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

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Contents

Acronyms

AC:	Air conditioning
AR4:	Fourth Assessment Report of the IPCC (2007)
CFC:	Chlorofluorocarbon
EOL:	End-of-life
F-gas:	Fluorinated greenhouse gas
GHG:	Greenhouse gas
GWP:	Global warming potential
HCFC:	Hydrochlorofluorocarbon
HFC:	Hydrofluorocarbon
HFE:	Hydrofluorether
IPCC:	Intergovernmental Panel on Climate Change
$KTCO_2eq$:	Kilotonne of carbon dioxide equivalent (equal to 1,000 TCO_2eq.)
MVAC	Motor vehicle air conditioner
ODP:	Ozone depleting potential
ODS:	Ozone depleting substances
PFC:	Perfluorocarbon
SF_6:	Sulfur hexafluoride
TCO_2eq.:	Tonne of carbon dioxide equivalent
$TgCO_2eq$.:	Teragram of carbon dioxide equivalent (equal to 1,000,000 TCO_2eq.)
TAR:	Third Assessment Report of the IPCC (2001)

Executive Summary

In the European Union, the Montreal Protocol on Substances that Deplete the Ozone Layer is implemented through Regulation (EC) No 1005/2009 of the European Parliament and of the Council on Substances that Deplete the Ozone Layer, which entered into force on 1 January 2010 and supersedes Regulation (EC) No 2037/2000. The regulation contains a number of provisions to monitor ozone depleting substances (ODS) production and consumption, including the reporting of information on these substances and of products and equipment that contain them.

Although the phase-out of ODS production and consumption is required under the Montreal Protocol, there are no controls on *emissions* of ODS—including the treatment of unwanted ODS stockpiles contained in bulk or in obsolete equipment and products at end-of-life (EOL). As ODS are phased out of production, large quantities are banked in products and equipments in the EU and worldwide. As these equipment reach the end of their useful lifetimes, it is critical that any remaining ODS contained in these products/equipment be fully recovered for reuse (as permitted) or for destruction. The recovery and destruction of unwanted/unusable ODS is imperative not only to reverse the course of ozone depletion, but also to avoid negative climate impacts. ODS are potent greenhouse gases (GHGs) with global warming potentials (GWP) as much as 10,000 times that of carbon dioxide (CO_2). Therefore, if not properly managed, ODS represent a potentially significant source of GHG emissions.

A similar problem exists for fluorinated greenhouse gases (F-gases), which have largely replaced ODS in products and equipment in the refrigeration/air-conditioning (AC), foams, and fire extinguishing sectors. Although emissions of F-gases do not deplete the ozone layer, they do contribute to global climate change and are covered under the Kyoto Protocol. F-gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), hydrofluorethers (HFEs), and can have GWPs as high as 23,900 times that of CO_2. Banked quantities of F-gases in products and equipment will become increasingly significant over time, as users transition away from ODS.

The recovery and recycling/reclamation or destruction of ODS/F-gas banks poses a serious and important challenge, especially because not all gases contained in products and equipment are readily "accessible" for recovery; the technologies and levels of effort needed to capture ODS/F-gases contained in products and equipment can vary significantly. Moreover, the costs associated with the recovery, recycling, reclamation, and destruction can vary significantly depending on the type and quantity of ODS/F-gases recovered. Furthermore, there is a general lack of industry awareness of the location of nearest ODS/F-gas destruction facilities, which effectively limits the extent of destruction activities within the EC, and policy gaps and limitations can add to the challenge of recycling/reclaiming or destroying banks (ICF 2008a).

To increase the amount of ODS/F-gases recovered from products and equipment at EOL in the EU, this report aims to: (1) assess current and future ODS/F-gas banks; (2) identify the current state of recovery and destruction across the EU; (3) assess the technical and economic feasibility of recovering and destroying ODS/F-gases from different types of products and equipment; and (4) contribute to the development of appropriate policies to promote the recovery and destruction of ODS/F-gases banked in products and equipment across the EU. The main findings of this study are summarized below.

Assessment of Current and Future ODS/F-Gas Banks

Current and future ODS/F-gas banks were calculated in two ways; one using a top-down methodology, and the other using a bottom-up methodology. This approach was taken so that banks data reported at the national/international level can be compared to data built from Member State specific statistics, to both enhance the depth of the analysis and allow for potential discrepancies to be identified. It should be noted that the top-down and bottom-up models differ significantly in terms of how HFC banks are projected post-2010; the top-down model projects future HFC growth based on historical trends, while the bottom-up model projects future HFC growth assuming an increasing push to climate-friendly alternatives. It should also be noted that, while country-level data are critical in developing a robust bottom-up model, only a limited dataset was made available from certain Member States. The resulting Banks Model should therefore be considered preliminary, with model improvements and refinements to be made as additional data become available in future.

Table ES-1 presents a comparison of the total EU top-down and bottom-up estimates in 2010 developed for this study, by sector and sub-sector. As shown, the two methodologies lead to similar results for ODS and HFCs installed in foam applications, but the bottom-up estimates are significantly lower than the top-down estimates for CFC and HCFC banks in the refrigeration/AC sector. To uncover the reasons for this variability, a deeper understanding of the assumptions used to build the IPCC/TEAP (2005) estimates would be needed. For example, end-use definitions may differ between data sets or methods employed (e.g., types of vehicle AC systems included in mobile AC, and types of foam applications included in foam banks), as may the treatment of imports/exports. In particular, the top-down estimates are based on consumption of the gases (production plus import minus export) as currently reported by EU countries, and do not include the gases imported to or exported from the EU in pre-charged equipment. This may in part explain the discrepancy between the top-down and bottom-up estimates.

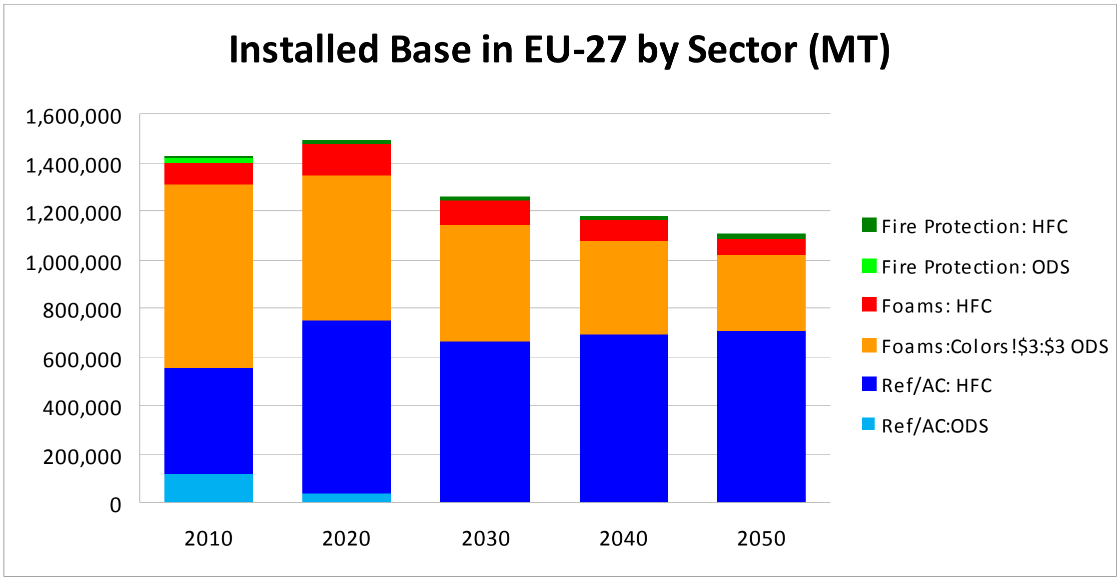
Table ES-1: Comparison of EU-27 Top-Down and Bottom-Up Estimates of Installed Banks in 2010, by Sector/Sub-Sector (T)

Sector	Sub-sector	Bottom-Up Estimates (2010)				Top-Down Estimates (2010)			
		CFC	HCFC	HFC	Halon	CFC	HCFC	HFC	Halon
Ref/AC	Mobile AC	2,400	-	113,432	-	13,100	4,000	97,308	-
Ref/AC	Stationary AC	1,218	43,774	184,504	-	9,800	187,100	123,277	-
Ref/AC	Refrigeration	6,793	64,623	138,669	-	33,300	90,300	102,462	-
Total Ref/AC		10,412	108,397	436,606	-	56,200	281,400	323,046	-
Foams	Appliance	59,041	9,089	8,102	-	100,932	45,127	15,025	-
Foams	Construction	456,829	226,570	84,112	-	370,083	165,464	55,092	-
Foams	Other	N/A	N/A	N/A	N/A	60,185	26,909	8,959	-
Total Foams		515,870	235,659	92,213	-	531,200	237,500	79,077	-
Fire Protection		N/A	N/A	N/A	N/A	-	800	9,338	18,100

Based on the bottom-up modelling methodology used for the refrigeration/AC and foams sectors, and the top-down methodology used for the fire protection sector,[1] Figure ES-1 presents the projected banks of ODS (CFC, HCFC, and halon) and HFCs installed in the EU-27 from 2010 through 2050. As shown, the vast majority of ODS remaining in the EU-27 by 2010 is installed in the foams sector (86%), while the vast majority of HFCs installed are in the refrigeration/AC sector (83%). By 2050, a significant amount of ODS foams will still remain in the EU, while all other types of ODS will be fully phased out. By 2050, it is also projected that banks of HFCs will be significant—over 700,000 tonnes—but that they will begin to decline, in response to the increasing push away from high-GWP refrigerants.

[1] No bottom-up methodology was developed for the fire protection sector.

Figure ES-1: Bottom-Up Estimates of Installed ODS and HFC Banks in the EU-27 by Sector (T) (2010-2050)



Only a certain percent of the ODS and HFC banks shown in Figure ES-1 will reach end-of-life in any given year, and only a certain percent of that amount will be technically and economically recoverable. The next section summarizes the key findings on the technical and economic feasibility of recovering these banks.

Technical and Economic Feasibility of Recovery/Destruction

Based on assumptions regarding equipment/product lifetime, chemical remaining at EOL, and percent of chemical technically recoverable at EOL, the total percent of refrigerant and foam blowing agent recoverable at EOL was estimated by end-use. For some product/equipment types, it is assumed that EU-15 countries are able to achieve slightly higher recovery levels than EU-12 countries as a result of improved recovery technologies/processes believed to be in place.

For each end-use, feasibility to recover was ranked as High, Medium, or Low, based on the percent of original refrigerant or blowing agent content recoverable at end of life, with consideration given to the level of effort required to perform recovery, the history of EOL treatment, and the existing infrastructure in place. Specifically, feasibility of refrigerant recovery from all end-uses was ranked as "high," as refrigerant recovery requires a low level of effort, has a long history of being practiced in the field, and existing infrastructure is largely in place. Similarly, there is a history of EOL treatment and existing infrastructure in place for recovery of appliance foams, which also have recovery potentials of >75%. Therefore, recovery feasibility from appliance foams was also ranked as "high." For construction foams, however, there is virtually no history of EOL treatment or infrastructure in place, the level of effort to recover such foams is high, and the quantity of original blowing agent that is actually recoverable is relatively low (6%-63%). As such, the feasibility for foams was ranked based on the following thresholds:

- High: > 75%
- Medium: 30%-75%
- Low: <30%

Table ES-2 presents the total percent of refrigerant and foam blowing agent recoverable at EOL, as well as the feasibility rankings, by end-use.

Table ES-2: Average Refrigerant and Blowing Agent Recovery Potential at EOL, by End-Use and Region[a]

Sub-sector	End-Use	Total Potentially Recovered at EOL in EU		Feasibility to Recover
		EU-15	EU-12	
Refrigeration/AC				
Mobile AC	Passenger Cars	54%	45%	High
	Buses	54%	45%	High
Refrigeration	Domestic Refrigerators& Freezers	NA	NA	High
	Small Commercial	81%	72%	High
	Medium/ Large Commercial	67%	57%	High
	Refrigerated Transport—Land	63%	54%	High
	Refrigerated Transport—Ships	57%	48%	High
	Industrial Refrigeration	57%	48%	High
Stationary AC	Small Stationary	81%	72%	High
	Large Stationary (Chillers)	76%	67%	High
Foams				
Appliances	PU Rigid: Domestic Refrigerators/Freezers	88%		High
Appliances	PU Rigid: Commercial Refrigeration	79%		High
Construction	PU Rigid: Sandwich Panels – Continuous	63%		Medium
Construction	PU Rigid: Sandwich Panels – Discontinuous	60%		Medium
Construction	PU & PIR Rigid: Boardstock (FFL)	40%		Medium
Construction	PU Rigid: Spray foam	16%		Low
Construction	XPS Foam Boards	6%		Low

[a] See Section 4.1 for information on the assumptions and sources used to develop these estimates.
NA= Not applicable; since data on actual charge recoverable were available from appliance demanufacturers, assumptions on the percent potentially recoverable were not developed; rather, the total charge potentially recovered at EOL for CFC-systems is assumed to be 0.13 kg/unit in Sweden and Finland, 0.11 kg/unit in other EU-15 countries, and 0.06 kg/unit in EU-12 countries; for HFC-systems, it is assumed to be 0.12 kg/unit in Sweden and Finland, 0.10 kg/unit for other EU-15 countries, and 0.05 kg/unit in EU-12 countries (DUH 2007, RAL 2007a 2007b; ICF 2008b).

As shown, in the refrigeration/AC sector, between 45% and 81% of original refrigerant charge is estimated to be recoverable at EOL, depending on equipment type and region. Refrigerant recovery from mobile AC is estimated to result in the lowest potential for recovery, given the low levels of refrigerant generally remaining at EOL and the small original charge size; however, given the low level of effort required to perform recovery from passenger car mobile ACs, feasibility to recover is still deemed to be high.

In the foams sector, the recovery potential for blowing agent from appliances at EOL from both domestic refrigerators/freezers and commercial refrigeration units is relatively high, at roughly 88% and 79%, respectively. However, construction foam end-uses have lower levels of recovery potential than the appliance sub-sector, due to higher annual emission rates, longer lifetimes, and increased complexity associated with foam separation and removal (which leads to higher blowing agent losses). The ability to extract foam-containing elements from demolition waste depends largely on the original form of the foam and how it was applied. Sandwich panels and boardstock foams exhibit the highest potential for recovery. Recovery from spray foam and XPS foam boards is deemed to have a low feasibility of recovery at this time, as less than 10% of the blowing agent is potentially recoverable and only at a high level of effort and cost.

Based on these assumptions regarding recovery potential, Table ES- 3 presents the estimated quantities of CFC, HCFC, and HFCs projected to be technically recoverable at product/equipment EOL in 2010, 2020, and 2050, based on the bottom-up modelling methodology.

Table ES- 3: Quantity Technically Recoverable at EOL in the EU-27 (T), Based on Bottom-Up Model

Sector/Sub-sector	2010			2020			2050		
	CFC	HCFC	HFC	CFC	HCFC	HFC	CFC	HCFC	HFC
Refrigeration/AC									
Mobile AC: Passenger cars	98	0	4,144	0	0	4,040	0	0	0
Mobile AC: Buses	3	0	132	0	0	156	0	0	0
Small Stationary AC	0	2,667	12,173	0	0	26,472	0	0	32,858
Large Stationary AC	60	451	1,526	0	0	3,449	0	0	5,837
Refrigerators/ Freezers	276	0	84	0	0	20	0	0	0
Small Commercial Refrigeration	18	122	366	0	0	608	0	0	500
Medium & Large Commercial Refrigeration	0	267	1,520	0	0	2,323	0	0	1,853
Refrigerated Transport (Land)	11	35	182	0	22	380	0	0	632
Refrigerated Transport (Ships)	0	766	111	0	730	274	0	0	615
Industrial Refrigeration	0	556	2,439	0	98	3,111	0	0	2,224
Subtotal	*466*	*4,864*	*22,676*	*0*	*850*	*40,834*	*0*	*0*	*44,519*
Foams									
PU Rigid: Domestic Refrigerators/ Freezers	2,935	258	0	1,507	133	0	204	18	0
PU Rigid: Commercial Refrigeration	574	261	373	295	134	462	40	18	63
PU Rigid:Sandwich Panels – Continuous	868	557	86	711	456	166	390	250	91
PU Rigid: Sandwich Panels – Discontinuous	421	296	115	345	242	161	189	133	89
PU & PIR Rigid: Boardstock (FFL)	987	242	6	808	198	13	444	109	7
PU Rigid: Spray foam	106	77	79	87	63	148	48	35	81
XPS Foam Boards	256	134	39	209	110	58	115	60	32
Subtotal	*6,147*	*1,826*	*698*	*3,962*	*1,336*	*1,009*	*1,429*	*623*	*363*
TOTAL	6,613	6,690	23,375	3,962	2,186	41,843	1,429	623	44,881

Economic feasibility was assessed for those end-uses with high and medium recovery feasibility, namely: domestic refrigerators/freezers, medium/large commercial refrigeration, and PU rigid sandwich panels (construction foam). The costs developed for these three end-uses, calculated on a per-kilogram basis, were then used as proxies to estimate costs for all other end-uses. The resulting cost estimates for the recovery and destruction of ODS/HFC refrigerant and foam are presented in Table ES-4 on a per kg basis.

Table ES-4: Assumed Average per kg Costs for EOL Treatment of Refrigerant and Foam Blowing Agent, by End-Use

End-Use	Per kg Cost		Proxy End-Uses to Which per Kg Costs are Applied
	Refrigerant	Foam Blowing Agent	
Domestic Refrigerators/ Freezers	€14.10	€33.00	Small Stationary AC, Mobile AC, Transport Refrigeration (Land)
Medium/Large Commercial Refrigeration	€6.50 - €7.60	NA	Industrial Refrigeration, Large Stationary AC, Transport Refrigeration (Ships), Fire Protection
Sandwich Panels (with prior blowing agent recovery)	NA	€83.00[a]	Boardstock Foam[b]

[a] Costs without prior blowing agent recovery will be lower than those shown here, by at least €20/kg.
[b] The use of a proxy cost for boardstock foams is necessary given that no costs information is readily available (as boardstock recovery is not typically performed); however, it should be noted that actual costs to recover boardstock foam will be more expensive as that of sandwich panels, given that the process is more difficult.

Based on the costs presented above, and the estimated emissions avoidable through recovering banks reaching EOL each year, Table ES-5 presents total costs by end-use per ODP tonne and per tonne of carbon dioxide equivalent (TCO_2eq.) for CFCs, HCFCs, HFCs, and halons. Although per kilogram costs to recover/destroy ODS/HFCs were not assumed to change over time, actual costs are likely to decrease with time as technologies improve and additional experience is gained (particularly for construction foams, for which very limited field experience exists to date).

Table ES-5: Potential EU Costs of ODS/HFC Recovery and Destruction Per ODP Tonne and TCO_2eq, by Chemical Type

Sub-Sector	End-Use	€/TCO_2eq.				€/ODP Tonne			
		CFC	HCFC	HFC	Halon	CFC	HCFC	HFC	Halon
Mobile AC	Passenger Cars	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
	Buses	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
Refrigeration	Domestic Refrigerators/ Freezers	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
	Small Commercial	1.33	8.29	6.35	N/A	14,100	256,364	N/A	N/A
	Medium/Large Commercial	N/A	4.26	2.07	N/A	N/A	131,733	N/A	N/A
	Refrigerated Transport—Land	1.33	8.29	6.35	N/A	14,100	256,364	N/A	N/A
	Refrigerated Transport—Ships	N/A	4.12	2.56	N/A	N/A	127,193	N/A	N/A
	Industrial Refrigeration	N/A	4.35	2.35	N/A	N/A	134,581	N/A	N/A
Stationary AC	Small Stationary	N/A	8.29	7.77	N/A	N/A	256,364	N/A	N/A
	Large Stationary (Chillers)	0.95	4.20	4.40	N/A	7,206	129,918	N/A	N/A
Appliance Foam	PU Rigid: Domestic R&F	7.17	25.06	N/A	N/A	33,000	392,079	N/A	N/A
	PU Rigid: Commercial Refrigeration	7.17	25.06	20.99	N/A	33,000	392,079	N/A	N/A
Construction Foam	PU Rigid: Sandwich Panels – Continuous	18.04	55.96	52.78	N/A	83,000	1,106,667	N/A	N/A
	PU Rigid: Sandwich Panels – Discontinuous	18.04	118.57	52.78	N/A	83,000	754,545	N/A	N/A
	PU & PIR Rigid: Boardstock (FFL)	18.04	57.24	52.78	N/A	83,000	1,207,273	N/A	N/A
Fire Protection[a]	Fire protection	N/A	6.74	0.47	1.69	N/A	N/A	N/A	865.73

[a] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.

As shown, on a tonne of carbon dioxide equivalent basis, the incremental cost to recover/destroy refrigerants is very low—less than €1.50/TCO_2eq.for CFCs and not more than €11/TCO_2eq. for HCFCs or HFCs across all types of equipment/products. This is due to the low level of effort/cost associated with refrigerant recovery and, in the case of CFCs, extremely high GWP values. For foams contained in refrigerated appliances, the costs are higher as a result of the greater time and effort required to recover blowing agent. Costs are highest for construction foams due to the level of effort required to separate and recover foam blowing agent from building materials. Actual costs to recover/destroy boardstock foam are likely to be even higher than those presented above, given that the estimates were developed using sandwich panels as a proxy, but the process for boardstock foam is in fact more difficult.

Current State of Recovery and Destruction

Currently, multiple regulations target the recovery and destruction of banked ODS/F-gases at the EU level, including those related to the handling of ODS/F-gases, waste classification and shipment, the handling of appliances and small stationary AC systems at EOL, the handling of vehicles at EOL, and the treatment of construction and demolition waste. These regulations are summarized below:

Handling of ODS and F-Gases

- *Regulation (EC) 1005/2009*—requires the recovery for destruction, reclamation, or recycling of controlled substances contained in refrigeration/AC equipment (both commercial and residential), heat pump equipment, equipment-containing solvents and fire protection systems and fire extinguishers; requires that controlled substances contained in products and equipment not covered by Article 22§1 be recovered for destruction, recycling or reclamation "if technically and economically feasible,"[2] or shall be destroyed without prior recovery.
- *Regulation (EC) 842/2006*—essentially applies Regulation 1005/2009 to all F-gases, although it does not explicitly require the recovery of foam blowing agent from refrigerated equipment.

Waste Classification and Shipment

- *Directive 2008/98/EC*—requires Member States to ensure waste recovery, and, if necessary to comply with this requirement and to facilitate or improve recovery, to collect waste separately "if technically, environmentally, and economically practicable," and not mix it with other waste or material with different properties.
- *Regulation (EC) 1013/2006*—establishes procedures and control regimes for the shipment of waste, including waste CFCs, HCFCs, and HFCs, which are considered hazardous waste. As such, the shipment of waste ODS/HFCs requires prior written notification and consent, as well as certain labelling requirements.
- *Regulation (EC) 1272/2008*—standardises criteria for classification of substances and mixtures and requires the labelling of hazardous substances at manufacture, import, and use.

Handling of Appliances and Small Stationary AC at EOL

- *Directive 2002/96/EC*—requires that waste household appliances and small commercial refrigeration equipment containing ODS or gases with a GWP above 15 be collected separately, and that ODS be treated in accordance with Regulation 1005/2009. This pertains to the refrigerant and foam contained in appliances. The Directive also sets minimum recovery and recycling rates.

Handling of Vehicles at EOL

- *Directive 2000/53/EC*—requires Member States to ensure that EOL vehicles are dismantled and hazardous materials removed, including CFC and HFC refrigerants used in AC systems.

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[2] The Regulation covers chlorofluorocarbons, other fully halogenated chlorofluorocarbons, halons, carbon tetrachloride, 1,1,1-trichloroethane, methyl bromide, hydrobromofluorocarbons, hydrochlorofluorocarbons and bromochloromethane, whether alone or in a mixture, and whether they are virgin, recovered, recycled, or reclaimed.

Treatment of Construction and Demolition Waste

- *Directive 2008/98/EC*—requires that by 2020, 70% of construction and demolition waste (by weight) be recovered. This will have implications for the treatment of construction foam.

As illustrated above, existing EU regulations explicitly require the recovery of all ODS/F-gases from certain categories of products and equipment at end of life. The new ODS Regulations offer also the option of destruction without prior recovery. For the other categories, including construction foams, the obligation to recover (or immediately destroy) depends on its technical and economical feasibility. For some end-uses — namely vehicles and household/small commercial appliances — schemes are also mandated to assign responsibility for and ensure the safe disposal of products and equipment and the ODS/F-gases contained therein.

In practice, there is very little, if any, recovery of ODS/F-gases from construction foam applications at time of demolition. For other products/equipment for which ODS/F-gas recovery is required by law, actual recovery levels across the EU vary across Member State and end-use, and are somewhat uncertain due to a lack of consistently reported data. A number of factors may reduce actual recovery levels, including insufficient technician training, a lack of recovery equipment, high recovery/disposal costs, small quantities remaining in equipment at time disposal, potential losses during transport/handling, and others. The following bullets summarize what is known about actual recovery practices by end-use type.

- *Bulk refrigerant:* Overall, equipment handlers are well-trained in refrigerant recovery practices and abide by laws. In some countries (e.g., the UK) large refrigerant producers coordinate the transportation and destruction of bulk ODS/F-gases in ISO tanks from various sources through distributors, facilitating destruction activities. In other countries (e.g., Sweden), refrigerant importers/distributors offer free take-back services on used refrigerant to ensure proper disposal, with costs being recovered through a tax on the sale of new refrigerant.

- *Large commercial refrigeration/AC equipment:* At EOL, large commercial refrigeration/AC equipment is typically handled by installation companies that recover refrigerant for reuse, reclamation, or destruction, and then decommission the systems for metal recycling (Daikin Europe 2009; ECSLA 2009). Actual refrigerant recovery levels from this type of equipment is uncertain, although expected to be high; however, some industry sources have reported that costs are often a deterrent for sending recovered refrigerant on for destruction.

- *Appliances:* Reported refrigerant recovery levels from household refrigerators/freezers have historically been low, although levels may be increasing in light of newly mandated recovery standards in some countries (e.g., Germany). The recovery of foam from domestic appliances is widely practiced in compliance with regulations, although there is not believed to be much experience with foam removal/disposal from commercial refrigeration equipment.

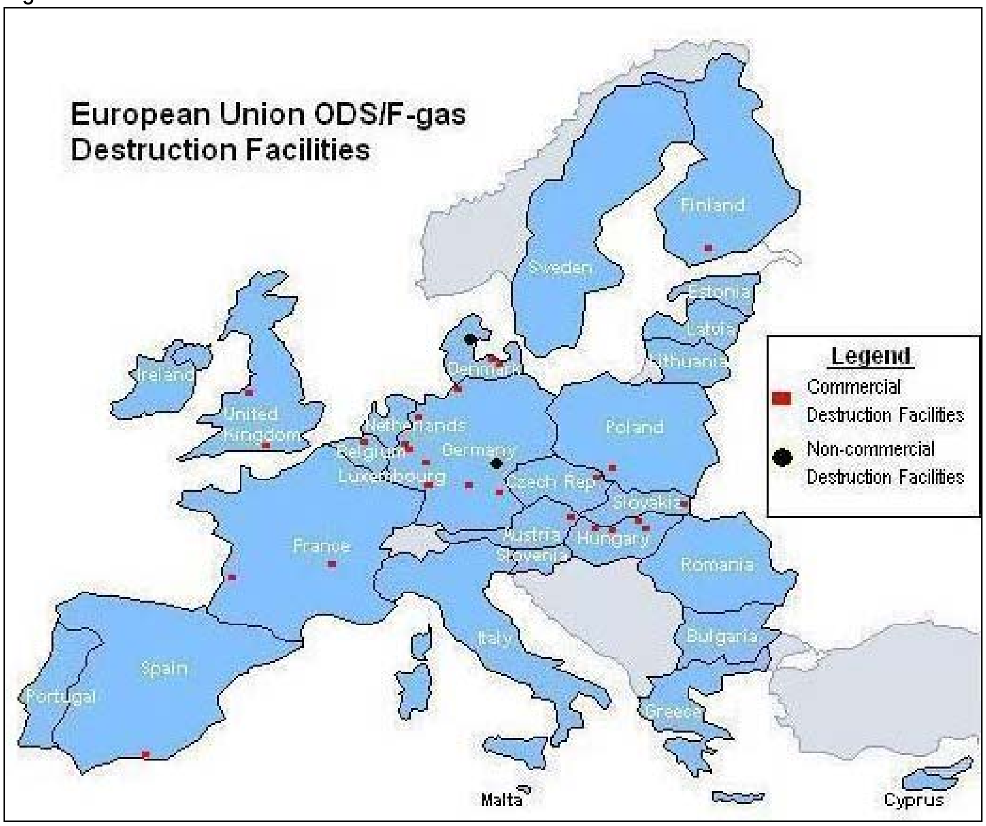
- *Motor vehicle AC (MVACs):* Recovery of refrigerant from old motor vehicles at EOL may not be common practice among scrapyard workers, given poor economic incentives and/or the lack of an organized collection system in place.

- *Construction foams:* Foam is not typically separated from other materials and recovered at EOL; it is most likely landfilled. Separating ODS/F-gas material at building EOL and ensuring proper disposal presents a significant challenge, especially in cases where the type of blowing agent in the insulating foam is not discernable.

- *Fire extinguishing agents:* There are established routes in the fire protection sector for destroying material at equipment the EOL, and current commercial drivers encourage recovery and recycling/reclamation. All containers are generally returned to the original equipment manufacture's specialist filling facility for recycling, since materials are generally sufficiently pure at EOL. Any material that is too contaminated (e.g., contains high levels of oil and other contaminants, or consists of blends or unintentionally mixed products) is most likely to be sent for destruction. (ASSURE 2009)

Currently, recovered ODS/HFCs are being destroyed at a number of approved facilities in the EU. Based on research conducted for this study, 23 commercial destruction facilities were confirmed to operate in 11 Member States,[3] as shown graphically in Figure ES-2. (See Appendix C for contact information for all known destruction facilities in the EU-27). In addition, an estimated 55 reclamation facilities are in operation across 17 Member States.

Figure ES-2: EU ODS/F-Gas Destruction Facilities[a]



Fourteen of the known commercial destruction facilities provided information on their estimated ODS/F-gas destruction capacity. Combined, these facilities reported an estimated ODS/F-gas destruction capacity of approximately 130,000 tonnes (t) per year. While the reported destruction capacity of individual destruction facilities ranged significantly—from 20 t per year in Hungary to over 65,000 t per year in the UK—it is possible that estimated ODS destruction capacity at the lower end of this range may be explained by insufficient throughout of other materials being destroyed, as ODS capacity is dependent on overall destruction capacity in order to limit amounts of chlorine, fluorine, and bromine to control air emissions and limit corrosion (e.g., 1% of overall waste capacity can be ODS). Based on the average and median values, however, ODS/F-gas destruction capacity across the whole EU-27 is estimated to be between approximately 145,000 t and 225,000 t. Based on bottom-up estimates generated for this report, this capacity is more than sufficient to handle the quantities of ODS/F-gases projected to be recoverable at EOL from the refrigeration/AC and foam sectors across the EU-27, which are not expected to exceed 50,000 t through 2050. However, while

[3] Commercial destruction facilities accept bulk ODS/F-gases from outside sources, while non-commercial destruction facilities do not accept outside sources of bulk ODS/F-gases for the purpose of destruction.

capacity is believed to be sufficient in the EU, the uneven distribution of destruction facilities may pose problems in areas where no facilities are available. This may be particularly problematic if ODS containing wastes must be transported over large distances (e.g., >1,000 km), such that transportation and labour costs may become prohibitive. For example, the labour cost alone to transport an ODS shipment a distance of 1,000 km would cost approximately €2,000, assuming an hourly (fully-loaded)[4] labour charge of €100,[5] and a travel speed of 50 km/hour.

Conclusions and Recommendations

Existing EU regulations explicitly require the recovery of all ODS/F-gases from certain categories of products and equipment at end of life. For the "other" categories, including construction foams, the obligation to recover (or immediately destroy) depends on its technical and economical feasibility. The new ODS Regulations offer also the option of destruction without prior recovery. For some end-uses— namely vehicles and household/small commercial appliances — schemes are also mandated to assign responsibility for and ensure the safe disposal of products and equipment and the ODS/F-gases contained therein.

Currently, there is very little, if any, known recovery of ODS/F-gases from construction foam applications at time of demolition, with the exception of some in Germany (BING 2008). For other products/equipment for which ODS/F-gas recovery is required by law, actual recovery levels across the EU vary across Member State and end-use, and are somewhat uncertain due to a lack of comprehensive reported data. A number of factors may reduce actual recovery levels, including insufficient technician training, a lack of recovery equipment, high recovery/disposal costs, small quantities remaining in equipment at time disposal, potential losses during transport/handling, and others.

The bottom-up estimates developed for this report offer some useful insights. Based on these estimates, the levels of CFCs, HCFCs, and HFCs that will be technically recoverable from products/equipment reaching end-of-life between 2010 and 2050 is significant, reaching nearly 37,000 t in 2010 and climbing steadily to reach nearly 47,000 t by 2050. By recovering and destroying these quantities, the ozone and climate benefits can be substantial, leading to the avoided emissions of over 7,000 ODP-t and over 91,000 $KTCO_2$eq. in 2010 alone. Current destruction capacity within the EU-27, estimated to be between 145,000 t and 225,000 t per annum, is more than sufficient to meet this projected demand; therefore, there is no need to develop further capacity within the EU. However, while capacity is believed to be sufficient in the EU, the uneven distribution of destruction facilities may pose problems in areas where no facilities are available, particularly if ODS containing wastes must be transported over large distances (e.g., >1,000 km), such that transportation and labour costs may become prohibitive.

Based on the technical and economic assessment performed for this study, it is cost-effective to recover ODS/HFCs contained in all types of products/equipment, with the possible exception of construction foams. In particular, recovery from spray foam and foam boards is unlikely to be feasible, given the very low levels of blowing agent (less than 20% of the original quantity) that are estimated to be technically recoverable at building EOL. Moreover, while sandwich panels may be the most feasible type of construction foam to recover, the cost—including blowing agent recovery—is relatively high—estimated at €83/kg, or roughly €18/TCO_2eq for CFC blowing agents, €56-€118/TCO_2eq for HCFC blowing agents, and €53/TCO_2eq for HFC blowing agents. On a weighted basis, the cost to recover all blowing agents from construction foam applications is estimated at

[4] This cost is assumed to cover employee wage plus fringe benefits, insurance, overhead, and profit.

[5] Labor charges are based loosely on labor wage rates for employees in the manufacturing and private services sectors in the EU, which ranged from roughly €25 to €30 in the western EU countries; however, labor rates were "substantially lower" for southern EU Member States (particularly Spain, Greece and Portugal) and Member States that joined the EU after May 2004 (Eurofound 2006).

roughly €24/TCO_2eq in 2010, but will increase in future as the relative amount of CFC foams from C&D waste declines. Destruction of construction foam without prior blowing agent recovery may be considerably lower that these estimated costs, on the order of €63/kg, or roughly 25% less on a TCO_2eq or ODP-weighted basis. On a weighted basis, the cost to recover all blowing agents from construction foam applications is estimated at roughly €19/TCO_2eq in 2010. Given the limited field experience to date at recovering construction foams, however, it is difficult to assess feasibility and costs within this sector with certainty. Additional information on actual recovery/processing methods and their associated costs across the various types of construction foams and across Member States is needed.

It is important that the bottom-up estimates of banks and recoverable banks developed for this report be viewed as preliminary only, given the limited country-level data on which they are based. Additional data from Member States—particularly in the construction foams and stationary AC sectors, believed to account for the majority of installed banks—are needed on a continuing basis in order to improve estimates from the bottom-up model and inform policy decisions as appropriate. More specifically, the main areas for **model improvement** include:

1. Cross-check/***validate overall bank estimates*** against other available data, including that from EFCTC bank estimates, as well as (HFC) end-use-specific assumptions from national inventory reports submitted by Member States under the UN Framework Convention on Climate Change (UNFCCC) requirements.

2. Review/validate ***stationary AC sector***, including assumed average charge sizes; based on input from the European Partnership for Energy and the Environment (EPEE), Germany, and Poland, the model may be over-estimating banks in this sector. Data should be solicited on AC stocks and charge sizes from Member States, and consideration should be given to the thresholds used to define "small" versus "large" AC systems (e.g., 12 kW in lieu of 75 kW, based on input from EPEE). Also, additional data sources that are or will become available should be reviewed, including:
   - Study for the Ecodesign Directive (EuP) Lot 10—provides market data for EU-27 and growth scenarios for stationary AC units below 12 kW capacity.
   - European Commission study on Eco-design ENTR Lot 6—currently being prepared (by Armines) and will provide information on stationary AC units above 12 kW capacity.
   - Future studies addressing market data for heat pumps (air-to-water and water-to-water types, potentially Ecodesign Lot 1 or others to be identified through coordination with EPEE.

3. Review/validate assumptions for ***MVAC charge size in buses***; data on HFC charge size from Germany suggests that the current estimate (of 6 kg) may be too small (by about half); more data is needed from other Member States and/or industry to confirm that a charge increase is appropriate across all EU countries.

4. Review the ***ODS phaseout dates for refrigeration/AC equipment in the EU-12*** to ensure that the projected years in which banks reach 0% installed base for CFCs and HCFCs are appropriate.

5. Review/validate the ***construction foam end-uses***. In particular, a better understanding is needed of the varying consumption patterns for ODS/HFC construction foams across the EU-27 to more accurately disaggregate foam banks by Member State, including information on CFC and HCFC phase-in and phase-out dates for sandwich panels and boardstock foams. While much of this data has recently been made available from Germany and Poland,

additional input is needed from other Member States as well as industry associations (e.g., EURIMA, PU Europe, Exiba), especially on key country markets (e.g., UK, Germany, France, Italy). In addition, several studies on the recovery and destruction of construction foam are nearly complete, and will provide useful information. For example, an EC study on construction and demolition waste was launched in October 2009, to assess current levels of and practices for recovery of different demolition materials in a representative sample of Member States (EC website).[6] Similarly, the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA) has commissioned research on the segregation of building insulation foams containing ODS on demolition sites, which is currently undergoing peer review.

6. ***Reconcile the discrepancies between top-down and bottom-up estimates*** by conducting further research into the assumptions used to develop top-down estimates. This may involve collaboration with TEAP to (a) ensure consistency across the specific end-uses included in "banks," and (b) explore the treatment of imports and exports of pre-charged equipment.

In addition to the above model validations and updates, the **model functionality** could also be expanded in a number of key areas. Specifically:

1. ***Multiple value assumptions*** could be developed for key variables with high uncertainty. For example, upper and lower-bound estimates could be modelled for stationary AC charge sizes, building lifetime, percentages of construction foam blowing agent recoverable at EOL, construction foam recovery costs, etc.

2. The mobile AC sector could be expanded to include ***AC systems in trucks, ships, rail vehicles, and agricultural machinery***; to this end, coordination with USNEF and Member States is suggested in order to develop assumptions on stock and charge size.

3. Assumptions on percent of blowing agent remaining at EOL could be disaggregated for construction foams by chemical type, to ***account for differences in lifetime loss rates for ODS versus HFC blowing agents***.

4. ***Construction foam banks could be disaggregated*** by end-use (i.e., commercial, industrial, domestic) to allow assumptions on lifetime to vary; additional research and industry consultation would be needed to determine if shorter lifetimes should be assumed for industrial/commercial buildings (e.g., 20- 30 years) across all countries or only some (e.g., the UK).

5. ***Building replacement could be modelled*** in addition to demolition for the construction foams sector; additional research would be needed to determine whether the estimated commercial/industrial building replacement rates estimated for the UK are applicable to other countries in the EU-27, and if not, how they vary.

To perform the above model improvements and expand model functionality, a process should be established for systematically collecting new data and performing model updates for the EC on an ongoing basis.

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[6] The study aims to (1) specify the requirements resulting from the EU waste legislation regarding construction and demolition (C&D) waste by establishing operational definitions of some crucial concepts, and (2) perform a quantitative and qualitative analysis of the status quo of C&D waste and establish a scenario for 2014 (European Commission, 2009b website).

In addition, while it is premature to recommend concrete actions for improving ODS/HFC recovery at product/equipment end-of-life, the following **preliminary options for promoting ODS/F-gas recovery at EOL** should be considered (in no particular order):

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).

As additional information is collected and incorporated into the Banks Model, it will be possible to more fully explore the opportunities associated with each of the options described above.

1 Introduction

More than 190 countries have signed the Montreal Protocol, a landmark international agreement to restore the Earth's deteriorating stratospheric ozone layer. In the European Union, the Montreal Protocol is implemented through Regulation (EC) No 1005/2009 of the European Parliament and of the Council on Substances that Deplete the Ozone Layer, which entered into force on 1 January 2010 and supersedes Regulation (EC) No 2037/2000. The regulation contains a number of provisions to monitor ozone depleting substances (ODS) production and consumption, including the reporting of information on these substances and of products and equipment that contain them.

Although the phase-out of ODS production and consumption is required under the Montreal Protocol, there are no controls on *emissions* of ODS—including the treatment of unwanted ODS stockpiles contained in bulk or in obsolete equipment and products at end-of-life (EOL). As ODS are phased out of production, large quantities are banked in products and equipments in the EU and worldwide. As these equipment reach the end of their useful lifetimes, it is critical that any remaining ODS contained in these products/equipment be fully recovered for reuse (as permitted) or for destruction. The recovery and destruction of unwanted/unusable ODS is imperative not only to reverse the course of ozone depletion, but also to avoid negative climate impacts. ODS are potent greenhouse gases (GHGs) with global warming potentials (GWP) as much as 10,000 times that of CO_2. Therefore, if not properly managed, ODS represent a potentially significant source of GHG emissions.

A similar problem exists for fluorinated greenhouse gases (F-gases), which have largely replaced ODS in products and equipment in the refrigeration/air-conditioning (AC), foams, and fire extinguishing sectors. Although emissions of F-gases do not deplete the ozone layer, they do contribute to global climate change and are covered under the Kyoto Protocol. F-gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), hydrofluorethers (HFEs), and can have GWPs as high as 23,900 times that of CO_2.

Previous assessments conducted by the European Commission found that ODS banks within the EU could amount to 700,000 ODP tonnes by 2010, and that emissions from these banks could reach 24,000 ODP tonnes (170 million tonnes of CO_2eq) per year through 2015. Banked quantities of F-gases will also become increasingly significant over time and available for destruction, as users transition away from ODS.

Given these volumes, the recovery and recycling/reclamation or destruction of ODS banks poses a serious and important challenge. This is especially true because not all ODS contained in products and equipment are readily "accessible" for recovery; the technologies and levels of effort needed to capture ODS contained in products and equipment can vary significantly. Moreover, the costs associated with the recovery, recycling, reclamation, and destruction vary significantly depending on the type and quantity of ODS recovered.

Policy gaps and limitations result in insufficient recovery levels, adding to the challenge of recycling/reclaiming or destroying ODS banks. The extent to which legislation is implemented varies considerably across Member States, and the technical and economic feasibility of recovering ODS from certain products and equipment (e.g., building insulation) is questionable. Likewise, the level of enforcement and compliance with current EC Directives related to waste and waste handling has been highly variable across Member States.

In addition to a lack of consistent legislation regarding ODS/F-gas recovery and destruction across the Member States, another challenge to properly disposing of unwanted ODS is gaining access to ODS destruction facilities in some areas of the EU. Moreover, there is a general lack of industry awareness of the location of nearest ODS destruction facilities. This uncertainty effectively limits the extent of ODS destruction activities within the EC. Therefore, work is needed to develop a comprehensive listing of destruction facilities to facilitate logistics and help determine if and where additional capacity is needed.

To significantly increase the amount of ODS/F-gases recovered from products and equipment at EOL in the EU, this report aims to: assess current and future ODS/F-gas banks; identify the current state of recovery and destruction across the EU; assess the technical and economic feasibility of recovering and destroying ODS/F-gases from different types of products and equipment; and develop appropriate policy action to promote the recovery and destruction of ODS/F-gases banked in products and equipment across the EU.

The remainder of the report is organized as follows:

- Section 2 describes the methodology for estimating ODS and F-gases banked in products and equipment throughout the EU now through 2050;
- Section 3 maps the current state of ODS and other F-gases in the EU, including existing EU legislation, technical standards for recovery in member and non-member states, recovery practices, and EU destruction capabilities and costs;
- Section 4 assesses the technical and economic feasibility of ODS/F-gas recovery from banks, as well as other factors affecting feasibility;
- Section 5 identifies possible policy options to promote the recovery and destruction of ODS from banks;
- Section 6 concludes with a presentation of findings and possible options for improving existing legislation and incentive mechanisms to promote recovery and destruction of ODS/F-gas from banks;
- Appendix A presents the detailed methodology for developing the bottom-up and top-down bank estimates;
- Appendix B presents the approved OD destruction technologies;
- Appendix C provides contact information for known EU destruction facilities;
- Appendix D presents the contact information for known EU reclamation facilities;
- Appendix E presents the TEAP estimated costs for ODS collection, transport, recovery, and destruction; and
- Appendix F presents the comments made on the draft report in March 2010 and ICF's response.

2 Estimated ODS/HFC Banks

2.1 Methodology

ODS/F-gas bank estimates for the EU-27 were calculated in two ways, one using a top-down methodology and the other using a bottom-up methodology. This approach was taken so that banks data reported at the national/international level can be compared to data built from Member State specific statistics, to both enhance the depth of the analysis and allow for potential discrepancies to be identified. It is envisioned that the resulting Banks Model will serve as a living model, which will be updated and refined as additional data become available.

The sections below provide a general overview of the top-down and bottom-up methodologies by sector. A more detailed methodological breakdown by end-use is available in Appendix A. It should be underscored that the top-down and bottom-up models differ significantly in terms of how HFC banks are projected; the top-down model projects future HFC growth based on historical trends, while the bottom-up model projects future HFC growth assuming an increasing push to climate-friendly alternatives.

2.1.1 Top-Down Methodology

Country-specific banks data are not currently available for the EU-27; therefore, to estimate banks using a top-down methodology, ICF used international banks data on the refrigeration/AC, foams, and fire sectors from Ecosphere/Milieu (2007) and IPCC/TEAP (2005),[7] apportioned by the GDP of each EU Member State to calculate country-specific banks.

Specifically, top-down ODS bank estimates were calculated using data from Ecosphere/Milieu (2007), which reported banks of CFCs, HCFCs, and halons for 2007 and 2010 based on IPCC/TEAP (2005). Ecosphere/Milieu (2007) reported banks for the following sub-sectors: refrigeration, mobile AC, stationary AC, foams, fire protection, and other. Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015.

To project banks through 2050 in the refrigeration/AC sector, CFCs and HCFCs were assumed to continue their downward linear trends. HFC banks in this sector were assumed to grow at half their 2002-2015 growth rate—except for the mobile AC sub-sector. In light of Directive 2006/40/EC, HFC banks in the mobile AC sub-sector were assumed to decline linearly beginning in 2011.[8]

Similarly, to project banks through 2050 in the foams sector, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Next, banks were disaggregated into thee sub-sectors: appliances, construction, and other, based on confidential market information.[9]

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[7] TEAP (2009a) provides bank estimates for 2010, which were not specifically used in this analysis; however, those estimates are in line with the 2002 and 2015 estimates provided in IPCC/TEAP (2005).

[8] An annual decline of roughly 7% is modeled, based on the assumption that no new HFC mobile AC units will be used beginning in 2011 and that such units have a lifetime of 14 years (i.e., 1/14= 7%). While this simplifying phase-out rate assumption was required for modeling purposes, it may be optimistic, as Directive 2006/40/EC does not prohibit HFC-134a use in all new mobile AC systems in 2011 (including those in buses or in pre-existing model vehicles).

[9] Market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

To project banks through 2050 in the fire extinguishing sector, it was assumed that halon banks continue their downward linear trend, and that HFC banks grow at half their 2002-2015 growth rate. For HCFCs, because EC bank data reported by Ecosphere/Milieu (2007) remained constant from 2007 and 2010, it was assumed that a decline would begin in 2010.[10]

Finally, All EU banks by sector and sub-sectors were allocated to Member States based on GDP (World Bank 2007).

2.1.2 Bottom-Up Methodology

ICF conducted research on each sector/sub-sector and selected the following end-uses for robust bottom-up inventory assessment/development, based on data availability and share of total estimated ODS/HFC bank. Table 1 displays all of the sectors, sub-sectors, and end-uses included in the inventory.

Table 1: Table Sectors, Sub-Sectors, and End-Uses Selected for Robust Inventory Assessment/Development

Sector	Sub-sector	End-use
Refrigeration/AC	Mobile AC	Passenger Cars
		Buses
	Refrigeration	Domestic Refrigerators/Freezers
		Small Commercial
		Medium/Large Commercial
		Refrigerated Transport—Land
		Refrigerated Transport—Ships
		Industrial
	Stationary AC	Small Stationary
		Large Stationary (Chillers)
Foams	Appliance	PU Rigid: Domestic Refrigerators/Freezers
		PU Rigid: Commercial Refrigeration
	Construction	PU Rigid: Sandwich Panels – Continuous
		PU Rigid: Sandwich Panels – Discontinuous
		PU & PIR Rigid: Boardstock (FFL)
		PU Rigid: Spray Foam
		XPS: Foam Boards

Definitions for the above end-uses are summarised below.

[10] An annual decline of 5% is modeled, based on the assumption that no new HCFC fire extinguishing systems will be used beginning in 2010 and that such systems have a lifetime of 20 years (i.e., 1/20= 5%).

Table 2: End-Use Definitions Used in Bottom-Up Model

Sector/ Sub-sector	End-use
Refrigeration/AC	
Passenger Cars	Includes motor vehicles used for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat. This is a sub-sector of Category M (as defined in Directive 2006/40/EC), which includes motor vehicles having at least four wheels, or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of passengers.
Buses	Includes motor coaches, buses, and trolley buses.
Domestic Refrigerators & Freezers	Includes household refrigerator and freezer appliances.
Small Commercial	Includes small condensing units (e.g., walk-ins), stand-alone refrigerator/freezer display cases, reach-in refrigerators/freezers, vending machines, ice machines, soda fountains, and other self-contained and plug-in equipment.
Medium/Large Commercial	Assumed to represent the combined charge installed in large condensing units and parallel systems (or other full systems) in supermarkets; the number of systems and their individual charge sizes will vary based on store size and layout.
Refrigerated Transport – Land	Includes road transport (van, truck, or trailer mounted systems), refrigerated railcars, and intermodal containers (which allow uninterrupted storage during transport on different mobile platforms, including railways, road trucks, and ships).
Refrigerated Transport – Ships	Includes reefer ships and merchant marine, naval, and fishing vessels.
Industrial Refrigeration	Includes industrial process cooling systems, including those used primarily for food/beverage processing, as well as chemical manufacturing, machine cooling, ice rinks, etc.
Small Stationary	Includes unitary, split, multisplit, packaged, and single duct residential and small commercial AC, residential and small commercial heat pumps, window units, <75 kW.
Large Stationary (Chillers)	Includes positive displacement and centrifugal chillers >75 kW.
Foams	
Domestic Refrigerators/Freezers	Application: refrigerator and freezer insulation.
Commercial Refrigeration	Application: commercial refrigeration equipment, including display units, vending machines, and water heaters.
Sandwich Panels - Continuous	Application: construction for factories and warehouses where temperature control and hygiene are essential. Cold storage accounts for roughly 40% of use. Other uses include high technology manufacturing buildings, such as electronics, pharmaceuticals, and food preparation.
Sandwich Panels - Discontinuous	Application: construction, including cold stores, cold rooms, and insulated buildings; used by producers where volumes cannot support continuous production.
Boardstock (FFL)	Application: construction; roof and wall insulation.
Spray Foam	Application: construction; used for roofs (that do not have to be flat or unobstructed), walls, pipes and storage tanks.
XPS Foam Boards	Application: construction; used for wall, roof and floor insulation in dwellings and commercial buildings.

To estimate banks using a bottom-up methodology for the **refrigeration/AC** end-uses, ICF used the following data:[11]

- GDP (World Bank 2007) and population (Eurostat 2009a) for each Member State.
- Estimated total stock of products/equipment (number of units) containing ODS/HFCs in use in each Member State.

[11] When the bulleted data items are not available by country, international or EU-specific statistics are apportioned by the GDP or population of each Member State in order to calculate country-specific data.

- Estimated average charge size of ODS/HFC within each product/equipment type for each Member State, or aggregated groups of Member States based on similar types/sizes of equipment.
- Estimated percent of charge remaining at end-of-life (EOL) within each product/equipment type for each Member State, or aggregated groups of Member States based on similar types/sizes of equipment.
- Estimated percent of charge remaining at EOL that is technically recoverable within each product/equipment type for each Member State, or aggregated groups of Member States based on similar types/sizes of equipment.
- Estimated percent of installed base by chemical type (CFC, HCFC, HFC) for each end-use in 2010, 2020, and 2050.
- Estimated year in which installed base reaches 0%— i.e., full equipment retirement—by end-use and chemical type (CFC, HCFC, HFC) (if prior to 2050).
- Assumed primary chemicals installed in each end-use (e.g., CFC-11, HCFC-22, HFC-134, etc.).
- Short-term growth rates (2009-2020) were estimated based on average historical growth rates (when available) or on estimated annual growth rates. Long-term grown rates (2021-2050) are assumed to be half of the short-term rate, to account for market saturation.
- Average 100-year GWP (global warming potential) for each primary chemical from both IPCC's Third Assessment Report (TAR) (IPCC 2001) and Fourth Assessment Report (AR4) (IPCC 2007), used to calculate GWP-weighted installed base.
- Average ODP for each CFC or HCFC primary chemical used to calculate ODP-weighted installed base.

The following is a sample formula (simplified) that was used to calculate bank estimates for refrigeration/AC end-uses using a bottom-up methodology:

> *Total stock (number of units) x Percent of units containing ODS x Average charge recoverable at EOL per unit x Percent of units disposed each year = Recoverable ODS bank in given year*
>
> *Where:*
>
> *Average charge recoverable at EOL per unit = average original charge size * % charge remaining at EOL x % charge technically recoverable at EOL*

Table 3 and Table 4 below present the summary assumptions used to develop the refrigeration/AC end-use characteristics, as well as the data/methods for estimating stock (number of units) by end-use and by Member State. Please see *Appendix A: Detailed Methodology for Developing Bank Estimates* for additional detail by end-use.

Table 3: Summary Assumptions for Refrigeration/AC End-Use Characteristics

End-Use	Charge Size (kg)	Lifetime (yrs)	Growth Rate		Refrigerant Transitions in Banks (i.e., equipment *in use*)
			2009-2020	2020-2050	
Refrigeration					
Refrigerators/ Freezers	NA	15	1.0%	0.5%	5% HFCs, 15-30% CFCs today; will transition almost fully to HCs by 2020
Small Commercial	2 - 3	12	3.0%	1.5%	75% HFC, 20% HCFC, 5% CFC today; 100% HFCs by 2020, gradual decrease through 2050 (50%)
Medium/Large Commercial	255 - 300	15	3.0%	1.5%	85% HFC, 15% HCFC today; 100% HFCs by 2002, gradual decrease through 2050 (50%)
Land Transport	5	25	6.0%	3.0%	80% HFC, 15% HCFC, 5% CFC today; increased reliance on HFC through 2020 (95%), gradual decrease through 2050 (65%)
Ships Transport	1,500 - 2,000	25	2.0%	1.0%	75-85% HCFC, 10-15% HFC, 5-10% natural refrigerants today; by 2020, increasing shift to HFC (30%), with gradual shift to natural refrigerants (50% by 2050)
Industrial Refrigeration	850 - 1,000	20	1.0- 2.0%	0.5- 1.0%	10% HCFC, 15% HFC, remainder natural refrigerants today; HFC banks rise to 20% by 2020 but decline to 5% by 2050
Mobile AC					
Passenger Cars	0.70 - 0.85	14	2.0- 3.5%	1.0- 1.75%	98% HFC, 2% CFC today; 70% HFC in 2020, 0% in 2050 (full transition to alternatives)
Buses	6 - 7	14	0.5- 1.75%	0.25- 0.75%	98% HFC, 2% CFC today; 95% HFC in 2020, 0% in 2050 (full transition to alternatives)
Stationary AC					
Small	3 - 3.5	10	3.5- 8.0%	1.75- 4.0%	65-85% HFC, 15-35% HCFC today; 100% HFCs by 2020, then transition to alternatives to reach 50% HFC by 2050
Large (Chillers)	210 - 250	15	5.5%	2.75%	65-75% HFC, 20-30% HCFC, 5% CFC today; 100% HFCs by 2020; transition to alternatives reduces HFC banks to 75% in 2050

NA= Not available; only charge *recoverable* at EOL was estimated, assumed to be 0.06 - 0.15 kg (depending on country).

Table 4: Summary Data/Methods Used to Estimate Refrigeration/AC Stock (Number of Units) by Country

Ref/AC End-Use	Stock Data	Data Sources	Disaggregation by Member State
Refrigerators/ Freezers	Stock data for EU-25 for 2000 & 2005	LOT 13: Domestic Refrigerators and Freezers Final Report (ISIS 2007)	Disaggregated units by population; used average ratio of units/population for Bulgaria & Romania
Small Commercial Refrigeration	Number of minimarkets & supermarkets in the Netherlands in 2000, assuming average of 10 units per store, each with 2-3 kg charge	GAIN Report on the Netherlands Retail Food Sector (USDA 2000)	Scaled estimates for the Netherlands based on population
Medium/ Large Commercial Refrigeration	Number of supermarkets in the Netherlands in 2000, assuming average charge size of 250-300 kg per store	GAIN Report on the Netherlands Retail Food Sector (USDA 2000)	Scaled estimates for the Netherlands based on population
Land Refrigerated Transport	EU-27 stock estimates for road (in 2005), rail (in 2002), and intermodal container refrigerated transport (1990-2004)	RTOC (2006) and the GDV (2009)	Stock estimates scaled based on GDP
Ships Refrigerated Transport	Stock estimates for reefer ships (2009) & merchant marine/ naval/ fishing vessels (2003)	Stock from Lloyd's Maritime Intelligence Unit (2009), RTOC (2006); DWT from United Nations Conference on Trade and Development on the world merchant fleet by flag of registration and type of ship (UNCTAD 2009)	Scaled based on total dead weight tonnes (DWT) for merchant fleets
Industrial Refrigeration	Approximately 100,000 HCFC-containing IPR systems in the EU in 2009, another 185,000 IPR systems containing HFCs	ICF (2006)	Disaggregated stock by GDP
Passenger cars	Historical data on passenger cars by Member State from 1990 – 2004	Eurostat (2009b)	Not applicable (data already disaggregated by country)
Buses	Historical data on the stock of motor coaches, buses, and trolley buses by Member State from 1990 – 2004	Eurostat (2009c)	Not applicable (data already disaggregated by country)
Small Stationary AC	Number of units based on EU-15 data on room AC units & centralized AC units	Armines (1999, 2003)	EU-10 estimates based on average ratio of units per capita for EU-15
Large Stationary AC	EU-15 data on centralized AC units	Armines (2003)	EU-10 stocks based on average ratio of units per capita in the EU-15

To estimate banks using a bottom-up methodology for the **foams** end-uses, ICF used the following data/assumptions:

- Banks were developed based on confidential data provided by global foam manufacturers regarding quantities placed on the market in years 2001 and 2008, by foams application type, and by chemical type.[12] To estimate installed banks, historical annual sales were estimated from the first known year of consumption, assuming linear growth to 2009 (using the known 2001 and 2008 data points). The installed base in each year was then estimated using a decay function, assuming a lifetime of 15 years for appliance foams and 50 years for construction foams. The annual disposal for each year was then estimated as the change in the installed base from the previous year. Specifically, foams banks in year *t* were calculated as follows:

$$\sum_{i=t_0}^{t} c_i \bullet e^{-(t-i)/l}$$

Where:

t	= The current year
t_0	= The first year in which f-gases were used
c_i	= The consumption of f-gases in year i
l	= The median lifetime of the installed foam
e	= Mathematical constant

- Within all foams sub-sectors, future growth of CFC and HCFC blowing agents was assumed to be 0%, as these chemicals have been phased out. Similarly, a 0% growth rate was assumed for HFC blowing agents in the appliances, as this sub-sector has already transitioned to climate friendly alternatives. Conversely, the future transition away from F-gases in the construction sub-sector is highly uncertainty; in light of the increasing push away from high-GWP gases, it was assumed that the future growth of HFCs will decline linearly from 2009 to reach 0 by 2020.
- To allocate the installed foams bank by Member State, the following methodology was used:
  - *For appliance foams*: the EU bank was disaggregated based on GDP (World Bank 2007).
  - *For PU rigid spray foams used in the construction*: it was assumed that 75% of the banks are installed in Spain and Italy, as these two countries account for the majority of use. Prior to 1990, the remaining 25% was apportioned to other EU-15 countries based on GDP; beyond 1990, the remaining 25% was apportioned to the other EU-27 countries based on GDP.
  - *For all other construction foam applications*: it was assumed that all consumption pre-1990 occurred in the EU-15, with banks apportioned to those 15 countries based on GDP (World Bank 2007). Beginning in 1990, banks were then allocated to the whole EU-27 according to GDP. These assumptions account for the slower uptake of the use of foam insulation in buildings in the EU-12.
- The quantity of blowing agent available at EOL was calculated based on the percent of blowing agent by weight by chemical type, and known emission factors (in year 1 and annually thereafter), based on IPCC (2006) and TEAP (2005).[13]

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[12] Data on chemical types (i.e., CFCs, HCFCs, and HFCs) were provided by application type based on estimated market share and known phase-in and phase-out dates.

[13] In cases where lifetime losses of blowing agents varied among or across chemical types (CFCs, HCFCs, HFCs), average values were used.

- The percent of charge remaining at EOL that is technically recoverable within equipment/products was estimated based on quantitative and qualitative assessment by application.

The specific assumptions used to translate 2001 and 2008 EU consumption data by end-use into historical annual EU consumption by chemical are summarised in Table 5. Please see *Appendix A: Detailed Methodology for Developing Bank Estimates* for additional details.

Table 5: Assumptions Used to Translate Foam Sales Data (2001, 2008) by End-Use Into Annual Historical Consumption by Chemical

Foams End-Use	CFC Consumption			HCFC Consumption			HFC Consumption			% by weight			Assumed Chemical		
	Start (EU-15)[a]	End	% of Market	Start (EU-15)[b]	End	% of Market	Start*	End	% of Market	CFC	HCFC	HFC	CFC	HCFC	HFC
Domestic Refrigeration	1959	1994	100%	1994	1998	20%	NA	NA	NA	12%	10%	NA	CFC-11	141b, 141b/22, 142b/22	NA
Commercial Refrigeration	1959	1995	100%	1995	2000	80%	2000	2020	40%	12%	10%	6%	CFC-11	141b, 141b/22, 142b/22	245fa, 365mfc/ 227ea
Sandwich Panels – Continuous	1969	1994	100%	1994	2003	70%	2003	2020	7.5%	8%	6.5%	6%	CFC-11	141b, 22, 22/142b	245fa, 365mfc/ 227ea
Sandwich Panels – Discontinuous	1969	1994	100%	1994	2003	80%	2003	2020	50%	8%	6.5%	5%	CFC-11	141b	245fa, 365mfc/2 27ea
Boardstock (FFL)	1965	1994	100%	1994	2003	30%	2003	2020	1%	12%	10%	5%	CFC-11	22, 141b/22	245fa, 365mfc/2 27ea
Spray foam	1965	1994	100%	1994	2003	90%	2003	2020	95%	12%	10%	7%	CFC-11	141b	245fa, 365mfc/2 27ea
XPS Foam Boards	1965	1994	100%	1994	2001	90%	2001	2020	15%	12%	10%	10%	CFC-12	142b, 142b/22	134a, 152

[a] It is assumed that CFC start dates in construction foam applications began 10 years later in EU-12.
[b] It is assumed that HCFC consumption in construction foam applications in EU-12 began only six years prior to the end (phase-out) dates.

2.2 Results

Table 6 below presents a comparison of the total EU top-down and bottom-up estimates in 2010 developed for this study, by sector and sub-sector. As shown, the two methodologies lead to similar results for ODS and HFCs installed in foam applications, but the bottom-up estimates are significantly lower than the top-down estimates for CFC and HCFC banks in the refrigeration/AC sector. To uncover the reasons for this variability, a deeper understanding of the assumptions used to build the IPCC/TEAP (2005) estimates would be needed. For example, end-use definitions may differ between data sets or methods employed (e.g., types of vehicle AC systems included in mobile AC, and types of foam applications included in foam banks), as may the treatment of imports/exports. In particular, the top-down estimates are based on consumption of the gases (production plus import minus export) as currently reported by EU countries, and do not include the gases imported to or exported from the EU in pre-charged equipment. This may in part explain the discrepancy between the top-down and bottom-up estimates.

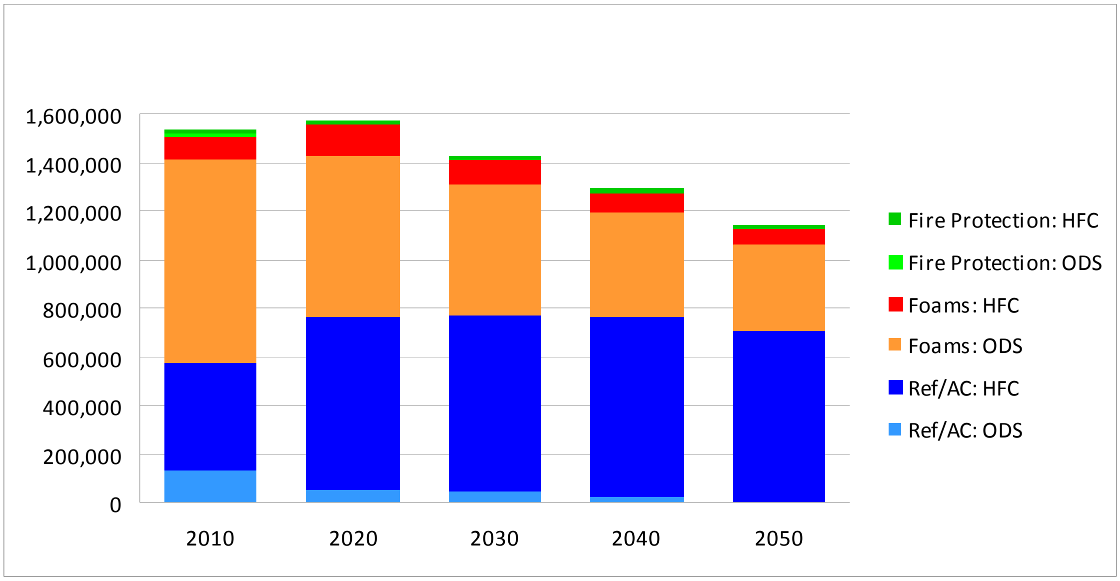
Table 6: Comparison of EU-27 Top-Down and Bottom-Up Estimates of Installed Banks in 2010, by Sector/Sub-Sector (T)

Sector	Sub-sector	Bottom-Up Estimates (2010)				Top-Down Estimates (2010)			
		CFC	HCFC	HFC	Halon	CFC	HCFC	HFC	Halon
Ref/AC	Mobile AC	2,400	-	113,432	-	13,100	4,000	97,308	-
Ref/AC	Stationary AC	1,218	43,774	184,504	-	9,800	187,100	123,277	-
Ref/AC	Refrigeration	6,793	64,623	138,669	-	33,300	90,300	102,462	-
Total Ref/AC		10,412	108,397	436,606	-	56,200	281,400	323,046	-
Foams	Appliance	59,041	9,089	8,102	-	100,932	45,127	15,025	-
Foams	Construction	456,829	226,570	84,112	-	370,083	165,464	55,092	-
Foams	Other	N/A	N/A	N/A	N/A	60,185	26,909	8,959	-
Total Foams		515,870	235,659	92,213	-	531,200	237,500	79,077	-
Fire Protection		N/A	N/A	N/A	N/A	-	800	9,338	18,100

Based on the bottom-up modelling methodology used for the refrigeration/AC and foams sectors, and the top-down methodology used for the fire protection sector,[14] Figure 1 presents the projected banks of ODS (CFC, HCFC, and halon) and HFCs installed in the EU-27 from 2010 through 2050. As shown, the vast majority of ODS remaining in the EU-27 by 2010 is installed in the foams sector (86%), while the vast majority of HFCs installed are in the refrigeration/AC sector (82%). By 2050, a significant amount of ODS foams will still remain in the EU, while all other types of ODS will be fully phased out. By 2050, it is also projected that banks of HFCs will be significant—over 700,000 tonnes—but that they will begin to decline, in response to the increasing push away from high-GWP refrigerants.

[14] No bottom-up methodology was developed for the fire protection sector.

Figure 1: Bottom-Up Estimates of Installed ODS and HFC Banks in the EU-27 by Sector (T) (2010-2050)



Of the ODS and HFCs installed, however, only a certain percentage will reach end-of-life in any given year, and only a certain percentage of that amount will be technically recoverable. Section 4 reviews the technical feasibility of recovery based on assumed quantities of refrigerant or blowing agent remaining at product/equipment EOL, and the percent of those quantities that are assumed to be technically recoverable using available technologies. All projected quantities of CFC, HCFC, and HFCs recoverable at product/equipment EOL in 2010, 2020, and 2050 are based on the bottom-up modelling methodology.

3 Mapping Current State

This chapter summarises current legislation targeting the recovery and destruction of banked ODS/F-gases at the EU, Member State level, and international levels.

3.1 Existing Legislation in the EU

Multiple regulations target the recovery and destruction of banked ODS/F-gases at the EU level. These regulations include those focused on bulk ODS/F-gases, classification and shipment of waste, domestic and small commercial appliances and small stationary AC, vehicles, and emissions trading schemes. Each of these regulations is summarized below.

3.1.1 Bulk ODS and F-Gases

Regulation (EC) 1005/2009 on substances that deplete the ozone layer entered into force on 1 January 2010 and supersedes Regulation (EC) No 2037/2000. It covers the production, importation, exportation, placing on the market, use, recovery, recycling, reclamation, and destruction of ODS. Articles 22§1 requires the recovery for destruction, reclamation, or recycling of controlled substances contained in refrigeration/AC equipment (both commercial and residential), heat pump equipment, equipment-containing solvents and fire protection systems and fire extinguishers. Article 22 requires that controlled substances contained in products and equipment other than those mentioned in paragraph 1 be recovered for destruction, recycling or reclamation "if technically and economically feasible,"[15] or be destroyed without prior recovery. In addition, Annex VII lists approved destruction technologies for each group of substances and destruction efficiencies (see Appendix B). The Regulation also mandated the decommissioning of all halon systems and extinguishers in the EU by the end of 2003 (with the exception of those applications that are defined as critical uses).

Regulation (EC) 842/2006, adopted on 17 May 2006, establishes a regulatory framework to reduce the emissions of F-gases and assist the EU in making a significant contribution toward the European Community's Kyoto Protocol target. The regulation essentially applies Regulation 1005/2009 to all F-gases, although it does not explicitly require the recovery of foam blowing agent from refrigerated equipment.

3.1.2 Waste Classification and Shipment

Directive 2008/98/EC on waste management categorizes ODS and F-gases intended to be discarded as hazardous waste. The directive requires Member States to ensure waste recovery, and, if necessary to comply with this requirement and to facilitate or improve recovery, to collect waste separately "if technically, environmentally, and economically practicable," and not mix it with other waste or material with different properties. Compliance with this Directive entails not mixing hazardous wastes. The Directive states that "Member States shall take the necessary measures to ensure that hazardous waste is not mixed, either with other categories of hazardous waste or with other waste, substances or materials." Mixing includes diluting hazardous substances.

However, Member States may allow mixing of such waste if (a) the activity is carried out by a specifically permitted establishment, (b) there is no increase in the adverse impact of the waste management on human health and the environment, and (c) the mixing operation conforms to the best

[15] The Regulation covers chlorofluorocarbons, other fully halogenated chlorofluorocarbons, halons, carbon tetrachloride, 1,1,1-trichloroethane, methyl bromide, hydrobromofluorocarbons, hydrochlorofluorocarbons and bromochloromethane, whether alone or in a mixture, and whether they are virgin, recovered, recycled, or reclaimed.

available techniques. In addition, it is not practical to enforce the dilution ban since it is very difficult to determine whether or not mixed waste has been diluted. Furthermore, if hazardous waste has already been mixed, then "subject to technical and economic feasibility criteria," it must be separated "where possible and necessary" in order to ensure no harm to human health or the environment. Similarly, waste oils (such as those contained in refrigerators/freezers) must be collected separately, where technically feasible and where waste oils of different characteristics are not mixed, where technically feasible and economically viable. However, if hazardous waste is mixed with non-hazardous waste at concentrations lower than those laid out in **Directive 2008/98/EC**, it is not considered hazardous, and is therefore not subject to the hazardous waste regulations. That said, according to the directive, the "reclassification of hazardous waste as non-hazardous waste may not be achieved by diluting or mixing the waste with the aim of lowering the initial concentrations of hazardous substances to a level below the thresholds for defining waste as hazardous."

Furthermore, for ODS that are part of products—namely, foams—it is unclear whether those products or substances are considered to be hazardous waste at EOL. Moreover, if such waste products or substances were to be deemed hazardous, there is no known standard labelling of ODS foams to ensure proper identification and subsequent treatment according to existing hazardous waste regulations.

Regulation (EC) 1013/2006 establishes procedures and control regimes for the shipment of waste between Member States, within the Community or via third countries; waste imported into and exported from the Community from/to third countries; and waste in transit through the Community, on the way from and to third countries. All CFCs, HCFCs, and HFCs because they are not explicitly listed as a "green waste" in Annex III, are considered and treated as hazardous waste, according to Title II, Article 3.1.b.iii. Consequently, shipment of ODS requires prior written notification and consent. In addition, this regulation includes labelling requirements. Because many Member States have few if any ODS and F-gas destruction facilities, these gases are often shipped across Member State borders, which triggers the administrative requirements of this regulation.

Regulation (EC) 1272/2008 on classification, labelling and packaging of substances and mixtures, repealing Directive 67/548/EEC and 1999/45/EC and amending Regulation (EC) 1907/2006 (REACH), standardises criteria for classification of substances and mixtures and requires the labelling of hazardous substances at manufacture, import, and use.

3.1.3 Domestic and Small Commercial Appliances, Small Stationary AC (Foam and Refrigerant)

Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) covers large and small household appliances, including household refrigeration and air conditioning appliances, as well as small commercial refrigeration equipment such as automatic dispensers of cold bottles and cans that are designed for use with a voltage rating not exceeding 1,000 Volt AC and 1,500 Volt DC. The Directive requires that by 31 December 2006, at least 4 kg per inhabitant per year should be collected separately. Once equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15 are collected separately, the ODS must be treated in accordance with Regulation 1005/2009. Finally, the Directive requires a recovery rate of at least 80% (by average weight per appliance) for all WEEE listed among the large household appliances and automatic dispensers, and a component, material, and substance reuse and recycling rate of at least 75% (by average weight per appliance).

The European Commission is currently reviewing Directive 2002/96/EC. Specific considerations include Member State collection, recovery, reuse, and recycling targets, the scope of the Directive, operation of the producer responsibility provisions, and treatment requirements.

3.1.4 Vehicles

Directive 2006/40/EC states that, "starting in 2011, Member States shall no longer grant EC type-approval or national type-approval for a type of vehicle fitted with an AC system designed to contain F-gases with a GWP higher than 150" (e.g., HFC-134a). In addition, it stipulates that by 2017, *all* new vehicles fitted with AC systems must contain refrigerants with a GWP of 150 or less. This directive applies to vehicles type M1 and N1, where category M1 is defined as "vehicles used for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat," and category N1 is defined as "vehicles used for the carriage of goods and having a maximum weight not exceeding 3.75 metric tons." Thus, while this Directive does not pertain to the recovery or destruction of refrigerants contained in MAC systems, it will require that future generations of MACs no longer contain high-GWP substances. The Directive requires the Commission to consider extending its application to AC in buses, coaches and trucks (EC 2009a).

Directive 2000/53/EC on vehicle end-of-life (EOL) requires Member States to ensure that EOL vehicles are dismantled and hazardous materials removed. Air conditioning system fluids must be removed and stored separately before the vehicle is shredded. While most foam used in automotive applications typically does not contain ODS or HFCs, the directive requires that it be recovered at vehicle EOL for proper disposal.

3.1.5 Construction and Demolition (Foam)

There is currently no EU-wide legislation regulating the handling of waste ODS/F-gas foams from building construction and demolition activities, *per se*. However, because foam building end-uses contain hazardous materials, they are subject to the separation requirement delineated in Directive 2008/98/EC on Waste. According to the Waste Framework Directive, by 2020, 70% by weight of construction and demolition waste must be recovered. Despite this requirement, very little is known regarding current demolition/recovery practices in the EU, particularly with regard to ODS/F-gas foams. An EC study on construction and demolition waste was launched in October 2009 in order to review current practices across a representative sample of Member States, and to assess the current levels of and practices for recovery of different demolition materials (EC website).

3.1.6 Emissions Trading

Article 24a of Directive 2003/87/EC on the European Union Emissions Trading Scheme details the procedures for unilateral inclusion of additional activities and gases, stating that from 2008, Member States "may apply emission allowance trading in accordance with this Directive to activities, installations and greenhouse gases which are not listed in Annex I, provided that inclusion of such activities, installations and greenhouse gases is approved by the Commission…taking into account all relevant criteria, in particular effects on the internal market, potential distortions of competition, the environmental integrity of the scheme and reliability of the planned monitoring and reporting system." This Article provides a potential opportunity for the Commission to include ODS destruction credits within the emissions trades. In addition, provision 3 of the article states that, "[a] Member State can refuse to issue allowances or credits in respect of certain types of projects that reduce greenhouse gas emissions on its own territory." As such, Member States could regulate the recovery and destruction of certain types of ODS (e.g., construction foams), which may render them ineligible for carbon credits.

3.2 National Legislation/Programs in Place

This section summarises national regulations and programs in place in selected countries, based on readily available information, including ICF (2008b) and information provided by Member State and association representatives. Specifically, information is provided on selected Member State regulations and policies that apply to (1) refrigerated appliances and small stationary AC units, (2) building construction foam, and (3) vehicles.

3.2.1 Refrigerated Appliances and Small Stationary AC Units

National regulations and policies targeting the treatment of refrigerated appliances and small AC units at end-of-life (EOL) were available for Austria, the Czech Republic, Germany, the Netherlands, and the UK. A summary of these regulations and programs is presented below.

Austria banned both the incineration of foams from waste refrigeration appliances and the incineration of complete appliances in 2006.

The **Czech Republic** has enacted Act 86/2002, which mandates that for the appliance sector, all ODS be recovered by technicians during the servicing of equipment. When these appliances are disassembled, ODS must be recovered for destruction, reclamation, or reuse from the compressor circuit, as well as from insulating foam. An import tax of approximately US$21 is placed on every kilogram of ODS imported and placed on the Czech market. To comply with regulations, the appliance industry has formed Elektrowin, a. s., whose collection network consists of 1,350 retailers, 465 municipal collection yards, and 2,100 mobile collection operators. Refrigerated appliances are recycled at four Czech demanufacturing centres, with one facility currently accounting for the lion's share (>90%) of throughput. (ICF 2008b)

In **Germany**, the ElektroG act holds German importers and manufacturers of electrical and electronic equipment responsible for the disposal of such waste equipment. For any appliances containing ODS, this includes the recovery and disposal of ODS. Appliances are collected at approximately 1,500 municipal waste centres known as "Communal Handover Offices." The Federal Environmental Agency directs a selected manufacturer to arrange for the pickup of the waste from these centres, while a national producers' association provides coordination. There are approximately 20 appliance recyclers in Germany. (ICF 2008b)

In the **Netherlands**, producers and importers have established a system, based on the WEEE Management Decree, for the efficient collection and environmentally sound recycling/processing of waste electrical equipment, also covering household-type refrigerating and cooling equipment containing CFCs, HCFCs, HFCs, and HC. The Netherlands Foundation for the Disposal of metal and Electrochemical Products (NVMP) manages the system, and Coolrec processes and recycles all refrigeration appliances in 1 processing line. This system is financed through a fee of approximately €17 paid by consumers at the time new equipment is purchased.

In **Sweden**, obsolete refrigerators and freezers are covered by Ordinance (2005:209) on Producers Responsibility for Electrical and Electronic Equipment, which implements the WEEE Directive. According to the ordinance, refrigerators and freezers must be collected separately from other waste and transported to designated recovery facilities where ODS and HFCs can be recovered from the insulation foam and the refrigeration circuits. Appliance producers are responsible for setting up the collection systems, which is achieved primarily through a collective scheme. The main actor for collection and recycling of electrical and electronic products on the Swedish market is El-kretsen. Household collection is organised through individual municipalities. The organisation offers a national recycling system with approximately 950 collection sites. Appliance recycling facilities are required to have operating permits, which are granted by the regional environmental authority. Compliance assurance is carried out through reports and inspections. (Ujfalusi 2010)

Finally, in 2002, the **UK** implemented the "*Controls on Ozone-Depleting Substances"* (Statutory Instrument 2002 No 528) which regulates both residential and commercial refrigeration unit disposal. The controls require the recovery of ODS from all disposed refrigerator and AC units during dismantling. Business owners face heavy penalties for the deliberate release of ODS to the atmosphere. Currently, end-users are responsible for the proper disposal of both commercial and residential units, although equipment manufacturers have established a take-back system and must finance the collection, transportation, and dismantling of residential units. Consumers can drop off their waste appliances at any one of 1,400 municipal collection sites or through appliance retailers. There are 11 refrigerated appliance demanufacturers that recycle the collected units. (ICF 2008b)

3.2.2 Building Construction Foam

Under the Priority Waste streams Programme, initiated in 1990, Member States identified construction and demolition waste as a priority waste stream. In response, various Member States have implemented national legislation to reduce ODS emissions and more effectively manage waste from this sector. However, to date, there has been no concerted effort to recover ODS in building foams in Europe (Ecosphere/Milieu 2007).

Germany, the **Netherlands**, **Austria**, and Flanders (**Belgium**) have enacted a ban on landfilling of recoverable or mixed construction and demolition waste. Thus, all construction foams must be recovered for destruction—typically in a municipal solid waste or hazardous waste incinerator. In the UK, the List of Wastes (LOW) Regulations 2005 classifies wastes containing ODS in demolition materials as "hazardous" if concentrations exceed 0.1%, which in turn restricts the recovery/disposal options to those facilities that are authorised to accept hazardous wastes (e.g., hazardous wastes recovery facilities, hazardous wastes landfills) (Jones 2009). In addition, the **UK**, as well as the **Netherlands**, and the Walloon region (**Belgium**), have subsidies for construction and demolition waste projects. (VITO et al. 2007).

In **Austria**, waste management laws classify all CFC and HCFC foam XPS- and PU- insulation recovered during building demolition, sanitation, or deconstruction, as "hazardous." Thus, such foams must be treated per Directive 98/2008/EC, described above. (Obernosterer 2005)

No other country-specific information is readily available on the required treatment of construction foams at EOL.

3.2.3 Vehicles

There are no known national collection systems in place for the recovery of refrigerant from mobile air conditioning units in the EU. In some countries (e.g., Germany) the owner of a mobile air conditioning unit must pay the cost of disposing the CFC (ICF 2008b).

3.2.4 Shipment of Waste ODS/F-Gases

While it was not possible to obtain information on national regulations related to the transport of used/unwanted ODS/F-gases in each of the 27 Member States, according to EFCTC (2009), some countries exempt small quantities (i.e., $\leq$30 kg) of hazardous waste from licensing. In general, however, contractors are required to obtain a license and report all movement of recovered fluorocarbons. In addition, several Member States have implemented regional regulations that render it difficult to transport recovered fluorocarbons within a single country (EFCTC 2009).

3.3 Non-EU National Regulations and Policies

This section summarises selected national regulations and programs in place in Australia, Canada, Japan, Norway, and the Unites States, based on readily available information, including ICF (2008b) and country-specific information provided by government representatives. Specifically, information is provided on selected countries' regulations and policies that apply to (1) bulk ODS/F-gas, (2) appliances, (3) building construction and demolition, and (4) vehicles.

3.3.1 Bulk ODS/F-Gas

National regulations and policies targeting the treatment of bulk ODS/F-gases were available for Japan and the United States. A summary of these regulations and programs is presented below.

Japan: Fluorocarbons Recovery and Destruction Law

The *Fluorocarbons Recovery and Destruction Law* requires the recovery and destruction of fluorocarbons from commercial equipment during service and disposal events. (Japanese Ministry of the Environment 2007a) The law also requires that refrigerant recovery be performed by recovery operators/firms registered with prefecture government. Fluorocarbon recovery operators must report annually to prefecture governors on the amount of fluorocarbons recovered from commercial AC and refrigerators in the previous year. In addition, the law requires that any refrigerant destruction must be performed by permitted facilities using sound environmental technologies. Destruction facility permits are granted by the national government (the Ministry of the Environment [MOE] and the Ministry of Economy, Trade and Industry [METI]). The law also mandates that the fee for fluorocarbon recovery and destruction be paid by end-users. (ICF 2008b)

In June 2006, this law was amended to improve refrigerant recovery levels from commercial equipment. The amendments require increased reporting and recordkeeping for commercial equipment owners to increase responsibility and accountability. The amendments also added responsibility for building dismantlers to check for and properly dispose of any commercial refrigeration/AC equipment containing fluorocarbons. In addition, the amendments strengthened the authority of local governments so that they can give guidance, advice, recommendations and orders to the equipment owners, and to those receiving the equipment to guarantee recovery operators recover the fluorocarbons installed. Previously, the authority of local governments had been limited to the issuance of guidance to recovery operators. The amendments entered into force in October 2007. (ICF 2008b)

United States: ODS and Waste Regulations

National regulations are in place in the United States regarding the use, reclamation, and disposal of CFC and HCFC refrigerants, as well as their substitutes. According to these regulations, it is illegal to knowingly vent or release any CFC, HCFC, or ODS substitute refrigerants in the course of maintaining, servicing, repairing, or disposing of refrigeration equipment, although *de minimis* emissions associated with good faith attempts to contain the ODS are permissible. In addition to the requirement to properly recover ODS refrigerant prior to the disposal of equipment, federal requirements specify that mercury, used oil, and PCBs—including that contained in household refrigerators/freezers—must also be properly managed and stored.

In addition, U.S. regulations specify that ODS must be destroyed using technologies approved by the Montreal Protocol Parties. Further, ODS must be "completely destroyed" which, according to US regulations, means that ODS must be destroyed to a 98% destruction efficiency (DE).Waste ODS classified as hazardous wastes must be destroyed in hazardous-waste permitted destruction facilities. Permitted hazardous waste facilities that operate hazardous waste combustors (e.g., incinerators) are also required by the standards for Maximum Achievable Control Technology (MACT) to adhere to a minimum 99.99% DRE and meet certain air emissions limits. While most waste ODS types are not classified as hazardous wastes (e.g., CFC/HCFC refrigerants, halons), research has indicated that, in practice, most ODS are destroyed in the US by hazardous waste permitted facilities, and that all ODS are destroyed to at least a 99.99% DRE when sent to such facilities. (ICF 2008b)

3.3.2 Appliances

Both Japan and the United States have implemented national regulations/programmes targeting the treatment of appliances. A summary of these regulations and programs is presented below.

Japan: Home Appliance Recycling Law

The *Home Appliance Recycling Law* establishes procedures for the recycling of home refrigerators, air-conditioners (including split systems), televisions, and washing machines (Japanese Ministry of the Environment 2007a). These four appliance types were selected because they are delivered and installed by retailers, who can serve as channels for appliance return. The law mandates the recovery of fluorocarbon refrigerants and foams,[16] and also sets minimum recycling rates for the durable components of these appliances (of 50%-60%).[17] The law also requires that appliances be collected by retailers and recycled by manufacturers or importers. Fees for the collection, transport, and recycling are paid by consumers at the time of disposal.

United States: ODS Recovery and Disposal Regulations

Although it is illegal to knowingly vent ODS or ODS substitute refrigerant at appliance end-of-life (EOL), the recovery and treatment of ODS-containing foams from appliances is not required by Federal or State regulations. Moreover, while there is no national program or standard procedures in place for disposing of appliances, the U.S. EPA launched the voluntary Responsible Appliance Disposal (RAD) Program in 2006, to promote the responsible disposal of refrigerated appliances. RAD partners must recover ODS from old refrigerators, freezers, air conditioners, and dehumidifiers using best practices to ensure that (1) refrigerant is recovered and reclaimed or destroyed as required by law; (2) foam is recovered and destroyed or the foam blowing agent is recovered and reclaimed; (3) metals, plastic, and glass are recycled, to the extent possible; and (4) PCBs, mercury, and used oil are recovered and properly disposed as required by law. RAD partners include utilities, municipalities, retailers, manufacturers, universities, and other interested organizations (e.g., military). (ICF 2008b)

3.3.3 Building Construction and Demolition

Few countries have known requirements for foam recovery/treatment from building construction and demolition waste. **Norway** is one country that has implemented a national regulation on the recovery and treatment of waste, which targets building and demolition waste. While this regulation prompted 30-40 municipalities to implement regulations on building and demolition waste starting in 2002, the Norwegian Regulation on Recovery and Treatment of Waste was amended in 2007 to include a new chapter on the proper treatment of waste from building and demolition activities—given that the original regulation lacked consistency and provided no reporting or enforcement guidelines. Under the revised regulation, producers of waste are required to identify the building waste and classify it by type, and develop a management and disposal plan, for activities including the construction changes, demolition and rehabilitation of buildings greater than 300 m^2, demolition and rehabilitation of buildings greater than 100 m^2, and the building, rehabilitation or demolition of constructions that generate more than 10 tonnes of building and demolition waste (i.e., bridges). Building activities in areas greater than 400 m^2 require more comprehensive reporting. For all listed activities, at least 60% of waste weight must be segregated at the building activity site. While this practice may have implications for the recovery of ODS/F-gases foams, it cannot be confirmed. (Waste Regulation Chapter 15 Outline)

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[16] Manufacturers/importers began testing the feasibility of foam recovery/destruction in 2001; by 2004, it was proven to be feasible, and the recovery and destruction of foam from domestic refrigerators/freezers became legally required in 2004.

[17] National standards for recycling ratios are defined based on commercial value of recyclable materials. If materials are reused but no commercial value is assigned for that use (e.g., if plastics are used as fuel but no payment is received for it), Japanese law does not consider this to be "recycled." If commercial value were not considered in the definition of "recycling," current Japanese recycling rates for appliances would be over 90%.

3.3.4 Vehicles

Japan has implemented national regulations targeting the treatment of vehicles, as summarized below. Other countries may also have regulations that target vehicles and the treatment of ODS/F-gases from them, but information on such regulations was not readily available for this report.

Japan End-of-life Vehicle Recycling Law

Adopted in 2002 to address the recycling of EOL vehicles and the recovery of fluorocarbon refrigerants during the recycling process (Japanese Ministry of the Environment 2007a), this regulation requires that disposed vehicles be collected by registered collection operators (i.e., registered car dealers and auto repair shops), transferred to registered recovery operators to remove refrigerant, and then transferred to permitted dismantling and shredding operators (Japanese Ministry of the Environment 2007a). Fees for the recovery, transport, and destruction are paid by consumers. In addition, consumers must also pay fees for the recycling of air-bags and shredder-residues. (ICF 2008b)

3.4 Technical Standards for Recovery from Appliances

Technical standards are in place in many countries for refrigeration and air conditioning appliances. Standards in Austria, Luxembourg, Denmark, the Czech Republic, the UK, and Germany are summarized below.

Many Member States have technical standards for recovery of ODS refrigerants and foam blowing agents in refrigeration and air-conditioning appliances. For instance, **Austria**, **Luxembourg** and **Denmark** have set a statutory minimum standard of 90% recovery from both refrigerant and foam in appliances. In Austria, this entails an average of at least 115 grams of refrigerant per appliance, and at least 240 g of CFC-11 blowing agent per appliance (DUH 2007). However, TA Luft, the German air-pollution law, only stipulates recycling rate of at least 90% for extraction of coolants from the refrigeration circuit, providing no standard for the recovery of foam blowing agent. In addition, it requires one pre-announced official inspection per year (Capitol 09 2008). However, authorities rarely verify ODS recovery per unit (ICF 2008b).

Czech Decree No 117/2005 implements requirements for the recovery of refrigerant and blowing agent (Parliament of the Czech Republic 2005). After refrigerant recovery, the coolant oil cannot contain more than 0.1% refrigerant by mass. The foam, after degasification, cannot contain more than 0.2% blowing agent by mass. In addition, ODS-containing foams must be treated by both heating and mechanical crushing in an enclosed environment, the exhaust gas from which cannot contain more than 5 grams of ODS per house. Finally, refrigerator recyclers must complete extensive annual testing on at least 1,000 units, to determine the average charge recovered per unit (ICF 2008b).

In the **UK**, a minimum of 99% of the coolant-oil mixture must be drained out of each unit, and the mixture must be distilled such that the concentration of refrigerant remaining is no more than 0.9%. In addition, damaged refrigerators must be drained within 48 hours of arrival at the facility. For all units, destruction of the refrigerator carcass (i.e., once foam has been removed and metals have been shredded) must be done in a contained environment. The foam remaining on the shredded metal after separation should not exceed 0.5% of the weight; the foam on the plastic should not exceed 1%. After the foam is degassed, it cannot contain more than 0.5% ODS by weight. The Agency’s regulations also specify the maximum amount of ODS that can be released through exhaust gases (in grams per hour), given the numbers of refrigerated appliances recycled (units per hour). (ICF 2008b)

In Germany, facilities were given until 30 October 2007 to meet recovery standards, for which an average refrigerant recovery rate of 90% on step one (separation of the CFC from the oil) is required (German Federal Environment Agency 2010).

Given the existing recovery technologies available today, companies across all Member States should be able to achieve minimum recovery standards of 90% for refrigerant as well as foam blowing agent from domestic refrigerators/freezers; but a critical consideration is how to track and report on actual recovery levels, and how to monitor recovery practices and/or enforce that entities are meeting regulatory requirements/standards.

3.5 Member State Recovery Practices

ODS/F-gas refrigerant and foam blowing agent recovery practices vary by Member State and by end-use. This section highlights known practices based on available literature, as well as input from industry experts and Member State representatives. Specifically, Member State practices regarding bulk ODS/F-gas, refrigeration/AC end-uses, domestic refrigerators and freezers, foam end-uses, and the fire sector are summarized below.

3.5.1 Bulk ODS/F-gas

Common recovery practices for bulk ODS/F-gases were reported for the Netherlands and the UK. A summary of these practices is presented below.

In the **Netherlands**, most recovered HCFCs are believed to be destroyed and not recycled/reclaimed because most recovered gases are highly contaminated. According to Member State representatives, although refrigerant recovery is required at the end-of-life (EOL) and during servicing, it cannot be said with 100% certainty that everyone follows these requirements. Likewise, while technicians are required to register whenever they handle ODS gases, there may be some people illegally dealing with them.

In the **UK**, a large refrigerant producer coordinates the transportation and destruction of bulk ODS/F-gases in ISO tanks from various sources through its distributors. By managing the ISO tank fleet and logistics, there is an economy of scale, and refrigerant handling is facilitated for destruction companies.

3.5.2 Refrigeration/AC

According to EU industry representatives in the refrigeration/AC sector contacted for this report, equipment installers are commonly trained on how to recover refrigerant and where to send it for disposal. Likewise, the vast majority of installers have the necessary equipment to perform refrigerant recovery. However, refrigerant recovery levels vary across Member States; in some Member States, equipment installers recover over 90% of refrigerant, while in others, recovery levels may be closer to only 40%-70%. According to one large equipment user (in France), estimated levels of recovery from 2004-2007 were significantly lower than this—estimated at less than 10%. (ICF 2008a)

There is also a wide variation in recovery levels across end-use types. According to a recent study by Barrault and Clodic (2008), there are no economic drivers that create an incentive to improve the recovery of F-gas refrigerant from small equipment (e.g., domestic refrigerators, small AC units, MVACs), since the costs of recovery equipment (about €3,000 for an MVAC recovery device) and labour (roughly 15 minutes required) outweigh the economic gains that can be reaped by recovering a few kilogrammes of refrigerant worth approximately €1.50/kg. In addition, because small equipment is often transported to a recycling plant prior to refrigerant recovery, refrigerant losses during transport/handling are common. As a result, it is estimated that 2% or less of refrigerant is recovered from small equipment at EOL, whereas 70%-80% of refrigerant is recovered from large equipment (Barrault and Clodic 2008). For this reason, large equipment manufacturers and service providers are likely to exhibit high levels of recovery, as are those dealing with very large equipment types (e.g., industrial refrigeration systems, chillers). This is especially true in countries that have a long history of rigorous technician training/certification programs. (ICF 2008a) At EOL, large commercial refrigerated equipment is typically handled by installation companies that recover refrigerant for reuse, reclamation, or destruction, and then decommission the equipment for recycling (Daikin Europe 2009; ECSLA 2009).

According to a major refrigerant supplier in the **UK**, compliance with refrigerant recovery laws is generally very high (A-Gas 2009). However, according to another industry representative in the UK who supplies large refrigeration systems to retail food and industrial customers, there is a lack of motivation to recover refrigerant from large systems for destruction because of the costs to destroy the refrigerant. In addition, recovered refrigerant is considered hazardous waste, which introduces additional administrative and cost barriers associated with transport. The representative pointed to estimates that suggest that less than half of the refrigerant contained in decommissioned equipment is actually being destroyed. (JTL Systems 2009)

In **Sweden**, Swedish Ordinance (2007:846) on fluorinated greenhouse gases and ozone depleting substances was introduced in the early 1990s, which requires importers and distributors (suppliers) to take back recovered refrigerant from stationary and mobile systems at no charge. The cost is covered by a fee included in the sale price of refrigerant, and the system is run by the companies involved (i.e., independent from government agencies). The ordinance was designed to avoid the placement of contaminated recovered refrigerants on the market and to minimize end-user venting due to costs (Ujfalusi 2010).

The remainder of this section provides additional information available regarding the recovery of refrigerant from domestic refrigerators/freezers and MVACs.

Domestic Refrigerator/Freezers

ODS/F-gas recovery practices from domestic refrigerators and freezers were reported by Member State representatives, industry associations, and ICF (2008b, 2008c). A summary of these practices in Austria, the Czech Republic, France, Germany, and the UK is provided below.

Despite the regulatory mandate to recover refrigerant and foam from household refrigerators/freezers , the widespread availability of equipment to perform refrigerant recovery, and the capability of state-of-the-art refrigerator recycling services to remove more than 90% of refrigerants and foams from waste appliances for destruction, actual recovery levels have been low. While refrigerant (and foam) recovery practices can vary from recycler to recycler, overall, it is estimated that only 27% of household refrigerators/freezers are collected at EOL in compliance with the WEEE Directive (United Nations University et al. 2008). Indeed, according to RAL (2008), very few refrigerators were properly being recycled in **France** until 2007. Similarly, based on data from 2004/2005, DUH (2007) reported that refrigerator recycling companies in Germany were operating at a lower technological standard than those in other countries, such as Austria, Switzerland, Luxembourg, Sweden and Greece; however, German facilities were given until 30 October 2007 to meet recovery standards, for which Germany requires an average refrigerant recovery rate of 90% on step one (separation of the CFC from the oil).

In addition, the money paid for appliances sent to recyclers is thought to affect the level of ODS recovery. Values can range from less than €2/appliance in **Germany** up to €8/appliance in **Austria** (Capitol 09 2008).

In the **Czech Republic**, there is a strong trend among consumers towards improper disposal of household refrigerators/freezers. The pirating of compressors and other refrigerator parts is one factor that reduces proper recycling. Effective enforcement is needed, according the Czech Ministry of the Environment. Additionally, the Ministry estimates indicate that the recovery rate for ODS foams is even lower than ODS refrigerant, likely because foam recovery is a more arduous process, and, for producers, this drives up costs. (ICF 2008b)

According to ICF (2008b), an estimated 5% of refrigerators/freezers in Germany are landfilled at EOL, or otherwise illegally disposed of, while over 80% of ODS refrigerant and foam is properly recovered from appliances collected through the national recycling program (ICF 2008b). More recent information from the government of Germany indicates that refrigerators/freezers are not disposed of without proper pre-treatment (German Federal Environment Agency 2010).

An appliance recycling company in the **UK** reported that they struggle to recover 50% of CFC from domestic refrigerators and freezers, given that so many units arrive at recycling facilities in poor condition, with little refrigerant charge remaining. They report that HFC recovery rates are even lower than for CFCs (ICF 2008a).[18] However, DEFRA[19] estimates that in the UK more than 90% of EOL refrigerators are sent to refrigerator recyclers, while the other 10% are most likely illegally exported, disassembled, or landfilled. One of the challenges associated with appliance collection/recycling in the UK is that many refrigerators arrive at recycling facilities in poor condition, with no tubing, broken walls, or missing components; thus the opportunity to recover ODS at recycling facilities is diminished. In addition, doors are often removed from refrigerators during the demanufacture process, for safety reasons; these doors may sometimes be diverted directly to scrap metal recyclers, resulting in possible ODS release from unenclosed door shredding. This release of ODS can be prevented by ensuring that the doors are sent to shredders with built-in ODS recovery mechanisms. (ICF 2008b)

Vehicles

ODS/F-gas recovery practices from vehicles were reported by industry associations and ICF (2008b). A summary of these practices in across Member States, in Germany, and in the UK is provided below.

Recovery of ODS/HFCs from old motor vehicles at EOL may not be common practice among scrapyard workers, given the lack of economic incentive to do so (due to the small quantities recoverable weighed against the cost for recovery equipment and labour time). According to the **UK** Motor Vehicle Dismantlers Association (MVDA), it is possible that technicians involved in motor vehicle disposal are not fully collecting refrigerant and other hazardous waste for which there is a disposal charge. Furthermore, there is generally no organized collection system in place to ensure the proper recovery of refrigerant from MVACs. In **Germany**, for instance, there are no specific regulations or organized collection systems in place for MVACs, and owners of MVACs must pay the cost of disposing CFC. (ICF 2008b)

While the **UK** Retail Motor Industry Federation did not comment on actual recovery practices from MVACs in the field, they noted that vehicles over 10-12 years old typically do not contain refrigerant by the time they reach EOL, due to collisions and the fact that old AC system tend to not be maintained (RMIF 2009). The UK Retail Motor Industry Federation estimated that only 50% of the original MVAC charge is intact by the time the unit reaches EOL. According to the UK Motor Cabin Air Conditioning Committee (MCACC), the recovery of HFC-134a from the vehicle dismantling/salvage sector is currently low, but will likely increase in the future with improved technology and reduced leak rates from equipment. (ICF 2008a)

3.5.3 Foam End-Uses

The recovery of foams from domestic appliances, some small commercial equipment, and vehicles is required. However, actual recovery levels vary among Member States. The remainder of this section describes known foam recovery practices from appliances and commercial refrigeration systems and construction/demolition.

[18] This recycling company noted that estimates of F-gas recovery are difficult to obtain because the rate of recovery remains unknown, and has historically not been monitored (in the UK).

[19] The United Kingdom's Department for Environment, Food, and Rural Affairs (DEFRA) is the policymaking department that has jurisdiction over ODS and works directly with the EU on European environmental policy.

PU Foam in Domestic Appliances and Commercial Refrigeration Systems

Industry associations and experts provided information regarding recovery practices for PU foam in domestic appliances and commercial refrigeration systems. These practices are summarized below.

According to RAL (2008), "Many domestic waste incinerators struggle to handle polyurethane (PU) foams, because the low density of these ODS-containing foams leads to insufficiently long residence times in the incinerator's combustion chamber." (RAL 2008)

According to EU industry sources, domestic refrigerator and freezer cabinets are usually shredded after the compressor is removed and copper is recovered, etc.

While Regulation (EC) 1005/2009 and WEEE require the recovery and destruction of foams from certain types of commercial equipment, the level of compliance is questionable. Overall, there is not believed to be much experience with foam removal/disposal from commercial refrigeration equipment.

Construction and Demolition (C&D)

Foam is not typically separated from other materials and recovered at EOL; it may either be landfilled or—in Member States where foam is considered a hazardous waste— destroyed in a hazardous waste incinerator (since organic hazardous substances are prohibited from being landfilled).

Since buildings/storages are relatively easily dismantled, both continuous and discontinuous panels can be technically recovered either for re-use to clad another building/storage or for destruction. In many cases, thermal destruction is often the most cost-effective treatment at EOL (EFCTC 2009). According to a 1999 report by the Symonds Group, cross-contamination and mixing of materials was frequently observed on construction and demolitions sites, which is a concern especially when the mixing includes hazardous materials. Control of such hazardous waste should be easier on construction than on demolition sites, and on larger rather than smaller areas (Symonds Group 1999). However, physically separating the material at EOL and ensuring proper disposal presents a significant challenge. Moreover, in many cases, the type of blowing agent in the insulating foam is not discernable (EFCTC 2009). Recovery for reclamation is not viewed by industry as a realistic option; incineration is considered the most cost-effective solution (EFCTC 2009). That said, actual recovery of foams at EOL is not generally practiced in the EU-27; there is little practical experience or learning with regards to foam recovery from construction demolition. Overall, the level of recycling and re-use of C&D waste varies greatly—between 5% and 90% across the Union (EC website).

In **Austria**, the disposal of large volumes of foam insulation in landfills is prohibited (RMA 2005).

In **Germany**, due to the landfill ban for materials with more than 5% loss on ignition (LOI), rigid PUR/PIR foam demolition waste is usually separated with other insulation, plastic materials, wood, metal, glass, and other materials. The insulation is then forwarded to incineration plants for energy recovery. There are no significant known recycling activities in Germany for PUR/PIR material from demolition activities, apart from small quantities in exceptional cases, such as for research purposes. (BING 2008)

In the **UK**, PUR/PIR waste is partly collected mixed together with mineral and other materials, and typically sent to landfills. A small share (e.g., <20%) of foam demolition waste is sent for incineration/energy recovery. The recycling of PUR/PIR is primarily in the "research phase," focused on flexible foams. No significant recycling quantities from demolition waste have been identified. There are several reported cases of undamaged PUR/PIR boards, such as well-preserved sandwich boards that are being re-used on-site. (BING 2008)

Similarly, in **France**, rigid PUR/PIR foam material from demolition waste is partly collected, mixed together with mineral and other materials, and typically disposed of in landfills. Due to costs, quantities sent for incineration/energy recovery are still on a low level, with incineration plants concentrating more on pre-sorted household waste, due to environmental concerns. There are no known significant recycling activities for demolition wastes. (BING 2008)

Overall, several barriers prevent significant recycling of PUR/PIR waste from demolition activities in Europe. Contamination of the PUR/PIR waste material with other substances or construction materials (e.g., bitumen, glue, stone or other non-PUR/PIR insulation materials) is problematic, since recycling companies generally prefer "pure" (non-contaminated) waste materials Moreover, inspection, pre-sorting, cleaning of materials, and the removal of foreign matter requires a high effort on the part of recyclers. Also, given the low quantities of construction foam waste as a percent of overall demolition waste (estimated at 0.5%-3%), there are logistical barriers associated with its collection and separation (BING 2008).

3.5.4 Fire Sector

According to ASSURE (2009), the ODS gases used in fire protection have been removed from general use (as required) and recycled for critical uses or destroyed. Any remaining halon is therefore installed in critical use applications, or being held in storage for future use in such applications.

There are established routes in the fire sector for destroying material at equipment the EOL. Moreover, F-gases are valuable materials and are easily recycled for reuse, which encourages recovery and recycling. Current commercial and environmental concerns are sufficient to encourage recovery and recycling at EOL. Recovery is never undertaken on a user's site; all containers are generally returned to the original equipment manufacture's specialist filling facility. Very little recovered fire extinguishing agents are reclaimed, as the materials are generally pure at EOL so can be recycling. Any material that is contaminated or possibly mixed is most likely to be sent for destruction. (ASSURE 2009)

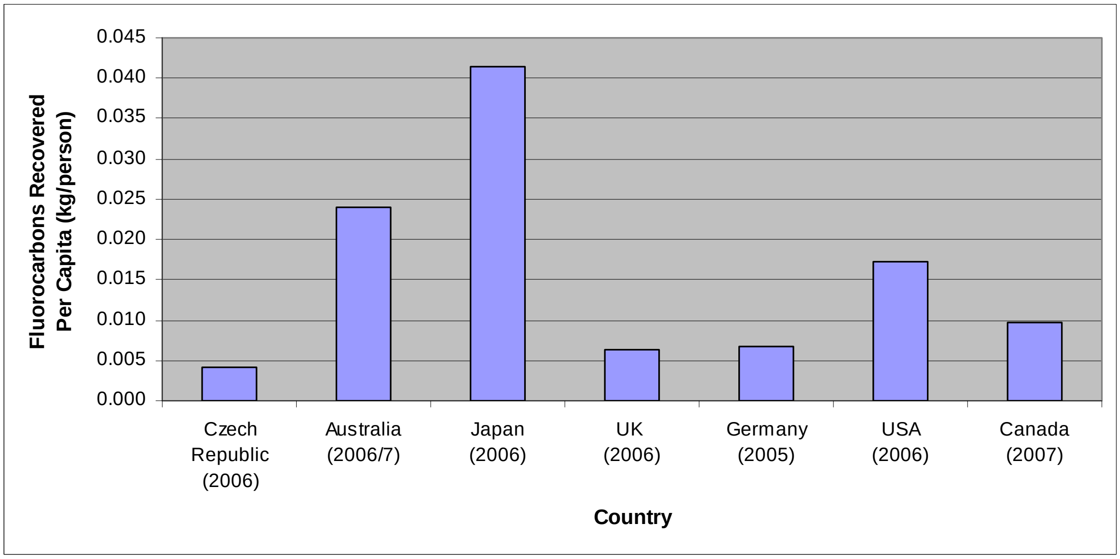
3.6 Non-EU Countries Recovery Practices

Recovery practices regarding bulk ODS/F-gases, and ODS/F-gases in domestic refrigerators and freezers, small stationary AC, and vehicles were obtained through ICF (2008b). Practices in Australia, Canada, Japan, and the United States are summarized below.

3.6.1 Bulk ODS/F-gases

Figure 2 from ICF (2008b) presents *available* data on fluorocarbon recovery for destruction/ reclamation by country and year. It should be emphasized that the data shown are not parallel across countries: data from the three EU countries represent ODS/HFC refrigerant and foam recovered from domestic appliances; data from Australia represent ODS/HFC refrigerant collected in bulk, largely from the commercial sector; data from Canada represent ODS refrigerant collected in bulk, largely from the commercial sector; data from Japan represent ODS/HFC refrigerant and foam collected from the appliance, commercial, and MAC sectors; and data from the United States represent all types of domestic ODS reclaimed and destroyed at US facilities (i.e., may include refrigerant, foams, or solvents).

Figure 2: Annual Fluorocarbons Recovered Per Capita in Selected Countries (ICF 2008b)[a]



[a] Data shown are not parallel across countries: data from the Czech Republic, UK, and Germany represent ODS/HFC refrigerant and foam recovered from domestic appliances; data from Australia represent ODS/HFC refrigerant collected in bulk, largely from the commercial sector; data from Canada represent ODS refrigerant collected in bulk, from the commercial sector; data from Japan represent ODS/HFC refrigerant and foam collected from the residential appliance/AC, commercial, and MAC sectors; and data from the United States represent all types of domestic ODS reclaimed and destroyed at US facilities (i.e., may include refrigerant, foams, or solvents).

Australia and **Canada** have implemented programs to facilitate ODS destruction by removing the financial burden from end-users. Specifically, Australia and Canada have industry-run programs that collect and destroy bulk ODS. Both programs are funded by levies placed on the production/import of virgin/reclaimed ODS, but these programs differ in several important aspects: Australia's program is mandated by law, whereas the scheme in Canada is a voluntary industry initiative[20] (although a full 95% of the commercial stationary refrigeration/AC industry participates); Australia's program provides a rebate on the return of used refrigerant, whereas Canada's program simply allows technicians to return it at no cost; and Australia's program applies to all fluorocarbon refrigerants (including HFCs), while Canada's program applies exclusively to ODS refrigerants (i.e., CFCs and HCFCs) (ICF 2008b).

3.6.2 Domestic Refrigerator/Freezers and Small Stationary AC

In **Japan**, retailers (of which there are roughly 74,000) are required to take back old units from consumers and transport them to one of 380 designated appliance collection sites. At time of disposal, consumers pay a fee that covers collection, transport, and recycling – which costs approximately US$40 for a refrigerator and US$30 for an AC unit. Recycling receipts are issued which allow consumers to track the fate of their old unit, as well as the government to ensure program compliance and success. With funding from consumer fees, the Association for Electric Home Appliances (AEHA) serves as the "Designated Agent" responsible for managing the recycling of appliances produced by unknown manufacturers or ones that are no longer in business. There are 24 refrigerator/freezer recycling facilities and 37 AC recycling facilities in Japan. In 2006, over 1,000 metric tons of refrigerant were collected

[20] The Canadian Federal Government supports the Extended Producer Responsibility scheme but it does not mandate it. However, voluntary industry participation is a key element of the Canadian Council of Environment Minister's (CCME's) CFC and Halon Disposal Strategy, which Environment Canada has been working on with the provinces and territories.

from AC units, while roughly 300 metric tons were collected from refrigerators/freezers. A further 600 metric tons of fluorocarbons was recovered from foams contained in refrigerators/freezers—excluding amounts recovered using the direct decomposition method, for which no data are available. Thus, in total, nearly 2,000 metric tons of fluorocarbons were recovered from domestic appliances in Japan in 2006 (ICF 2008b)

3.6.3 Vehicles

Recovery practices in Japan, and the United States were reported in ICF (2008b). These practices are summarized below.

Japan has implemented a systematic process for refrigerant recovery from MACs based on a comprehensive producer responsibility program in place for motor vehicles. Specifically, the Japan Auto Recycling Partnership (JARP) was established by the auto industry to comply with Japanese requirements that vehicle parts be recycled and that fluorocarbons be recovered at vehicle end-of-life (EOL). Under the program, vehicle owners are responsible for returning cars to dealerships and shops that are registered as EOL handling firms. The EOL handling firms transfer the vehicles to registered recovery operators, of which there are approximately 24,000 nationwide, who remove the refrigerant and send it to one of eight destruction centres. Recovery operators must report annually to the Japan Automobile Recycling Promotion Center's Information Management Institution on the amounts and types of fluorocarbons recovered. They are paid by JARP based on the number of MACs from which refrigerant is recovered; they are not paid if they recover less than 270 g of refrigerant per system. The operating costs of Japan's vehicle producer responsibility scheme are funded through consumer fees placed on new vehicles at time of purchase (which ranges from US$60 to US$160, depending on vehicle type). For vehicles purchased before 2005, the fee is paid at time of vehicle re-inspection/registration or at EOL—whichever occurs first. (ICF 2008b)

In the **United States**, although there is no data on actual refrigerant recovery from MACs at service or disposal, refrigerant recovery from MACs is believed to be common practice. From an economic standpoint, it is cost-effective to recover and recycle/reuse (non-contaminated) refrigerant from MACs at service. At disposal, used refrigerant can be collected for reclamation, which can be quite profitable—especially CFC-12. There is no financial incentive, however, to destroy contaminated or unwanted refrigerant from MACs. (ICF 2008b)

3.7 EU Destruction Capabilities and Destruction Costs

This section summarises available data on destruction facilities operating in the EU-27, as well as their capacities to destroy ODS/F-gases, the technologies used, and the associated costs. To develop this information, known destruction facilities in the EU were contacted via phone to confirm operation, determine capacity and destruction costs, and determine willingness to accept materials for destruction from new customers. Specifically, an initial list of 66 facilities was developed based on previous EC studies,[21] information submitted by Member States under regulation 2037/2000, and additional information submitted by Member State representatives;[22] these various lists were aggregated and then refined based on information collected through telephone inquiries, or expanded upon based on new information provided by industry sources. In many cases, facilities identified in reports or by Member State representatives were found to perform refrigerant and/or foam recovery, not destruction *per se*. Similarly, in other cases, facilities were operating technologies capable of destroying ODS, but were not actively accepting ODS (or HFCs) for commercial destruction.

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[21] Previous studies used to generate the list of facilities to contact include ICF International (2008a, 2008b).

[22] Member State representatives also submitted information on reclamation facilities. A list of reclamation facilities can be found in Appendix C.

Of the initial 66 facilities identified, 63 were successfully contacted,[23] and 24 confirmed that they perform destruction. Two additional facilities were confirmed to destroy ODS/F-gases by an industry association and Member State representative. One facility was found to have previously destroyed ODS/F-gases in a pilot facility, but the pilot facility is no longer in operation.[24] An additional two facilities confirmed that they perform destruction, but for non-commercial (internal) purposes. This information is summarised in Table 7. Appendix C provides contact information for all confirmed destruction facilities.

Table 7: Summary of Facilities Contacted

Facility Status	Number of Facilities
Starting Number	66
New facilities added	2
Confirmed to Perform Destruction	25
Confirmed Not to Perform Destruction	33[a]
Confirmed Non-Commercial Destruction	2
Unconfirmed	8[b]

[a] One company, ScanArc Plasma Technologies AB, previously operated a pilot facility in Sweden with capacity of 100 tonnes per year; however, the pilot phase is complete and the facility is no longer operational due to insufficient demand. The company would consider new business opportunities.

[b] Of the companies that could not be confirmed, , three had no contact information available, three were due to language barriers, and two were due to a lack of response by phone or email.

About half of the commercial destruction facilities contacted specified they are willing to accept materials from new customers. Of those facilities accepting new sources of ODS/F-gas waste, the majority preferred long-term business as opposed to short-term business or one-time jobs. Table 8 presents destruction facilities by Member State.[25] The locations of these facilities are shown graphically in Figure 3.

Table 8. Commercial Destruction Facilities and Facilities Possibly Performing Destruction by Member State

Member State	Facility
Commercial Destruction Facilities	
Austria	Fernwärme Wien GmbH – EBS
Belgium	Indaver Poldervlietweg
Czech Republic	SPOVO A/S
Denmark	Kommunekemi A/S
	Odense Kraftvarmevaerk
Finland	Ekokem Oy Ab
France	SIAP
	Tredi-Groupe Séché
Germany	CURRENTA GmbH & Co. OHG
	HIM GmbH

[23] Contact information could not be found for the remaining three facilities, or they are simply no longer in operation. A list of confirmed commercial destruction facilities can be found in Appendix D.

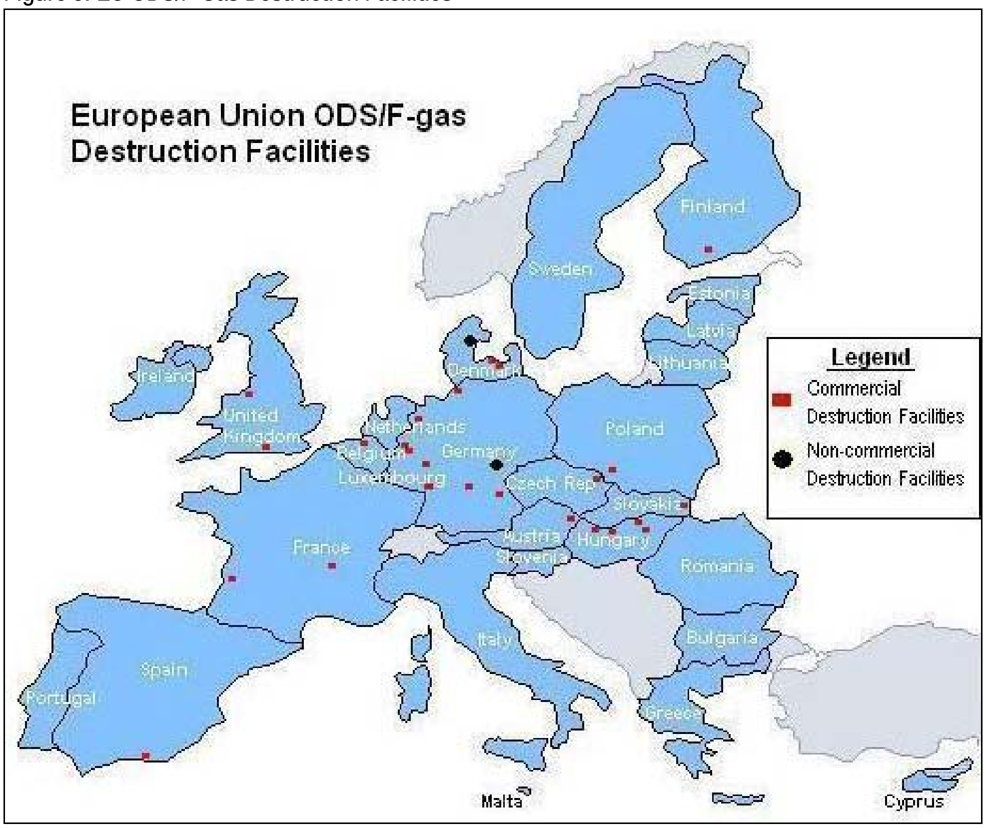
[24] The Scan Arc Plasma Technologies AB pilot facility (SE) was recently closed as the pilot phase has concluded. Originally Scan Arc planned to commercialize the plasma arc technology from their pilot plant to a full sized plant; however, as the market for ODS/F-gas destruction has declined in Sweden, a hold has been put on establishing full-sized plants. Scan Arc is preparing to conduct a market review to determine the feasibility of constructing full-sized destruction facilities using plasma arc technology in Sweden. Scan Arc may also interested in establishing full-sized facilities outside of Sweden if collaboration with external partners is possible.

[25] Commercial destruction facilities accept bulk ODS/F-gases from outside sources, while non-commercial destruction facilities do not accept outside sources of bulk ODS/F-gases for the purpose of destruction.

Member State	Facility
	GSB – Sonderabfall-Entsorgung Bayern GmbH
	Pfahler Müllabfuhr GmbH
	REMONDIS Industrie Service GmbH
	REMONDIS SAVA GmbH
	REMONDIS TRV GmbH & Co. KG
	Solvay Fluor (ODS/F-gas collected by RCN Chemie GmbH)
Hungary	Ecomissio Kft.
	Észak-Magyarországi Környezetvédelmi Kft.
	Győri Hulladékégető Kft. (Waste Incinerator Ltd, Győr)
	SARPI Dorog Environmental, Limited (previously ONYX Magyarország)
Poland	SARPI Dabrowa Gornicza Sp. z.o.o.
Spain	Kimikal S.L
Slovakia	Fecupral, Ltd. spol sro
UK	Pyros Environmental Ltd
	Veolia
Non-Commercial Destruction Facilities	
Denmark	Uniscrap A/S[a]
Germany	Deuna Zement GmbH

[a] Uniscrap A/S is a facility that demanufactures appliances and destroys refrigerants onsite; however, they do not accept bulk ODS/F-gases from outside sources for the purpose of destruction (Uniscrap 2009).

Figure 3: EU ODS/F-Gas Destruction Facilities[a]



As shown above, destruction facilities do not exist in all Member States; only 11 of the 27 Member States (41%) are known to have operational commercial destruction facilities that accept bulk ODS/F-gases. That said, it is not efficient or necessary to have destruction facilities in every country. According to several Member State and industry representatives, existing infrastructure is believed to be sufficient to satisfy demand, as current facilities generally are not running at full capacity (see section below for more detail). Moreover, many refrigerant manufacturing companies have sister facilities in neighbouring countries to which they send ODS/F-gases for destruction. Finally, the construction of additional facilities is not desirable, particularly in densely populated countries, given that residents are opposed to having incinerators and other types of destruction technologies in their vicinity. It should be noted that a significant number of reclamation facilities also exist across the EU, which may deal with used ODS/F-gases. Appendix D presents contact information for known reclamation facilities in the EU-27.

3.7.1 Destruction Capacity

Fourteen of the known commercial destruction facilities provided information on their estimated ODS/F-gas destruction capacity. Combined, these facilities reported an estimated ODS/F-gas destruction capacity of approximately 130,000 tonnes (t) per year. The estimated ODS/F-gas destruction capacity of individual destruction facilities, as reported by company representatives contacted for this study, ranged from 20 t per year (Hungary) to 66,667 t per year (UK). As shown in Table 9, the median estimated ODS/F-gas destruction capacity of the 14 facilities is approximately 1,300 t, with the average being approximately 9,350 t. It should be noted that it is possible that estimated ODS destruction capacity at the lower end of this range may be explained by insufficient throughout of other materials being destroyed, as ODS capacity is dependent on overall destruction capacity in order to limit amounts of chlorine, fluorine, and bromine to control air emissions and limit corrosion (e.g., 1% of overall waste capacity can be ODS). Based on the average and median values, ODS/F-gas destruction capacity across the whole EU-27 is estimated to be between approximately 145,000 t and 225,000 t. Based on bottom-up estimates generated for this report (see Table 18), this capacity is more than sufficient to handle the quantities of ODS/F-gases projected to be recoverable at EOL from the refrigeration/AC and foam sectors across the EU-27, which are not expected to exceed 50,000 t through 2050. However, while capacity is believed to be sufficient in the EU, the uneven distribution of destruction facilities may pose problems in areas where no facilities are available. This may be particularly problematic if ODS containing wastes must be transported over large distances (e.g., >1,000 km), such that transportation and labour costs may become prohibitive. For example, the labour cost to transport an ODS shipment a distance of 1,000 km would cost approximately €2,000, assuming an hourly (fully-loaded)[26] labour charge of €100,[27] and a travel speed of 50 km/hour.

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[26] This cost is assumed to cover employee wage plus fringe benefits, insurance, overhead, and profit.

[27] Labor charges are based loosely on labor wage rates for employees in the manufacturing and private services sectors in the EU, which ranged from roughly €25 to €30 in the western EU countries; however, labor rates were "substantially lower" for southern EU Member States (particularly Spain, Greece and Portugal) and Member States that joined the EU after May 2004 (Eurofound, 2006).

Table 9. Estimated ODS/F-gas Destruction Capacity (t) of Commercial Destruction Facilities by Member State

Member State	Company Name	Estimated Destruction Capacity for ODS and F-Gases (tonnes/year)[a]
Czech Republic	SPOVO A/S	40
Denmark	Kommunekemi A/S	5,000
Finland	Ekokem Oy Ab	10,000
Germany	Currenta GmbH&Co. OHG	4,000
	GSB GmbH	1,000
	HIM GmbH	1,000
	REMONDIS Industrie Service GmbH	400
	REMONDIS SAVA GmbH	800
	REMONDIS TRV GmbH & Co. KG	800
	Solvay Fluor	1,600[b]
Hungary	Észak-Magyarországi Környezetvédelmi Kft.	19,600[c]
	SARPI Dorog Environmental, Limited (previously ONYX Magyarország)	20
UK	Pyros Environmental Ltd	20,000
	Veolia	66,667
TOTAL		130,927
Median		1,300
Average		9,352

[a] Total destruction capacity by facility is greater than the quantities listed here, which reflect annual destruction capacities strictly for ODS and F-gases.
[b] The Solvay facility uses a gas conversion process, whereby ODS is cracked with hydrogen and oxygen in the process of making fluorinated products (ICF 2008b).
[c] For halon, capacity is only 10 tonnes per year.

In addition to the ODS destruction capacities listed in Table 9, destruction capacity estimates are available for four other facilities in Hungary, Poland, and Slovakia; however, it was not possible to confirm whether such capacities are specific to ODS/F-gases, or whether they refer more broadly to facilities' overall destruction capacity. These destruction capacity estimates are listed in Table 10.

Table 10. Unconfirmed Destruction Capacity (t) of Commercial Facilities

Member State	Company Name	Estimated Destruction Capacity (tonnes/year)[a]
Hungary	Ecomissio Kft.	15,320
	Gyõri Hulladékégetõ Kft. (Waste Incinerator Ltd, Gyõr)	8,000
Poland	SARPI Dabrowa Gornicza Sp. z.o.o.	30,000
Slovakia	Fecupral, Ltd. spol sro	1,310

[a] Additional research is needed to confirm whether the estimated destruction capacities refer strictly to annual capacities for ODS/F-gases, or more broadly to other materials destroyed at the facilities each year.

3.7.2 Destruction Technologies

According to IPCC/TEAP (2005), reactor cracking is the most common commercial process for the destruction of fluorocarbons in Europe, which has a destruction efficiency of 99.999%. In France and Germany, it is reported that reactor cracking technologies operate at a capacity of 200 kg fluorocarbons per hour (TEAP 2005). Of the commercial destruction facilities confirmed in this study, only 14 facilities were willing to provide information on the types of destruction technologies in operation. Based on this information, the destruction technologies in use include high temperature incineration in rotary kilns and gas conversion systems. Table 11 presents the known destruction technologies by facility.

Table 11. Known Destruction Technologies used in Commercial Destruction Facilities by Member State

Member State	Facility	High Temperature Incineration	Gas Conversion
Austria	Fernwärme Wien GmbH – EBS	✓	
Denmark	Kommunekemi A/S	✓	
	Odense Kraftvarmevaerk	✓	
Germany	REMONDIS Industrie Service GmbH	✓	
	REMONDIS SAVA GmbH	✓	
	REMONDIS TRV GmbH & Co. KG	✓	
	Solvay Fluor (ODS/F-gas collected by RCN Chemie GmbH)		✓
Hungary	Ecomissio Kft.	✓	
	Észak-Magyarországi Környezetvédelmi Kft.	✓	
	Gyõri Hulladékégetõ Kft. (Waste Incinerator Ltd, Gyõr)	✓	
	SARPI Dorog Environmental, Limited (previously ONYX Magyarország)	✓	
Slovakia	Fecupral, Ltd. spol sro	✓	
Spain	Kimikal S.L	✓	
UK	Pyros Environmental Ltd	✓	
	Veolia	✓	

3.7.3 Destruction Costs

Based on input from destruction facilities and industry associations contacted, the price charged to customers for ODS/F-gas destruction in EU Member States varies depending on a variety of factors, including gas type, volume, and whether or not the customer is long-term or short-term.[28] However, although costs vary depending on many different factors, costs of destruction are relatively uniform across all applications, and are not primarily substance-driven (i.e., CFC/HCFC/HFCs) (TEAP 2009a). The cost of destruction generally ranges from €1.00- €10.00 per kg of bulk ODS/F-gases in the EU (EFCTC 2009).[29] Long-term customers sending large quantities of ODS/F-gases on a regular basis will generally be charged less—between €1.00 and €3.40 per kilogram, with a median price of €2.20/kg. The majority of facilities do not provide recovery/collection services, and will only accept bulk ODS/F-gases contained in cylinders or tanks. Additionally, transportation services are not typically provided by the destruction facility for bulk ODS/F-gases. Transportation costs in the EU are estimated to be €0.10 per tonne per kilometre.[30]

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[28] Commercial destruction facilities and industry associations that provided cost information include: EFCTC (2009), REMONDIS Industrie Service GmbH (DE), REMONDIS SAVA GmbH (DE), REMONDIS TRV GmbH & Co. KG (DE), and SARPI Dorog Environmental, Limited (HU).

[29] This is inline with other available international estimates. For example, the Task Force on Destruction Technologies (2002) cited costs for CFCs in the range of US$ 3-5/kg (€2.15- €3.55/kg), and for halons in excess of US$7/kg (€5/kg) because of the need for slower throughput. In the intervening period, TEAP (2009a) notes that prices for (unverified) CFC destruction has dropped significantly and prices as low as US$1.00-$1.50/kg (€0.70- €1.05/kg) have been reported from some sources.

[30] According to TEAP (2009a), for pre-concentrated shipments of ODS, shipping costs may be as low as US $0.12-$0.15 per tonne/km. For condensed hazardous waste cargos, such as metal tubes, oil products and electrical equipment, the cost of shipment is roughly €0.05-€0.15 per tonne/km. For general waste streams, the figure is in the order of €0.04-€0.06 per tonne/km (TEAP, 2009).

4 Assessing Technical and Economic Feasibility of ODS Recovery from Banks

This section reviews the technical and economic feasibility of recovering ODS and F-gases from equipment and products at end-of-life (EOL). Specifically, the discussion on *technical feasibility* focuses on the types of tools and technologies commercially available to recover/destroy ODS contained in appliances, construction foam, and large refrigeration/AC equipment. For equipment and products from which recovery is deemed technically feasible, *economic feasibility* is assessed based on the monetary costs associated with the processes and technologies required to perform recovery/destruction.

4.1 Technical Feasibility

Technical feasibility refers to the ability to recover ODS/HFCs from the products/equipment in which they are contained at a reasonable level of effort and cost. To assess technical feasibility by end-use, this analysis reviews the following:

- Quantity of ODS/HFCs remaining in equipment/products at EOL, considering the percent of original charge lost over the equipment/products' lifetime.
- Amount of remaining ODS/HFCs that is technically recoverable, considering inadvertent losses during recovery/separation and transport, based on available technologies and best practices

According to TEAP (2009a, b), Table 12 presents the level of effort required for ODS recovery by end-use.[31] As shown, all but certain types of foam applications are recoverable with low to medium-effort.

Table 12: Effort Required to Manage ODS Banks (TEAP 2009a, b)

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

[31] The levels of effort required to manage specific sectoral banks is relatively homogeneous around the world and across gas types (i.e., ODS and F-gases).

The remainder of this section explores the actual technologies and practices in use to recover ODS/HFCs in the EU-27 across the different sectors and end-uses, to develop independent feasibility estimates. In this analysis, feasibility is based on consideration of the amount of refrigerant or blowing agent remaining at end-of-life, as well as the feasibility of recovering/separating that refrigerant/blowing agent.

It should be noted that, while this report reviews technical feasibility within the context of current EU technologies in use and market conditions at play, technical feasibility will change over time, in response to technological improvements and economic drivers. In particular, ODS/HFCs contained in products/equipment that are now very difficult to segregate, recover and destroy may not be so in future due to technological improvements, which are likely to emerge if the demand for recovery grows from an ozone and climate policy perspective. Similarly, even relatively impractical methods of recovery—such as manual separation of foam—can become viable options if financial benefits (e.g., carbon credits) of recovery are sufficient to support the effort required (TEAP 2009a, b).

4.1.1 Refrigerant from Refrigeration/AC Equipment

Technologies for refrigerant recovery are widely used across the EU, in compliance with Regulation (EC) No 1005/2009. Various models of recovery devices are available to evacuate fluorocarbon refrigerants from all types of refrigeration/AC equipment; thus, there are no technical barriers to the recovery of refrigerant from any types of refrigeration/AC equipment. Recovery devices essentially pump the fluorocarbon refrigerants out of equipment and through an elementary cleaning mechanism that removes contaminants such as moisture, oil, and other particles. The evacuated fluorocarbons are then transferred to recovery tanks in which they can be stored or shipped to a final location (e.g., a reclamation or destruction facility).

Evacuated refrigerant that is sent for reclamation must be reprocessed in order to meet a specific standard of performance. Typically, refrigerant is sent for reclamation in small capacity cylinders (of 10-60 kg). (EFCTC 2009) During reclamation, the recovered refrigerant is passed through a series of filters and dryers in a large-scale distillation unit in order to remove remaining particulates, and is then laboratory tested to ensure it meets the necessary purity standard. The material is reprocessed until the standard is achieved.

Contaminated (unusable) or unwanted refrigerant can be destroyed using a number of commercially available destruction technologies. The destruction technologies most commonly used to destroy fluorocarbons in Europe are discussed in greater detail in Section 3.7.

To assess the recovery potential of refrigerant from refrigeration/AC equipment at EOL, a number of factors were considered, as presented in Table 13. To estimate the percent of refrigerant remaining at EOL, the percent of original refrigerant charge remaining in equipment at time of disposal and the percent of refrigerant technically recoverable at EOL were estimated by equipment type based on quantitative information or, in cases where no data were available, consideration was given to lifetime leak and service rates (see Appendix A for details). EU-15 countries are assumed to be able to achieve slightly higher recovery levels than EU-12 countries as a result of improved recovery technologies/processes believed to be in place. The percent of refrigerant potentially recoverable at EOL was calculated by multiplying these two factors, the results of which are presented in Table 13

Table 13: Recovery Potential from Refrigeration/AC Equipment

Sub-Sector	End-Use	Refrigerant Remaining at EOL		Refrigerant Technically Recover-able at EOL	Total Potentially Recovered at EOL		Total Charge Recoverable at EOL per Unit (kg)			
		EU-15	EU-12		EU-15	EU-12	ODS		HFC	
							EU-15	EU-12	EU-15	EU-12
Mobile AC	Passenger Cars	60% [a]	50%	90%	54%	45%	0.5	0.4	0.4	0.3
	Buses	60% [a]	50%	90%	54%	45%	3.8	3.2	2.4	2.0
Refrig-eration	Domestic Refrigerators & Freezers	NA[b]		90%	NA		0.06- 0.13[c]		0.05- 0.12[d]	
	Small Commercial	90%	80%	90%	81%	72%	2.4	2.2	1.6	1.4
	Medium/ Large Commercial	70%	60%	95%	67%	57%	199.5	171.0	169.6	145.4
	Refrigerated Transport—Land	70%[e]	60%	90%	63%	54%	3.2	2.7	2.8	2.4
	Refrigerated Transport—Ships	60%	50%	95%	57%	48%	1140.0	950.0	855.0	712.5
	Industrial Refrigeration	60%	50%	95%	57%	48%	570.0	475.0	485.0	404.0
Stationary AC	Small Stationary	90%	80%	90%	81%	72%	2.8	2.5	2.4	2.2
	Large Stationary (Chillers)	80%	70%	95%	76%	67%	190.0	166.3	159.6	139.7

[a] Based on EC (2003), which estimates that EOL refrigerant charge in MVACs in EU-15 is approximately 57% of original charge.
[b] For domestic refrigerators and freezers, assumptions on refrigerant remaining at EOL are based on absolute values based DUH (2007) and consideration of other sources (ICF 2008b; RAL 2007a, 2007b); they are not based on an assumed percentage of original charge. The quantity of charge assumed to remain in CFC-systems at EOL is 0.145 kg/unit in Sweden and Finland, 0.127 kg/unit in other EU-15 countries, and 0.065 kg/unit in EU-12 countries; the quantity of charge assumed to remain in HFC-systems at EOL is 0.13 kg/unit in Sweden and Finland, 0.11 kg/unit in other EU-15 countries, and 0.06 kg/unit in EU-12 countries.
[c] For domestic refrigerators and freezers, the total charge potentially recovered at EOL for CFC-systems is 0.13 kg/unit in Sweden and Finland, 0.11 kg/unit in other EU-15 countries, and 0.06 kg/unit in EU-12 countries.
[d] For domestic refrigerators and freezers, the total charge potentially recovered at EOL for HFC-systems is 0.12 kg/unit in Sweden and Finland, 0.10 kg/unit for other EU-15 countries, and 0.05 kg/unit in EU-12 countries (DUH 2007; RAL 2007a, 2007b; ICF 2008b).
[e] According to CARB (2008), it is estimated that 70% of the original charge of modern shipping containers is intact at decommissioning.

As presented above, between 45% and 81% of original equipment charge is estimated to be recoverable at EOL from refrigeration/AC equipment, depending on equipment type and region. Refrigerant recovery from mobile AC from passenger cars is estimated to result in the lowest potential for recovery, given the low levels of refrigerant generally remaining at EOL and the small original charge size; however, given the low level of effort required to perform recovery from passenger car mobile ACs, feasibility to recover is still deemed to be high.

4.1.2 Appliance Foam

Per Regulation (EC) No 1005/2009, the recovery of ODS foam from all refrigerated appliances is required, and thus, technologies for foam removal have been developed and are widely used across the EU. Large appliance recycling facilities in the EU typically have full mechanical recovery plants that utilise large shredders with built-in foam recovery systems to separate and capture foam blowing agent from the shredded metal. In these foam recovery systems, equipment is shredded using a rotor knife or granulator, while air-separation is used to separate the ODS blowing agent and foam "fluff" from the shredded metals (Adelmann 2009). Alternatively, foam insulation can be removed manually, once the appliance is cut open (e.g., using automated saws). Some facilities use a hybrid approach of manual separation of the foam prior to mechanical separation of the blowing agent from the foam fluff (TEAP 2009a).

Foam insulation can be directly destroyed (e.g., in an incinerator), or processed further to separate the blowing agent for reclamation purposes. It is assumed that direct incineration of foam has the same recovery potential as shredding with recovery of blowing agent, because of similar front-end handling requirements (IPCC/TEAP 2005).

To assess the recovery potential of foam blowing agents from appliances at EOL, a number of factors were considered, as presented in Table 14. To estimate the percent of blowing agent remaining at EOL, lifetime emissions were considered, while the percent of blowing agent technically recoverable was based on consideration of losses due to foam separation and removal at EOL. The total percent potentially recoverable at EOL was calculated by multiplying these two factors, and is presented in Table 14.

Table 14: Appliance Foams Recovery Potential

End-Use	Blowing Agent Remaining at EOL[a]	Blowing Agent Technically Recoverable at EOL[b]	Total Potentially Recovered at EOL[c]
PU Rigid: Domestic Refrigerators/Freezers	92.5%	95%	87.9%
PU Rigid: Commercial Refrigeration	92.5%	85%	78.6%

[a] Calculated by multiplying estimated original charge size by lifetime emissions assumptions from IPCC (2006).
[b] Estimated based on assumptions of blowing agent losses from separation and removal at EOL.
[c] Calculated by multiplying charge remaining at EOL percent by blowing agent technically recoverable at EOL.

As presented above, the recovery potential for blowing agent from appliances at EOL from both domestic refrigerators/freezers and commercial refrigeration units is relatively high, at roughly 88% and 77%, respectively. Therefore, foam recovery from appliances is deemed to be technically feasible.

4.1.3 Construction Foam

The recovery of construction foam—including PU rigid sandwich panels, PU & PIR rigid boardstock (FFL), PU rigid spray foam, and XPS foam boards—during building retrofits or demolition is more difficult than foam removal from appliances, given the challenges associated with physically separating foam insulation from the rest of the demolished material. The ability to extract foam-containing elements from demolition waste depends largely on the original form of the foam and how it was applied. For example, PU spray foams are usually applied directly onto building walls and have natural adhesive properties. As such, the process of removal would be complex and time-intensive. Furthermore, it is possible that a portion (or all) of the ODS blowing agent contained in the foam insulation would be released during separation. These issues of complexity, time, and blowing agent loss were studied by the Japanese Technical Committee on Construction Materials (JTCCM) in 2005, which concluded that it was "not practical to mandate recovery based on observations concerning practicality and cost" (TEAP 2009a).

However, other types of construction foams may present greater opportunities for separation and recovery, such as steel-faced sandwich panels or PU boardstock, depending on the application and location of the material. In the EU, work in support of the Recast of Ozone Regulation (EC) No 2037/2000 investigated this issue concluded that the technical (and economic) feasibility of segregating ODS containing waste from buildings depended not only on the original building practices used within a specific country or region, but also the level of demolition waste segregation already required by national law (TEAP 2009a).

In addition, a number of existing or new technologies may be potentially available for the recovery of sandwich panel and boardstock foams from building insulation. Sandwich panels that have PUR/PIR insulation bonded to two facings can be manually removed and treated at recycling facilities that handle domestic/commercial refrigeration equipment (which also include PUR/PIR insulation bonded to two facings). However, because sandwich panels are typically longer, thicker, and more durable (because of their higher density foam and the thicker steel skins) than refrigerated appliance panels, recycling plants designed specifically for domestic refrigerators may have difficulty processing sandwich panels. In the UK, for example, most refrigerator recycling plants can only handle panels up to 2x1x1 meters (m) in size, while sandwich panels typically have a standard length of 1.8 -12 m, and modern roof panels can reach up to 20 m in length. Thus, in order for sandwich panels to be processed at appliance recycling facilities, they would need to be cut into more manageable pieces using band saws prior to shredding. Plants that are set up for recycle larger appliances, such as commercial refrigerators and freezers, would be better suited to handle these panels. In addition, it would be critical to handle the panels carefully during the cutting process, to minimize the liberation of blowing agent (Caleb 2009).

Another potential technology that could be developed to recover sandwich panels and/or boardstock foam from buildings may be "vacuum" technologies, which have been historically used to remove asbestos-containing insulation from buildings during demolition (National Demolition Association 2009). Such vacuums are designed with high efficiency particulate air-filtering (HEPA) capabilities and use high-powered suction to remove large volumes of asbestos material sprayed in bulk as insulation in buildings (as well as that deposited on the ground or in the soil). However, because rigid foam is very durable and is a natural adhesive, asbestos-removing vacuum technologies may have limited applicability for effective recovery of construction foam. Furthermore, in order to effectively recover ODS/HFC blowing agents from foam insulation, research and development would be necessary to develop an airtight system that prevents the release of any blowing agent during the vacuum removal process. Additionally, the removed material would then need to be incinerated.

Depending on the type of construction foam and the recovery process employed, it can either be recovered, directly destroyed (i.e., in a municipal solid waste [MSW] incinerator or waste-to-energy [WTE] boiler) or recycled. While the cost may be lowest for direct foam destruction without prior recovery, several important issues must be considered, including the location of the MSW or WTE facilities, regional or plant capacity issues, requisite throughput, and training requirements to ensure appropriate operating conditions (e.g., feed rates, temperatures, residence time) for safe destruction.

In terms of recycling, carefully recovered polystyrene foams can be melted and reprocessed through the application of heat, which means that reuse/recycling may be an option.[32] However, the economic feasibility of recycling polystyrene may be low given that polystyrene waste from demolition would likely be contaminated with other waste (e.g., soil, minerals, facing material, paint etc), which would require expensive separation and cleaning. Moreover, because polystyrene insulation is very low density, transport would be expensive in relation to any recovery value (Jones 2010).

Regarding polyurethane foam, the Spray Polyurethane Foam Alliance (SPFA) maintains that recycling is not feasible, as it cannot be melted or reprocessed after the initial heat-forming (SPFA 2009).[33] However, at least one company is known to be using shredded polyurethane foam waste to make boards as a replacement for wood materials, and another chemical recycling commercial venture is using thermal glycolysis of polyurethane waste to produce secondary raw materials (Jones 2010).

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[32] Polystyrene (e.g., XPS foam boards) is a "thermoplastic" substance that softens when heated and hardens/strengthens after cooling.

[33] Polyurethane is a "thermoset plastic" substance that strengthens when heated.

Another potentially feasible option for polyurethane foam—particularly for sandwich panels—is to recover the steel and the foam for reuse. Depending on the value of steel, it may be viable to recover it for reuse. Likewise, if the recovered foam could be matched to new uses with identical specifications, its reuse would be viable; this would likely require the development of a clearinghouse to match the specifications of recovered insulation foams with those for new construction insulation.

To assess the recovery potential of ODS/HFC blowing agent from construction foams, a number of factors were considered, as presented in Table 15. As shown, all construction foam end-uses have lower levels of recovery potential than appliance foam end-uses. This is due to higher annual emission rates, longer lifetimes, as well as increased complexity associated with foam separation and removal (which leads to higher blowing agent losses).

Table 15: Construction Foam Recovery Potential

End-Use	Average Blowing Agent Remaining at EOL[a]	Blowing Agent Technically Recoverable at EOL[b]	Total Potentially Recovered at EOL[c]
PU Rigid: Sandwich Panels – Continuous	70.5%	90%	63.5%
PU Rigid: Sandwich Panels – Discontinuous	66.5%	90%	59.9%
PU & PIR Rigid: Boardstock (FFL)	57.25%	70%	40.1%
PU Rigid: Spray foam	31.1%	50%	15.6%
XPS Foam Boards	12.75%	50%	6.4%

[a] Calculated by multiplying estimated original charge size by lifetime emissions assumptions from IPCC (2006).
[b] Estimated based on assumptions of blowing agent losses from separation and removal at EOL.
[c] Calculated by multiplying charge remaining at EOL percent by blowing agent technically recoverable at EOL.

As shown, sandwich panels and boardstock foams exhibit the highest potential for recovery. Since the feasibility for recovery is deemed to require a medium level of effort for these end-uses, economic feasibility is explored further in Section 4.2. Conversely, with less than 20 percent of blowing agent recoverable from spray foam, and less than 10% recoverable from XPS foam boards, and a high level of effort required in order to recover even that much, the feasibility of recovery is deemed low; therefore, economic feasibility for these end-uses is not further explored in this analysis.

4.1.4 Automotive Foam

Foam from automotive applications does not typically contain ODS or HFCs. Moreover, foams used in automotive applications are often emissive (i.e., open cell) and, as a result, there is little blowing agent remaining at vehicle EOL. For these reasons, technical (or economic) feasibility of recovery from this end-use is not considered further in this analysis.

4.1.5 Fire Protection

Per Regulation (EC) No 1005/2009, the recovery of ODS/HFC fire extinguishing agents from all fire extinguishing equipment is required, and thus, technologies for their removal have been developed and are widely used across the EU.

At EOL, there are established routes to recycling or destroying fire extinguishing agents. While most halons have already been decommissioned (apart from critical uses), HFC fire extinguishing agents are valuable, and thus a financial incentive encourages recycling. HFCs are easily recycled for reuse; all containers are generally returned to the original equipment manufacture's specialist filling facility, and because the materials are generally pure after use, they can be reused are recycling without the need for reclamation. Any material that is contaminated or possibly mixed is most likely to be sent for destruction. (ASSURE 2009)

Based on an assumed annual leak rate of 2%, an average equipment lifetime of 20 years, and a recovery efficiency of 95%, it is estimated that 91.2% of the original charge of total flooding systems is recoverable at equipment EOL, as presented in Table 16.

Table 16: Recovery Potential from Total Flooding Fire Extinguishing Systems

Extinguishing Agent Remaining at EOL	Extinguishing Agent Technically Recoverable at EOL	Total Potentially Recovered at EOL
96%[a]	95%[b]	91.2%

[a] Assumes an annual leak rate of 2% and average lifetime of 20 years (2%*20= 4% lost by EOL).
[b] Estimated based on recovery efficiency of available technologies.

4.1.6 Summary

Based on assumptions regarding equipment/product lifetime, chemical remaining at EOL, and percent of chemical technically recoverable at EOL, the total percent of refrigerant and foam blowing agent recoverable at EOL is summarized by end-use in Table 17. Additionally, for each end-use, feasibility to recover was ranked as High, Medium, or Low, based on the percent of original refrigerant or blowing agent content recoverable at end of life, with consideration given to the level of effort required to perform recovery, the history of EOL treatment, and the existing infrastructure in place. Specifically, feasibility of refrigerant recovery from all end-uses was ranked as "high," as refrigerant recovery requires a low level of effort, has a long history of being practiced in the field, and existing infrastructure is largely in place. Similarly, there is a history of EOL treatment and existing infrastructure in place for recovery of appliance foams, which also have recovery potentials of >75%. Therefore, recovery feasibility from appliance foams was also ranked as "high." For construction foams, however, there is virtually no history of EOL treatment or infrastructure in place, the level of effort to recover such foams is high, and the quantity of original blowing agent that is actually recoverable is relatively low (6%-63%). As such, the feasibility for foams was ranked based on the following thresholds:

- High: > 75%
- Medium: 30%-75%
- Low: <30%

Table 17: Refrigerant and Blowing Agent Recovery Potential at EOL, by End-Use and Region[a]

Sub-sector	End-Use	Total Potentially Recovered at EOL in EU		Feasibility to Recover
		EU-15	EU-12	
Refrigeration/AC				
Mobile AC	Passenger Cars	54%	45%	High
	Buses	54%	45%	High
Refrigeration	Domestic Refrigerators& Freezers	NA	NA	High
	Small Commercial	81%	72%	High
	Medium/ Large Commercial	67%	57%	High
	Refrigerated Transport—Land	63%	54%	High
	Refrigerated Transport—Ships	57%	48%	High
	Industrial Refrigeration	57%	48%	High
Stationary AC	Small Stationary	81%	72%	High
	Large Stationary (Chillers)	76%	67%	High
Foams				
Appliances	PU Rigid: Domestic Refrigerators/Freezers	88%		High
Appliances	PU Rigid: Commercial Refrigeration	79%		High
Construction	PU Rigid: Sandwich Panels – Continuous	64%		Medium
Construction	PU Rigid: Sandwich Panels – Discontinuous	60%		Medium
Construction	PU & PIR Rigid: Boardstock (FFL)	40%		Medium
Construction	PU Rigid: Spray foam	16%		Low
Construction	XPS Foam Boards	6%		Low

[a] See Section 4.1 for information on the assumptions and sources used to develop these estimates.
NA= Not applicable; since data on actual charge recoverable were available from appliance demanufacturers, assumptions on the percent potentially recoverable were not developed; rather, the total charge potentially recovered at EOL for CFC-systems is assumed to be 0.13 kg/unit in Sweden and Finland, 0.11 kg/unit in other EU-15 countries, and 0.06 kg/unit in EU-12 countries; for HFC-systems, it is assumed to be 0.12 kg/unit in Sweden and Finland, 0.10 kg/unit for other EU-15 countries, and 0.05 kg/unit in EU-12 countries (DUH 2007; RAL 2007a, 2007b; ICF 2008b).

The resulting feasibility rankings closely parallel those developed by TEAP (2009a), as summarized in Table 14—with the exception of boardstock foam, which was ranked by TEAP as requiring “high” levels of effort, but by this analysis as “medium” feasibility to recover.

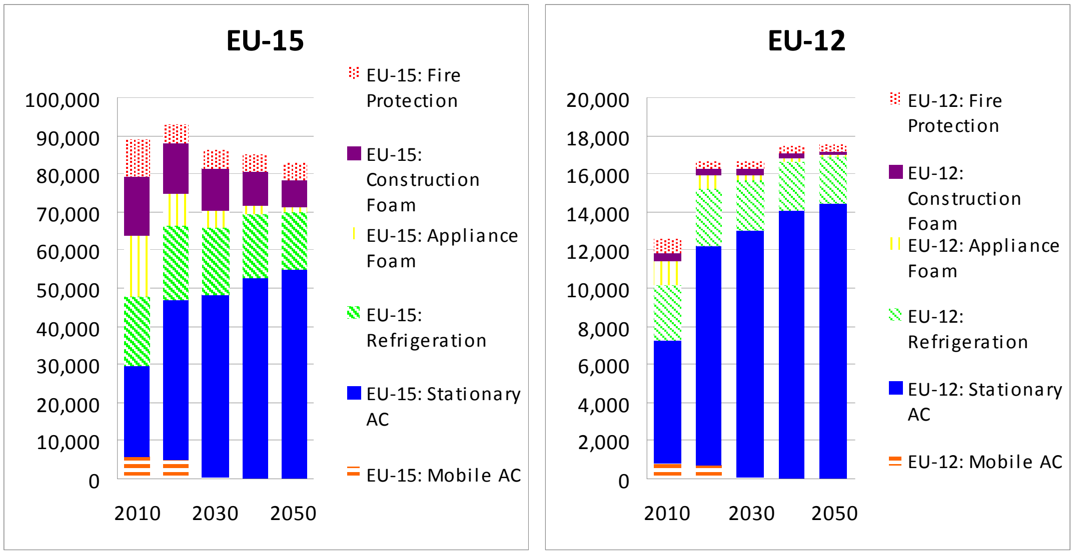
Based on these assumptions regarding recovery potential, Table 18 presents the estimated quantities of CFC, HCFC, and HFCs projected to be technically recoverable at product/equipment EOL in 2010, 2020, and 2050, based on the bottom-up modelling methodology used to estimate banks.

Table 18: Quantity Technically Recoverable at EOL in the EU-27 (T), Based on Bottom-Up Model

Sector/Sub-sector	2010			2020			2050		
	CFC	HCFC	HFC	CFC	HCFC	HFC	CFC	HCFC	HFC
Refrigeration/AC									
Mobile AC: Passenger cars	98	0	4,144	0	0	4,040	0	0	0
Mobile AC: Buses	3	0	132	0	0	156	0	0	0
Small Stationary AC	0	2,667	12,173	0	0	26,472	0	0	32,858
Large Stationary AC	60	451	1,526	0	0	3,449	0	0	5,837
Refrigerators/ Freezers	276	0	84	0	0	20	0	0	0
Small Commercial Refrigeration	18	122	366	0	0	608	0	0	500
Medium & Large Commercial Refrigeration	0	267	1,520	0	0	2,323	0	0	1,853
Refrigerated Transport (Land)	11	35	182	0	22	380	0	0	632
Refrigerated Transport (Ships)	0	766	111	0	730	274	0	0	615
Industrial Refrigeration	0	556	2,439	0	98	3,111	0	0	2,224
Subtotal	*466*	*4,864*	*22,676*	*0*	*850*	*40,834*	*0*	*0*	*44,519*
Foams									
PU Rigid: Domestic Refrigerators/ Freezers	2,935	258	0	1,507	133	0	204	18	0
PU Rigid: Commercial Refrigeration	574	261	373	295	134	462	40	18	63
PU Rigid:Sandwich Panels – Continuous	868	557	86	711	456	166	390	250	91
PU Rigid: Sandwich Panels – Discontinuous	421	296	115	345	242	161	189	133	89
PU & PIR Rigid: Boardstock (FFL)	987	242	6	808	198	13	444	109	7
PU Rigid: Spray foam	106	77	79	87	63	148	48	35	81
XPS Foam Boards	256	134	39	209	110	58	115	60	32
Subtotal	*6,147*	*1,826*	*698*	*3,962*	*1,336*	*1,009*	*1,429*	*623*	*363*
TOTAL	6,613	6,690	23,375	3,962	2,186	41,843	1,429	623	44,881

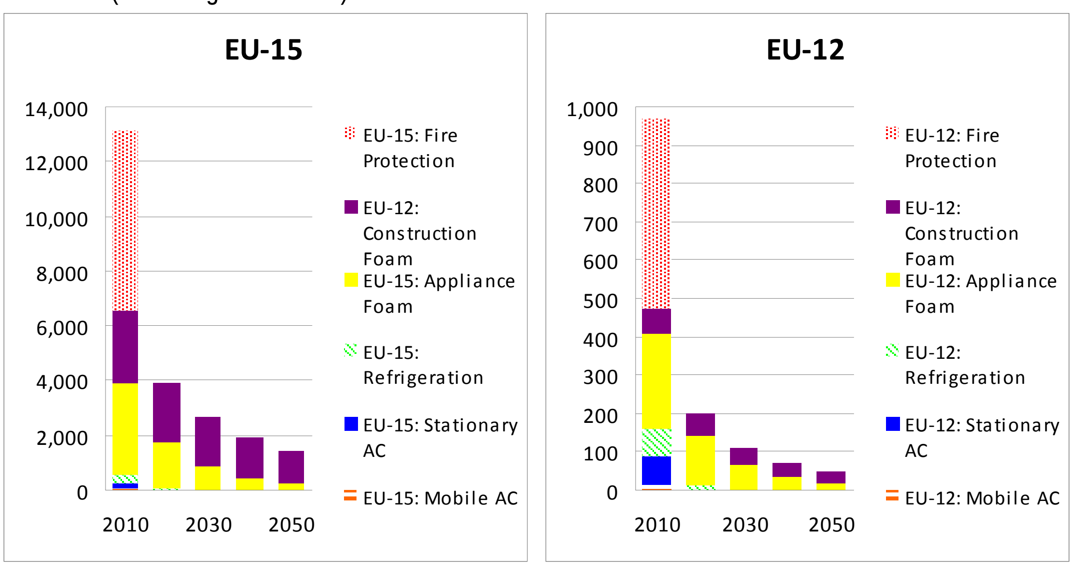
Figure 4 and Figure 5 present the projected quantities of ODS and HFCs believed to be *recoverable* from products and equipment at end-of-life, on CO_2-weighted and ODP-weighted bases in the EU-15 and EU-12. As shown, from a GHG perspective, the stationary AC sector will represent the most important sector for recovering banks at EOL from 2010 through 2050, although the refrigeration sub-sector, as well as the construction foams sub-sector in the EU-15, will also be very significant. From an ODS perspective, the foams sector will represent the most important sector for recovery at EOL from 2010 through 2050, particularly in the construction sub-sector.

Figure 4: Bottom-Up Estimates of Quantity Recoverable at Product/Equipment End-of-Life in EU-15-and EU-12 by Sub-Sector (KTCO$_2$E) (TAR) (2010-2050)



Note: Axes are scaled differently to allow for better readability of EU-12 values.

Figure 5: Bottom-Up Estimates of Quantity Recoverable at Product/Equipment End-of-Life in EU-15 and EU-12 by Sub-Sector (ODP-Weighted Tonnes)



Note: Axes are scaled differently to allow for better readability of EU-12 values.

4.2 Economic Feasibility

This section assesses the economic feasibility of the following three end-uses: domestic refrigerators/ freezers, medium/large commercial refrigeration, and PU rigid: sandwich panels (construction foam). For each end-use, average per kilogram costs are estimated based on costs charged to end-users/consumers for the EOL treatment of ODS/HFC refrigerant and foam. The per-kilogram costs developed for these three end-uses are used as proxies to estimate costs for all other end-uses as follows:

- *Domestic refrigerators/freezers*: per kg refrigerant and foam costs are used as a proxy for small commercial refrigeration equipment; per kg refrigerant costs are used as a proxy for small stationary AC, mobile AC (passenger cars and buses), and transport refrigeration (land).
- *Medium/large commercial refrigeration*: per kg refrigerant costs are used as a proxy for industrial refrigeration equipment, large stationary AC equipment, transport refrigeration (ships), and fire protection.
- *Sandwich panels*: per kg foam costs are used as a proxy for boardstock foam. The use of a proxy cost for boardstock foams is necessary given that no costs information is readily available (as boardstock recovery is not typically performed); however, it should be noted that actual costs to recover boardstock foam will be *at least* as expensive as that of sandwich panels, given that the process is more difficult.

Average per-kg costs are based on consideration of labour time, transportation/storage, and destruction. It should be noted that actual costs will vary based on location, population density, labour rates, availability of infrastructure, local unit costs and, in the case of building foams, building types and methods of construction. Where possible, consideration is given to vary regional costs by known variables (e.g., labour rates), though a more in-depth analysis would be needed to quantify the full range of costs across and within countries. In addition, the distribution of ODS/HFC banks (for which population density may be used as a proxy) can drive the cost of collection, recovery and destruction, with diffuse banks leading to higher costs for recovery and transport (TEAP 2009a). Other costs are considered qualitatively, such as those associated with recordkeeping, verification and reporting. For informational purposes, capital costs for equipment used by EOL service providers are also discussed, where available (see text box in Section 4.2.3 for more information). As this analysis focuses strictly on the costs associated with the handling of ODS/HFC at EOL, it does not consider the potential value, costs, or energy associated with the separation/recycling of metals, plastics, glass, or other durable goods from products/equipment.[34] It also does not consider costs associated with transport of the products/equipment to centralized collection facilities or demanufacturing facilities, as such costs must be incurred regardless of the ODS/HFC treatment (in compliance with other national/EU waste requirements).

The per kg cost estimates developed in this analysis (shown in Table 19, Table 20, and Table 21) can be compared to global estimated per kg costs developed by TEAP (2009b) (see Appendix E). However, it should be noted that TEAP's analysis considers total cost of managing the disposal of banks *in addition to* the products/equipment in which they are contained; because many EU-27 countries already separate and recover materials at equipment/product EOL, a significant share of the costs outlined in TEAP (2009b) are already being borne to comply with EU and national waste regulations. As such, some of the total costs presented in this report (e.g., for appliances) are significantly lower than the total costs presented in TEAP (2009b).

4.2.1 Domestic Refrigerators and Freezers (Refrigerant and Foam)

This section presents an economic feasibility assessment of recovering refrigerant and foam installed in domestic refrigerators/freezers. It is assumed that each unit contains approximately 0.05 to 0.13 kg of recoverable refrigerant (depending on refrigerant type and country/region). Because foam banks have been modelled on a mass (kg) basis and not on a stock (number of units) basis, no assumptions of foam blowing agent per unit have been developed.

Per Unit Costs

Per unit costs associated with ODS/HFC recovery/disposal often vary, depending on factors such as the size of the equipment or type of technology used. For example, the total cost of recovering both refrigerant and foam from domestic refrigerators/freezers in Germany is estimated at €6 - €12 per unit (ICF 2008b), while foam recovery alone is estimated at US$15 - US$25 per unit (approximately €11.00 to €18.00) in the UK, and US$13.50 per unit in the United States[35] (Caleb 2009). This analysis assumes an average cost of €10 per unit for the recovery of both refrigerant and foam from domestic refrigerators/freezers; 90% of this cost is assumed to be associated with foam recovery (as a result of the more complicated and time-intensive processes involved, and the higher capital costs of equipment required for foam recovery). [36]

Once the refrigerant and blowing agent have been evacuated from the appliances, they are transferred to storage tanks to await shipment to an off-site destruction or reclamation facility. The capacity of these tanks typically ranges from 400 kilograms to over 13,500 kilograms of refrigerant or condensed blowing agent (ICF 2008b; ARCA 2009). Such bulk quantities are the most economical to transport, though transportation costs vary depending on transport mode, distance, and whether transport is within or beyond national borders. This report assumes that transport of bulk ODS to a destruction/reclamation facility will cost approximately €0.10 per tonne per km, which equates to approximately €0.0001 per kg per km. Assuming an average distance of 50 kilometres, the cost to transport one kg of bulk ODS to a destruction facility in the EU would be approximately €0.005, or €0.0036 per domestic refrigerator/freezer unit.[37] It should be noted that the costs associated with transporting whole appliances to demanufacturing facilities—estimated by TEAP (2009b) at US$6 - $8 per kg (~€4 – €6/ kg)—are not included in this analysis, given that such costs must be incurred regardless of the handling of the ODS/HFCs, in compliance with other waste provisions.

Direct incineration of insulation foams can be the least expensive of all options, but only if appropriate incinerators (e.g., municipal solid waste or rotary kiln incinerators) are available. The cost and logistics penalty of moving to a hazardous waste incinerator network could be prohibitive for direct foam incineration. This analysis assumes that the cost associated with destruction of bulk ODS/HFC refrigerant and blowing agent is €3.00 per kg (see Section 3.7.3 for further explanation), which equates to approximately €1.20 per appliance.[38] Reclamation costs can often be less than destruction, depending on the purity level and market value of the particular ODS/HFC. Although reclamation costs are not quantitatively considered in this analysis, reclamation in lieu of destruction

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[35] The U.S. estimate is based on the cost using an automated recycling system (i.e., a shredder with a built-in foam separation/capture system); manual foam recovery would be more expensive given that the process would require approximately 20 minutes of labor time per unit.

[36] These costs are in line with TEAP (2009a), which estimates a recovery cost of approximately US $0.65 – $0.90 (~€0.50 – €0.65) for refrigerant per unit, and approximately $12 – $19 (~€8 – €13) for foam per unit—if it is assumed that 0.09 kg of refrigerant and 0.3 kg of blowing agent are recoverable per unit. (DUH, 2007; RAL, 2007a; 2007b; ICF, 2008a)

[37] The assumed amount of refrigerant recoverable at EOL ranges from 0.05 kg to 0.13 kg per unit (0.09 kg average), depending on refrigerant type and country of origin. The assumed quantity of blowing agent remaining at EOL is approximately 0.3 kg per unit. Thus, there is a total of approximately 0.39 kg of ODS material remaining at EOL per unit. (DUH, 2007; RAL, 2007a; 2007b; ICF, 2008a)

[38] The assumed amount of refrigerant recoverable at EOL ranges from 0.05 kg to 0.13 kg per unit (0.09 kg average), depending on chemical type and country of origin. The assumed quantity of blowing agent remaining at EOL is approximately 0.3 kg per unit. Thus, there is a total of approximately 0.39 kg of ODS material remaining at EOL per unit. (DUH, 2007; RAL, 2007a; 2007b; ICF, 2008a)

would likely drive down the average per unit cost of EOL treatment for domestic refrigerators/freezers.[39]

The total estimated costs for the recovery and destruction of ODS/HFC refrigerant and foam from domestic refrigerators/freezers are presented in Table 19 on per unit and per kg bases.

Table 19: Assumed Average per Unit and per kg Costs for EOL Treatment of Domestic Refrigerators/Freezersa

Activity	Cost per Refrigerator/Freezer	Per kg Cost	
		Refrigerant	Foam
Recovery of Refrigerant	€1.00	€11.10[b]	NA
Recovery of Foam	€9.00	NA	€30.00[c]
Transport	<€0.01	<€0.01	<€0.01
Destruction	€1.20	€3.00	€3.00
Total	€11.20	€ 14.10	€ 33.00

[a] Sources: ICF (2008b), Caleb (2009), TEAP (2009b), ARCA (2009). See Section 4.2.1for additional information on recovery and transportation costs, and Section 3.7.3 for additional information on destruction costs.
[b] Assuming an average of 0.09 kg of recoverable refrigerant per unit (DUH 2007, RAL 2007a, 2007b; ICF 2008b).
[c] Assuming an average of 0.3 kg of recoverable blowing agent per unit (DUH 2007, RAL 2007a, 2007b; ICF 2008b).
NA= Not applicable.

In addition to these costs, it should be noted that there are costs associated with labour time needed to comply with recordkeeping and permitting requirements, given that recovered ODS are considered “hazardous waste” in the EU (per Directive 2008/98/EC). In general, contractors must obtain a license and report all individual movements of recovered fluorocarbons, though in some Member States transportation of small quantities (typically 30 kg or less) of hazardous waste such as recovered ODS is exempt from licensing (EFCTC 2009). Given the variability of individual Member States’ requirements, the costs associated with recordkeeping and permitting are not quantitatively considered in this analysis. However, such costs are likely to increase the assumed average per unit cost of EOL treatment for ODS/HFCs from domestic refrigerators/freezers.

4.2.2 Medium/Large Commercial Refrigeration (Refrigerant)

This section presents an economic feasibility assessment of recovering ODS/HFCs from the refrigerant installed in medium/large commercial refrigeration units. This end-use category includes large parallel refrigeration systems used in supermarkets (as well as other full supermarket systems). Each unit is assumed to contain approximately 145 kg to 200 kg of recoverable refrigerant (depending on refrigerant type and country/region).

Per Unit Costs

The cost associated with ODS recovery from medium/large commercial refrigeration units—as well as other large refrigeration/AC and fire extinguishing equipment—depends primarily on the time required to complete the recovery process and the labour rate at which technicians work. According to industry estimates, it can take anywhere from three to eight hours to recover ODS from a large commercial refrigeration unit, depending on the quantity/type of refrigerant and recovery device used. Assuming an average of 8 hours, to be conservative, and an hourly (fully-loaded)[40] labour charge of

[39] Some reclaimed materials could be used within the EU (e.g., HFCs and HCFCs until 2015), whereas others (e.g., CFCs) would need to be exported due to use prohibitions.

[40] This cost is assumed to cover employee wage plus fringe benefits, insurance, overhead, and profit.

€75 to €100,[41] the total cost of ODS recovery from medium/large refrigeration equipment ranges from €600 to €800 per unit (or roughly €3.50 to €4.60 per kg).[42]

Once refrigerant is recovered, costs are incurred to transport the bulk ODS/HFCs to their final EOL treatment location (i.e., a destruction or reclamation facility). Based on the assumptions presented in Section 4.2.1, the cost to transport bulk refrigerant to a final EOL location (assuming an average distance of 50 km) is approximately €0.005 per kg, or approximately €0.90 per medium/large commercial refrigeration unit.[43]

The cost associated with destruction of bulk ODS refrigerant is assumed to be approximately €3.00 per kg (see Section 3.7.3 for further explanation), or approximately €520 per medium/large commercial refrigeration unit. Reclamation costs can often be less than destruction, but actual cost depends on the purity level and market value of the particular ODS/HFC. Although reclamation costs are not quantitatively considered in this analysis, reclamation in lieu of destruction would likely drive down the average per unit cost of EOL treatment for medium/large commercial refrigeration equipment.

The total estimated costs for the recovery and destruction of ODS/HFC refrigerant from medium/large commercial refrigeration equipment are presented in Table 20 on per unit and per kg bases. As stated previously in Section 4.2.1, costs associated with recordkeeping/permitting requirements are not quantitatively considered in this analysis, which would increase the average per unit costs shown.

Table 20: Assumed Average per Unit and per kg Costs for EOL Treatment of Medium/Large Commercial Refrigeration (Refrigerant)[a]

Activity	Cost per Medium/Large Commercial Refrigeration System	Per kg Cost
Recovery of Refrigerant	€600 to €800	€3.50 to €4.60
Transport	€0.90	<€0.01
Destruction	€520	€3.00
Total	~€1,120- €1,320[b]	€6.50 - €7.60[b]

[a] Sources: Eurofound (2006), ICF (2008b), TEAP (2009b), ARCA (2009). See Section 4.2.1for additional information on recovery and transportation costs, and Section 3.7.3 for additional information on destruction costs.

[b] The lower bound estimate applies to Spain, Portugal, Greece, and EU-12 countries; the upper bound estimate applies to all other EU-15 countries. The difference in costs is due to differences in labour rates based on Eurofound (2006).

4.2.3 PU Rigid: Sandwich Panels

Specific recovery costs for construction foams is scarce because very little recovery actually occurs in practice. This section presents cost data that is available on recovering ODS/HFC-containing blowing agent from sandwich panels, which is the type of construction foam that represents the highest potential for recovery.

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[41] Labor charges are based loosely on labor wage rates for employees in the manufacturing and private services sectors in the EU, which ranged from roughly €25 to €30 in the western EU countries; however, labor rates were "substantially lower" for southern EU Member States (particularly Spain, Greece and Portugal) and Member States that joined the EU after May 2004 (Eurofound, 2006).

[42] These per kg recovery costs (calculated assuming an average of 172.5 kg recoverable refrigerant per unit) are in line with TEAP (2009a), which estimates a recovery cost of approximately US$6.00 – $8.00 per kg (~€4.00 – €6.50 per kg).

[43] Assuming that the average amount of refrigerant recoverable per medium/large commercial refrigeration unit is approximately 172.5 kg.

Per kg Costs

TEAP (2009b) provides global average cost estimates for various processes of EOL treatment of sandwich panels—assuming prior recovery of blowing agent—in both densely and sparsely populated areas. These costs include segregation/collection, transport for recovery, transport for destruction, recovery processing, and destruction (see Appendix E). Because the EU is composed primarily of densely populated countries, and because the separation/recycling of materials from construction demolition is more advanced in the EU-27 than most other countries, the lower bound cost estimates presented by TEAP are used in this analysis (converted from U.S. dollars to Euros). As explained in TEAP (2009a), an average transportation distance of 50 km is assumed for densely populated areas. The total estimated costs for the recovery and destruction of ODS/HFC foam from sandwich panels are presented in Table 21 on a per kg bases. It should be noted that actual collection and transport costs for sandwich panels can vary significantly across the EU based on differences in labour costs; however, the information and assumptions used by TEAP in developing these estimates is generic, and does not allow costs to be scaled by country. In addition, it should be underscored that the costs of panel recovery and treatment without prior recovery of the ODS/HFC blowing agent will be lower than those shown here (e.g., at least €20/kg less given the lack of recovery processing required), and is the recommended option for destroying ODS foam by PU Europe (BING 2008).

Table 21: Assumed Average Per kg Costs for EOL Treatment of Sandwich Panels (with prior BA recovery)[a]

Activity	Per kg Cost
Segregation/Collection	€55.00[b]
Transport	€5.00[b, c]
Recovery Processing	€20.00
Destruction	€3.00
Total	€83.00

[a] Source: TEAP (2009b).

[b] Actual collection and transport costs for sandwich panels may vary significantly across the EU based on differences in labour costs.

[c] This transport cost estimate includes both the cost of transporting segregated/collected panels to a recovery processing facility, as well as cost of later transporting the recovered ODS material to a destruction facility.

As stated previously in Section 4.2.1, costs associated with recordkeeping/permitting requirements are not quantitatively considered in this analysis, which would increase the average per unit costs shown above. Similarly, reclamation in lieu of destruction is also not quantitatively considered in this analysis, which would likely decrease the average per unit costs.

Capital Costs Associated with ODS/F-Gas Recovery and Destruction

Refrigerant Recovery Equipment--The cost of basic refrigerant recovery devices ranges from €1,000 to €2,500, depending on capacity and cleaning capability (EFCTC 2009). For more advanced refrigerant recovery technologies, such as those used at appliance recycling facilities, capital costs are significantly greater. For example, the German-made SEG technology, which recovers refrigerant from up to four appliances simultaneously in roughly one minute, costs approximately US$175,000 (JACO 2009).

Foam Recovery Equipment--Appliance foam is often removed by large shredders with built-in, automated foam recovery systems; such systems cost roughly US$5 million. The capital cost of appliance foam recovery equipment is much lower if less sophisticated technologies are used, such as automated band saws, which cost approximately US$50,000-$65,000, or hand-held electric reciprocating saws, which cost US$100-$150. (JACO 2009).

If large vacuum recovery systems historically used for asbestos removal can be adapted for safe and effective removal of construction foam, capital costs may equal approximately US$85,000. For smaller hand-held vacuum systems, capital costs may be approximately US$300. (National Demolition Association 2009, Industrial Vacuum Equipment Corporation 2009)

Destruction of Bulk ODS/F-gases--The wide range of technologies available to destroy ODS and F-gases vary in capital cost from roughly US$60,000 for a cement kiln to $1.4 million for a plasma arc system (ICF 2008b). (For more information on per kg costs of destruction, see Section 3.7.3).

4.2.4 Potential Emission Savings by End-Use

Potential emissions savings estimates have been calculated for each end-use, based on bottom-up estimates for the refrigeration/AC and foams sectors, and top-down estimates for the fire sector. These estimates are summarized in Table 22 and Table 23, on an ODP-weighted and GWP-weighted bases, respectively. Table 24 presents the emission savings potential on a GWP-weighted basis by end-use and chemical type (CFC, HCFC, HFC) for 2010 and 2050. These estimates are based on assumptions about total percent of refrigerant/blowing agent technically recoverable at EOL (as presented in Table 13, Table 14, and Table 15), ODS/HFC banks installed in products/equipment reaching EOL (calculated in the Banks Model), and average ODP/GWP values for common types of refrigerants/blowing agents installed.

Table 22: Emissions Saving Potential by End-Use in 2010, 2020, and 2050 (ODP Tonnes)

Sub-Sector	End-Use	Emissions Savings Potential (ODP t)		
		2010	2020	2050
Mobile AC	Passenger Cars	98	-	-
	Buses	3	-	-
Refrigeration	Domestic Refrigerators/Freezers	276	-	-
	Small Commercial	25	-	-
	Medium/Large Commercial	15	-	-
	Refrigerated Transport—Land	13	1	-
	Refrigerated Transport—Ships	42	40	-
	Industrial Refrigeration	31	5	-
Stationary AC	Small Stationary	147	-	-
	Large Stationary (Chillers)	85	-	-
Appliance Foam	PU Rigid: Domestic Refrigerators/Freezers	2,957	1,518	205
	PU Rigid: Commercial Refrigeration	596	306	41
Construction Foam	PU Rigid: Sandwich Panels – Continuous	910	745	409
	PU Rigid: Sandwich Panels – Discontinuous	454	371	204
	PU & PIR Rigid: Boardstock (FFL)	1,004	822	451
	PU Rigid: Spray Foam[a]	115	94	52
	XPS: Foam Boards[a]	264	216	119

Sub-Sector	End-Use	Emissions Savings Potential (ODP t)		
		2010	2020	2050
Fire Protection	Fire Protection[b]	7,047	-	-
TOTAL		14,082	4,118	1,481

[a] Associated recovery costs are not estimated for PU rigid spray foams or XPS foam boards, as these applications were deemed to have low recovery feasibility.
[b] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.
- Represents a value of 0.

As shown, the potential to avoid ODS emissions will decrease rapidly over the years as banks reach EOL. In 2010, it is estimated that there will be over 14,000 ODP tonnes technically avoidable through recovery/destruction at equipment EOL across the EU-27, with less than one-third of that amount of emissions avoidable from retired equipment in 2020. Conversely, the potential to avoid GHG emissions through recovery/destruction at equipment/product EOL is projected to increase steadily from 2010 to 2020, but decrease by 2050. By 2010, over 101,000 $KTCO_2eq$. are projected to be potentially avoided through recovery/destruction at equipment/product EOL, rising to over 109,000 $KTCO_2eq$ by 2020—if recovery is performed across all end-uses, including those with low recovery feasibility (i.e., PU rigid spray foam and XPS foam boards). In 2010, the construction foams subsector accounts for 16% of the technically recoverable CFC/HCFC banks reaching EOL on a GWP-weighted basis, but by 2050, this subsector accounts for 7%.

Table 23: Emissions Saving Potential by End-Use in 2010, 2020, and 2050 ($KTCO_2eq$.)

Sub-Sector	End-Use	Emissions Savings Potential ($KTCO_2eq$.)		
		2010	2020	2050
Mobile AC	Passenger Cars	6,423	5,251	-
	Buses	202	203	-
Refrigeration	Domestic Refrigerators/Freezers	3,034	26	-
	Small Commercial	1,209	1,349	1,110
	Medium/Large Commercial	5,765	8,117	6,473
	Refrigerated Transport—Land	583	882	1,402
	Refrigerated Transport—Ships	1,608	1,997	1,698
	Industrial Refrigeration	8,597	9,930	6,980
Stationary AC	Small Stationary	26,613	48,014	59,596
	Large Stationary (Chillers)	3,729	5,665	9,588
Appliance Foam	PU Rigid: Domestic Refrigerators/Freezers	13,844	7,108	962
	PU Rigid: Commercial Refrigeration	3,570	2,259	306
Construction Foam	PU Rigid: Sandwich Panels – Continuous	4,953	4,206	2,308
	PU Rigid: Sandwich Panels – Discontinuous	2,324	2,009	1,102
	PU & PIR Rigid: Boardstock (FFL)	4,901	4,024	2,209
	PU Rigid: Spray Foam[a]	543	445	244
	XPS: Foam Boards[a]	3,008	2,463	1,352
Fire Protection	Fire Protection[b]	10,405	5,541	4,901
TOTAL		101,311	109,489	100,230

[a] Associated recovery costs are not estimated for PU rigid spray foams or XPS foam boards, as these applications were deemed to have low recovery feasibility.
[b] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.
- Represents a value of 0.
Note: estimates have been calculated using 100-year GWP values from the IPCC Third Assessment Report (TAR).

Table 24: Emissions Saving Potential by End-Use and Chemical in 2010 and 2050 (KTCO2eq.)

Sub-Sector	End-Use	Emissions Savings Potential (KTCO2eq.)					
		2010			2050		
		CFC	HCFC	HFC	CFC	HCFC	HFC
Mobile AC	Passenger Cars	1,035	-	5,388	-	-	-
	Buses	31	-	171	-	-	-
Refrigeration	Domestic Refrigerators/Freezers	2,925	-	110	-	-	-
	Small Commercial	189	208	812	-	-	1,110
	Medium/Large Commercial	-	454	5,311	-	-	6,473
	Refrigerated Transport—Land	120	59	404	-	-	1,402
	Refrigerated Transport—Ships	-	1,302	306	-	-	1,698
	Industrial Refrigeration	-	944	7,652	-	-	6,980
Stationary AC	Small Stationary	-	4,534	22,079	-	-	59,596
	Large Stationary (Chillers)	457	767	2,506	-	-	9,588
Appliance Foam	PU Rigid: Domestic Refrigerators/Freezers	13,503	340	-	938	24	-
	PU Rigid: Commercial Refrigeration	2,639	344	587	183	24	98
Construction Foam	PU Rigid: Sandwich Panels – Continuous	3,992	827	135	1,794	371	143
	PU Rigid: Sandwich Panels – Discontinuous	1,937	207	180	870	93	139
	PU & PIR Rigid: Boardstock (FFL)	4,541	350	10	2,040	157	11
	PU Rigid: Spray Foam[a]	489	54	124	220	24	128
	XPS: Foam Boards[a]	2,710	299	26	1,218	134	22
Fire Protection	Fire Protection[b]	-	40	6,757	-	-	4,901
TOTAL		34,568	10,729	42,558	7,263	827	92,267

[a] Associated recovery costs are not estimated for PU rigid spray foams or XPS foam boards, as these applications were deemed to have low recovery feasibility.
[b] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates. Emission savings associated with halon recovery/destruction are additional to those shown here.
- Represents a value of 0.
Note: estimates have been calculated using 100-year GWP values from the IPCC Third Assessment Report (TAR).

4.2.5 EU-Wide Potential Costs

EU-wide potential recovery/destruction costs have been calculated for 2010, 2020, and 2050 for end-uses deemed to have high or medium recovery feasibility based on per kilogram costs of refrigerant and foam developed for refrigerated appliances, medium/large commercial refrigeration, and foam sandwich panels, as summarised in Table 25. These costs are based on average per kilogram cost estimates for refrigerant and foam recovery/destruction (as presented in Table 22, Table 19, Table 20, and Table 21), the projected amount of ODS/HFC banks installed in products/equipment reaching EOL, and average ODP/GWP values for common types of refrigerants/blowing agents installed in each type of product/equipment.

Table 25: EU-Wide Potential Costs for Recovery/Destruction in 2010, 2020, and 2050 (€1,000)

Sub-Sector	End-Use	Proxy End-Use	EU-Wide Potential Costs (€1,000)		
			2010	2020	2050
Mobile AC	Passenger Cars	Domestic Refrigerators/Freezers	59,813,130	56,958,297	-
	Buses	Domestic Refrigerators/Freezers	1,896,540	2,199,753	-
Refrigeration	Domestic Refrigerators/Freezers	NA	5,080,752	283,665	-
	Small Commercial	Domestic Refrigerators/Freezers	7,135,440	8,571,463	7,051,518
	Medium/Large Commercial	NA	12,947,108	16,831,698	13,423,109
	Refrigerated Transport—Land	Domestic Refrigerators/Freezers	3,217,266	5,676,107	8,905,834
	Refrigerated Transport—Ships	Medium/Large Commercial Ref/AC	6,140,586	7,041,035	4,313,750
	Industrial Refrigeration	Medium/Large Commercial Ref/AC	22,076,963	23,760,545	16,475,060
Stationary AC	Small Stationary	Domestic Refrigerators/Freezers	209,243,969	373,261,875	463,297,054
	Large Stationary (Chillers)	Medium/Large Commercial Ref/AC	14,674,042	24,854,927	42,065,754
Appliance Foam	PU Rigid: Domestic Refrigerators/Freezers	Domestic Refrigerators/Freezers	105,399,623	54,113,971	7,323,530
	PU Rigid: Commercial Refrigeration	Domestic Refrigerators/Freezers	39,878,068	29,409,376	3,980,126
Construction Foam[b]	PU Rigid: Sandwich Panels – Continuous	NA	125,384,126	110,623,898	60,711,682
	PU Rigid: Sandwich Panels – Discontinuous	NA	69,025,561	62,105,734	34,084,350
	PU & PIR Rigid: Boardstock (FFL)	PU Rigid: Sandwich Panels	102,520,877	84,542,535	46,397,927
Fire Protection[b]	Fire protection	Medium/Large Commercial Ref/AC	9,517,371	5,032,203	5,597,386

NA= Not applicable; cost estimates were developed specifically for this end-use.
[a] Construction foam estimates shown here assume prior recovery of blowing agent; without prior recovery, overall costs are estimated at roughly €63/kg, or approximately €20/kg less. This would reduce total costs by nearly 25% across all years.
[b] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.
- Represents a value of 0.

Table 26 presents total costs by end-use per ODP tonne and per tonne of carbon dioxide equivalent ($TCO_2eq.$) for CFCs, HCFCs, HFCs, and halons. Table 27 presents the weighted costs across all ODS compared to those for HFCs by end-use per ODP tonne and TCO_2eq. While per kilogram costs to recover/destroy ODS/HFCs were not assumed to change over time, it should be noted that actual costs are likely to decrease with time, as technologies improve and additional experience is gained (particularly for construction foams, for which very limited field experience exists to date).

Table 26: Potential EU Costs of CFC/HCFC/HFC Recovery and Destruction Per ODP Tonne and TCO_2eq, by Chemical Type

Sub-Sector	End-Use	€/$TCO_2eq.$				€/ODP Tonne			
		CFC	HCFC	HFC	Halon	CFC	HCFC	HFC	Halon
Mobile AC	Passenger Cars	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
	Buses	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
Refrigeration	Domestic Refrigerators/ Freezers	1.33	N/A	10.85	N/A	14,100	N/A	N/A	N/A
	Small Commercial	1.33	8.29	6.35	N/A	14,100	256,364	N/A	N/A

Sub-Sector	End-Use	€/TCO2eq.				€/ODP Tonne			
		CFC	HCFC	HFC	Halon	CFC	HCFC	HFC	Halon
	Medium/Large Commercial	N/A	4.26	2.07	N/A	N/A	131,733	N/A	N/A
	Refrigerated Transport—Land	1.33	8.29	6.35	N/A	14,100	256,364	N/A	N/A
	Refrigerated Transport—Ships	N/A	4.12	2.56	N/A	N/A	127,193	N/A	N/A
	Industrial Refrigeration	N/A	4.35	2.35	N/A	N/A	134,581	N/A	N/A
Stationary AC	Small Stationary	N/A	8.29	7.77	N/A	N/A	256,364	N/A	N/A
	Large Stationary (Chillers)	0.95	4.20	4.40	N/A	7,206	129,918	N/A	N/A
Appliance Foam	PU Rigid: Domestic R&F	7.17	25.06	N/A	N/A	33,000	392,079	N/A	N/A
	PU Rigid: Commercial Refrigeration	7.17	25.06	20.99	N/A	33,000	392,079	N/A	N/A
Construction Foam[a]	PU Rigid: Sandwich Panels – Continuous	18.04	55.96	52.78	N/A	83,000	1,106,667	N/A	N/A
	PU Rigid: Sandwich Panels – Discontinuous	18.04	118.57[b]	52.78	N/A	83,000	754,545	N/A	N/A
	PU & PIR Rigid: Boardstock (FFL)	18.04	57.24	52.78	N/A	83,000	1,207,273	N/A	N/A
Fire Protection[b]	Fire protection	N/A	6.74	0.47	1.69	N/A	N/A	N/A	865.73

[a] Construction foam estimates shown here assume prior recovery of blowing agent; without prior recovery, overall costs are estimated at roughly €63/kg, or €20/kg less. This reduces weighted costs by nearly 25%.
[b] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.
[b] The high cost of recovery/destruction is due to the relatively low GWP (700) of HCFC-141b, which is the only HCFC assumed to be used in continuous sandwich panels.

Table 27: Potential EU Costs of ODS vs. HFC Recovery and Destruction Per ODP Tonne and TCO_2eq, by Chemical Type, 2010[a]

Sub-Sector	End-Use	€/TCO2eq.		€/ODP Tonne	
		ODS	HFCs	ODS	HFCs
Mobile AC	Passenger Cars	1.33	10.85	14,100	NA
	Buses	1.33	10.85	14,100	NA
Refrigeration	Domestic Refrigerators/ Freezers	1.33	10.85	14,100	NA
	Small Commercial	4.98	6.35	80,446	NA
	Medium/Large Commercial	4.26	2.07	131,733	NA
	Refrigerated Transport—Land	3.64	6.35	49,389	NA
	Refrigerated Transport—Ships	4.12	2.56	127,193	NA
	Industrial Refrigeration	4.35	2.35	134,581	NA
Stationary AC	Small Stationary	8.29	7.77	256,364	NA
	Large Stationary (Chillers)	2.99	4.40	43,059	NA
Appliance Foam	PU Rigid: Domestic R&F	7.61	NA	35,641	NA
	PU Rigid: Commercial Refrigeration	9.24	20.99	46,263	NA
Construction Foam[b]	PU Rigid: Sandwich Panels – Continuous	24.55	52.78	130,029	NA
	PU Rigid: Sandwich Panels – Discontinuous	27.76	52.78	131,198	NA
	PU & PIR Rigid: Boardstock (FFL)	20.85	52.78	101,608	NA
Fire Protection[c]	Fire protection	1.75	0.47	866	NA

[a] Weighted ODS costs for recovery will vary by over time, as the mix of CFCs and HCFCs recovered from retired products/equipment will vary.
[b] Construction foam estimates shown here assume prior recovery of blowing agent; without prior recovery, costs are estimated at roughly €63/kg, or approximately €20/kg less. This reduces estimated costs by nearly 25%.
[c] No bottom-up estimates were developed for the fire protection sector; therefore, the estimates presented here are based on top-down estimates.

As shown, on a tonne of carbon dioxide equivalent basis, the incremental cost to recover/destroy refrigerants is very low—less than €1.50/TCO_2eq.for CFCs and not more than €11/TCO_2eq. for HCFCs or HFCs across all types of equipment/products. This is due to the low level of effort/cost associated with refrigerant recovery and, in the case of CFCs, extremely high GWP values. For foams contained in refrigerated appliances, the costs are higher as a result of the greater time and effort required to recover blowing agent. Costs are highest for construction foams due to the level of effort required to separate and recover foam and foam blowing agent from building materials. However, the break-even carbon price for CFC construction foams (roughly €18/TCO_2eq.) is moderate enough such that it could become an attractive project on a carbon market—should such projects meet eligibility criteria. However, given that it is often difficult to discern the blowing agent contained in construction foam at time of demolition, it is useful to consider the *weighted* carbon costs associated with recovering and destroying all types of ODS construction foam, or even all fluorinated foams (i.e., ODS plus HFCs); based on quantities projected to reach EOL in 2010, it is estimated that the weighted cost of recovery and destruction of across ODS from all construction foam applications, with prior recovery, would equate to €23.60/TCO_2eq, and approximately €24.38/TCO_2eq if the costs for ODS and HFCs are combined. Over time, these weighted costs will increase, as the share of ODS construction foam reaching EOL will decreases relative to HFC and alternative blowing agents. In particular, the weighted cost of recovery and destruction of all ODS and HFC construction foams is estimated to reach roughly €24.90/TCO_2eq by 2015, and €25.13/TCO_2eq by 2020. Costs for destruction without prior recovery are estimated to be approximately 25% lower.

4.3 Other Factors that could Affect Technical or Economic Feasibility

In addition to technical and economic feasibility, a number of other factors affect the levels to which ODS/HFCs are and will be recovered from products and equipment at end-of-life in the EU-27. In particular, the following factors are at play:

1. Lack of economic incentives
2. Legal barriers within and across Member States
3. Unclear roles and responsibility

Each of these factors is described further below.

4.3.1 Lack of Economic Incentives

Even for the types of products and equipment from which ODS/HFC recovery is relatively inexpensive and requires little effort, no economic drivers are in place to compel stakeholders to recover at end-of-life. Currently, the only driver compelling recovery at EOL is compliance with EC and national regulations. Yet reliance on an enforcement/compliance regime may prove risky, given the large and dispersed nature of the regulated community. As noted by TEAP (2009a), avoiding venting as a consequence of even relatively minor cost components can represent a major challenge.

Moreover, according to ICF (2008a), EU stakeholders have reported the cost and lack of financial assistance to facilitate the purchase and operation of equipment for the recovery and recycling of F-gases as a barrier—especially for smaller companies. Similarly, the burden associated with recovery/destruction is particularly heavy for small volumes of ODS/F-gases, since transport and destruction costs for low volumes can be cost-prohibitive. Although such costs may be passed on to consumers, market competition may force technicians not to charge (A-Gas 2009), and hence, to absorb the costs and/or to be less than careful when it comes to recovery.

4.3.2 Legal Barriers

Per Regulation (EC) 1013/2006 on shipments of waste, the shipment of ODS/F-gas refrigerant sent for destruction within the EU-27 requires prior written notification and consent (in addition to labelling requirements), which is perceived as a barrier by industry stakeholders (ICF 2008a; A-Gas 2009; EFCTC 2009). Indeed, the classification of unwanted ODS/F-gas as “hazardous waste” triggers a number of administrative burdens for handlers that are costly and time-consuming. In particular, handlers of used refrigerant for reclamation or destruction must be licensed/registered and must complete transfer notes and other paperwork. Additionally, the transport of used refrigerant for reclamation or destruction often triggers different requirements within and across Member States, resulting in a disjointed process (EFCTC 2009; A-Gas 2009).[44] In several countries, for example, waste handling companies are required to provide a deposit or a bank guarantee covering their potential liabilities in case of non-compliance (EFCTC 2009). As a result, waste shipment regulations significantly effect the practicality and feasibility of ODS/HFC destruction.

In addition, according to industry, EC waste legislation has resulted in confusion over classification of waste ODS/F-gases. Article 18 of Waste Directive 2008/98/EC places a ban on the mixing of waste, and requires that hazardous mixed waste be separated “where possible.” However, “where possible” is left undefined. As it currently reads, this phrase weakens the enforceability of the mixing ban and may lead to perverse incentives for the handling of construction foams at EOL.

Moreover, the classification of waste ODS/HFC foams as “hazardous” creates additional burdens, as the destruction of foam in hazardous-waste-permitted facilities is significantly more costly than in municipal solid waste or rotary kiln incinerators, which are TEAP-approved for the destruction of ODS foam. Furthermore, the designation of ODS/HFC- containing foam as hazardous waste may affect additionality as it applies to the EU emissions trading scheme; unless ODS/HFC-containing foam is classified as non-hazardous waste, its destruction would not trigger the additionality requirement to qualify for emissions reductions credits. As a result, incentives for recovering and destroying ODS/HFC-containing foams would be significantly lower.

4.3.3 Unclear Roles and Responsibilities

Unlike refrigeration and air-conditioning appliances covered under the WEEE Directive 2002/96/EC, there are no specific guidelines or requirements in place for the recovery and treatment of refrigerant from large commercial equipment. Therefore, while some countries may have well-established networks in place to enable the return of used refrigerant from end-users through existing distribution channels back to manufacturers for consolidation and reclamation/destruction, it is unclear if such infrastructure exists across all Member States.

[44] According to the European Fluorocarbons Technical Committee, in many Member States, such as the UK, Spain and Italy, recovered fluorocarbons are classified as waste at the point of recovery, thereby requiring contractors and distributors to comply with all hazardous waste regulatory requirements including permits and reporting. In fact, several member States have implemented regional regulations that make it difficult to transport recovered material within a single country.

5 Promoting the Recovery and Destruction of ODS/HFCs from Banks

In light of the large potential ODS and GHG emission savings that can be achieved through proper recovery and destruction at equipment/product EOL through 2050, as well as the significant costs that are associated with such activities, it is critical that more be done to promote maximum recovery and destruction. This can be achieved through a number of different regulatory and non-regulatory mechanisms, including: expedited regulatory requirements on "waste" ODS/F-gases, a tradable credit/certificate system, a tax/rebate scheme, subsidies on destruction, and/or voluntary programs. Each of these approaches is discussed further below. In addition, the potential impacts of one of these approaches—allowing certain ODS destruction projects to be eligible for carbon credits—is explored in Section 5.2.

5.1 Policy Options

5.1.1 Expedite Regulatory Requirements within the EU-27

Both real and perceived legal barriers must be overcome to facilitate recovery and shipment of recovered ODS/HFCs for the purposes of destruction (and reclamation). As many Member States do not have their own reclamation or destruction facilities, it is imperative that end-users in those countries are able to ship their recovered substances for reclamation and destruction easily and without great expense. Accordingly, the EC should consider options for facilitating the inter-Member State shipment of used ODS/HFC refrigerants, blowing agents, and fire extinguishing agents that can be safely transported for destruction (or reclamation). Handlers of used ODS/HFCs are generally the same as those handling virgin ODS/HFCs, and all are trained and certified in order to ensure that best practices are employed to limit emissions. The required paperwork associated with the handling and transport of "hazardous waste" adds a layer of complexity and cost that could be avoided by requiring more simplified reporting/recordkeeping to track the movement of unwanted ODS/HFCs sent for reclamation or destruction. Thus, to the extent possible, synergies should 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.

5.1.2 Make recovery of ODS -containing foams from all equipment/products mandatory under Regulation (EC) 1005/2009

The European Commission could specifically require that recovery of some or all types of ODS-containing construction foams for the purpose of destruction, recycling or reclamation under Regulation (EC) 1005/2009 if deemed "technically and economically feasible." Feasibility of recovery (see Table 18) could be considered in determining which construction foam subsectors should fall under this mandate (e.g., steel-faced panels). Such a mandate would likely enhance the feasibility of recovery by setting the right market signals. In particular, such a mandate would lead to a guaranteed demolition waste stream of ODS building foams, which would in turn facilitate and encourage industry to develop methods and mechanical plants to recover ODS waste, as well as new specialised recovery and recycling capacity. It could also stimulate the development of new products manufactured from foam waste.

5.1.3 Tradable credit/certificate system (with robust emission monitoring/reporting systems for validation and verification)

The recovery and destruction of ODS construction foams could be eligible for carbon credits, as recovery from this end-use is not definitively required by existing EU legislation. Moreover, given that it costs roughly five times more to recover this type of ODS on a per kg basis compared to any other ODS contained in products/equipment (€83/kg, equivalent to €18/TCO_2eq. for CFC-containing foams, versus €7-17/kg, equivalent to €0.95-3.80TCO_2eq.), a financial incentive is important to ensure that recovery and destruction of this type of ODS will occur. With EU ETS credits currently trading around €10-15//TCO_2eq,[45] earning carbon credits for the destruction of ODS construction foams could help to offset the cost of recovery and destruction (estimated at about €18/TCO_2eq for CFC-containing foam).[46] Some market experts expect EUA prices to stay in the €10-20/ tCO_2eq for the remainder of Phase II, and to increase to €30-40/$MTCO_2$eq in Phase III (World Bank 2009). 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.[47]

5.1.4 Taxes on virgin refrigerant sales and rebates on the return of used refrigerants for destruction

To create a financial incentive for refrigerant recovery and destruction, a tax can be placed on virgin and reclaimed ODS/HFC refrigerant placed on the market in the EU, while the revenue from the tax could be used to offer a rebate on the return of recovered ODS/HFC refrigerants. A number of countries (e.g., Norway, France, Australia) have implemented this type of scheme,[48] which has successfully resulted in increased amounts of refrigerants returned for reclamation/destruction.

For example, in France, where reclaimed refrigerant totals have been gathered, there has been a significant increase in the efficiency of the recovery program. In 1992, without any regulation, only 200 t of recovered refrigerant (CFCs and HCFCs) were reclaimed. In 1993, after making recovery mandatory and carrying out a deposit-refund scheme, the quantity grew to 300 t, and the number of refrigeration companies concerned doubled from 200 to 400 (out of 2,500). Government incentives were necessary to reach full development of recovery schemes. (RTOC 2006)

If such a scheme were to be considered at the EU level, reclamation for reuse should be promoted in certain cases in lieu of strict destruction. This is because it is often more cost effective and less energy-intensive to reclaim refrigerant than to produce virgin refrigerant. Moreover, if the reclamation of used refrigerant can displace the production of new refrigerant—be it in the EU or abroad—this is an important benefit that should not be overlooked.

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[45] Point Carbon (2009). *Point Carbon EUA OTC assessment (EUR/t).* Accessed 27 August 2009 from: http://www.pointcarbon.com/news/

[46] EU ETS prices have been volatile over the past year, ranging from a high of €28.73 in July 2008 to a low of €7.96 in February 2009 (World Bank, 2009)

[47] "Additionality" is defined on a carbon platform-specific basis; for some, the "regulatory" test applies, so any activities required by law are not eligible for credits; for others, there is leniency when a regulation is not enforced (e.g., a 50% compliance rate cut-off may apply).

[48] For example, in Australia, import levies apply to imports of ODS and F-gases in bulk and to those contained in pre-charged equipment. In 2008, the import and manufacture levy rates for F-gases were approximately US$140 per metric ton (ICF, 2008b).

5.1.5 Subsidies on Destruction

Another potential option to promote the destruction of ODS and HFCs is to subsidise the cost of destruction so that end-users do not bear the financial burden. Subsidies could be dispersed to end-users upon the return of used ODS/HFCs (e.g., in the form of a rebate), or to destruction facilities (to allow them to lower the price charged to customers for ODS/HFC destruction). Subsidies could be funded through a tax, such as that described above, or through carbon credits, in cases where aggregation is required.

5.1.6 Producer Responsibility Schemes

Producer responsibility schemes, be they voluntary or mandated by law, can also be used to promote the recovery and destruction of ODS/F-gases. For example, ODS/HFC producers could offer take-back programs for unwanted chemicals for the purpose of reclamation or destruction and/or establish centralised collection points for ODS prior to destruction; this would allow users to return unwanted ODS/F-gases at a low cost, or at no cost, to producers via distributors. In many cases, chemical producers would be able to reclaim the used ODS/F-gases more cost-effectively than they can produce virgin chemical, which could then be sold within the EU or abroad, depending on the type of ODS/F-gas and the associated regulatory restrictions in place.

5.2 Impacts of Proposed Options

Further study would be needed to evaluate the most appropriate design and infrastructure for any of the above schemes across the EU-27. However, a brief quantitative review is possible to consider the potential impacts on the EU ETS of allowing ODS destruction projects in the construction foams sector to be eligible for carbon credits.

Based on estimates presented in Table 23, less than 16 $TgCO_2eq$ are projected to be technically recoverable at EOL and available for destruction from ODS in construction foams (including sandwich panels boardstock, spray foam, and XPS foam boards) in 2010. This amount will decrease over time, as ODS blowing agents are phased out from decommissioned buildings; by 2020, roughly 13 $TgCO_2eq$ of ODS could be recovered and destroyed from construction foams, declining to 7 $TgCO_2eq$ by 2050.

The amount of ODS from construction foams that could be destroyed and eligible for crediting under the EU ETS is small compared to the total transaction volume in the EU ETS market. In 2008, the traded volume in the EU ETS exceeded 3,000 $TgCO_2eq$, over 185 times greater than the credits that could be generated from ODS construction foams (World Bank 2009).[49] While the demand for credits in the EU ETS is likely to grow in the future with the inclusion of additional sectors (e.g., aviation, chemical and aluminium industries) and gases (e.g., nitrous oxide and perfluorocarbons), the amount of ODS recoverable for destruction from construction foams is expected to decrease over time (World Bank 2009). Thus, the proportion that ODS construction foam products represents compared to the growing size of the EU ETS, will continue to decline.

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[49] The traded volume should be interpreted cautiously. This amount does not exactly equal the total number of credits demanded/supplied. Because each credit can be traded several times before being retired, the traded volume likely exceeds the number of credits demanded in the market. That said, even assuming a high turnover rate of 10 transactions per credit, the EU ETS is still substantially larger than the credits that could come available from ODS destruction, and the difference between the two is only expected to grow.

6 Findings and Recommendations

Existing EU regulations explicitly require the recovery of all ODS/F-gases from certain categories of products and equipment at end of life. For the "other" categories, including construction foams, the obligation to recover (or immediately destroy) depends on its technical and economical feasibility. The new ODS Regulations offer also the option of destruction without prior recovery. For some end-uses— namely vehicles and household/small commercial appliances — schemes are also mandated to assign responsibility for and ensure the safe disposal of products and equipment and the ODS/F-gases contained therein.

Currently, there is very little, if any, known recovery of ODS/F-gases from construction foam applications at time of demolition, with the exception of some in Germany (BING 2008). For other products/equipment for which ODS/F-gas recovery is required by law, actual recovery levels across the EU vary across Member State and end-use, and are somewhat uncertain due to a lack of comprehensive reported data. A number of factors may reduce actual recovery levels, including insufficient technician training, a lack of recovery equipment, high recovery/disposal costs, small quantities remaining in equipment at time disposal, potential losses during transport/handling, and others.

The bottom-up estimates developed for this report offer some useful insights. Based on these estimates, the levels of CFCs, HCFCs, and HFCs that will be technically recoverable from products/equipment reaching end-of-life between 2010 and 2050 is significant, reaching nearly 37,000 t in 2010 and climbing steadily to reach nearly 47,000 t by 2050. By recovering and destroying these quantities, the ozone and climate benefits can be substantial, leading to the avoided emissions of over 7,000 ODP-t and over 91,000 $KTCO_2$eq. in 2010 alone. Current destruction capacity within the EU-27, estimated to be between 145,000 t and 225,000 t per annum, is more than sufficient to meet this projected demand; therefore, there is no need to develop further capacity within the EU. However, while capacity is believed to be sufficient in the EU, the uneven distribution of destruction facilities may pose problems in areas where no facilities are available, particularly if ODS containing wastes must be transported over large distances (e.g., >1,000 km), such that transportation and labour costs may become prohibitive.

Based on the technical and economic assessment performed for this study, it is cost-effective to recover ODS/HFCs contained in all types of products/equipment, with the possible exception of construction foams. In particular, recovery from spray foam and foam boards is unlikely to be feasible, given the very low levels of blowing agent (less than 20% of the original quantity) that are estimated to be technically recoverable at building EOL. Moreover, while sandwich panels may be the most feasible type of construction foam to recover, the cost—including blowing agent recovery—is relatively high—estimated at €83/kg, or roughly €18/TCO_2eq for CFC blowing agents, €56-€118/TCO_2eq for HCFC blowing agents, and €53/TCO_2eq for HFC blowing agents. On a weighted basis, the cost to recover all blowing agents from construction foam applications is estimated at roughly €24/TCO_2eq in 2010, but will increase in future as the relative amount of CFC foams from C&D waste declines. Destruction of construction foam without prior blowing agent recovery may be considerably lower that these estimated costs, on the order of €63/kg, or roughly 25% less on a TCO_2eq or ODP-weighted basis. On a weighted basis, the cost to recover all blowing agents from construction foam applications is estimated at roughly €19/TCO_2eq in 2010. Given the limited field experience to date at recovering construction foams, however, it is difficult to assess feasibility and costs within this sector with certainty. Additional information on actual recovery/processing methods and their associated costs across the various types of construction foams and across Member States is needed.

It is important that the bottom-up estimates of banks and recoverable banks developed for this report be viewed as preliminary only, given the limited country-level data on which they are based. Additional data from Member States—particularly in the construction foams and stationary AC sectors, believed to account for the majority of installed banks—are needed on a continuing basis in order to improve estimates from the bottom-up model and inform policy decisions as appropriate. More specifically, the main areas for **model improvement** include:

1. Cross-check/***validate overall bank estimates*** against other available data, including that from EFCTC bank estimates, as well as (HFC) end-use-specific assumptions from national inventory reports submitted by Member States under the UN Framework Convention on Climate Change (UNFCCC) requirements.

2. Review/validate ***stationary AC sector***, including assumed average charge sizes; based on input from the European Partnership for Energy and the Environment (EPEE), Germany, and Poland, the model may be over-estimating banks in this sector. Data should be solicited on AC stocks and charge sizes from Member States, and consideration should be given to the thresholds used to define "small" versus "large" AC systems (e.g., 12 kW in lieu of 75 kW, based on input from EPEE). Also, additional data sources that are or will become available should be reviewed, including:
   - Study for the Ecodesign Directive (EuP) Lot 10—provides market data for EU-27 and growth scenarios for stationary AC units below 12 kW capacity.
   - European Commission study on Eco-design ENTR Lot 6—currently being prepared (by Armines) and will provide information on stationary AC units above 12 kW capacity.
   - Future studies addressing market data for heat pumps (air-to-water and water-to-water types, potentially Ecodesign Lot 1 or others to be identified through coordination with EPEE.

3. Review/validate assumptions for ***MVAC charge size in buses***; data on HFC charge size from Germany suggests that the current estimate (of 6 kg) may be too small (by about half); more data is needed from other Member States and/or industry to confirm that a charge increase is appropriate across all EU countries.

4. Review the ***ODS phaseout dates for refrigeration/AC equipment in the EU-12*** to ensure that the projected years in which banks reach 0% installed base for CFCs and HCFCs are appropriate.

5. Review/validate the ***construction foam end-uses***. In particular, a better understanding is needed of the varying consumption patterns for ODS/HFC construction foams across the EU-27 to more accurately disaggregate foam banks by Member State, including information on CFC and HCFC phase-in and phase-out dates for sandwich panels and boardstock foams. While much of this data has recently been made available from Germany and Poland, additional input is needed from other Member States as well as industry associations (e.g., EURIMA, PU Europe, Exiba), especially on key country markets (e.g., UK, Germany, France, Italy). In addition, several studies on the recovery and destruction of construction foam are nearly complete, and will provide useful information. For example, an EC study on construction and demolition waste was launched in October 2009, to assess current levels of and practices for recovery of different demolition materials in a representative sample of Member States (EC website).[50] Similarly, the United Kingdom's Department for

[50] The study aims to (1) specify the requirements resulting from the EU waste legislation regarding construction and demolition (C&D) waste by establishing operational definitions of some crucial concepts, and (2) perform a quantitative and qualitative analysis of the status quo of C&D waste and establish a scenario for 2014 (European Commission, 2009b website).

Environment, Food and Rural Affairs (DEFRA) has commissioned research on the segregation of building insulation foams containing ODS on demolition sites, which is currently undergoing peer review.

6. ***Reconcile the discrepancies between top-down and bottom-up estimates*** by conducting further research into the assumptions used to develop top-down estimates. This may involve collaboration with TEAP to (a) ensure consistency across the specific end-uses included in "banks," and (b) explore the treatment of imports and exports of pre-charged equipment.

In addition to the above model validations and updates, the **model functionality** could also be expanded in a number of key areas. Specifically:

1. ***Multiple value assumptions*** could be developed for key variables with high uncertainty. For example, upper and lower-bound estimates could be modelled for stationary AC charge sizes, building lifetime, percentages of construction foam blowing agent recoverable at EOL, construction foam recovery costs, etc.

2. The mobile AC sector could be expanded to include ***AC systems in trucks, ships, rail vehicles, and agricultural machinery***; to this end, coordination with USNEF and Member States is suggested in order to develop assumptions on stock and charge size.

3. Assumptions on percent of blowing agent remaining at EOL could be disaggregated for construction foams by chemical type, to ***account for differences in lifetime loss rates for ODS versus HFC blowing agents***.

4. ***Construction foam banks could be disaggregated*** by end-use (i.e., commercial, industrial, domestic) to allow assumptions on lifetime to vary; additional research and industry consultation would be needed to determine if shorter lifetimes should be assumed for industrial/commercial buildings (e.g., 20- 30 years) across all countries or only some (e.g., the UK).

5. ***Building replacement could be modelled*** in addition to demolition for the construction foams sector; additional research would be needed to determine whether the estimated commercial/industrial building replacement rates estimated for the UK are applicable to other countries in the EU-27, and if not, how they vary.

To perform the above model improvements and expand model functionality, a process should be established for systematically collecting new data and performing model updates for the EC on an ongoing basis.

In addition, while it is premature to recommend concrete actions for improving ODS/HFC recovery at product/equipment end-of-life, the following **preliminary options for promoting ODS/F-gas recovery at EOL** should be considered (in no particular order):

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).

As additional information is collected and incorporated into the Banks Model, it will be possible to more fully explore the opportunities associated with each of the options described above.

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Appendix A: Detailed Methodology for Developing Bank Estimates

This Appendix provides additional detail regarding the methodology used to develop the top-down and bottom-up ODS/HFC bank estimates used in this report. It should be underscored that the top-down and bottom-up models differ significantly in terms of how HFC banks are projected; the top-down model projects future HFC growth based on historical trends, while the bottom-up model projects future HFC growth assuming an increasing push to climate-friendly alternatives.

The methodology is presented by end-use, as follows:

Refrigeration

- Domestic Refrigerators and Freezers
- Small Commercial Refrigeration
- Medium/Large Commercial Refrigeration
- Land Refrigerated Transport
- Ships Refrigerated Transport
- Industrial Refrigeration
- Mobile AC
- Passenger Cars
- Buses
- Stationary AC
- Small Stationary AC
- Large Stationary AC (Chillers)

Foams

- PU Rigid: Domestic Refrigerators/Freezers
- PU Rigid: Commercial Refrigeration
- PU Rigid: Sandwich Panels – Continuous
- PU Rigid: Sandwich Panels – Discontinuous
- PU & PIR Rigid: Boardstock (FFL)
- PU Rigid: Spray foam
- XPS Foam Boards

Fire Protection

Refrigeration

Domestic Refrigerators and Freezers

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector was only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for domestic refrigerators and freezers are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Historical stock data are available for the EU-25 in 2000 and 2005 from the LOT:13 Domestic Refrigerators and Freezers Final Report (2007), which were then apportioned by Member State based on population for the EU-15 and EU-10 (Eurostat 2000, 2005). Based on the average ratio of units per capita calculated for the EU-10 in 2000 and 2005, stock estimates were scaled for the missing countries (i.e., Bulgaria and Romania). Based on these data, the assumed number of refrigerator/freezer units per person was calculated to be 0.60 for the EU-15 and 0.45 for the EU-12. Stock estimates for each Member State were then grown to 2009 based on average historical growth rates from the LOT:13 Domestic Refrigerators and Freezers Final Report (2007). Based on these average historical growth rates, the short-term (2009-2020) growth rate for the EU-15 and EU-12 is projected to be 1.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 0.5%), to account for market saturation. The quantity of charge assumed to remain in CFC-systems at EOL is 0.145 kg in Sweden and Finland, 0.127 kg in other EU-15 countries, and 0.065 kg in EU-12 countries; the quantity of charge assumed to remain in HFC-systems at EOL is 0.13 kg in Sweden and Finland, 0.11 kg in other EU-15 countries, and 0.06 kg in EU-12 countries (DUH 2007; RAL 2007a, 2007b; ICF 2008). Ninety percent of the above amounts remaining at EOL are assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-1: End-use Characteristics – Domestic Refrigerators and Freezers

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	NA	HFC-134a
Charge Remaining at EOL (kg)			
Sweden and Finland	0.145	NA	0.13
Other EU-15	0.127	NA	0.11
EU-12	0.065	NA	0.06
Lifetime (years)	15	15	15

Table A-2: Percent Installed Base – Domestic Refrigerators and Freezers

Region/Year		CFC	HCFC	HFC
EU-15	2010	15%[a]	0%	5%
	2020	0%	0%	1%
	2050	0%	0%	0%
EU-12	2010	30%[b]	0%	5%
	2020	0%	0%	1%
	2050	0%	0%	0%
EU-27 Stock Phase-out Date (if before 2050)		2015	NA	2025

[a] These assumptions yield estimates that align with others in the published literature. For example, TEAP (2009a) cites a 2008 Austrian study prepared by FHA that found more than 80% of disposed refrigerators/freezers contained CFC refrigerant; this study estimates that in 2009, roughly 72% of refrigerators/ freezers disposed in Austria contain CFCs.
[b] Based on estimates provided by the competent representative of Poland.

Small Commercial Refrigeration

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for small commercial refrigeration equipment are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

The number of minimarkets and supermarkets in the Netherlands in 2000 was estimated based on data from the GAIN Report on the Netherlands Retail Food Sector (USDA 2000). This total was then scaled up to 2009 based on an assumed growth rate of 3% (IPCC/TEAP 2005). It was then assumed that there is an average of 10 small commercial refrigeration units per store. Using the number of units per capita in the Netherlands, the total number of units for the EU-27 was then scaled by Member State based on population. Based on IPCC/TEAP (2005), the short-term (2009-2020) growth rate is assumed to be 3%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.5%), to account for market saturation. The percent of original charge assumed to remain at EOL is 90% in EU-15 countries and 80% in EU-12 countries, while 90% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-3: End-use Characteristics – Small Commercial Refrigeration

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-22	HFC-134a, R-404
Average charge (kg)	3	3	2
Lifetime (years)	12	12	12

Table A-4: Percent Installed Base – Small Commercial Refrigeration

Year	CFC	HCFC	HFC
2010	5%	20%	75%
2020	0%	0%	95%
2050	0%	0%	50%

Stock Phase-out Date (if before 2050)	2011	2016	NA

Medium/Large Commercial Refrigeration

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for medium/large commercial refrigeration equipment are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

The number of supermarkets in the Netherlands in 2000 was estimated based on data from the GAIN Report on the Netherlands Retail Food Sector (USDA 2000). This total was then scaled up to 2009 based on an assumed growth rate of 3% (IPCC/TEAP 2005). It was then assumed that there is one large/medium commercial refrigeration unit per store. Using the number of units per capita in the Netherlands, the total number of units for the EU-27 was scaled up by Member State based on population. Based on IPCC/TEAP (2005), the short-term (2009-2020) growth rate is assumed to be 3%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.5%), to account for market saturation. The percent of original charge assumed to remain at EOL is 70% in EU-15 countries and 60% in EU-12 countries, while 95% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A 5: End-use Characteristics – Medium/Large Commercial Refrigeration

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-22	R-404, R-507
Average charge (kg)	300	300	255
Lifetime (years)	15	15	15

Table A 6: Percent Installed Base – Medium/Large Commercial Refrigeration

Year	CFC	HCFC	HFC
2010	0%	15%	85%
2020	0%	0%	100%
2050	0%	0%	50%
Stock Phase-out Date (if before 2050)	2011	2016	NA

Land Refrigerated Transport

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for land refrigerated transport are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

EU-27 stock estimates for road (in 2005), rail (in 2002), and intermodal container refrigerated transport (1990-2004) were based on data from RTOC (2006) and the GDV (2009), respectively. These stock estimates were scaled to each Member State based on GDP, and grown to 2009 based on average historical growth rates (where available) or estimated annual growth rates. Based on a weighted average of historical container transport growth and estimated annual road/rail transport growth reported in RTOC and the GDV, the short-term (2009-2020) growth rate for the EU-27 is projected to be 6.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 3.0%), to account for market saturation. Based on CARB (2008), which estimates that 70% of the original charge of modern shipping containers is intact at time of decommissioning, the percent of original charge assumed to remain at EOL is 70% in EU-15 countries and 60% in EU-12 countries, while 90% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-7: End-use Characteristics – Land Refrigerated Transport

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-22	HFC-134a, R-404A
Average charge (kg)	5	5	4.5
Lifetime (years)	25	25	25

Table A-8: Percent Installed Base – Land Refrigerated Transport

Year	CFC	HCFC	HFC
2010	5%	15%	80%
2020	0%	5%	95%
2050	0%	0%	65%
Stock Phase-out Date (if before 2050)	2021	2026	NA

Ships Refrigerated Transport

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for ships refrigerated transport are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

EU-27 stock estimates for reefer ships (in 2009) and merchant marine/naval/fishing vessels (in 2003) were based on data from Lloyd's Maritime Intelligence Unit (2009) and RTOC (2006), respectively. Stock estimates were scaled to each Member State based on data from the United Nations Conference on Trade and Development on the world merchant fleet by flag of registration and type of ship (UNCTAD 2009), which provides the proportion of the EU merchant fleet (based on total dead weight tonnes [DWT]) by Member State. Stock estimates were then grown to 2009 assuming annual growth rates based on RTOC (2006). Specifically, the short-term (2009-2020) growth rate for the EU-

27 is projected to be 2.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.0%), to account for market saturation. Average lifetime is based on the Reports of Finnish Environment Institute (2006). The percent of original charge assumed to remain at EOL is 60% in EU-15 countries and 50% in EU-12 countries, while 95% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-9: End-use Characteristics – Ships Refrigerated Transport

Attribute	CFC	HCFC	HFC
Type(s)	NA	HCFC-22	R-507, R-404A
Average charge (kg)	NA	2000	1500
Lifetime (years)	25	25	25

Table A-10: Percent Installed Base – Ships Refrigerated Transport

Region/Year		CFC	HCFC	HFC
EU-15	2010	0%	75%	15%
	2020	0%	60%	30%
	2050	0%	0%	50%
EU-12	2010	0%	85%	10%
	2020	0%	60%	30%
	2050	0%	0%	50%
Eu-27 Stock Phase-out Date (if before 2050)		2021	2026	NA

Industrial Refrigeration

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for industrial refrigeration equipment are not available; rather, such estimates are included in the "refrigeration" sub-sector. The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Based on ICF (2006), it is assumed that there were approximately 105,000 HCFC-containing IPR systems in the EU in 2006, and that this stock has declined to 100,000 by 2009. It is further assumed that the HCFC stock represents 15% of all fluorinated IPR systems, with another 185,000 IPR systems containing HFCs. Based on estimated future growth rates from Research and Markets (RMA 2005), the short-term (2009-2020) growth rate for Europe's major food processing countries (i.e., Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Poland, Portugal, Spain, Sweden, and the UK) is projected to be 2.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.0%), to account for market saturation. For all other EU Member States, the short-term (2009-2020) growth rate is projected to be 1.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 0.5%), to account for market saturation. The percent of original charge assumed to remain at EOL is 60% in EU-15 countries and 50% in EU-12 countries, while 95% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-11: End-use Characteristics – Industrial Refrigeration

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-22	R-404A
Average charge (kg)	1000	1000	850
Lifetime (years)	20	20	20

Table A-12: Percent Installed Base – Industrial Refrigeration

Year	CFC	HCFC	HFC
2010	0%	10%	15%
2020	0%	5%	20%
2050	0%	0%	5%
Stock Phase-out Date (if before 2050)	2016	2021	NA

Mobile AC

Passenger Cars

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends. In light of Directive 2006/40/EC, HFC banks in this sub-sector were assumed to decline linearly beginning in 2011.[51] Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for passenger car mobile AC units are not available; rather, such estimates are included in the "mobile AC" sub-sector (which also includes mobile AC in buses). The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Historical data on passenger cars are available from Eurostat for each Member State from 1990 to 2004. Stock data was then grown to 2009 based on average historical growth rates (Eurostat 2009a). Based on average historical growth rates, the short-term (2009-2020) growth rate for the EU-15 total passenger car fleet is projected to be 2.0%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.0%), to account for market saturation. Similarly, based on average historical growth rates, the short-term (2009-2020) growth rate for the EU-12 total passenger car fleet is projected to be 3.5%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 1.75%), to account for market saturation. Of the existing 2009 vehicle fleet in the EU-15, 65% are assumed to contain AC units, while 60% of those in the EU-12 are assumed to contain AC units (U.S. EPA 2004, Kozakiewicz 2009). For passenger cars placed on the market after 2009, it is assumed that AC penetration rates are 70% in the EU-15 and 65% in the EU-12 (U.S. EPA 2004); for modelling purposes, it was assumed that it will take until 2020 for the AC penetration rates to reach these levels. Therefore, actual MVAC growth rates assumed for the 2009-2020 period are in fact higher than the overall growth rate for passenger cars, at 2.7% for the EU-15 and 4.6% for the EU-12.

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[51] An annual decline of roughly 7% is modeled, based on the assumption that no new HFC mobile AC units will be used beginning in 2011 and that such units have a lifetime of 14 years (i.e., 1/14= 7%). While this simplifying phase-out rate assumption was required for modeling purposes, it may be optimistic, as Directive 2006/40/EC does not prohibit HFC-134a use in all new mobile AC systems in 2011 (including those in buses or in pre-existing model vehicles).

Based on EC (2003), which found that 57% of the original equipment charge remains in MVACs at EOL in the EU-15, the percent of original charge assumed to remain at EOL is 60% in EU-15 countries and 50% in EU-12 countries. Recognizing that SAE Standard J2788 requires new MVAC recovery equipment to achieve a 95% efficiency within 30 minutes or less, it is conservatively assumed that 90% of that amount is recoverable at EOL.

Table A-13: End-use Characteristics – Passenger Cars

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	NA	HFC-134a
Average charge (kg)	0.85	NA	0.70
Lifetime (years)	14	14	14

Table A-14: Percent Installed Base – Passenger Cars

Year	CFC	HCFC	HFC
2010	2%	0%	98%
2020	0%	0%	70%
2050	0%	0%	0%
Stock Phase-out Date (if before 2050)	2015	NA	2031

Buses

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends. In light of Directive 2006/40/EC, HFC banks in this sub-sector were assumed to decline linearly beginning in 2011.[52] Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for AC units in buses are not available; rather, such estimates are included in the "mobile AC" sub-sector (which also includes mobile AC in passenger cars). The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Historical data on the stock of motor coaches, buses, and trolley buses are available from Eurostat (2009b) for each Member State from 1990 to 2004. Stock data were then grown to 2009 based on average historical growth rates (Eurostat 2009). Based on average historical growth rates, the short-term (2009-2020) growth rate for the EU-15 total bus fleet is projected to be 1.5%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 0.75%), to account for market saturation. Similarly, based on average historical growth rates, the short-term (2009-2020) growth rate for the EU-12 total bus fleet is projected to be 0.5%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 0.25%), to account for market saturation. Of the existing 2009 bus fleet in the EU-15, 65% are assumed to contain AC units, while 60% of those in the EU-12 are assumed to contain AC units (U.S. EPA 2004, Kozakiewicz 2009). For buses placed on the market after 2009, it is assumed that AC penetration rates are 70% in the EU-15 and 65% in the EU-12 (U.S.

[52] An annual decline of roughly 7% is modeled, based on the assumption that no new HFC mobile AC units will be used beginning in 2011 and that such units have a lifetime of 14 years (i.e., 1/14= 7%). While this simplifying phase-out rate assumption was required for modeling purposes, it may be optimistic, as Directive 2006/40/EC does not prohibit HFC-134a use in all new mobile AC systems in 2011 (including those in buses or in pre-existing model vehicles).

EPA 2004); for modelling purposes, it was assumed that it will take until 2020 for the AC penetration rates to reach these levels. Therefore, actual MVAC growth rates assumed for the 2009-2020 period are in fact higher than the overall growth rate for buses, at 2.2% for the EU-15 and 1.26% for the EU-12.

As with MVACs, the percent of original charge assumed to remain at EOL is 60% in EU-15 countries and 50% in EU-12 countries, while 90% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-15: End-use Characteristics - Buses

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-22	HFC-134a
Average charge (kg)	7	NA	6
Lifetime (years)	14	14	14

Table A-16: Percent Installed Base - Buses

Year	CFC	HCFC	HFC
2010	2%	0%	98%
2020	0%	0%	95%
2050	0%	0%	0%
Stock Phase-out Date (if before 2050)	2015	NA	2031

Stationary AC

Small Stationary AC

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for small stationary AC units are not available; rather, such estimates are included in the broader "stationary AC" sub-sector (which also includes large stationary AC units). The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Units of small stationary AC were calculated by manipulating EU-15 data on room AC units provided in Armines (1999) and on centralized AC units provided in Armines (2003). All derived stock estimates were grown to 2009 based on average historical growth rates from Armines (1999, 2003). Stock estimates were developed for the EU-10 countries based on the average ratio of units per capita for the EU-15 (excluding Spain and Italy, since those countries experienced exceptionally high growth in AC sales) (Armines, 1999).

Based on average estimated annual growth rates from Armines (1999, 2003), the short-term (2009-2020) growth rates for EU-27 are as follows: Austria (8.0%), France (6.0%), Germany (7.5%), Greece (5.5%), Italy (3.5%), Portugal (6.5%), Spain (5.5%), UK (6.0%), Other EU-15 (7.5%), and EU-12 (6.0%). The long-term (2021-2050) growth rate is assumed to be half of the short-term amount for each country, to account for market saturation. The percent of original charge remaining at EOL is assumed to be 90% in EU-15 countries and 80% in EU-12 countries, while 90% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-17: End-use Characteristics – Small Stationary AC

Attribute	CFC	HCFC	HFC
Type(s)	NA	HCFC-22	R-410, R-407
Average charge (kg)	NA	3.5	3
Lifetime (years)	10	10	10

Table A-18: Percent Installed Base – Small Stationary AC

Region/Year		CFC	HCFC	HFC
EU-15	2010	0%	15%	85%
	2020	0%	0%	100%
	2050	0%	0%	50%
EU-12	2010	0%	35%	65%
	2020	0%	0%	100%
	2050	0%	0%	50%
EU-27 Stock Phase-out Date (if before 2050)		2009	2014	NA

Large Stationary AC (Chillers)

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because bank data for the refrigeration/AC sector were only disaggregated into three categories (refrigeration, mobile AC, and stationary AC), top-down estimates for large stationary AC (chillers) are not available; rather, such estimates are included in the "stationary AC" sub-sector (which also includes small stationary AC). The EU bank estimates for this sub-sector were then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Units of large stationary AC were calculated by manipulating EU-15 data on centralized AC units provided in Armines (2003). Stock estimates were then grown to 2009 based on average historical growth rates from Armines (2003). For the EU-10 countries, stocks were developed based on the average ratio of units per capita in the EU-15 (excluding Spain and Italy, since those countries experienced exceptionally high growth in AC sales) (Armines, 1999). Based on average historical growth rates, the short-term (2009-2020) growth rate for the EU-27 is projected to be 5.5%, while the long-term (2021-2050) growth rate is assumed to be half that amount (i.e., 2.75%), to account for market saturation. The percent of original charge remaining at EOL is assumed to be 80% in EU-15 countries and 70% in EU-12 countries, while 95% of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-19: End-use Characteristics – Large Stationary AC

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11 and CFC-12	HCFC-22	HFC-134a, R-407C
Average charge (kg)	250	250	210
Lifetime (years)	15	15	15

Table A-20: Percent Installed Base – Large Stationary AC

Region/Year		CFC	HCFC	HFC
EU-15	2010	5%	20%	75%
	2020	0%	0%	100%
	2050	0%	0%	75%
EU-12	2010	5%	30%	65%
	2020	0%	0%	100%
	2050	0%	0%	75%
EU-27 Stock Phase-out Date (if before 2050)		2011	2016	NA

Foams

PU Rigid: Domestic Refrigerators/Freezers

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[53]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU rigid foam in domestic refrigerators/freezers are included in the broader "appliance foam" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for the domestic appliance sector were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. Specifically, to estimate installed banks, historical annual sales were estimated from the first known year of consumption (1959), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming an equipment lifetime of 15 years[54] (TEAP 2009a, ISIS 2007). The annual disposal for each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) and HFC blowing agents is assumed to be 0%, as this sub-sector has already transitioned to ozone and climate friendly alternatives. The total installed bank was apportioned to Member States based on GDP. The percent of blowing agent available at EOL was calculated to be 92.5%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) in year 1 and annually thereafter,

[53] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

[54] A 15-year lifetime is consistent with other estimates in the published literature (TEAP 2009, ISIS 2007); however, as recognised by TEAP (2009a), appliances may be being used for longer periods in some developed countries, often as secondary refrigerators.

and the assumed equipment lifetime. Ninety-five percent of that amount is assumed to be technically recoverable at EOL, based on the recovery efficiency of available technologies.

Table A-21: End-use Characteristics – PU Rigid: Domestic Refrigerators/Freezers

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-141b, HCFC-141b/22, HCFC-142b/22	NA
Percent Blowing Agent by Weight	12%	10%	NA
Losses in Year 1	4%	4%	4%
Annual Losses After Year 1	0.25%	0.25%	0.25%
Lifetime (years)	15	15	15

PU Rigid: Commercial Refrigeration

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[55]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU rigid foam in commercial refrigeration equipment are included in the broader "appliance foam" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for the commercial refrigeration sector were estimated based on confidential EU sales data provided by global foam chemical manufacturers for 2001 and 2008. Specifically, to estimate installed banks, historical annual sales were estimated from the first known year of consumption (1959), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates for CFCs, HCFCs and HFCs). Installed bank in each year was then estimated using a decay function (beginning in year 2009), assuming an equipment lifetime of 15 years. The annual disposal for each year was then estimated as the change in the installed base from the previous year. The total installed bank was then apportioned to Member States based on GDP. Future growth of ODS (i.e., CFC and HCFC) and HFC blowing agents is assumed to be 0%, as this sub-sector has already transitioned to ozone and climate friendly alternatives. The quantity of blowing agent available at EOL was calculated to be 92.5%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) in year 1 and annually thereafter, and the assumed equipment lifetime. Eighty-five percent of that amount is assumed to be technically recoverable at EOL, based on the recovery efficiency of available technologies.

[55] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

Table A-22: End-use Characteristics – PU Rigid: Commercial Refrigeration

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-141b, HCFC-141b/22, HCFC-142b/22	CF-245fa, HFC-365mfc/227ea
Percent Blowing Agent by Weight	12%	10%	6%
Losses in Year 1	4%	4%	4%
Annual Losses After Year 1	0.25%	0.25%	0.25%
Lifetime (years)	15	15	15

PU Rigid: Sandwich Panels – Continuous

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[56]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU rigid continuous sandwich panels are included in the broader "construction" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for continuous sandwich panels were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. Specifically, to estimate installed banks, historical annual sales were estimated from the first known year of consumption (1969), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming a building lifetime of 50 years. The annual disposal for each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) blowing agents is assumed to be 0%, as these chemicals have been phased out of use. For HFCs, although the future transition to climate friendly alternatives in this application is highly uncertainty, it was assumed that the future growth of HFCs will decline linearly from 2009 to reach 0 by 2020 in light of the increasing push away from high-GWP gases. To disaggregate the installed banks by country, and account for the slower uptake of the use of foam insulation in buildings in the EU-12, the following assumptions were made:

- CFCs: all consumption pre-1990 occurred in the EU-15, with banks apportioned to those 15 countries based on GDP. Beginning in 1990, after the fall of the Soviet Union, CFC continuous sandwich panels begin penetrating the EU-12 markets. Thus, starting in 1990, CFC banks are allocated to the whole EU-27 according to GDP.

[56] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

- HCFCs: HCFC consumption in continuous sandwich panels in the EU-15 began in 1994, while consumption in the EU-12 began in 1997. Thus, prior to 1997, HCFC banks are apportioned to the EU-15 Member States based on GDP; beginning in 1997, HCFC banks are allocated to the whole EU-27 according to GDP.
- *HFCs*: HFC consumption in continuous sandwich panels began penetrating both the EU-15 and EU-12 markets in 2003.

The percent of blowing agent available at EOL was calculated to be 70.5%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) and TEAP (2005) in year 1 and annually thereafter, and the assumed building lifetime. Ninety percent of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-23: End-use Characteristics – PU Rigid: Sandwich Panels - Continuous

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-141b, HCFC-22, HCFC-22/142b	HCF-245fa, HFC-365mfc/227ea
Percent Blowing Agent by Weight	12%	10%	6%
Losses in Year 1	5%	5%	5%
Annual Losses After Year 1	0.5%	0.5%	0.5%
Lifetime (years)	50	50	50

PU Rigid: Sandwich Panels – Discontinuous

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[57]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU rigid discontinuous sandwich panels are included in the broader "construction" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for discontinuous sandwich panels were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. Specifically, to estimate installed banks, historical annual sales were estimated from the first known year of consumption (1969), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming a building lifetime of 50 years. The annual disposal for

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[57] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) blowing agents beyond 2009 is assumed to be 0%, as these chemicals have been phased out. For HFC blowing agents, although the future transition to climate friendly alternatives in this application is highly uncertainty, it was assumed that the future growth of HFCs will decline linearly from 2009 to reach 0 by 2020 in light of the increasing push away from high-GWP gases. To disaggregate the installed banks by country, and account for the slower uptake of the use of foam insulation in buildings in the EU-12, the following assumptions were made:

- *CFCs*: all consumption pre-1990 occurred in the EU-15, with banks apportioned to those 15 countries based on GDP. Beginning in 1990, after the fall of the Soviet Union, CFC discontinuous sandwich panels begin penetrating the EU-12 markets. Thus, starting in 1990, CFC banks are allocated to the whole EU-27 according to GDP.
- *HCFCs*: HCFC consumption in discontinuous sandwich panels in the EU-15 began in 1994, while consumption in the EU-12 began in 1997. Thus, prior to 1997, HCFC banks are apportioned to the EU-15 Member States based on GDP; beginning in 1997, HCFC banks are allocated to the whole EU-27 according to GDP.
- *HFCs*: HFC consumption in discontinuous sandwich panels began penetrating both the EU-15 and EU-12 markets in 2003.

The average percent of blowing agent available at EOL was calculated to be 66.5%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) and TEAP (2005) in year 1 and annually thereafter, and an assumed lifetime of 50 years. Ninety percent of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-24: End-use Characteristics – PU Rigid: Sandwich Panels - Discontinuous

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-141b	HFC-245fa, HFC-365mfc/227ea
Percent Blowing Agent by Weight	12%	10%	5%
Losses in Year 1	6%	6%	12%
Annual Losses After Year 1	0.5%	0.5%	0.5%
Lifetime (years)	50	50	50

PU & PIR Rigid: Boardstock (FFL)

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[58]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU and PIR rigid boardstock foam are included in the broader "construction"

[58] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for boardstock were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. To estimate installed banks, first historical annual sales were estimated from the first known year of consumption (1965), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming a building lifetime of 50 years. The annual disposal for each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) blowing agents beyond 2009 is assumed to be 0%, as these chemicals have been phased out. For HFC blowing agents, although the future transition to climate friendly alternatives in this application is highly uncertainty, it was assumed that the future growth will decline linearly from 2009 to reach 0 by 2020 in light of the increasing push away from high-GWP gases.

To disaggregate the installed banks by country, and account for the slower uptake of the use of foam insulation in buildings in the EU-12, the following assumptions were made:

- CFCs: all consumption pre-1990 occurred in the EU-15, with banks apportioned to those 15 countries based on GDP. Beginning in 1990, after the fall of the Soviet Union, CFC boardstock foam begins penetrating the EU-12 markets. Thus, starting in 1990, CFC banks are allocated to the whole EU-27 according to GDP.
- HCFCs: HCFC consumption in boardstock foam in the EU-15 began in 1994, while consumption in the EU-12 began in 1997. Thus, prior to 1997, HCFC banks are apportioned to the EU-15 Member States based on GDP; beginning in 1997, HCFC banks are allocated to the whole EU-27 according to GDP.
- *HFCs*: HFC consumption in boardstock foam began penetrating both the EU-15 and EU-12 markets in 2003.

The average percent of blowing agent available at EOL was calculated to be 57%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) and TEAP (2005) in year 1 and annually thereafter, and the assumed building lifetime. Seventy percent of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-25: End-use Characteristics – PU & PIR Rigid: Boarstock (FFL)

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-22, HCFC-141b/22	HFC-245fa, HFC-365mfc/227ea
Percent Blowing Agent by Weight	12%	10%	5%
Losses in Year 1	6%	6%	6%
Annual Losses After Year 1	0.5%	0.5%	1%
Lifetime (years)	50	50	50

PU Rigid: Spray foam

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[59]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for PU and PIR rigid spray foam are included in the broader "construction" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for spray foam were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. To estimate installed banks, first historical annual sales were estimated from the first known year of consumption (1965), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming a building lifetime of 50 years. The annual disposal for each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) blowing agents beyond 2009 is assumed to be 0%, as these chemicals have been phased out. For HFC blowing agents, although the future transition to climate friendly alternatives in this application is highly uncertainty, it was assumed that future growth will decline linearly from 2009 to reach 0 by 2020 in light of the increasing push away from high-GWP gases. To disaggregate the installed bank by Member State, it was assumed that 75% of the banks are installed in Spain and Italy, as these two countries account for the majority of use. Prior to 1990, the remaining 25% of CFC spray foam was apportioned to other EU-15 countries based on GDP; beyond 1990, the remaining 25% was apportioned to the other EU-27 countries based on GDP. These assumptions account for the slower uptake of the use of foam insulation in buildings in the EU-12. For HCFCs and HFCs, the following assumptions were made:

- *HCFCs: HCFC consumption in spray foam in the EU-15 began in 1994, while consumption in the EU-12 began in 1997.*
- *HFCs*: HFC consumption in spray foam began penetrating both the EU-15 and EU-12 markets in 2003.

The average percent of blowing agent available at EOL was calculated to be 31%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) and TEAP (2005) in year 1 and annually thereafter, and the assumed building lifetime. Fifty percent of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

[59] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

Table A-26: End-use Characteristics – PU Rigid: Spray Foam

Attribute	CFC	HCFC	HFC
Type(s)	CFC-11	HCFC-141b	HFC-245fa, HFC-365mfc/227ea
Percent Blowing Agent by Weight	12%	10%	7%
Losses in Year 1	15%	15%	15%
Annual Losses After Year 1	0.75%	0.75%	1.5%
Lifetime (years)	50	50	50

XPS Foam Boards

Top-Down Methodology

Top-down bank estimates of ODS (i.e., CFCs and HCFCs) were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, CFCs and HCFCs were assumed to continue their downward linear trends, and HFC banks were assumed to grow at half their 2002-2015 growth rate. Because the top-down bank data for the foams sector were not disaggregated by use applications, the banks were apportioned into sub-sectors—appliances, construction, and other[60]—based on market share. Specifically, market share was estimated based on confidential data provided by global chemical manufacturers on 2008 foam sales by application in the EU. Given this level of aggregation, top-down estimates for XPS foam boards are included in the broader "construction" sub-sector. The EU bank estimates for foams was then disaggregated by Member States based on GDP.

Bottom-Up Methodology

Annual EU-27 foam sales for XPS foam boards were estimated based on confidential EU sales data obtained from global foam chemical manufacturers for 2001 and 2008. To estimate installed banks, first historical annual sales were estimated from the first known year of consumption (1965), assuming linear growth through 2009 (using the known 2001 and 2008 data points). Annual sales were then apportioned by chemical (i.e., CFCs, HCFCs, and HFCs) for each year, based on estimated percent of market share for each chemical type (per historical phase-in and phase-out dates of CFCs, HCFCs and HFCs). Installed bank in each year was estimated using a decay function (beginning in year 2009), assuming a building lifetime of 50 years. The annual disposal for each year was then estimated as the change in the installed base from the previous year. Future growth of ODS (i.e., CFC and HCFC) blowing agents beyond 2009 is assumed to be 0%, as these chemicals have been phased out. For HFC blowing agents, although the future transition to climate friendly alternatives in this application is highly uncertainty, it was assumed that the future growth of HFCs will decline linearly from 2009 to reach 0 by 2020 in light of the increasing push away from high-GWP gases.

To disaggregate the installed banks by country, and account for the slower uptake of the use of foam insulation in buildings in the EU-12, the following assumptions were made:

- CFCs: all consumption pre-1990 occurred in the EU-15, with banks apportioned to those 15 countries based on GDP. Beginning in 1990, after the fall of the Soviet Union, CFC foam boards begin penetrating the EU-12 markets. Thus, starting in 1990, CFC banks are allocated to the whole EU-27 according to GDP.

[60] No banks were assumed in open-cell foam applications, such as automotive flexible PU foam or one component construction PU rigid foam.

- HCFCs: HCFC consumption in foam boards in the EU-15 began in 1994, while consumption in the EU-12 began in 1997. Thus, prior to 1997, HCFC banks are apportioned to the EU-15 Member States based on GDP; beginning in 1997, HCFC banks are allocated to the whole EU-27 according to GDP.
- *HFCs*: HFC consumption in foam boards began penetrating both the EU-15 and EU-12 markets in 2001.

The average percent of blowing agent available at EOL was calculated to be approximately 13%, based on the percent of blowing agent by weight by chemical type, known emission factors provided by IPCC (2006) and TEAP (2005) in year 1 and annually thereafter, and the assumed building lifetime. Seventy percent of that amount is assumed to be technically recoverable at EOL based on the recovery efficiency of available technologies.

Table A-27: End-use Characteristics – XPS Foam Boards

Attribute	CFC	HCFC	HFC
Type(s)	CFC-12	HCFC-142b, HCFC-142b/22	HFC-134a, HFC-152
Percent Blowing Agent by Weight	12%	10%	10%
Losses in Year 1	90%	90%	25% -50%
Annual Losses After Year 1	0.75%	0.75%	0.75- 25%
Lifetime (years)	50	50	50

Fire Protection

Top-Down Methodology

Top-down bank estimates of HCFCs and halons were calculated using data from Ecosphere/Milieu (2007), which reported banks for the EU-27 in 2007 and 2010 based on a linear trend analysis of data provided by IPCC/TEAP (2005). Banks of HFCs were calculated using data from IPCC/TEAP (2005), which reported total banks from Article 2 (developed) countries by key sector in 2002 and 2015. To project banks through 2050, it was assumed that halon banks continue their downward linear trend, while HFC banks grow at half their 2002-2015 growth rate. For HCFCs, because EC bank data reported by Ecosphere/Milieu (2007) remained constant from 2007 and 2010, it was assumed that a linear decline would begin in 2010.[61] The EU bank estimates for fire protection was then disaggregated by Member States based on GDP. To translate banks into quantities technically recoverable at equipment EOL, it was estimated that 91.2% of the original charge is recoverable, based on the following assumptions: annual leak rate of 2%; average equipment lifetime of 20 years; and recovery efficiency of 95%.

Bottom-Up Methodology

No bottom-up estimates were developed for this sector due to a lack of data. In addition, this end-use was identified as a low priority given that it only represents an estimated 1.5% of remaining ODS banks in the EC, based on top-down estimates developed by IPCC/TEAP (2005). Moreover, according to EC company reports, the fire protection sector accounted for only 0.7% of total F-gases placed on the market in the EU in 2007.

[61] An annual decline of 5% is modeled, based on the assumption that no new HCFC fire extinguishing systems will be used beginning in 2010 and that such systems have a lifetime of 20 years (i.e., 1/20= 5%).

Appendix B: Approved OD Destruction Technologies

The table below presents approved ODS destruction technologies per Annex VII of Regulation (EC) No 1005/2009. Approved destruction facilities referred to in Article 22(1) are listed along with the types of materials that may be destroyed in each facility.

Table B-1: List of Approved Destruction Technologies for Various Types of ODS

Technology	Applicability		
	Concentrated Sources[a]		Dilute Sources[b]
	Annex A, Group I; Annex B; Annex C, Group I.	Halon (Annex A, Group II)	Foam
Destruction and removal efficiency (DRE)[c]	99.99%	99.99%	95%
Cement kilns	Approved	Not Approved	
Liquid injection incineration	Approved	Approved	
Gaseous/fume oxidation	Approved	Approved	
Municipal solid waste incineration			Approved
Reactor cracking	Approved	Not Approved	
Rotary kiln incineration	Approved	Approved	Approved
Argon plasma arc	Approved	Approved	
Inductively coupled radio frequency	Approved	Approved	
Microwave plasma	Approved		
Nitrogen plasma arc	Approved		
Gas phase catalytic dehalogenation	Approved		
Superheated steam reactor	Approved		

[a] Concentrated sources refer to virgin, recovered and reclaimed ozone-depleting substances.
[b] Dilute sources refer to ozone-depleting substances contained in a matrix of a solid, for example foam.
[c] The DRE criterion presents technology capability on which approval of the technology is based. It does not always reflect the day-to-day performance achieved, which in itself will be controlled by national minimum standards.

Appendix C: Contact Information for Known EU Destruction Facilities

This appendix presents the available contact information for each known commercial destruction facility in the EU-27, based on ICF (2008a, b) and phone calls made/emails sent by ICF International to facilities for this report in order to confirm their acceptance of ODS/F-gas waste. As shown in Table C- 1, 23 commercial ODS/F-gas destruction facilities are confirmed to be in operation across 11 Member States.[62] In addition to these facilities, five others are believed to accept ODS/F-gas waste, but due to language or other logistical barriers, could not be confirmed through this study. These facilities are presented in Table C- 2.

Table C- 1: Confirmed Commercial Destruction Facilities in the EU-27 Accepting ODS/F-Gases

Country	Company Name	Address	Website Address
Austria	Fernwärme Wien GmbH – EBS	Fernwärme Wien GmbH – EBS 11. Haidequerstraße 6 1110 Wien	
Belgium	Indaver Poldervlietweg	Indaver Poldervlietweg 2030 Antwerpen	
Czech Republic	SPOVO s.r.o.	SPOVO s. r. o. Slovenska 2071 70900 Ostrava	http://www.spovo.cz
Denmark	Kommunekemi A/S	Kommunekemi A/S Lindholmvej 3 DK-5800 Nyborg	
Denmark	Odense Kraftvarmevaerk	Havnegade 120 5000 Odense C, Denmark	
Finland	Ekokem Oy Ab	Ekokem Oy Ab P.O.Box 181 FIN-11101 RIIHIMÄKI	www.ekokem.fi
France	SIAP	SIAP Boulevard de l'industrie Bassens	

[62] Scan Arc Plasma Technologies AB in Sweden was also contacted, however, this pilot facility is no longer in operation as its pilot phase has expired.

Country	Company Name	Address	Website Address
		33565 Carbon Blanc Cedex	
France	Tredi-Groupe Séché	Tredi Saint-Vulbas Parc Industriel de la Pleine de l'ain BP 55 Saint Vulbas 01150 Lagnieu	
Germany	CURRENTA GmbH & Co. OHG	CURRENTA GmbH & Co. OHG Kölner Straße 41538 Dormagen	
Germany	HIM GmbH	Bundesverband Deutscher, Sonderabfallverbrennungs-Anlagen e.V. (BDSAV), HIM GmbH, Waldstr. 11, D-64584 Biebesheim.	
Germany	GSB – Sonderabfall-Entsorgung Bayern GmbH	GSB – Sonderabfallentsorgung Bayern GmbH Äußerer Ring 50 85107 Baar-Ebenhausen	www.gsb-mbh.de
Germany	Pfahler Müllabfuhr GmbH	Pfahler Müllabfuhr GmbH Gleiwitzer Str. 1 91550 Dinkelsbühl	www.entsorgung.de
Germany	REMONDIS Industrieservice GmbH	REMONDIS Industrieservice GmbH Am Kanal 9 D-49565 Bramsche	
Germany	REMONDIS SAVA GmbH	REMONDIS SAVA GmbH Ostertweute 1 25541 Brunsbüttel	
Germany	REMONDIS TRV GmbH & Co. KG	REMONDIS TRV GmbH & Co. KG Rodenkirchener Str 50389 Wesseling	
Germany	Solvay Fluor	Solvay Fluor GmbH Brüningstrasse 50 65929 Frankfurt/Main	www.solvay-fluor.de
Hungary	Ecomissio Kft.	Ecomissio Kft. H-3580 Tiszaújváros, TVK Ipartelep, POB 11	http://www.ecomissiokft.hu
Hungary	Észak-Magyarországi Környezetvédelmi Kft.	Észak-Magyarországi Környezetvédelmi Kft. H-3792 Sajóbábony, Gyártelep, POB 17.	www.emkkft.hu
Hungary	Győri Hulladékégetõ Kft. (Waste Incinerator Ltd, Győr)	Győri Hulladékégető Kft. H-9010 Győr . POB 2	http://www.gyhk.hu

Country	Company Name	Address	Website Address
Hungary	SARPI Dorog Environmental, Limited (previously ONYX Magyarország)	SARPI Dorog Kft Hungary Postcode:H-2500 Town:Dorog Street: Bécsi u. 131.	http://sarpi.hu
Poland	SARPI Dabrowa Gornicza Sp. z.o.o.		
Slovakia	Fecupral, Ltd. spol sro	Fecupral, Ltd. spol sro Jilemnického 2 080 01 Prešov Slovakia	http://www.fecupral.sk/index.php
Spain	Kimikal S.L	Crla Aeropuerto-El Alquian km.8 04130 El Alquian- ALMERIA	http://www.kimikal.es/
UK	Pyros Environmental Ltd	Charleston Rd. Hardley Hyt South Hampton S0453NX	
UK	Veolia	Veolia Environmental Services Plc Veolia House 154A Pentonville Road London N1 9PE	

Note: An additional company, ScanArc Plasma Technologies AB, previously operated a pilot facility in Sweden with capacity of 100 tonnes per year; however, the pilot phase is complete and the facility is no longer operational due to insufficient demand. The company would consider new business opportunities. Contact person is Carl-Henrik Lindgren (Tel: +46-290 76 78 00; email: chl@scanarc.se or mail@scanarc.se).

Table C- 2: Other Commercial Destruction Facilities in the EU-27 Believed to Accept ODS/F-Gases

Country	Company Name	Address	Website Address
France	SITA	132 rue des Trois Fontanot 92758 Nanterre Cedex	www.sita.fr
Germany	KSR GmbH	KSR Kühl-System-Recycling GmbH & Co. Krayerstr. 48 44866 Bochum	
Germany	TEGA GmbH	Werner-von-Siemens-Str. 18 97076 Wurzburg	info@tega.de
Hungary	Első Vegyi Industria		
Sweden	Sydkraft SAKAB AB	Sydkraft SAKAB AB Norrtorp 69285 Kumla Sweden	

Appendix D: Contact Information for Known EU Reclamation Facilities

This appendix presents the available contact information for each known reclamation facility in the EU-27, based on ICF (2008a, b). In total, 56 commercial reclamation facilities are believed to be in operation across 17 Member States. Insufficient information is available to confirm whether any reclamation facilities are in operation in an additional six Member States (Denmark, Latvia, Malta, Portugal, Romania, and Sweden).

Table D-28: Known Reclamation Facilities in the EU-27[a]

Country	Company Name	Address	Website Address
Austria	AVE Beteiligungsverwaltungs-GesmbH	Airport Road 8, 4063 Hörsching, Upper Austria	
Austria	NÖ Kühlgeräte Entsorgungsges.mbH		
Austria	Saubermacher DienstleistungsAG	Saubermacher Dienstleistungs AG Conrad v Hötzendorfstraße 162 A-8010 Graz	http://www.saubermacher.at/web/at/
Belgium	Chemogas	Westvaartdijk 85 - B 1850 Grimbergen	www.chemogas.com
Belgium	Cogal Belgium	Europark-Noord 49 - B 9100 Sint-Niklaas	www.cogal.be
Belgium	Mebrom	Assenedestraat 4 - B 9940 Evergem	www.mebrom-group.com
Bulgaria	Cool Star		
Bulgaria	Institute of Refrigeration & Air Conditioning JSC	5, Kamenodelska St, Sofia, 1202	
Czech Republic	EKOTEZ spol. s r. o.		
Czech Republic	Esto Cheb, s.r.o.	Palacký 2087/8A, 350 02 Cheb, Czech Republic	http://www.esto.cz/
Czech Republic	KaS, s.r.o.s	Prague Nad Vršovskou horou 3020 11000	http://www.kas.cz/

Country	Company Name	Address	Website Address
Estonia	Estonian Environmental Research Centre	Marja 4D Estonia	http://www.klab.ee/?lang=eng
France	CALORIE FLUOR (ex CALORIE)	503, rue Hélène Boucher BP33 78534 BUC CEDEX	www.dehon.com
France	CREALIS (ex AVANTEC)	20 Rue de Bourgogne BP 211 69802 SAINT PRIEST CEDEX	www.dehon.com
France	CREALIS (ex GALEX, ex DEHON)	36 rue Emmanuel Eydoux BP 128 13321 MARSEILLE CEDEX 16	www.dehon.com
France	CREALIS SAS	rue Coulons 94360 BRY SUR MARNE	www.dehon.com
France	GAZECHIM FROID	13-19 rue Denis Papin 77290 MITRY MORY	www.gazechim.com/froid/
Germany	PDR		
Germany	RCN Chemie GmbH	RCN Chemie GmbH Daimlerstr. 26 47574 Goch	
Germany	Solvay Fluor	Solvay Fluor GmbH Brüningstrasse 50 65929 Frankfurt/Main	
Germany	TEGA		www.tega.de
Germany	Westfalen AG	Industrieweg 43, Muenster,48155	
Germany	TEGA	TEGA - Technische Gase und Gasetechnik GmbH Werner-von-Siemens-Str. 18 D-97076 Würzburg	http://www.tega.de
Hungary	Első Vegyi Industria Zrt	1139 Budapest Kartács u. 6 P.O.B 139	
Italy	Boz Carta Snc	Viale Zuccherificio, 25/a - 33078 San Vito al Tagliamento (PN)	

Country	Company Name	Address	Website Address
Italy	Ecocentro SpA	Via Don Tazzoli 9, 00040 Pomezia (RM)	
Italy	Tazetti S.p.A.	Corso Europa 600/A 10088, Volpiano, (TO), Italia	(Recovery and regeneration – see website: http://www.tazzetti.com/_eng/2_servizi_ambientali.asp)
Italy	ECOEL SRL	Facility address: via tori di confine, 36053 Gambellara Registered Office and Shop: via monte Ortigara 36/b, 36073 Cornedo Vicentino (VI)	
Italy	ECOPOLIS 2000 SRL	Sede Legale: Contrada Casellone sn 74012 Crispiano (Taranto) Sede Amministrativa: Zona Industriale sn 70015 Noci (Bari) Sede Operativa di Nettuno (Roma): Via Cisterna Km 18,300 00048 Nettuno (Roma)	
Italy	FG Soc. Coop. Arl		
Italy	General Gas		
Italy	Guido Tazzetti & C. S.p.A		
Italy	Tazzetti Fluids		
Italy	Eureco Srl – European Ecology International		
Italy	Metalchem Bertelli Srl		
Italy	Puli Ecol Recuperi Srl		
Italy	Tred Livorno SpA, Tred Sud Srl, and Tred Carpi Srl		

Country	Company Name	Address	Website Address
Italy	SIRA	Via Bellini 11 40067 Rastignano Bologna, Italy	
Italy	SIAT S.r.l.		
Italy	CR S.r.l.		
Italy	SEAB Sr.l.		
Ireland	Thermo King	Lisnaskea Auto Electric Refrigeration Derryree Lisnaskea, Co. Fermanagh BT92 0LA Ireland (Northern) Newry Transcold Refrigeration 7c Springhill Road Carnbane Industrial Estate Newry, Co. Down BT35 6EF Ireland (Northern) Ballymena Technical Transport Products Woodside Industrial Estate Woodside Road Ballymena, Co. Antrim BT42 4HX Ireland (Northern)	
Luxembourg	SuperDreckskëscht® fir Betriber	*SuperDrecksKëscht* ® Zone Industrielle Piret L-7737 Colmar-Berg	http://www.superdreckskescht.lu
The Netherlands	Coolrec	Croy 19-25 NL-5653 LC Eindhoven The Netherlands Grevelingenweg 3 NL-3313 LB Dordrecht The Netherlands	http://www.instapinternet.nl/0/97/index.php
The Netherlands	Uniechemie bv	Aruba 21 7332 BJ	

Country	Company Name	Address	Website Address
The Netherlands	Dehon Service Nederland (also part of Eco-collect and Climalife)	Van Konijnenburgweg 84 4612 PL	
Poland	PROZON Foundation		
Slovakia	ABC Klima, sro		
Slovakia	Chladenie, sro		
Slovenija	LTH Škofja Loka d.d.	Kidriceva cesta 66 4220 Skofja Loka	
Spain	Friogas SA		
Spain	Gas Servei		www.gas-servei.com
Spain	Kimical	Ctra Aeropuerto - El Alquián, Km 8 04130 Almeria	
UK	A-Gas UK Ltd	Banyard Road Portbury West Bristol BS20 7XH	www.agas.com
UK	BOC Ltd		
UK	Harp	Gellihirion Industrial Estate Pontypridd CF37 5SX Mid Glamorgan	

[a] Source: Review of the Availability of HCFCs and Feasible Alternatives in the EU 27 Beyond 2010. Report prepared by ICF International for the European Commission. June 2008.

Appendix E: TEAP Estimated Costs

The table below presents TEAP (2009b) cost estimates for ODS collection, transport, recovery, and destruction from various sectors in densely populated and sparsely populated areas requiring low to medium levels of effort. It should be noted that costs to recover "block-pipe" and "block-slab" sectors were not included in this report, as these types of rigid PU slabstock represent small installed volumes in the EU-27, are difficult to separate from other materials, and are likely to result in foam cutting losses of 30% or more. Therefore, the feasibility of recovery of rigid PU slabstock was deemed to be low. It should also be noted that TEAP's estimated costs for the segregation, collection, and transport (recovery) costs for domestic refrigerators were not considered in this analysis for the EU, given that such costs are already being borne in compliance with existing EU/national waste regulations.

Table E-1: TEAP Estimated Unit Costs for Each Sector of the Available Bank Falling into the Low and Medium Effort Categories

Effort Level	Sector	Population Density	ODS Recovered	Segregation/Collection Costs	Transport Costs (Recovery)	Recovery Processing Costs	Transport Costs (Destruction)	Destruction Costs	Total Cost
				(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)
Low Effort	Domestic Refrigerators	Dense	Refrigerant	6-10*	6-8	10-20	0.01-0.06**	5-7	27-45
	Domestic Refrigerators	Dense	Blowing Agent			20-30			37-55
	Commercial Refrigeration	Dense	Refrigerant	8-12*	8-10	8-15	0.01-0.06**	5-7	29-44
	Commercial Refrigeration	Dense	Blowing Agent			25-35		5-7	46-64
	Transport Refrigeration+	Dense/Sparse	Refrigerant	------	------	15-20	0.01-0.06**	5-7	20-27
	Industrial Refrigeration	Dense/Sparse	Refrigerant	------	------	4-6	0.01-0.06**	5-7	9-13
	Stationary A/C^	Dense	Refrigerant	1-2^^	------	4-25	0.01-0.06**	5-7	10-34
	Mobile A/C	Dense	Refrigerant	------	------	4-6	0.01-0.06**	5-7	9-13
	Fire Protection	Dense	Fire Suppressant	1-2^^	------	4-25	0.01-0.06**	6-8	11-35
Medium Effort	Domestic Refrigerators	Sparse	Refrigerant	10-15*	30-40^^^	10-20	0.01-0.06**	5-7	55-82
	Domestic Refrigerators	Sparse	Blowing Agent			20-30			65-92

Effort Level	Sector	Population Density	ODS Recovered	Segregation/Collection Costs	Transport Costs (Recovery)	Recovery Processing Costs	Transport Costs (Destruction)	Destruction Costs	Total Cost
				(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)	(US$ per kg)
	Commercial Refrigeration	Sparse	Refrigerant	15-20*	40-50^^^	8-15	0.01-0.06**	5-7	68-92
	Commercial Refrigeration	Sparse	Blowing Agent			25-35		5-7	85-112
	Stationary A/C	Sparse	Refrigerant	1-2^^	------	10-35	0.01-0.06**	5-7	16-44
	Mobile A/C	Sparse	Refrigerant	1-2^^	------	4-6	0.01-0.06**	5-7	10-15
	Steel-faced Panels	Dense	Blowing Agent	75-90	5-10	30-40	0.01-0.06**	5-7	115-147
	Block – Pipe	Dense	Blowing Agent	10-15	15-20	30-40	0.01-0.06**	5-7	60-82
	Block – Slab	Dense	Blowing Agent	80-100	5-10	30-40	0.01-0.06**	5-7	120-157
	Fire Protection	Sparse	Fire Suppressant	1-2^^	------	10-35	0.01-0.06**	6-8	17-45

* Very dependent on local collection strategy

** Covering shipment distances of 200-1000 km for destruction

+ Refrigerant only

^ Assumed on-site recovery

^^ Awareness raising for recovery schemes

^^^ Shipping complete units

Appendix F: Summary of Comments and ICF Response

This appendix presents the comments received on the draft report and ODS banking model as well as ICF's response. Specifically, this appendix first presents the list of registered participants for the Webinar held on 22 March 2010, the comments/responses made during the Webinar, and then a summary of the comments/responses provided subsequently in writing.

List of Registered Webinar Participants (22 March 2010)

Approximately 40 people attended the webinar in person, with roughly 90 others participating online. The list below includes all participants registered prior to the event.

Name	Affiliation
Alis Cantano	Blas de Lezo Abogados y Consultores
A. Moral	Ministerio de Medio Ambiente, y Medio Rural y Marino Área de SAO y Gases Fluorados
Alan Elder	Tyco Fire Suppression & Building Products
Alessandro Peru	ITALY- Ministry for the Environment, Land and Sea DG for Environmental Research and Development
Alexandra Maratou	Shecco
Alina Danielsen	Returgass
Andrzej Soboń	Stena--CFC Production Manager
Andy Craddock	Delphi Product & Service Solutions
Andy Lindley	Ineos Fluor
Anthony Aquilina	Environmental Permitting & Industry Unit Malta Environment and Planning Authority (MEPA) Environment Protection Directorate (EPD)
Antonella Angelosante	ITALY- Ministry for the Environment, Land and Sea DG for Environmental Research and Development
Arnie Vetter	Caleb Management
Åsa Grytli Tveten	NORWAY- Climate and Pollution Agency
Barry J. Lyons	BOC Refrigerants
Béatrice Vincent	Secrétariat du FFEM / French GEF Secretariat
Benoît Loicq	ECSA- European Community Shipowners' Associations
Boyan Rashev	
Brian Winning	Emissions Trading, Climate Change and Greener Scotland, Climate Change and Water Industries Directorate

Caitríona Collins	IRELAND - Environmental Protection Agency (Resource Use Unit, Office of Climate, Licensing and Resource Use)
Christianna Papazahariou	Shecco
Christoph Becker	RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment
Clare Perry	
Claudia Albuquerque	European Standards Center, LG Electronics European Shared Service Center BV
Cornelia Elsner	Federal Environmental Agenc, Dep.: Environmental Product Management (Dessau)
Cristina Vaz Nunes	Agência Portuguesa do Ambiente (PORTUGAL) DACAR - DPAAC
Dan Main	Delphi Product & Service Solutions
Darcy Nicolle	United Technologies Corporation
Dean Overton	Overton Recycling Ltd
Dennis Jones	BOC Limited
Dietram Oppelt	
Dolores Rollán Monedero	Ministerio de Medio Ambiente, y Medio Rural y Marino D.G. de Calidad y Evaluación Ambiental, S.G. de Calidad del Aire y Medio Ambiente Industrial
Duncan Roebuck	SEPA (Scottish Environment Protection Agency), Air Policy Unit
Elizabeth Chrominska	Defra, Atmosphere and Local Environment Programme
Emilio Tombolesi	Carnival Corporation& PLC
Ene Kriis	ODS and F Gas Uni, Estonian Environmental Research Centre
Fionnuala Walravens	Environmental Investigation Agency (EIA)
Francis Altdorfer	ECONOTEC
Francis Burraston	A-Gas (UK) Ltd
Georgina Le Neve	Foster British Soft Drinks Association
Graeme Milne	
Gunther Wolff	European Commission
Heidrun Gudmundsdottir	Department for environmental quality, Environment Agency of Iceland
Hilde Dhont	Daikin Europe N.V.
Hookyung Kim	Caleb Management
Ilias Manolis	
Ils Moorkens	Transitie, Energie en Milieu, VITO NV

Irena Koteska	Environmental Agency of the Republic of Slovenia
Irene Papst	
J. Roberts	
Jadwiga Poplawska-Jach	ODS/F-Gas banks expert for government of Poland
Jakob Graichen	Öko-Institut e.V. (Institute for Applied Ecology)
Jana Borská	Air Protection Department, Ministry of Environment of the Czech Republic
Janusz Kozakiewicz	Ozone Layer and Climate Protection Unit, Industrial Chemistry Research Institute, Warsaw, Poland
Jason Yapp	Caleb Management
Jean Clarke	Department of Environment, Heritage and Local Government (Dublin)
Jeff Cohen	EOS Climate Inc.
Jeff Weeks	environCom England Ltd
Jennifer Tonin	Euro Car Parts Ltd
John Allen	Tyco Fire Suppression & Building Products
Jurga Rabazauskaite	MINISTRY OF ENVIRONMENT OF THE REPUBLIC OF LITHUANIA, Pollution Prevention Department, Climate Change and Hydrometeorology Division
Karen Kendrick	Defra / Atmosphere and Local Environment
Keith Duncan	Design & Estimating Manager, Honeywell Control Systems Ltd
Keith Goodall	Goodall Consultancy
Kris Pollet	Pollet Environmental Consulting
Lissie Klingenberg Jørgensen	
Malcom Rochefort	Kingspan
María Lezcano Bermudez de Castro	Ministerio de Medio Ambiente, y Medio Rural y Marino Área de SAO y Gases Fluorados
Maria Ujfalusi	SWEDISH ENVIRONMENTAL PROTECTION AGENCY, Enforcement and Implementation Department
Marija Teriosina	MINISTRY OF ENVIRONMENT OF THE REPUBLIC OF LITHUANIA, Pollution prevetion department, Chemicals management division
Martin Dieryckx	Daikin
Mary Archer	BAE Systems Surface Ships Limited
Maxime Charles De La Brousse	Internal Affairs Manager, EPEE Secretariat
Melanie Miller	

Michael Cullen	Intel Ireland Limited (Branch), Collinstown Industrial Park, Leixlip, County Kildare, Ireland
Mike Jeffs	Consultant
Mike Nankivell	UK Air Conditioning and Refrigeration Industry Board's (ACRIB) committee on F-Gas Regulation, Chairman
Miki Yamanaka	Daikin Industries, Ltd, Global Environmental Promotion Group Leader CSR & Global Environment Center
Mikkel Aaman Sørensen	Danish Environmental Protection Agency
Nadine Rauscher	Dow Building Solutions - EU EH&S
Oliver Loebel	PU Europe (formerly BING)
Oliver Sloan	Director Styrenics Chain (incl EXIBA) CEFIC & PlasticsEurope
Olivier Janin	AREA
Paul Ashford	Caleb Management
Paul Mottram	National Refrigerants Ltd
Pauline Agius Farrugia	
Peter Dinnage	IDS Refrigeration Limited
Peter Jones	Consultant
Peter Seizov	Denkstatt--Consultant for the Bulgarian Executive Enviromental Agency (Ministry of Environment and Water)
Richard Catt	Carnival UK
Richard Marcus	RemTec
Sabine Gores	Öko-Institut e.V. (Institute for Applied Ecology)
Satoshi Kayano	Panasonic Europe Ltd. - Environment & Production Support Office
Shpresa Kotaji	Huntsman Polyurethanes - For ISOPA
Sofie Vanmaele	Flemish Government - Environment, Nature and Energy Department - International Environmental Policy Division
Stefano Vit	De'Longhi Appliances s.r.l.
Stephen P. Mandracchia	Hudson Technologies
Stephen Reeves	Defra, Ozone and F Gas Team, Atmosphere and Local Environment
Sven Claeys	Vlaamse Overheid Departement Leefmilieu, Natuur en Energie Afdeling Lucht, Hinder, Riscicobeheer, Milieu & Gezondheid
Tapio Reinikainen	
Tiago Seabra	Agência Portuguesa do Ambiente (PORTUGAL) DACAR - DPAAC
Tobias Schellenberger	Industrieverband Polyurethan-Hartschaum e. V.

Tom Batchelor	Touchdown Consulting Brussels
Tom Dauwe	VITO - Transition Energy and Environment
Tom Land	Stratospheric Protection Division, U.S. Environmental Protection Division
Valentina Bertato	CEFIC
Valérie HAMMER	Déléguée Générale - USNEF
Varvara Daubarienė	MINISTRY OF ENVIRONMENT OF THE REPUBLIC OF LITHUANIA, Chemicals Division, Environmental Quality Department Veerle DeSmedt Daikin Europe N.V.
Yvette Hood	Waste & Resources Evidence Programm, Department for Environment, Food and Rural Affairs (Defra)

Comments/Questions Raised During Webinar (22 March 2010)

1. The report assumes a 50-year life for building foam, but lots of evidence suggests this may not be realistic. What are the authors' thoughts?

   Response:
   Any of the parameters in the model can be updated as necessary in the future. Lifetimes can perhaps be disaggregated by building type in the future.

2. Foam sales data was provided for 2001 and 2008 for the bottom-up analysis. Does ICF think this is sufficient? Although the data is confidential, can anything be shared?

   Response:
   These two years of data were what was available, and they were used to benchmark the installed base. We believe it is the best available approach, but if more information is available from industry it would be great. It should be noted that one of the key areas of uncertainty is how the EU-wide bank is disaggregated by country; this is where we could use country specific data if available.

   No, we cannot share the industry data given to us on confidential basis.

3. A study undertaken by DEFRA (UK) estimated a bank of 22,700 tons of construction foams, which is not consistent with ICF's report. How can you explain the discrepancy?

   Response:
   ICF coordinated with Mike Jeffs and Paul Ashford on this effort, and the information sharing process is ongoing. Conceivably, we would work to incorporate new data over time into this modelling approach.

   Clarification from Paul Ashford on the message board: Just to confirm that my role on this project was only as an early Peer Reviewer of the model on behalf of DEFRA. There has been no effort, as yet, to reconcile or align the data included in this report with that contained in the BRE/ERM/Caleb report prepared by DEFRA.

4. What is the differentiation between Large/Small AC units and average charge of gases used? How were definitions determined?

   Response:
   The model defines "Small Stationary" to include unitary, split, multisplit, packaged, and single duct residential and small commercial AC, residential and small commercial heat pumps, window units, less than 75 kW. "Large Stationary (Chillers)" include positive displacement and centrifugal chillers greater than 75 kW. These definitions are based on the Armines reports.

   The model clearly defines these definitions, though they were not clearly laid out in the report. We will add the definitions to the report.

5. Were structural foams included in the model?

   Response:
   One component foam is included in the top-down estimates under the construction foam category; however, the bottom-up estimates do not include this type of foam.

6. How have exports and imports been treated for products and equipment?

   Response:
   Our approach in the bottom-up model was to estimate installed base by country based on consumption, not on where it came from or where it was manufactured. So exports and imports should not be a concern for the bottom-up model.

7. How were the top-down estimates handled?

   Response: Top-down estimates were disaggregated by GDP at the country level.

8. In reference to land transportation (i.e., temperature controlled trucks), there is both blowing agent and refrigerant in the body of the truck, and also refrigerant in the AC system of drivers' cabin. What is included in the banking model?

   Response:
   For Refrigerated Transport (Land) in the bottom-up model, foams in trucks are not included. Only refrigerants in the body of the truck—not the drivers' cabin—are included (i.e., the refrigeration associated with the refrigeration unit itself). The mobile AC sector of the bottom-up model could be expanded in future to estimate banks from the AC systems in drivers' cabins of trucks.

9. Where were the banks figures for refrigerated transport retrieved? Can you provide more information on where these estimates came from?

   Response:
   Please see details provided in Appendix A of the report.

10. What is the source of the numbers used for assumed refrigerant/blowing agent charge size and lifetime in domestic refrigerators?

    Response:

A lifetime of 15 years was assumed for refrigerators/freezers. Please see the details provided in Appendix A of the report for additional information on the source of the estimates used.

11. For refrigerators/freezers, a 15-year lifetime is questionable. For example, in Sweden, the average lifetime is much higher—22 years. One would expect that in countries with lower incomes, people would wait even longer before replacing units.

    Response:
    Average lifetimes of refrigerators/freezers are uncertain, and longer lifetimes have been reported. However, 15 years is a generally accepted lifetime (e.g., used by TEAP). If deemed appropriate, the assumed lifetime can be changed in future model updates.

12. Regarding MVACs, you assume a charge size of 750g for HFCs out to 2050. I would have thought the average charge would be smaller going forward. Why not trending smaller charge size across time series?

    Response:
    These are types of things we do need to get a handle on. Is there published information that says that charge size should trend down overtime? If so then we would want to incorporate.

    Currently the model isn't designed to allow for trending charge sizes over time. Rather, the model is designed to tailor charge size only by broad refrigerant type. (i.e., CFC, HCFC, HFC). Having charge sizes vary over time by chemical would require some adjusting to the model.

    But, if we're talking of going from 750g to 700g, that would be a change of less than 10%, which is a rather minor change in the grand scheme of things. Of primary importance is to obtain information on sectors/end-uses for which we don't have a lot of information, rather than focusing on small fixes to the other end-uses. [Note: based on additional comments provided by EFCTC, the assumed charge size for HFC MVACs in the bottom-up model has been reduced from 750 g to 700 g.]

13. What can be said about the accuracy of data used for the banks, recovery, and costs – how do you see the quality of your data?

    Response:
    This question was inadvertently not addressed during the webinar, but the areas of greater versus lesser certainty can be summarised as follows.

    Regarding equipment stocks, estimates for the following end-uses are deemed to be of high quality (low uncertainty):
    - Passenger cars and buses
    - Refrigerators/freezers
    - Refrigerated transport, land
    - Refrigerated transport, ships

    Regarding equipment stocks, estimates for the following end-uses are deemed to have greater uncertainty:
    - Industrial refrigeration
    - Commercial refrigeration: small and medium/large

- Stationary AC, small and large
- Construction foams (particularly with regards to disaggregation of stocks by Member State)

Regarding recovery feasibility and costs, there is greatest uncertainty regarding construction foams—particularly for boardstock foams, for which there is the least practical experience with recovery.

14. Poland submitted data/updates that are not in draft report, will the final report be changed to reflect the data?

    Response:
    Two requests for data changes from Poland have been received. We were able to incorporate the first, but not the second. The reason is that it's important to get a host of information, and then update the model comprehensively. We would wish to have information from other Member States, and then assess that data together with the data from Poland, in order to streamline updates and ensure that the overall methodology (for all EU-27 countries) is sound. For example, for many end-uses, we apply a single set of assumptions for all EU-12 countries, so if we change the approach for Poland, we need to determine if the approach should similarly be changed for other countries. Data is important, but we cannot perform model updates whenever we get new information from a Member State.

15. But some data assumptions in the report are false—for example, landlocked countries will not have banks in ship/transport.

    Response:
    Landlocked countries have rivers and may have flagged ships– but will look again at this to make sure it's accurate. [Based on further follow-up, we apportioned the estimated number of EU refrigerated transport ships by country using the 2008 UNCTAD handbook of statistics, which provides "world merchant fleet by flag of registration and by type of ship" in dead weight tons. Using this data, the only countries that had 0% of Europe's merchant fleet were the Czech Republic, Hungary, and Slovenia. Twelve countries had >1%, and the remaining 11 countries, including Poland, had <1%. Therefore, while Poland's share of EU ships is very small, it is not believed to be zero.]

16. Can you provide more details on the figures in the report? There appear to be some rounding errors.

    Response:
    We can look into rounding errors; please let us know if there are specific clerical errors and we will be sure to address them in the final report.

Summary of Additional Comments and Responses

In addition to comments received during the webinar, a number of additional comments were provided in writing by stakeholders following the webinar. Comments that resulted in quantitative model changes are summarized below.

1. One industry association commented on the percent of blowing agent content in sandwich panels.

    Corresponding model update:

Changed the percent of blowing agent content in sandwich panels from 12% for CFC-11 and 10% for HCFC-141b to 8% for CFC-11 and 6.5% for HCFC-141b.

2. One industry association commented on average blowing agent loss rates and the percent remaining at EOL.

   Corresponding model update:
   The percent of blowing agent remaining at EOL was revised based on average blowing agent loss rates for ODS and HFCs (in lieu of HFCs only), based on emission factors provided in IPCC (2006) and TEAP (2005) in year 1 and annually thereafter. This affected the following foam end-uses: commercial refrigeration (from 90.5% to 92.5% remaining at EOL); discontinuous sandwich panels (from (69.5% to 66.5% remaining at EOL); boardstock (from 45% to 57.25% remaining at EOL); spray foam (from 11.5% to 31.1% remaining at EOL), and foam boards (from 11.5% to 12.75% remaining at EOL).

3. One industry association commented on the percent of XPS foam assumed to be technically recoverable at EOL, noting that it is unlikely to exceed 50%.

   Corresponding model update:
   The assumed percent blowing agent recoverable at EOL from XPS foam was revised from 70% to 50%.

4. Three stakeholders commented on the charge size of passenger motor vehicle air-conditioners (MVACs).

   Corresponding model update:
   Changed HFC MVAC charge size in passenger vehicles from 750 g to 700 g.

5. One industry association questioned why so much ODS refrigerant remained installed in the refrigeration/AC sector in 2030 and 2040.

   Corresponding model update:
   Stock phaseout dates for CFCs, HCFCs, and, in some cases, HFCs, were applied to the refrigeration/AC end-use, as presented in Appendix A. As a result, the quantity of HCFC banks has been decreased. By 2030, there is no longer any CFC or HCFC banks in the refrigeration/AC sector.

6. One stakeholder commented on the foam end-uses included in the TEAP top-down bank estimates. Specifically, it was noted that the TEAP assessment of banks does not include blowing agents used in XPS sheet, since it is known that blowing agent retention in this applications is very short (much shorter than XPS Board).

   Corresponding model update:
   The methodology for disaggregating top-down foam estimates by end-use was revised such that XPS sheet foam is no longer included in the disaggregated construction foams banks.

Relevant comments that could not be quantitatively addressed at this time were flagged for future model updates as follows:

1. Representatives from two Member States and one industry association provided country-level data on banks, equipment charge size, stock, and/or other key data points.

2. Two industry associations provided EU-wide data on banks and/or specific end-uses. For example, one industry association suggested that the charge size for large stationary AC be reduced from 210 kg to 40 kg.

3. One stakeholder provided information on the relative consumption of XPS board foam in the EU, noting much greater consumption in Germany.

4. One stakeholder commented on the shorter lifetimes of industrial/commercial buildings compared to domestic buildings in the UK, as well as the importance of considering building replacement rates, not simply demolition rates.

5. One stakeholder commented on the need to quantify model uncertainty and apply multiple value assumptions (i.e., upper-bound and lower-bound assumptions) to key variables.

6. Two industry and Member State stakeholders commented on the need to systematically review and collect new data, including the UNFCCC reports on emission inventories to cross-walk/validate the Banking Model.

7. One Member State suggested further disaggregating the sub-sector "Mobile AC" to include "trucks", "ships", "rail vehicles", and "agricultural machinery."

Finally, a number of comments were addressed through text edits in the body of the report. Notable examples include:

1. One stakeholder noted the importance of highlighting the regulatory option of clearly mandating the recovery of ODS foam from certain C&D waste. [See added language in Section 5.1.2.]

2. One stakeholder suggested that indicative costs be provided to underscore how destruction costs will be greater for those States without destruction facilities located within their borders, due to additional transport needs. [Indicative costs for transport are now provided in Section 3.7.1.]

3. One stakeholder questioned whether the collection and destruction of ODS would be considered "additional"—i.e., eligible for carbon credits—if regulations are already in place to require its collection and destruction. [Text has been added to Sections 6.]

4. One Member State representative and one industry association provided information on the names and location of additional destruction and reclamation facilities operating in the EU. [These facilities were added to Section 3.7 and Appendices C and D.]