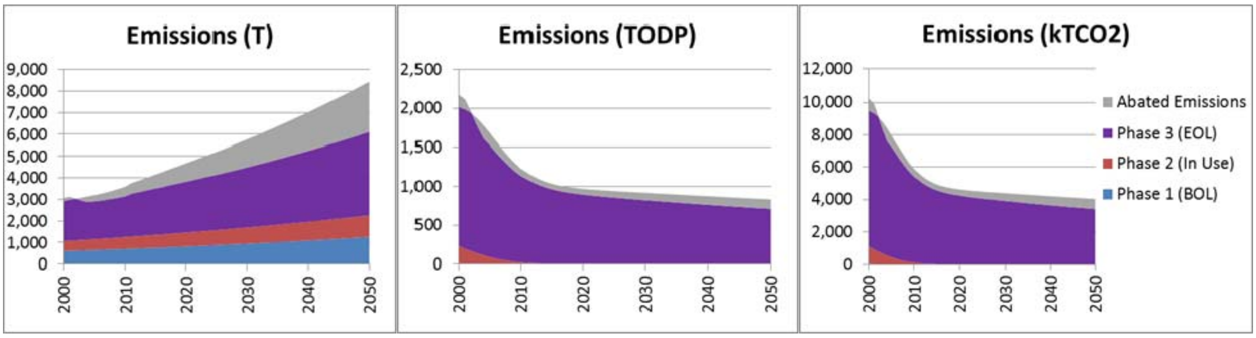


Figure C-10-4 Average ODP and GWP at End-Of-Use Retirement from Bank

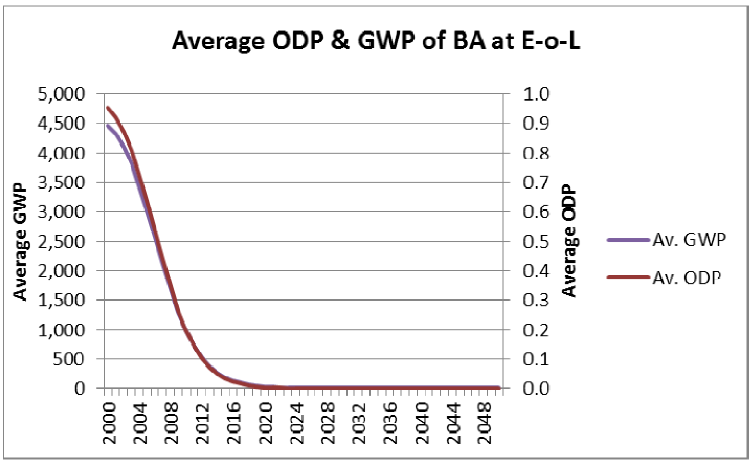


Table C-10-1 F1 Sector Characteristics

Main Foam Type	Polyurethane	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11 ~100%
	1994-2002	HCFC 141b (5%); Hydrocarbons (95%);
	2003-2011	Hydrocarbons (pentane) ~100%
	Likely future	Hydrocarbons and Hydro-fluoro-olefins (HFOs)
Typical Lifecycle (years)	12	
Lifetime diffusion rate	Very low (<0.5% per year)	
EOU Retirement from Bank 2015	CFCs	Majority of CFC bank gone by 2010, but some claims of considerable CFC component still
	HCFCs	Some from refrigerators manufactured in 1994 to 2002
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	None
Current legislation	Recovery and destruction required via Ozone Regulation (EC Reg. 1005/2009) and WEEE Regulation	
Current implementation	Fairly good	
Technical options	Refrigerators sent to Specialist Recovery Facility (SRF). Shredding/crushing to release blowing agent. Capture via cryogenics or activated carbon	
Infrastructure available	Yes, via network of Specialist Recovery Facilities	

C.11 Foam 2 - Other Small Appliances (e.g. Commercial Displays/Vending Machines/ Water Heaters)

Figure C-11-1 Bank in Product Forecast

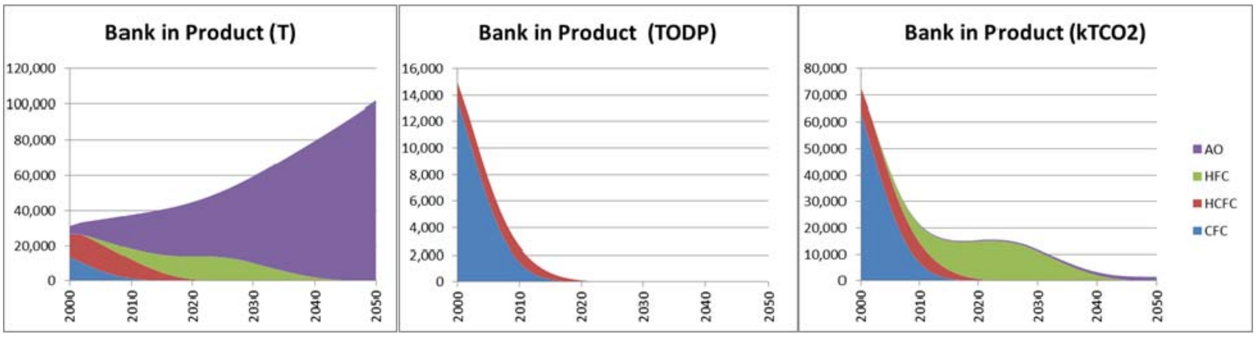


Figure C-11-2 End-Of-Use Retirement from Bank

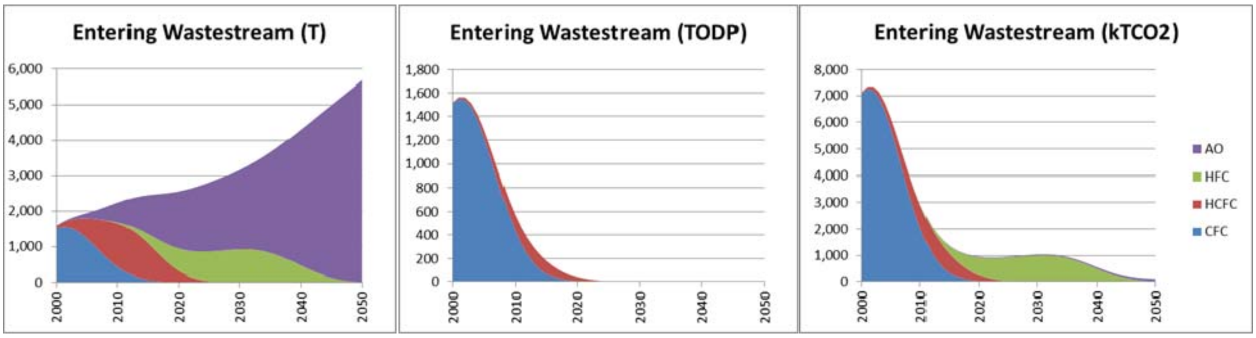


Figure C-11-3 Emissions by Lifecycle Phase

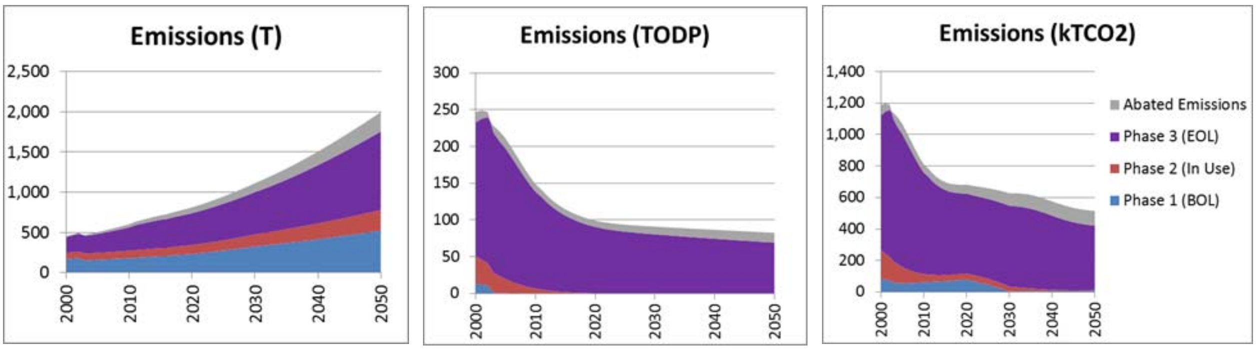


Figure C-11-4 Average ODP and GWP at End-Of-Use Retirement from Bank

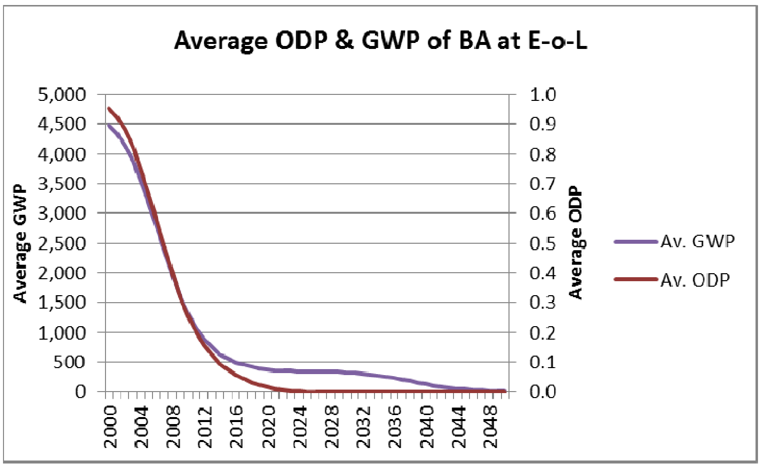


Table C-11-1 F2 Sector Characteristics

Main Foam Type	Polyurethane	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11 ~100%
	1994-2002	HCFC 141b (20%); Hydrocarbons (80%);
	2003-2011	HFCs (20%); Hydrocarbons (pentane) (80%);
	Likely future	Hydrocarbons and Hydro-fluoro-olefins (HFOs)
Typical Lifecycle (years)	15-20 years	
Lifetime diffusion rate	Low (<1% per year)	
EOU Retirement from Bank 2015	CFCs	Longer lifetime than Domestic Refrigerators hence CFCs still significant component in 2010
	HCFCs	Some from units manufactured in 1994 to 2002
	HFCs	None
EOU Retirement from Bank 2030	CFCs	None
	HCFCs	None
	HFCs	None
Current legislation	WEEE regulation unclear about coverage in this area. Ozone Regulation only if technically and economically feasible	
Current implementation	Unclear and likely to be variable	
Technical options	Where practised, units sent to Specialist Recovery Facilities (SRF). Shredding/ crushing to release blowing agent. Capture via cryogenics or activated carbon	
Infrastructure available	Some sectors (e.g. supermarkets) driven by Corporate Social Responsibility	

C.12 Foam 3 - Block Foam/Pipe Section (Building Services/Industrial)

Figure C-12-1 Bank in Product Forecast

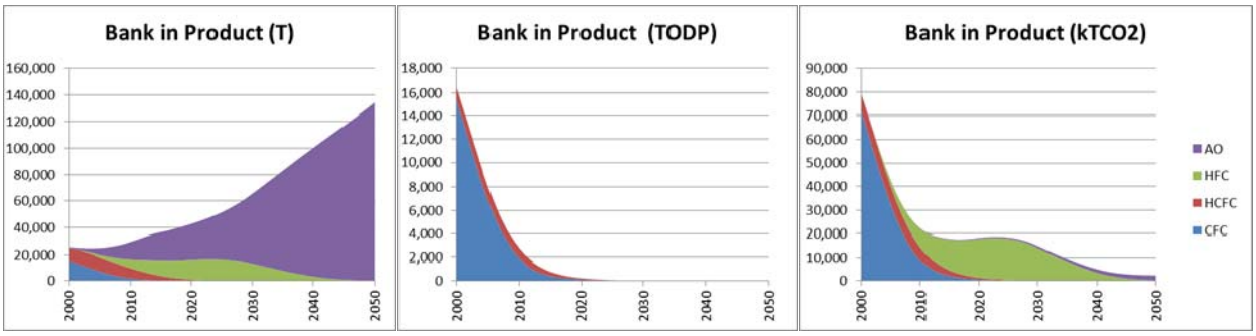


Figure C-12-2 End-Of-Use Retirement from Bank

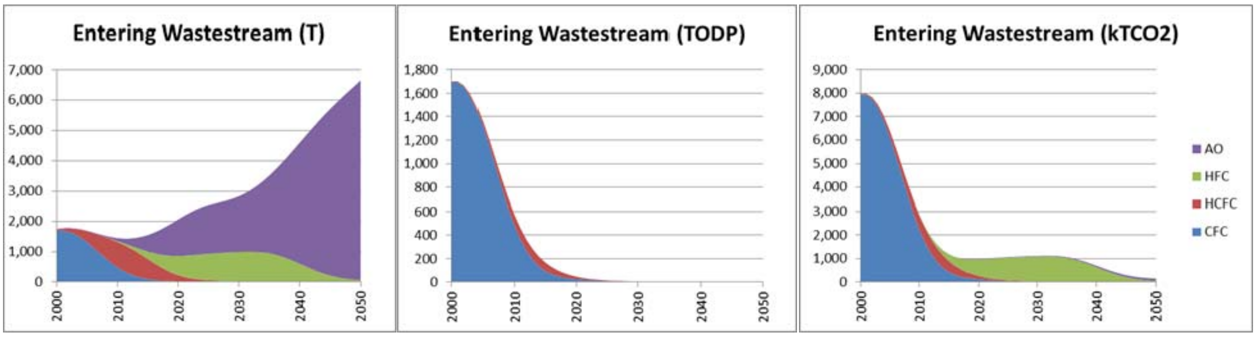


Figure C-12-3 Emissions by Lifecycle Phase

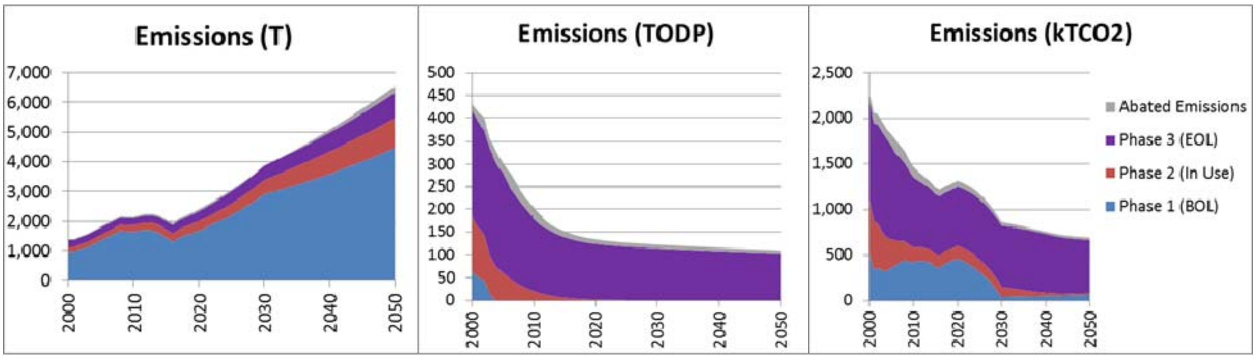


Figure C-12-4 Average ODP and GWP at End-Of-Use Retirement from Bank

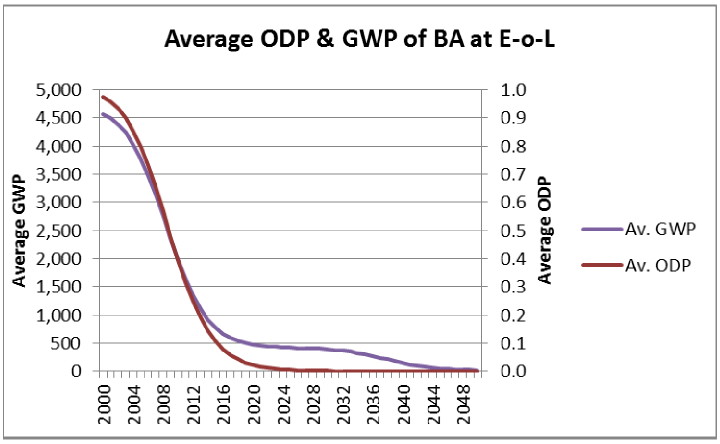


Table C-12-1 F3 Sector Characteristics

<table>
<tr><td>Main Foam Types</td><td colspan="2">Polyurethane (PU), Polyisocyanurate (PIR), Phenolic (PF)</td></tr>
<tr><td rowspan="4">Timeline for blowing agents (in new foams)</td><td>Before 1993</td><td>CFC 11 ~100%</td></tr>
<tr><td>1994-2003</td><td>HCFC 141b (20%); Hydrocarbons (80%);</td></tr>
<tr><td>2004-2011</td><td>HFCs (20%); Hydrocarbons (pentane) ~80%</td></tr>
<tr><td>Likely future</td><td>Hydrocarbons and Hydro-fluoro-olefins (HFOs)</td></tr>
<tr><td>Typical Lifecycle (years)</td><td colspan="2">15 years</td></tr>
<tr><td>Lifetime diffusion rate</td><td colspan="2">Moderately low (<1.5% per year)</td></tr>
<tr><td rowspan="3">EOU Retirement from Bank 2015</td><td>CFCs</td><td>Most CFC-containing pipe section already disposed of by 2015</td></tr>
<tr><td>HCFCs</td><td>Proportion of pipe insulation will be HCFC-containing</td></tr>
<tr><td>HFCs</td><td>None except site waste</td></tr>
<tr><td rowspan="3">EOU Retirement from Bank 2030</td><td>CFCs</td><td>None</td></tr>
<tr><td>HCFCs</td><td>Very limited</td></tr>
<tr><td>HFCs</td><td>Limited but depending on HFC phase-down</td></tr>
<tr><td>Current legislation</td><td colspan="2">Ozone and F-Gas Regulations only require recovery if technically and economically feasible</td></tr>
<tr><td>Current implementation</td><td colspan="2">Limited experience and evidence</td></tr>
<tr><td>Technical options</td><td colspan="2">Direct incineration is an option where local Municipal Solid Waste Incinerators exist. Technically possible to use SRFs.</td></tr>
<tr><td>Infrastructure available</td><td colspan="2">No formal infrastructure but should be possible through maintenance and demolition contracts</td></tr>
</table>

C.13 Foam 4 - Steel-faced Panels

Figure C-13-1 Bank in Product Forecast

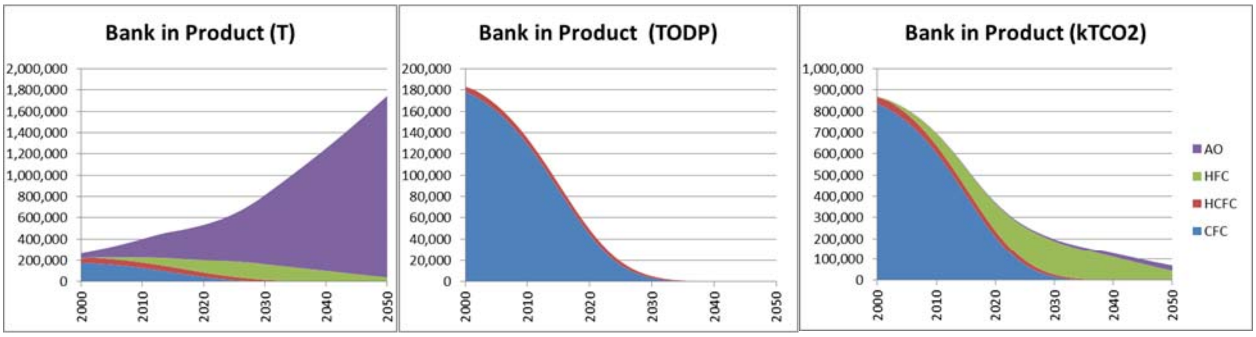


Figure C-13-2 End-Of-Use Retirement from Bank

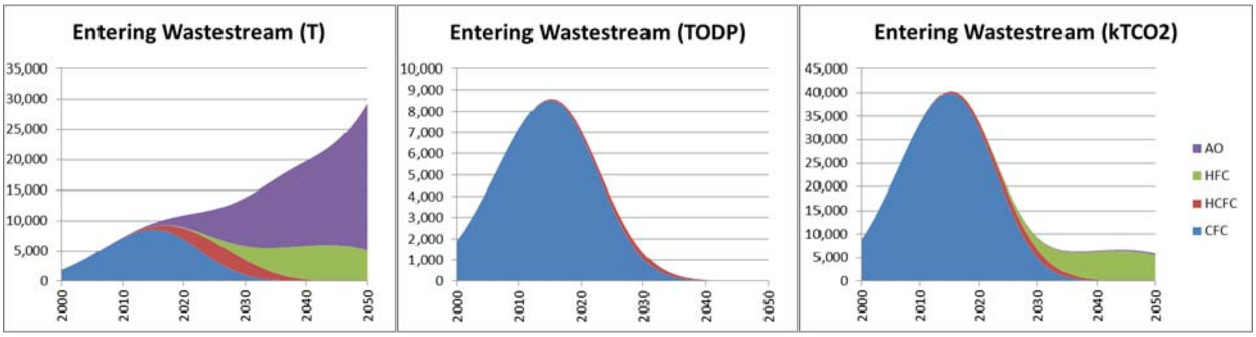


Figure C-13-3 Emissions by Lifecycle Phase

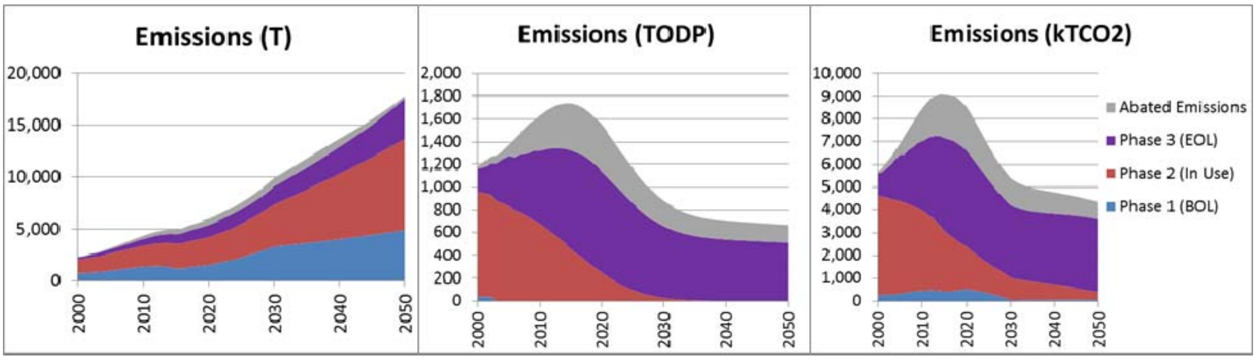


Figure C-13-4 Average ODP and GWP at End-Of-Use Retirement from Bank

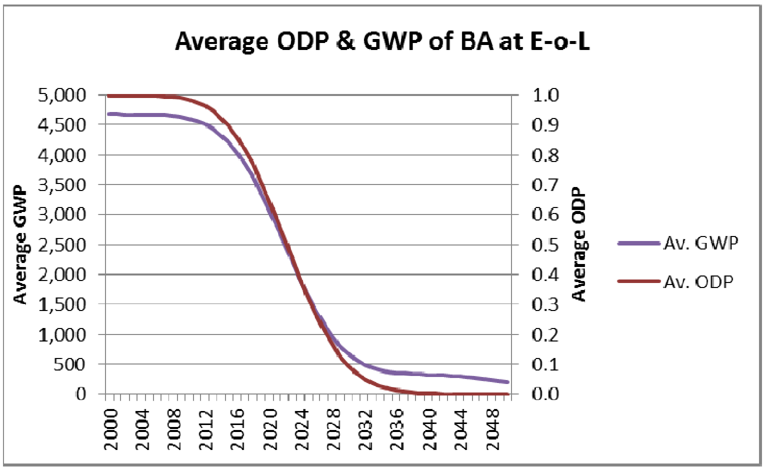


Table C-13-1 F4 Sector Characteristics

Main Foam Type	Polyurethane (PU), Polyisocyanurate (PIR), Phenolic (PF)	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11 ~100%
	1994-2003	HCFC 141b (40%); Hydrocarbons (60%);
	2004-2011	HFCs (20%); Hydrocarbons (pentane) (80%)
	Likely future	Hydrocarbons (HFOs less likely)
Typical Lifecycle (years)	30-50 years	
Lifetime diffusion rate	Low (<1% per year)	
EOU Retirement from Bank 2015	CFCs	Low levels of panel reaching E-o-L but almost exclusively CFC
	HCFCs	Very few HCFC-containing panels
	HFCs	None except for site waste
EOU Retirement from Bank 2030	CFCs	Majority CFC-containing panels
	HCFCs	Moderate levels of HCFC-containing panels
	HFCs	Initial traces of HFC-containing panels
Current legislation	Ozone and F-Gas Regulations only require recovery if technically and economically feasible	
Current implementation	Limited experience and evidence	
Technical options	Steel recovery is an important factor here so direct incineration less likely. Use of SRFs is technically possible although economics still to be fully demonstrated.	
Infrastructure available	No formal infrastructure, but should be possible through demolition contracts	

C.14 Foam 5 - Laminated Boards (Built-up Systems)

Figure C-14-1 Bank in Product Forecast

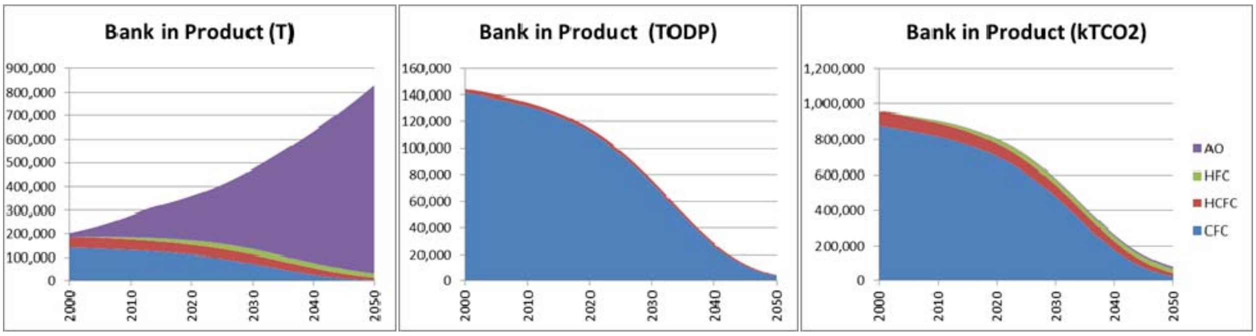


Figure C-14-2 End-Of-Use Retirement from Bank

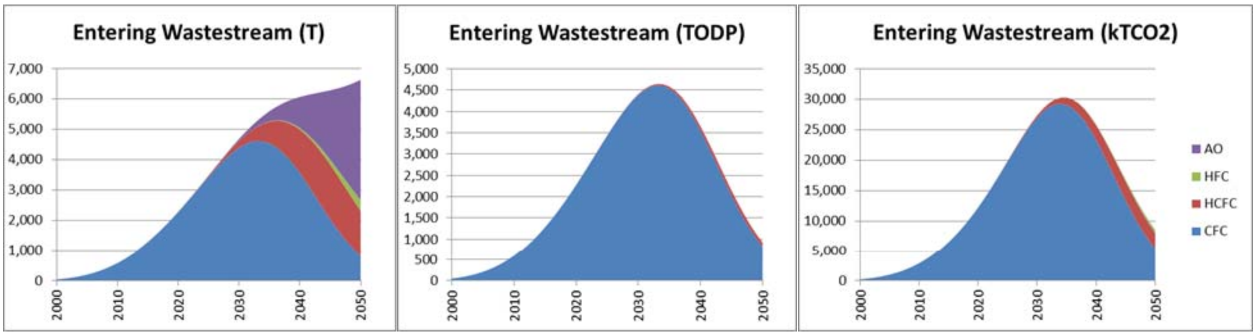


Figure C-14-3 Emissions by Lifecycle Phase

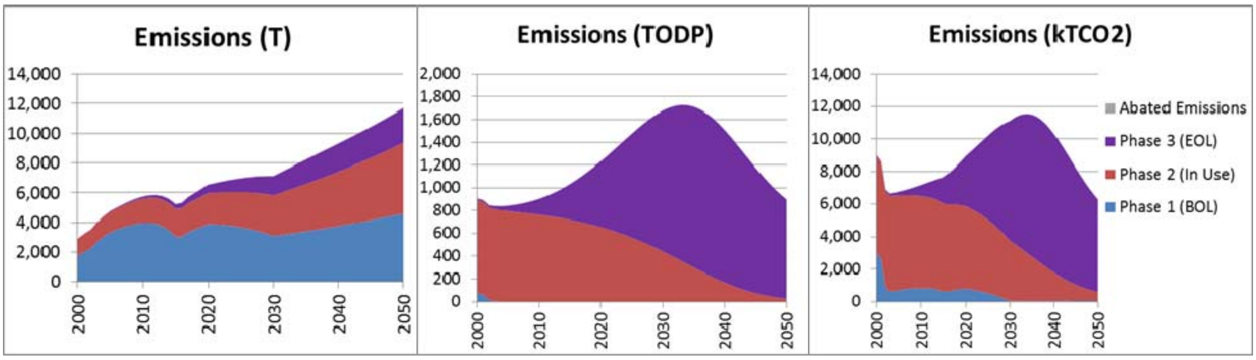


Figure C-14-4 Average ODP and GWP at End-Of-Use Retirement from Bank

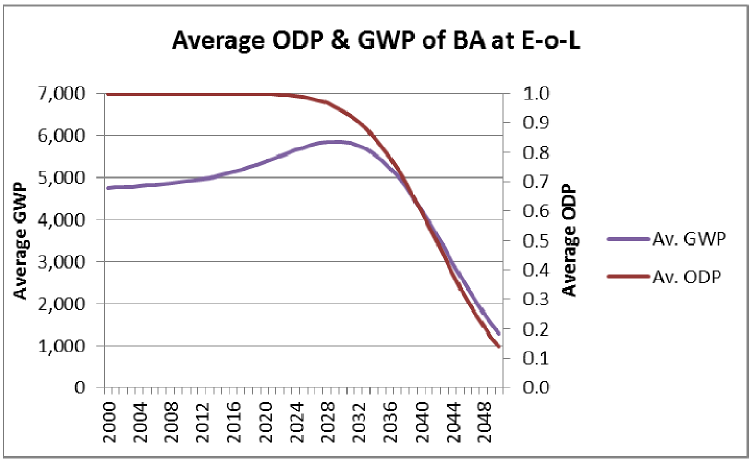


Table C-14-1 F5 Sector Characteristics

Main Foam Type	Polyurethane (PU), Polyisocyanurate (PIR), Phenolic (PF) – plus some XPS	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11/12 ~100%
	1994-2002	HCFC 141b; Hydrocarbons; HCFC 142b/22;
	2003-2011	Hydrocarbons (pentane); CO_2; HFCs;
	Likely future	Hydrocarbons, CO_2 and Hydro-fluoro-olefins (HFOs)
Typical Lifecycle (years)	50 years	
Lifetime diffusion rate	Moderately low (<1.5% per year)	
EOU Retirement from Bank 2015	CFCs	Very low level of boards reaching E-o-L but almost exclusively CFC-containing
	HCFCs	Very few (if any) HCFC-containing boards reaching E-o-L
	HFCs	None except site waste
EOU Retirement from Bank 2030	CFCs	Predominantly CFC-containing boards
	HCFCs	Low levels of HCFC-containing boards
	HFCs	Initial traces of HFC-containing boards
Current legislation	Ozone and F-Gas Regulations only require recovery if technically and economically feasible	
Current implementation	Limited experience and evidence	
Technical options	Direct incineration is a preferred option where local Municipal Solid Waste Incinerators exist. Technically possible to use SRFs	
Infrastructure available	No formal infrastructure, but should be possible through demolition contracts	

C.15 Foam 6 - Laminated Boards (Cavity Structures)

Figure C-15-1 Bank in Product Forecast

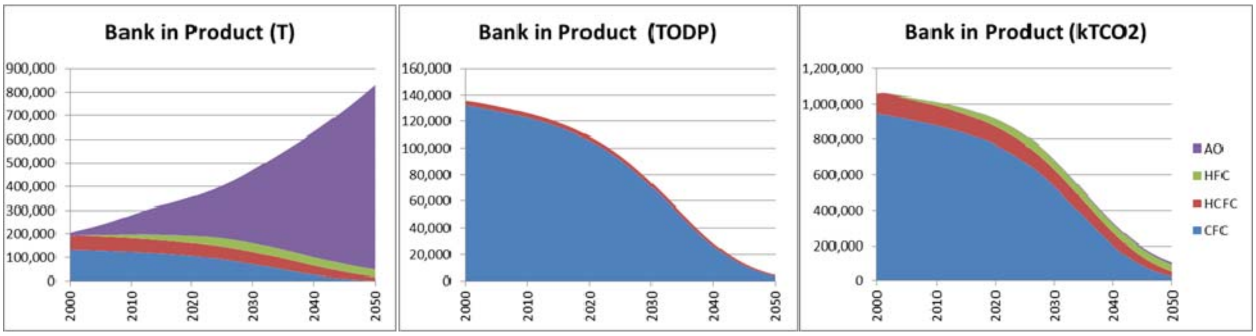


Figure C-15-2 End-Of-Use Retirement from Bank

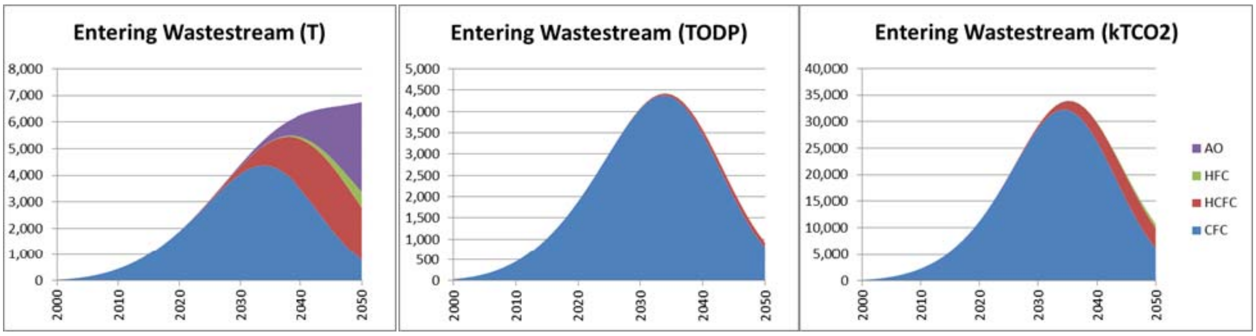


Figure C-15-3 Emissions by Lifecycle Phase

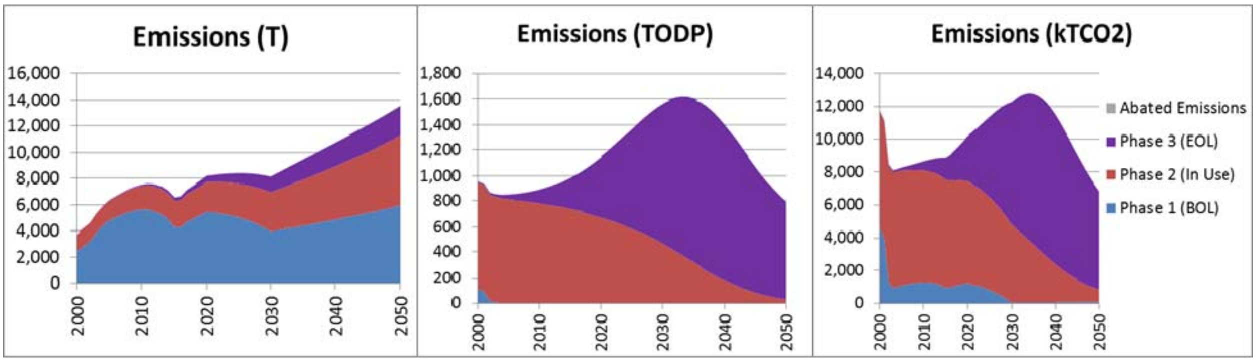


Figure C-15-4 Average ODP and GWP at End-Of-Use Retirement from Bank

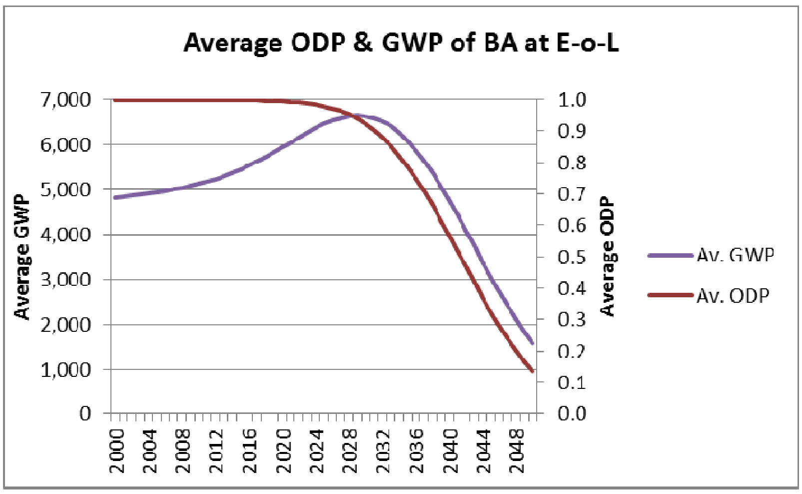


Table C-15-1 F6 Sector Characteristics

Main Foam Type	Polyurethane (PU), Polyisocyanurate (PIR), Phenolic (PF) – plus some XPS	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11/12 ~100%
	1994-2002	HCFC 141b; Hydrocarbons; HCFC 142b/22;
	2003-2011	Hydrocarbons (pentane); CO_2; HFCs;
	Likely future	Hydrocarbons, CO_2 and Hydro-fluoro-olefins (HFOs)
Typical Lifecycle (years)	50 years	
Lifetime diffusion rate	Moderately low (<1.5% per year)	
EOU Retirement from Bank 2015	CFCs	Very low level of boards reaching E-o-L but almost exclusively CFC-containing
	HCFCs	Very few (if any) HCFC-containing boards reaching E-o-L
	HFCs	None except site waste
EOU Retirement from Bank 2030	CFCs	Predominantly CFC-containing boards
	HCFCs	Low levels of HCFC-containing boards
	HFCs	Initial traces of HFC-containing boards
Current legislation	Ozone and F-Gas Regulations only require recovery if technically and economically feasible	
Current implementation	Limited experience and evidence	
Technical options	Direct incineration is a preferred option where local Municipal Solid Waste Incinerators exist. Technically possible to use SRFs	
Infrastructure available	No formal infrastructure, but should be possible through demolition contracts	

C.16 Foam 7 - Laminated Boards (Floor Insulation)

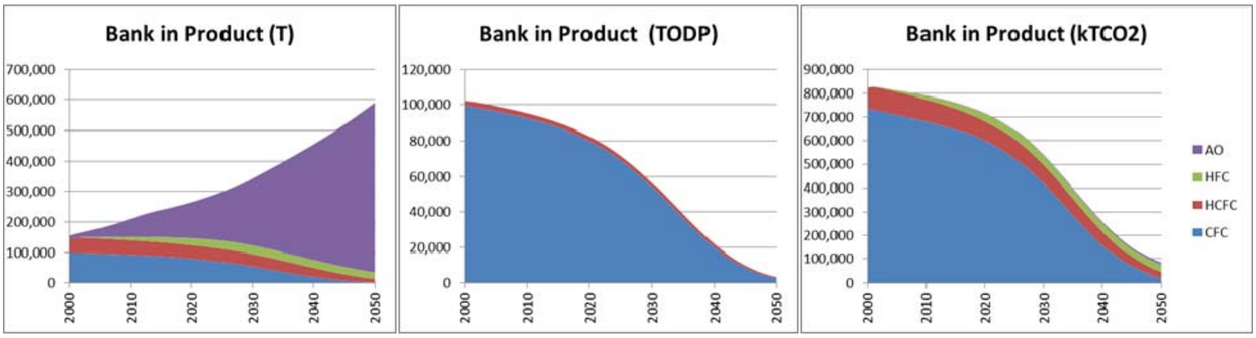


Figure C-16-2 End-Of-Use Retirement from Bank

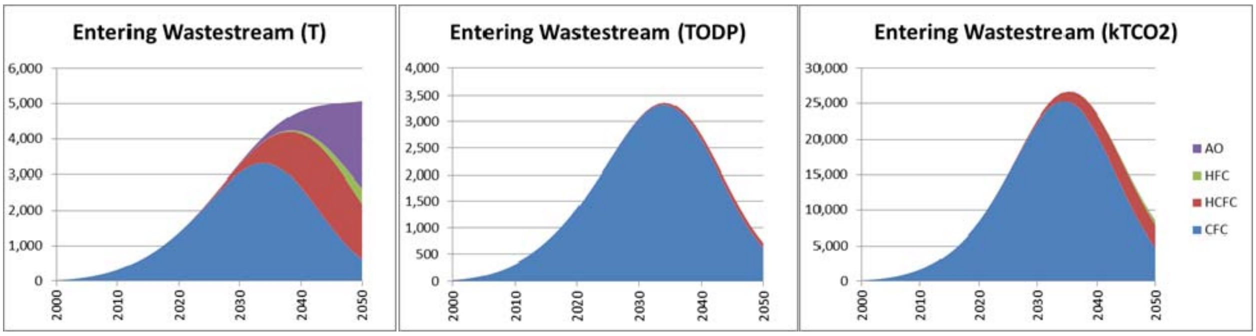


Figure C-16-3 Emissions by Lifecycle Phase

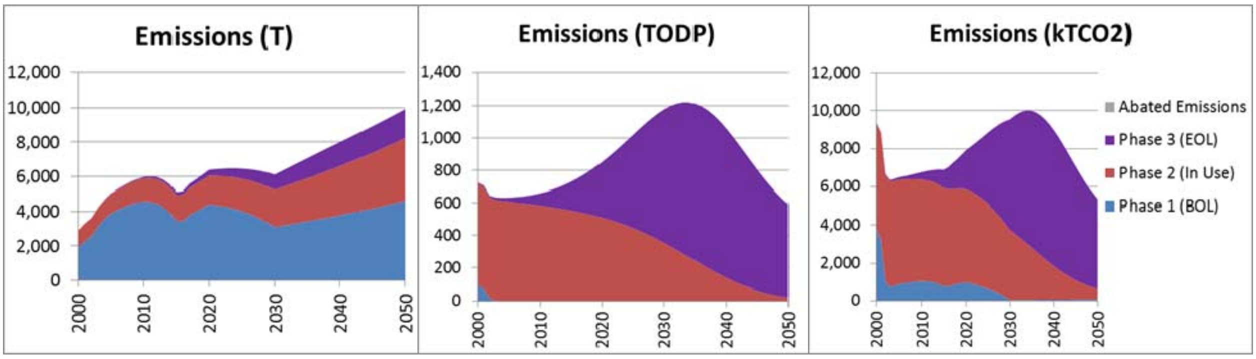


Figure C-16-4 Average ODP and GWP at End-Of-Use Retirement from Bank

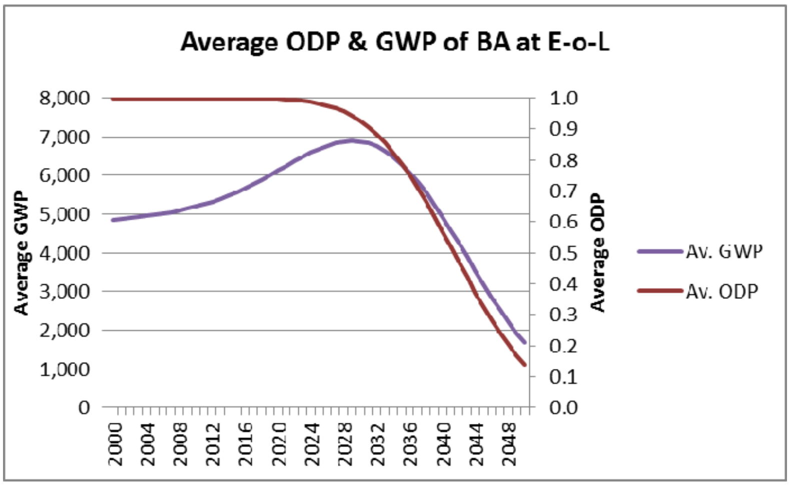


Table C-16-1 Sector Characteristics

Main Foam Type	Predominantly Extruded Polystyrene (XPS)	
Timeline for blowing agents (in new foams)	Before 1993	CFC 12 ~100%
	1994-2002	HCFC 142b/22 ~100%
	2003-2011	CO_2 (60%); HFCs (40%);
	Likely future	CO_2, hydrocarbons and Hydro-fluoro-olefins (HFOs)
Typical Lifecycle (years)	50 years	
Lifetime diffusion rate	Moderately low (<1.5% per year)	
EOU Retirement from Bank 2015	CFCs	Very low level of boards reaching E-o-L but almost exclusively CFC-containing
	HCFCs	Very few (if any) HCFC-containing boards reaching E-o-L
	HFCs	None except site waste
EOU Retirement from Bank 2030	CFCs	Predominantly CFC-containing boards
	HCFCs	Low levels of HCFC-containing boards
	HFCs	Initial traces of HFC-containing boards
Current legislation	Ozone and F-Gas Regulations only require recovery if technically and economically feasible	
Current implementation	Limited experience and evidence	
Technical options	Direct incineration is a preferred option where local Municipal Solid Waste Incinerators exist. Technically possible to use SRFs	
Infrastructure available	No formal infrastructure, but should be possible through demolition contracts	

C.17 Foams 8 - Spray Foam

Figure C-17-1 Bank in Product Forecast

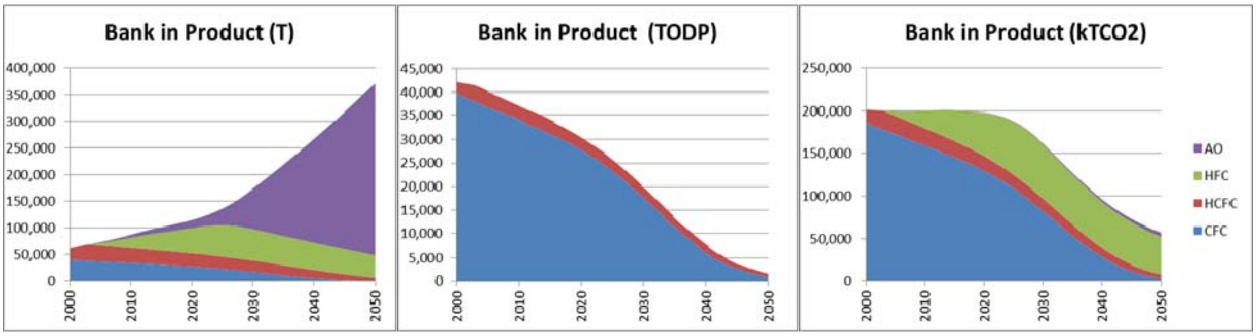


Figure C-17-2 End-Of-Use Retirement from Bank

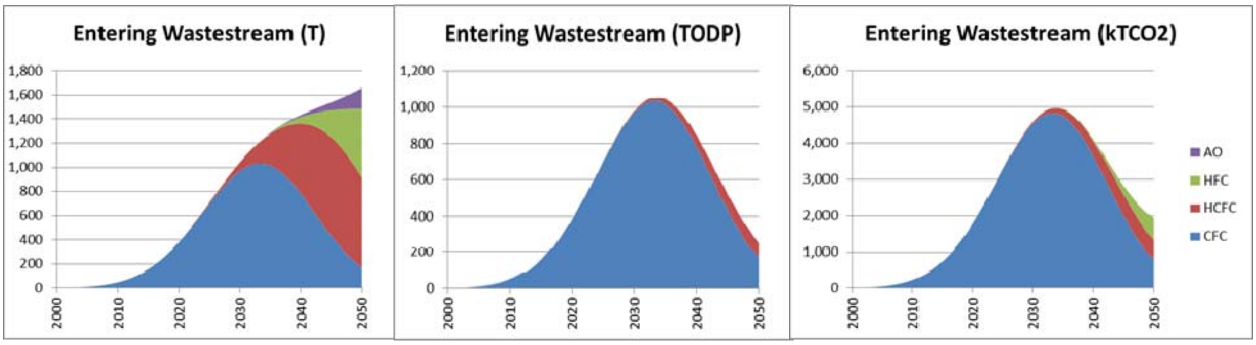


Figure C-17-3 Emissions by Lifecycle Phase

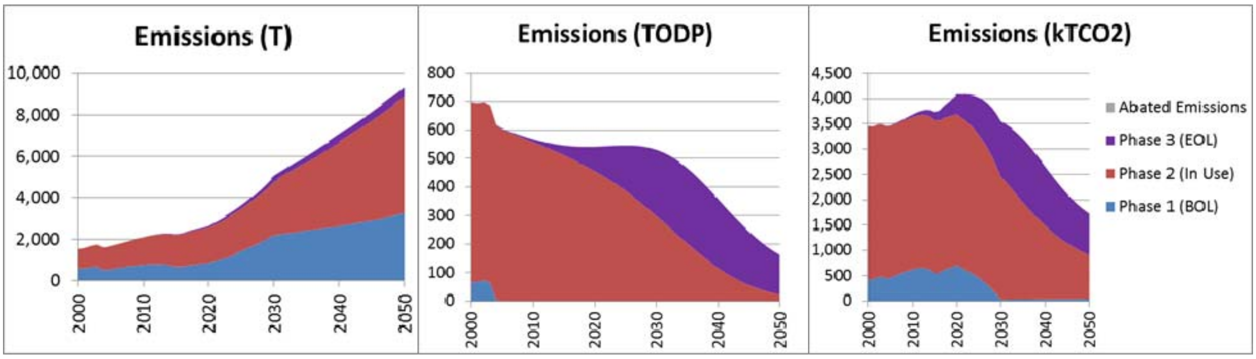


Figure C-17-4 Average ODP and GWP at End-Of-Use Retirement from Bank

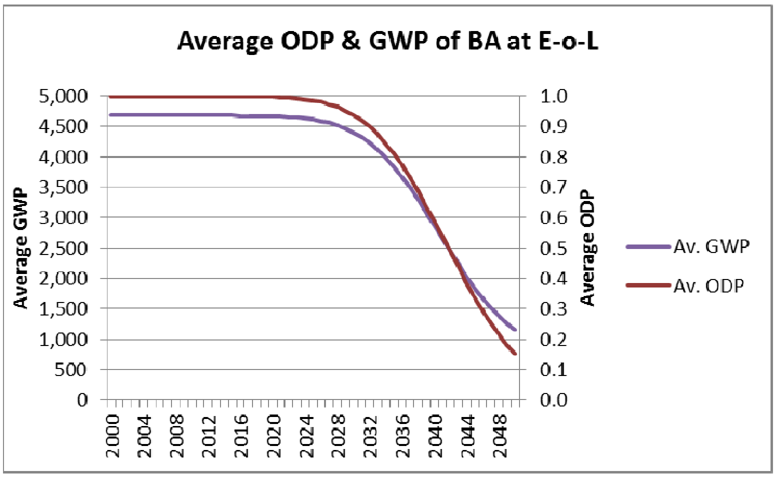


Table C-17-1 F8 Sector Characteristics

Main Foam Type	Polyurethane	
Timeline for blowing agents (in new foams)	Before 1993	CFC 11 ~100%
	1994-2004	HCFC 141b ~100%;
	2005-2011	HFCs ~100%
	Likely future	Hydro-fluoro-olefins (HFOs) and blends
Typical Lifecycle (years)	30-50 years	
Lifetime diffusion rate	Moderate (<2% per year)	
EOU Retirement from Bank 2015	CFCs	Very low levels of spray foam reaching E-o-L but almost exclusively CFC-containing
	HCFCs	None
	HFCs	None
EOU Retirement from Bank 2030	CFCs	Majority CFC-containing spray foam
	HCFCs	Moderate levels of HCFC-containing spray foam
	HFCs	Initial traces of HFC-containing spray foam
Current legislation	Ozone and F-Gas Regulations only require recovery if technically and economically feasible	
Current implementation	Limited experience and evidence	
Technical options	Separation is a major challenge for most spray foam applications. New technology likely to be required before significant amounts can be recovered	
Infrastructure available	Not applicable	

C.18 GIS – Gas Insulated Switchgear (Total MV + HV)

Figure C-18-1 Bank Forecast

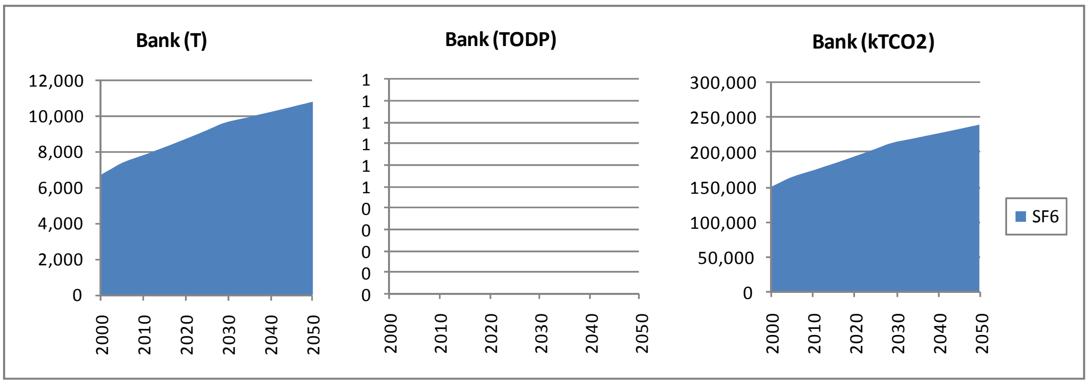


Figure C-18-2 End-Of-Use Retirement from Bank

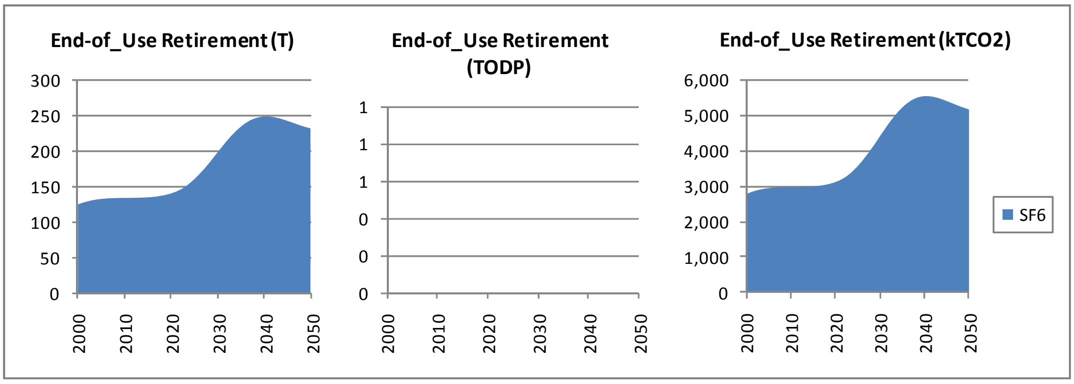


Figure C-18-3 Emissions by Lifecycle Phase

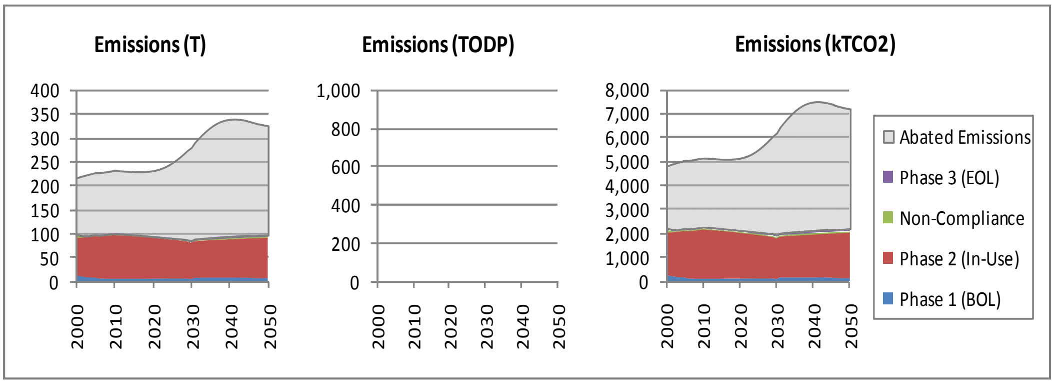


Figure C-18-4 Average ODP and GWP at End-Of-Use Retirement from Bank

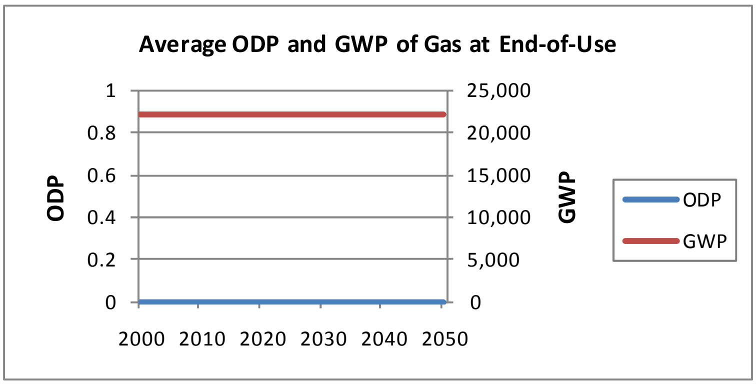


Table C-18-1 GIS Sector Characteristics

Main System Type/s	Gas insulated switchgear (GIS) – medium voltage (MV) and high voltage (HV)	
Typical refrigerant charge	MV: 6 kg HV: 500 kg	
Timeline for main refrigerants (in new systems)	SF6 has been used since around 1960. Air can also be used, but has lower insulation properties.	
Typical Lifecycle (years)	40	
Lifetime leakage rate	Around 1% per year	
EOU Retirement from Bank 2015	SF6	Normal retirement rate
EOU Retirement from Bank 2030	SF6	Normal retirement rate
Current legislation	Recovery required via F Gas Regulation	
Current implementation	Not certain. Good compliance is reported as end-users, manufacturers, contractors and employees are qualified and are aware of recovery rules.	
Technical options	Industry “best practice” recovery procedure (IEC/TR 62271-303) for on-site SF6 recovery, offering around 98% recovery efficiency	
Infrastructure available	Yes, via manufacturers and GIS contractors	