Supply and Demand of Recycled Hydrochlorofluorocarbons (HCFCs) in Existing Refrigeration and Air Conditioning Equipment Beyond 2009: Analysis of Regulatory Phaseout Scenarios

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Executive Summary

This study collected and compiled available data from EU-25 Member States, as well as Bulgaria and Romania, to develop a top-down consumption model to estimate the supply and demand for recycled HCFCs from refrigeration/AC equipment, by country and by year. Based on the model output, the costs and benefits of equipment abandonment under the following three phaseout scenarios were projected:

- Reference scenario: existing measures in the Regulation are maintained (i.e., phaseout of recycled/reclaimed HCFCs occurs in 2015);
- Advanced phaseout scenario: recycled/reclaimed HCFC consumption is prohibited to service equipment beginning in 2012;
- Extended phaseout scenario: recycled/reclaimed HCFC consumption is allowed to service equipment until 2020.

In addition to the model, a separate analysis was conducted to assess the feasibility of available HCFC alternatives that qualitatively explored the economic and environmental impacts of HCFC replacement.

The major findings of this report are summarised below. It is recommended that the data output from the top-down consumption model estimates developed for this report be compared to estimates generated through a bottom-up modelling exercise on a sector or country basis, if possible, to substantiate the results provided herein.

Alternatives

Figure ES-1 summarises the feasibility of alternative refrigerants and technologies by end use. As shown, alternatives to HCFCs are available for all equipment types. Although not explored quantitatively in this analysis, feasible drop-in alternatives also exist in a variety of end uses (e.g., medium- and low-temperature retail food systems and residential and commercial AC units, food processing and storage applications). However, in some end uses, only alternatives with high GWPs (i.e., HFCs) are currently available. The affected applications include some small commercial refrigeration, certain refrigerated transport applications, and small and large stationary air conditioning systems (chillers, window AC, and unitary AC). An earlier phaseout of HCFCs will entail a greater dependence on HFCs, as less time will be available to develop/advance non-GWP or low-GWP alternatives that are safe, reliable, energy-efficient, and cost-effective. Further, industry has raised concerns that an expedited phaseout (pre-2015) would impose disproportionate economic and technical burdens on the competitiveness of European companies, particularly small and medium-sized enterprises (SMEs).

Figure ES-1: Feasibility of Alternative Refrigerants and Technologies by End Use[a]

Alternative	Small Retail Food	Large Retail Food		Refrigerated Transport	Industrial Process Refrigeration	Small AC		Large AC (Chillers)
	Stand-Alone Equipment	Large Supermarket Systems	Cold Storage			Unitary AC (Commercial & Residential)	Window AC Units	
Alternative Refrigerants								
R-32					✓			
R-134a	✓	✓	L	✓	✓		✓	✓
R-236fa					P			
R-245fa					P			P
R-365mfc					P			
R-404A	✓	✓R	✓	✓	✓		✓	
R-407C		✓R	✓	✓L		✓	✓	✓

Alternative	Small Retail Food	Large Retail Food		Refrigerated Transport	Industrial Process Refrigeration	Small AC		Large AC (Chillers)
	Stand-Alone Equipment	Large Supermarket Systems	Cold Storage			Unitary AC (Commercial & Residential)	Window AC Units	
R-407D		R		RL				
R-410A			M	✓L	✓	✓	✓	✓
R-417A	✓R	✓R	✓R		✓R	✓R	✓R	
R-422A	✓R	✓R	✓R		✓R			
R-422D	✓R	✓R	✓R		✓R	✓R	✓R	
R-507A		✓R	✓	✓L	✓		✓	
Propane (R-290)	✓L		M	✓L	✓	P	✓	✓L
Isobutane (R-600a)	✓L			✓L				✓L
Propylene (R-1270)				✓L	✓			✓L
Ammonia (R-717)	✓L		✓	✓L	✓L			✓L
CO_2 (R-744)	✓L	P	ML	P	✓	P		P
Alternative Technologies								
Secondary Loop		✓	✓L		✓			
Cascade		M	M	M	M			
Distributed		✓						

[a] New technologies are always entering the market that could further facilitate the transition to alternatives.
✓ = Feasible now in new equipment
M = New market entrant (associated with higher costs, at least in short-term)
P = Potential for use in future
L = Limited application (in new equipment or as retrofit, as specified)
R = Retrofit is feasible or potentially feasible
Note: blank spaces represent lack of actual or potential feasibility in new or existing systems.

Supply

Figure ES-2 presents the total R-22 servicing demand (in metric tonnes) projected in 2005 through 2019, by country for the EU-25, Bulgaria, and Romania. (Assumptions used to estimate servicing demand are presented in Section 2.1.) Figure ES-3 presents the projected year-end annual supply of recycled R-22 by country and year from 2010 to 2019, as well as the inventory of recycled R-22 estimated to be stockpiled over the years 2000-2009 if stockpiling is assumed to occur in preparation for the 1 January 2010 prohibition on the use of newly produced R-22 in refrigeration and AC equipment (assumptions used to estimate stockpiled refrigerant from 2000-2009 are presented in Section 2.2.2.)

In terms of available supply of recycled/reclaimed HCFCs, it is critical that pre- and post-2010 recovery and stockpiling of R-22 occur in order to avoid shortfalls, regardless of the phaseout scenario selected, even with aggressive stockpiling efforts. The EU-10 however, and especially Bulgaria and Romania, will require additional supply from the EU-15 to meet on-going needs. Additional reclamation capacity from the EU-15 may be needed to help the EU-10 and Bulgaria and Romania maximise refrigerant reuse. A mechanism and proper infrastructure will also be needed to facilitate trade in recycled R-22 between the EU-15 and the EU-10, Bulgaria, and Romania.

Should a supply shortfall materialise in the EU-10, Bulgaria, or Romania, additional equipment abandonment may occur in these countries beyond what is projected in this analysis. Or, at a minimum, equipment in those countries may operate sub-optimally and/or be topped off with other fluids for which the systems were not designed, leading to operational inefficiencies and potentially, health or safety hazards.

Figure ES-2: Total Year-End R-22 Servicing Demand Projected by Country for the EU-25+2, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	2,562	2,295	2,028	1,761	1,494	1,228	963	697	496	302	107	86	64	43	21
Belgium	3,060	2,741	2,422	2,103	1,784	1,467	1,150	833	593	360	128	103	77	51	26
Bulgaria	55	55	55	51	46	42	37	33	28	24	19	15	12	9	7
Cyprus	135	123	111	99	87	75	63	50	39	31	23	16	10	3	2
Czech Rep.	35	32	29	26	22	19	16	13	10	8	6	4	3	1	1
Denmark	2,146	1,922	1,698	1,475	1,251	1,029	806	584	416	253	90	72	54	36	18
Estonia	26	24	22	20	17	15	13	11	9	7	6	4	2	1	1
Finland	1,634	1,464	1,293	1,123	953	783	614	445	316	192	68	55	41	27	14
France	1,967	1,758	1,548	1,339	1,129	938	746	555	429	310	191	153	114	76	38
Germany	882	760	637	515	393	318	243	174	106	38	30	23	15	8	0
Greece	1,604	1,436	1,268	1,100	932	765	598	430	306	186	66	53	40	26	13
Hungary	114	104	93	83	73	63	53	43	33	26	19	14	8	3	2
Ireland	1,409	1,262	1,114	966	818	671	524	377	268	163	58	46	35	23	12
Italy	7,947	7,109	6,270	5,431	4,592	3,758	2,924	2,090	1,485	903	321	257	193	128	64
Latvia	35	32	29	26	23	20	16	13	10	8	6	4	3	1	1
Lithuania	83	75	68	61	53	46	38	31	24	19	14	10	6	2	2
Luxembourg	269	241	213	184	156	128	100	71	51	31	11	9	7	4	2
Malta	69	62	56	50	44	38	32	26	20	16	12	8	5	2	1
Netherlands	558	503	448	393	339	284	230	176	132	89	46	37	28	19	9
Poland	531	484	436	389	341	294	246	199	154	122	90	64	38	12	10
Portugal	1,483	1,328	1,173	1,019	864	710	557	403	287	174	62	50	37	25	12
Romania	285	285	285	262	238	215	192	168	145	121	98	76	60	44	32
Slovakia	32	29	26	24	21	18	15	12	9	7	5	4	2	1	1
Slovenia	69	62	56	50	44	38	32	26	20	16	12	8	5	2	1
Spain	3,388	3,018	2,647	2,277	1,906	1,537	1,168	800	557	339	120	96	72	48	24
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	4,590	4,107	3,624	3,140	2,657	2,176	1,696	1,216	864	525	187	149	112	75	37
EU-25+2	*34,970*	*31,311*	*27,651*	*23,964*	*20,277*	*16,674*	*13,072*	*9,476*	*6,808*	*4,272*	*1,796*	*1,416*	*1,043*	*670*	*350*

Figure ES-3. Total Estimated Year-End Supply of Recycled R-22 Projected by Country, 2010-2019 (Tonnes)

Country	Assumed Stockpiled R-22 (2000-2009)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	5,703	2,176	2,176	2,176	1,223	1,102	1,102	50	50	50	50
Belgium	6,811	2,599	2,599	2,599	1,462	1,316	1,316	60	60	60	60
Bulgaria	19	12	12	12	12	12	12	11	8	8	6
Cyprus	63	29	29	29	28	20	20	13	13	13	1
Czech Rep.	16	7	7	7	7	5	5	3	3	3	0
Denmark	4,845	1,847	1,847	1,847	1,049	948	948	42	42	42	42
Estonia	10	5	5	5	5	4	4	3	3	3	0
Finland	3,641	1,390	1,390	1,390	781	702	702	32	32	32	32
France	4,384	1,659	1,659	1,659	634	507	507	89	89	89	89
Germany	4,019	463	463	423	423	423	18	18	18	18	18
Greece	1,469	546	546	546	349	329	329	31	31	31	31
Hungary	53	24	24	24	24	17	17	11	11	11	1
Ireland	3,240	1,243	1,243	1,243	672	595	595	27	27	27	27
Italy	7,370	2,752	2,752	2,752	1,701	1,595	1,595	150	150	150	150
Latvia	17	8	8	8	7	5	5	3	3	3	0
Lithuania	39	18	18	18	17	12	12	8	8	8	1
Luxembourg	626	239	239	239	114	114	114	5	5	5	5
Malta	32	15	15	15	14	10	10	6	6	6	1
Netherlands	1,020	363	363	363	276	275	275	22	22	22	22
Poland	250	113	113	113	111	77	77	50	50	50	6
Portugal	1,346	499	499	499	325	308	308	29	29	29	29
Romania	88	56	56	56	56	56	56	55	38	38	25
Slovakia	15	7	7	7	7	5	5	3	3	3	0
Slovenia	32	15	15	15	14	10	10	6	6	6	1

Country	Assumed Stockpiled R-22 (2000-2009)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Spain	3,344	1,279	1,279	1,279	705	599	599	56	56	56	56
Sweden	1,671	0	0	0	0	0	0	0	0	0	0
UK	10,566	4,068	4,068	4,068	2,096	1,855	1,855	88	88	88	88
EU-15	*60,054*	*21,124*	*21,124*	*21,084*	*11,811*	*10,667*	*10,262*	*700*	*700*	*700*	*700*
EU-10	*528*	*240*	*240*	*240*	*235*	*163*	*163*	*106*	*106*	*106*	*12*
Bulgaria & Romania	*107*	*68*	*68*	*68*	*68*	*68*	*68*	*66*	*46*	*46*	*31*
EU-25 + 2	60,690	21,432	21,432	21,392	12,113	10,898	10,493	873	853	853	744

Undue Abandonment

Figure ES-4 presents the projected number of units, by end use, to be retired in each region, under each of the three phaseout scenarios. It should be noted that the estimates of undue abandonment assume that equipment will need to be abandoned as soon as the use ban (for servicing and maintenance) comes into effect, which is unlikely to be the case; rather, some equipment may be retrofit or may stay in use until it can no longer function. Therefore, the levels of undue abandonment projected in this report should be considered an upper bound.

Figure ES-4: Number of Units Retired Prematurely by End Use, Region, and Phaseout Scenario

	Small Commercial Refrigeration	Large Commercial Refrigeration	Refrigerated Transport	Industrial Refrigeration	Small Stationary A/C	Large Stationary A/C	*All End Uses*
EU-15 Countries							
Advanced Phaseout Scenario (2012)	0	60,678	0	14,892	871,373	241,805	*1,188,748*
Reference Phaseout Scenario (2015)	0	0	0	9,290	0	0	*9,290*
Extended Phaseout Scenario (2020)	0	0	0	0	0	0	*0*
EU-10 Countries							
Advanced Phaseout Scenario (2012)	45,564	787	0	359	54,172	5,087	*105,969*
Reference Phaseout Scenario (2015)	0	394	0	261	0	2,543	*3,198*
Extended Phaseout Scenario (2020)	0	0	0	98	0	0	*98*
Romania and Bulgaria							
Advanced Phaseout Scenario (2012)	23,779	310	1,466	128	61,077	2,281	*89,040*
Reference Phaseout Scenario (2015)	11,889	206	0	100	15,269	1,520	*28,986*
Extended Phaseout Scenario (2020)	0	34	0	55	0	253	*342*
TOTAL (EU-25 + 2)							
Advanced Phaseout Scenario (2012)	69,343	61,775	1,466	15,379	986,621	249,172	*1,383,756*
Reference Phaseout Scenario (2015)	11,889	600	0	9,652	15,269	4,064	*41,474*
Extended Phaseout Scenario (2020)	0	34	0	153	0	253	*440*

In the 2015 reference phaseout scenario, less than 10 percent of all equipment projected to be abandoned is located in EU-10 countries, and those countries are also expected to bear under 10 percent of the total cost. The EU-15 countries, while not projected to hold the majority of prematurely retired equipment (22 percent), are projected to bear the majority of the total cost of early retirement (about 83 percent). Finally, Bulgaria and Romania together are projected to prematurely retire 70 percent of all equipment facing undue abandonment, but are projected to only bear about 8 percent of the total cost. These latter countries bear the brunt of undue equipment abandonment but not of costs because their inventory consists largely of small units. By comparison, the EU-15 bears the majority of costs because their inventory tends to be in the large end use sectors (e.g., industrial process refrigeration, large commercial refrigeration, and large stationary AC), which have a high economic value on a per unit basis. However, the estimates of undue abandonment projected in this analysis likely *over*estimate actual abandonment levels, given that (a) no retrofits are assumed to occur and (b) equipment may continue to operate at sub-optimal levels without additional servicing/refilling with R-22 (in lieu of actual retirement).

Costs and Benefits

Figure ES-5 and Figure ES-6 present the projected costs and benefits for the three phaseout scenarios. It should be noted that the actual cost of each phaseout scenario is likely to be *lower* than estimated in this analysis, given that no drop-in replacements (with zero ODP refrigerants) have been assumed to occur. To the extent that low-cost retrofits do occur, the cost effectiveness of each phaseout scenario will be increased, as the costs of undue abandonment will be significantly lower, but the ODP-weighted benefits will be the same as those presented in the analysis.

Figure ES-5. Comparison of Costs by End Use and Phaseout Scenario

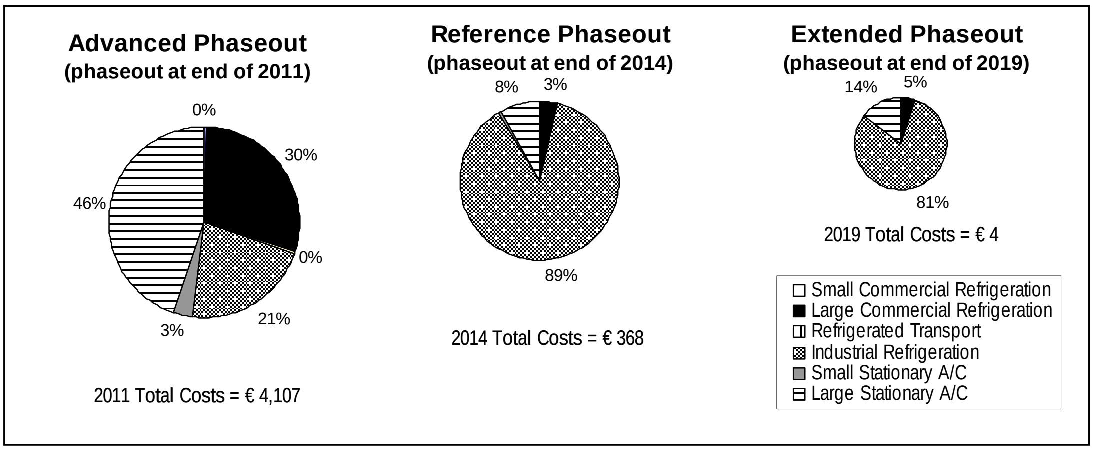
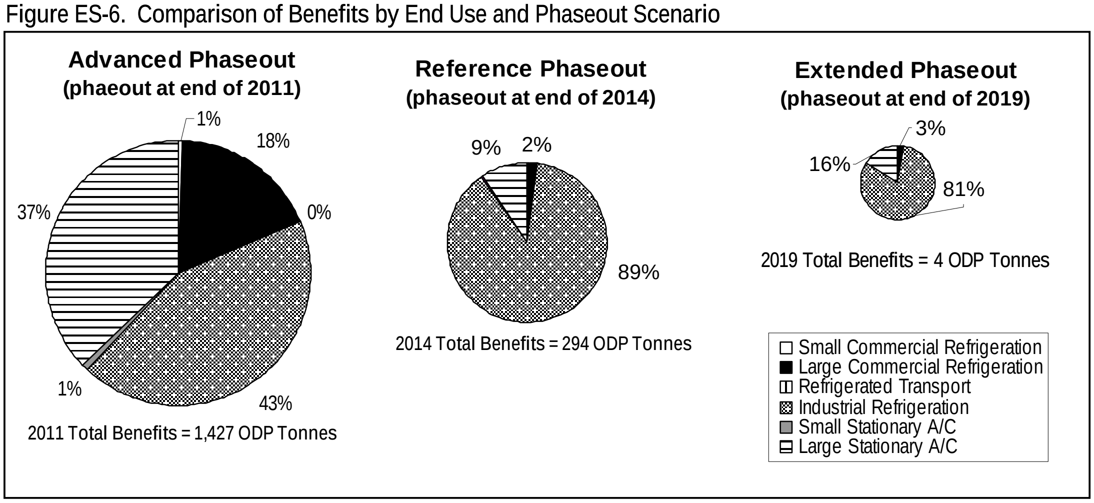


Figure ES-6. Comparison of Benefits by End Use and Phaseout Scenario



Compared to the reference scenario, advancing the phaseout date to 2012 would result in five times greater benefits (1,427 vs. 294 ODP tonnes) but 11 times greater costs (€4,107 vs. €368). The EU-15 would bear the majority of these costs. The economic impact of the advanced phaseout would be 3 times greater than the reference scenario for the EU-15, 4 times greater for the EU-10, and 3 times greater for Bulgaria and Romania. Extending the phaseout date to 2020 yields virtually no costs (€4 million) or benefits (4 ODP tonnes). Indeed, for the EU-15, the extended phaseout is expected to actually yield zero costs or benefits, since equipment in all end uses is expected to be naturally phased out by that date. It should be noted that the actual cost of each phaseout scenario is likely to be lower than estimated in this analysis, given that no drop-in replacements (with zero ODP refrigerants) have been assumed to occur. To the extent that low-cost retrofits do occur, the cost effectiveness of each phaseout scenario will increase. Hence, the costs of undue abandonment will be significantly lower, but the ODP-weighted benefits will be the same as those presented in the analysis. Further, the actual costs and benefits of each scenario may be lower if equipment continues to operate beyond the phaseout date without servicing.

The majority of both costs and benefits are projected to come from industrial refrigeration, large commercial refrigeration, and large stationary air conditioning end uses—large systems with high costs and refrigerant charge sizes/leak rates. In the 2012 phaseout scenario, the large commercial refrigeration and large stationary AC end uses are projected to represent a higher percentage of total costs than total benefits. Conversely, phasing out HCFCs in the industrial refrigeration end use in 2012 will lead to a greater share of total benefits than total costs (43% and 21%, respectively). However, it is still more cost-effective to phaseout industrial refrigeration equipment in 2015 than 2012 (0.8 tonnes per million Euro in 2015 compared to 0.7 tonnes in 2012).

Recommendations

Based on the findings identified in this analysis, **it is recommended that the phaseout date for the EU-25+2 be maintained at 1 January 2015** and that appropriate infrastructure be established to facilitate trade in recycled supplies of HCFCs across EU countries. This conclusion is supported by the following rationale:

- A 2012 phaseout date will lead to higher costs and benefits compared to the reference scenario. Incremental costs, however, are greater than incremental benefits in 2012 compared to 2015. Moreover, many components of European industry would not be prepared for an advanced phaseout date, which could lead to economic hardships beyond those estimated in this report. For example, possible plant closures and impacts on competitiveness have not been considered in the cost calculations. Conversely, business decisions have been made with Regulation (EC) No. 2037/2000 in mind, so that a 2015 phaseout date should not lead to undue burden. Further, a 2012 phaseout date may lead to greater dependence on f-gases, which may be lessened by 2015 with an additional three years for research and development activities.

- A 2020 phaseout date is not recommended because it will lead to virtually no environmental benefits and will postpone industry action (to phaseout HCFC equipment) that has been under preparation for years. Moreover, this study has confirmed the wide availability of alternatives for each end use. Therefore, there is no reason to postpone the phaseout date of 2015 agreed upon in 2000.

One exception to this recommendation that should be considered is the **phaseout of industrial process refrigeration equipment on an advanced schedule**. This is because an advanced phaseout in this end use could yield significant ODS emission reductions (estimated at over 615 ODP tonnes in 2012) and the relative cost-effectiveness for achieving such benefits is quite high (about 0.7 tonnes per million Euro in 2012 assuming a cost of € 883 million). In addition, many non- or low-GWP alternatives are available in this sector, especially for the larger equipment types. However, prior to this type of policy decision being adopted, additional research should be conducted to validate the estimates derived in this analysis. For example, the data from the top-down consumption model developed for this report could be compared to a bottom-up model developed on a sector or country basis and supported by an engineering cost assessment.

Industry input should also be solicited. Indeed, if an expedited (i.e., pre-2015) phaseout is to occur in the IPR sector, industry consultation should begin immediately, as it is recommended that industry be given no less than a five-year lead time to assess and implement alternatives. Because industrial process refrigeration equipment tend to be large, custom-designed systems, companies will require this time to fully analyse safety, space constraints, and energy issues in order to select the refrigerant type and/or system design that is most appropriate for their particular application/facility, and to install the alternative selected.

1. Introduction

1.1 Legislative Background

EC Regulation No. 2037/2000 was adopted in October of 2000 to reduce emissions of ozone depleting substances (ODS) in accordance with the Montreal Protocol. This regulation covers the production, importation, exportation, placing on the market, use, recovery, recycling, reclamation, and destruction of ODS, including chlorofluorocarbons (CFCs), halons, and hydrochlorofluorocarbons (HCFCs). Production of HCFCs began in the 1980s as part of the measures to reduce emissions of more potent ozone-depleting CFCs; however, HCFCs also have ozone depletion potentials (ODP) and must be phased out. The Montreal Protocol, therefore, required non-Article 5 parties to freeze HCFC production as of 2004. The EC implemented more stringent requirements and began the freeze at 1997 production levels in 2001, as required by Article 3(3) of the Regulation. This freeze will be followed by further reductions in production, leading to a halt in production by 2026. The complete EC HCFC phaseout schedule is summarised in Figure 1.

Figure 1: EC Phaseout Schedule for HCFCs

Control Date	Phaseout Schedule
1 January 2001	Freeze HCFC production at baseline of 1997 level
1 January 2009	Reduce HCFC production by 65% of 1997 level
1 January 2015	Reduce HCFC production by 80% of 1997 level
1 January 2021	Reduce HCFC production by 85% of 1997 level
1 January 2026	Reduce HCFC production by 100% of 1997 level

In order to implement the phaseout schedule summarised above, the consumption and sale bans listed in Figure 2 have been established.

Figure 2: EC Control Measures on HCFC Refrigerant Use

Control Date	HCFC Control Measure
1 January 2001	Ban on use of HCFCs in new equipment[a]
1 January 2004	Ban on use of HCFCs in all equipment produced after 31 December 2003
1 January 2010	Ban on use of virgin HCFCs for servicing existing refrigeration/air conditioning equipment
1 January 2015	Ban on use of recycled HCFCs for servicing existing refrigeration/air conditioning equipment
1 January 2016	Ban on use of all HCFCs

[a] The sale of new cold store produced after 31 December 1999 and all other refrigeration and air conditioning equipment produced after 31 December 2000 (with several exceptions noted below) was banned on 1 January 2000 and 2001, respectively. The following exceptions were made to the 31 December 2000 ban on all refrigeration and air conditioning equipment: fixed air conditioning equipment, with a cooling capacity of less than 100 kW, where the use of HCFCs was prohibited from 1 July 2002 in equipment produced after 30 June 2002; and reversible air conditioning/heat pump systems where the use of HCFCs was prohibited from 1 January 2004 in all equipment produced after 31 December 2003.

1.2 HCFC Uses

HCFCs are consumed worldwide in refrigeration, air conditioning (AC), and foam end uses, and to a lesser extent, in aerosol and solvent end uses. HCFC consumption is greatest in the refrigeration/AC sector. Figure 3 presents the most commonly used HCFCs in the air conditioning and refrigeration industry and their ozone depletion potentials (ODPs).

Figure 3: Common HCFC Refrigerants and their ODPs

Chemical Name	ODP
HCFC-22 (CHF_2Cl)	0.055
HCFC-123 ($C_2HF_3Cl_2$)	0.02
HCFC-124 (C_2HF_4Cl)	0.022
HCFC-142b (CH_3CF_2Cl)	0.065

Source: EC Regulation (EC) No 2037/2000.

HCFC-22 is the most commonly used HCFC refrigerant. In AC systems, HCFC-22 is predominantly used in centrifugal and positive displacement compressor water chillers and residential air conditioners and heat pumps. In refrigeration systems, it is most commonly used in retail food and transport refrigeration systems. HCFC-123, another common HCFC, is used primarily in centrifugal water chillers for commercial comfort air conditioning and in industrial process refrigeration.

Many refrigerants are blends of several HCFCs, as well as other substances, such as hydrofluorocarbons (HFCs) or propane. Figure 4 presents the composition of some of the more common refrigerant blends containing HCFCs used in refrigeration and AC equipment worldwide.

Figure 4: Common HCFC Blends Used in Refrigeration and Air Conditioning Equipment

Refrigerant	Composition
R-401A	53% HCFC-22, 13% HFC-152a, 34% HCFC-124
R-402A	60% HFC-125, 2% propane, 38% HCFC-22
R-409A	60% HCFC-22, 25% HCFC-124, 15% HCFC-142b
R-502	48.8% HCFC-22, 51.2% CFC-115

Source: Calm, James M. and Glenn C. Hourahan. “Physical, Safety, and Environmental Data for Refrigerants” in *HPAC Engineering*, August 1999.

As production and consumption of HCFCs are being phased out in developed countries, air conditioning and refrigeration equipment is being manufactured with and retrofitted to use alternative refrigerants. In addition, alternative technologies have been developed for these end uses to facilitate the transition away from ODS.

1.3 Purpose

Article 5(1)(c)(v) of Regulation (EC) No 2037/2000 requires the European Commission to “review the technical and economic availability of alternatives to recycled hydrochlorofluorocarbons in existing refrigeration equipment with the view to avoiding undue abandonment of equipment” before 31 December 2008. The Commission will determine, if appropriate, whether the originally scheduled phaseout date of 2015 should be altered, and if so, how.

To that end, this study assesses the technical feasibility, economic cost, and environmental impact of HCFC alternatives for refrigeration and AC equipment according to the following three phaseout scenarios:

- Reference scenario: existing measures in the Regulation are maintained (e.g., phaseout occurs in 2015);
- Advanced phaseout scenario: virgin and recycled HCFC consumption is prohibited to service and to maintain equipment beginning in 2012;
- Extended phaseout scenario: recycled HCFC consumption is allowed to service and to maintain equipment until 2020.

To assess the possibility of altering the scheduled HCFC phaseout in these end uses, the remainder of the report is organised as follows:

- Section 2 summarises the methodology used to develop this study;
- Section 3 presents a qualitative analysis of the feasible alternatives to HCFCs, by end use;
- Section 4 presents the a summary of the modelling results by end use and Member State;
- Section 5 presents a summary of the modelling results by phaseout scenario;
- Section 7 presents the conclusions and recommendations;
- Section 0 lists the references used to develop this report; and
- Appendix A discusses the feasible alternatives.

2. Methodology

This chapter summarises the methodology used to assess the supply and demand of HCFCs in refrigeration and air conditioning equipment throughout the EU-25, Bulgaria, and Romania, as well as the availability of feasible HCFC alternatives, to evaluate the impacts of the following three policy scenarios:

- Reference scenario: existing measures in the Regulation are maintained (i.e., phaseout of recycled/reclaimed HCFCs occurs in 2015);
- Advanced phaseout scenario: recycled/reclaimed HCFC consumption is prohibited to service and to maintain equipment beginning in 2012;
- Extended phaseout scenario: recycled/reclaimed HCFC consumption is allowed to service and to maintain equipment until 2020.

Section 2.1 describes the model used to estimate historical consumption and project future demand for HCFCs by country for EU-25, Bulgaria, and Romania. Section 2.2 evaluates the potential HCFC supply available to serve the projected demand. Finally, Section 2.3 estimates the costs of undue abandonment of equipment under the three scenarios described above, using the estimated supply and demand calculated in the first two sections.

2.1 HCFC Refrigerant Consumption Model

The first step in evaluating the costs of undue abandonment of HCFC-containing equipment is to estimate the stock of such equipment currently in use for each of the countries involved in this study, determine the remaining lifetime of equipment, and estimate future HCFC demand. This section describes the top-down consumption model that was developed for this study, based on HCFC refrigerant consumption data from several sources. Consumption was then used to calculate the numbers of equipment and projected HCFC demand.

2.1.1 Data Sources

The data used to build a model of HCFC demand and consumption included historical HCFC consumption by country, gas, and type of equipment for the period 1992-2003, as well as average equipment parameters on charge size, leak rate, and lifetime. Data was collected from a variety of sources, including:

- Member States' data submissions, solicited through a survey conducted for this study (Member State survey);
- Data submissions from industry (including companies and associations representing equipment users and producers), solicited through a survey conducted for this study (industry survey);
- UNEP reports;[1] and
- Freedonia Market Group report (2005).

Country-level consumption estimates provided by Member States or industry formed the basis of the dataset; UNEP consumption data was used where Member-State-provided consumption was not available, and data from the Freedonia Market Group was used to help disaggregate UNEP

[1] Production and Consumption of Ozone Depleting Substances under the Montreal Protocol, 1986 – 2000 (2002) and annual data reports of parties to the Montreal Protocol.

consumption by country. The data collected from each of these sources are described below, as are the assumptions that were applied to fill any data gaps.

After examining the consumption estimates, and apportioning consumption of HCFC blends (e.g., R-401a, R-401b) into their constituent gases, it was determined that HCFC-22 refrigerant (R-22) accounted on average for 96 percent of all HCFC refrigerants.[2] Thus, the analysis focuses only on building demand inventories—by equipment type and by country—for R-22. For consumption reported as HCFC-containing blends, the portion of R-22 was extracted for use in the analysis.

Country-Level Consumption Estimated by Member States and Industry

Twenty-two Member States (or future Member States) responded to the Member State survey, of which nine included information that was specific enough (e.g., data on HCFC refrigerant consumption by weight, percent of HCFC refrigerant consumption by end use) to apply to the refrigerant consumption model: Austria, Bulgaria, Estonia, Germany, Hungary, the Netherlands, Poland, Spain, and Sweden. The Slovak Association for Cooling and Air Conditioning Technology provided useful country-wide data for Slovakia. Consumption and end use data for France came from an independent study (Palandre, et al., 2003) that included a comprehensive survey of refrigerant use in France.

In addition, while some country-provided data distinguished consumption by gas type, most of the country data that were provided referred generally to "HCFC refrigerants;" in these cases, it was assumed that 96 percent of this consumption was HCFC-22 (as described above). In cases where consumption was estimated for all HCFCs (not just refrigerants), R-22 was assumed to represent a steadily increasing percentage of total HCFC consumption through the years.[3]

This country-estimated consumption was used for the consumption model where possible, but additional information was necessary to complete the dataset or to disaggregate the data that were provided. For countries and years for which no data were reported through survey submissions from Member States or industry, consumption was estimated using data reported in UNEP reports, adjusted and disaggregated to suit modelling needs based on data obtained from the Freedonia Market Group (2005), as described in the following sections.

UNEP HCFC Consumption Data

UNEP collects HCFC consumption data, as reported annually by each Party to the Montreal Protocol. This data served as the basis for our primary dataset in cases where no country-estimated consumption was submitted or found. More specifically, the following data were obtained from UNEP reports:

- 1992-2000 consumption data: Production and Consumption of Ozone Depleting Substances under the Montreal Protocol, 1986-2000, available on the UNEP Ozone Secretariat website.[4]

- 2001-2004 consumption data: data reports submitted yearly at each Meeting of the Parties.[5]

Two adjustments were required to apply the UNEP data by HCFC and by country. First, UNEP consumption data are reported in aggregate ODP tonnes, which required that a method be chosen to disaggregate consumption by species, described in Section 2.1.2. Additionally, while most UNEP

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[2] Based on data reported by Member States, it appears that on average approximately 10 percent of HCFC refrigeration consumption in the EU consists of HCFC blends rather than pure R-22. Most of these blends are used in the commercial refrigeration sector.

[3] Based on information provided in a Member State survey, as well as expert judgement, R-22 consumption for the EU-15 was assumed to be 70 percent of all HCFC consumption in 2000, increasing to 90 percent in 2004. In the EU-10 plus Bulgaria and Romania, R-22 consumption was assumed to be 75 percent of all HCFC consumption in 2000, increasing to 98 percent in 2004.

[4] <http://hq.unep.org/ozone/teap/Reports/Other_Task_Force/index.asp>

[5] <http://hq.unep.org/ozone/Meeting_Documents/mop/index.asp>

consumption data is reported by country, EU consumption is reported as a bloc; therefore, as countries joined the EU, their national data ceased to be reported separately. As described in Section 2.1.2, a method was developed for this analysis to disaggregate the European Community HCFC consumption by country in order to generate consumption data where none were gathered from the surveys.

The Freedonia Market Group HCFC Demand Data

Market research (including a detailed literature search) was undertaken to identify other sources of HCFC consumption data for the EU. One report prepared by The Freedonia Market Group (hereafter, Freedonia) was found to have the best available data on HCFC demand[6] for selected countries and regions.[7] These demand data were used to disaggregate the UNEP consumption by country, as described below, and provided a second set of data against which to verify the data gathered from other sources.

2.1.2 Method for Estimating R-22 Consumption by Country

The data sources described above were used to estimate annual R-22 consumption by country for the EU-25+2, with country data used preferentially, then UNEP data, then Freedonia data. Although country-level data were provided by many Member States, some data gaps remained to be filled. UNEP HCFC consumption estimates were used to round out the estimates by country. Because the UNEP HCFC consumption estimates were provided in aggregate for EU, the Freedonia (2005)[8] dataset, and country GDPs, were used to estimate the proportion of EU consumption data to assign to each of the EU states that did not provide consumption information to the Member State survey. Additionally, UNEP consumption estimates are only available in ODP-weighted metric tons of HCFCs; a weighted average ODP[9] was applied to the OPD-weighted metric tons of HCFCs to estimate the unweighted total metric tons of HCFCs, of which a fraction was assumed to be R-22.

2.1.3 Method for Estimating and Projecting R-22 Consumption by End Use

Using the R-22 consumption by country estimated as described above, the R-22 consumption was broken into the following 6 end uses for each country, based on Member State survey responses:

- *Small commercial refrigeration*—includes stand-alone refrigerator and freezer cases and small condensing units (reach in refrigerators and freezers, vending machines, ice machines, soda fountains, etc.);

- *Large commercial refrigeration*—includes large parallel systems for supermarkets and other full supermarket systems, and cold storage;

- *Refrigerated transport*—includes primarily sea transport, fishing, and truck trailers, and to a more limited extent, rail transport containers;

- *Industrial process refrigeration*—includes industrial process cooling systems, including food processing, machine cooling, ice rinks, etc.;

- *Small stationary AC*—includes unitary and split residential and small commercial AC, residential and small commercial heat pumps, window units, <75 kW; and

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[6] While Freedonia reported demand, UNEP reported consumption, and Member states reported demand, consumption, or sales. These measures were taken to be equivalent. The Freedonia report says, "The term 'demand' is used synonymously with sales and/or apparent consumption."

[7] From a Freedonia Market Group report purchased entitled *Industry Survey #1966: World Fluorochemicals*.

[8] The Freedonia report included HCFC consumption for each of France, Germany, Italy, Spain, and the UK; proportions of consumption from these countries relative to total HCFC consumption in Europe were used to apportion UNEP EU consumption data to these countries. All other countries reported in the UNEP data set for the EU region were disaggregated using GDP.

[9] Estimating using the relative share of ODP tonnes by HCFC cited in UNEP (2003).

- *Large stationary AC*—includes chillers >75 kW;

Country-level R-22 consumption was broken into the six end uses described above, based on the following end use consumption data provided by Member States:

Figure 5: R-22 Consumption by End Use (Percent)

End Use	Member State Data[a]				
	France	Estonia	Netherlands	Sweden	Slovakia
Commercial Refrigeration					
Small Commercial Refrigeration	6.7%	5.7%	15.5%	5.1%	11.0%
Large Commercial Refrigeration	24.5%	50.6%	57.9%	19.0%	8.0%
Refrigerated Transport	5.7%	0.0%	0.7%	0.3%	3.0%
Industrial Refrigeration	28.4%	11.6%	22.7%	9.6%	8.0%
Stationary AC					
Small Stationary AC	14.8%	13.7%	0.4%	28.1%	21.0%
Large Stationary AC	19.9%	18.5%	2.9%	37.9%	49.0%
Country/Region for which data is used as a proxy	France	Estonia	Netherlands	Sweden & all other EU-15	Slovakia & all other EU-10, Bulgaria, and Romania

[a] In some cases, data provided by Member States was aggregated or disaggregated to classify group equipment according to the six end uses categories selected for this study.

From the consumption, the total number of units within each end use was calculated as total consumption for servicing divided by leak rate and charge size. Total consumption was assumed to equal total consumption for servicing in the years following the last legal year of R-22 original equipment manufacture. Leak rates, lifetimes, and charge sizes were determined based on Member State survey responses and the published literature (as shown in Figure 6).

Figure 6: Assumed Charge Sizes, Lifetimes, and Leak Rates Used in Consumption Model

End Use	Charge Size (kg)	Lifetime (years)	Leak Rate (Annual %)		
			Greece, Italy, Portugal, Spain[a]	Other EU-15	EU-10, Bulgaria & Romania
Commercial Refrigeration					
Small Commercial Refrigeration	10	12	7.3%	6.5%[b, c]	8%[c]
Large Commercial Refrigeration	300	15	15.8%	12.0%[b, c]	20%[d, e]
Refrigerated Transport	10	9	20.0%	10.0%[f]	30%[g]
Industrial Refrigeration	1,000	20	16.0%	16.0%[c]	16%[c]
Stationary AC					
Small Stationary AC	3.5	10	8.5%	2.0%[f]	15%[d, h]
Large Stationary AC	250	15	12.5%	5.0%[i]	20%[d, h]

[a] Due to a lack of data, assumed leak rates for these countries are the average values assumed for "Other EU-15" and EU-10/ Bulgaria/Romania.
[b] A leak rate of 5% is assumed for the Netherlands, based on specific data provided by that Member State.
[c] Based on IPCC/TEAP (2005).
[d] For Bulgaria, based on specific data provided by that Member State, a leak rate of 17% is assumed for large commercial refrigeration, 13% for small stationary AC, and 15% for large stationary AC.
[e] Mid-point of average leak rates provided by IPCC (2000).
[f] Based on specific data provided by Germany.
[g] Approximate mid-point of average leak rates provided by IPCC (2000).
[h] Based on specific data provided by Hungary and Bulgaria.
[i] Based on specific data provided by the Netherlands.

Using equipment lifetimes, total consumption for servicing (and thus, total number of units of equipment by end use) was projected to decline linearly, by end use, starting in the final year of legal R-22 equipment manufacture and ending 9-20 years later, depending on the lifetime of the equipment within the end use.[10] The final year of legal R-22 equipment manufacture varied by country and end use, as summarized below:

- *Sweden:* consumption is assumed to be zero from 2002 onward, based on their national regulations.
- *All Other EU-15:* the model uses the national R-22 consumption dataset (as derived through this analysis) through 2001, the year in which consumption is assumed to be nearly entirely for servicing, except for those few end uses that were permitted new manufacture until 2002 or 2004. While some growth is assumed to occur in 2002 and 2003 for the manufacture of small AC and heat pumps, consumption for all other end uses is assumed to decline linearly, based on equipment lifetime.
- *EU-10:* the model uses the national R-22 consumption dataset (as derived through this analysis) through 2003. Consumption is linearly declined starting in 2004, the year in which these countries joined the EU and had to comply with EC regulations.
- *Bulgaria & Romania:* the model uses the national R-22 consumption dataset (as derived through this analysis) through 2004, and holds consumption constant until 2007. (Consumption was held constant because no trend was apparent based on their recent historical data.) A linear decline in consumption was assumed starting in 2007, when these countries will join the EU.

Thus, a profile of R-22 units in service was projected, by end use and by country, which can be used to estimate the cost of early retirement under the three policy scenarios being considered (see Chapter 5). Also, based on the loss rates of each end use, total R-22 demand for servicing was also projected.

2.2 Methodology to Estimate Supply

This section presents the methodology used to estimate the supply of recycled and reclaimed HCFCs available in each of the three phaseout scenarios (i.e., the use of recycled/reclaimed HCFCs is prohibited starting in 2012, 2015, and 2020). In all scenarios, this analysis assumes that refrigerant is recovered from all retired equipment, and either destroyed or recycled/reclaimed for reuse, in accordance with regulatory requirements (i.e., no venting).

2.2.1 Potential Supply: Recovered R-22 Available for Reuse

This analysis estimates that approximately 75 percent of the original charge installed in equipment is recoverable at end of life.[11] This percentage was applied to the original charge of equipment estimated to be retired in each year to determine the upper bound of recovered refrigerant available for

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[10] The feasibility of retrofits was explored for all end uses, with an eye toward identifying those equipment types that could be cost-effectively converted (based on their remaining years of useful life) and removing them from the R-22 demand pool. However, because of the limited nature of industry survey responses, and the lack of robust data available in the literature regarding the extent of retrofits and their economic feasibility by end use, analysis of retrofits for refrigeration/AC equipment are not considered further in this analysis.

[11] The recoverable charge at end of life (EOL) is a function of (a) refrigerant charge remaining at EOL, and (b) residual refrigerant remaining in systems. The 75% estimate used in this analysis is based broadly on estimates applied in other studies, including the following: Bateman (1999) assumes a 15% loss of charge at EOL in unitary AC equipment; Clodic et al. (1999) assumes a refrigerant recovery efficiency for centrifugal chillers in France ranging from 80-95%, based on the percentage of older chillers retired; Arthur D. Little (2002) assumes 15% EOL loss for unitary AC equipment and 100% EOL refrigerant recovery for commercial refrigeration; Corcoran et al. (1999) assumes an EOL loss of 15% for R-22 systems; Sand et al. (1997) applies a 15% EOL loss of charge for European unitary AC equipment and residential and roof top units, and a 5% EOL loss of charge for European chillers; and Rubenstein et al. (2004) assumes a 2-10% EOL loss for U.S. HVAC systems.

reuse (recycling or reclamation). In other words, potential annual supply was determined by multiplying the number of units of equipment retired in a given year by the charge size and the recovery rate of 75 percent. Cumulative supply is the annual supply aggregated over the time series.

2.2.2 Stockpiled R-22 Supply by 2010

Since use of virgin HCFC supplies will be illegal starting in 2010, it is reasonable to assume that no virgin R-22 will be stockpiled prior to 2010, but that R-22 refrigerant recovered and recycled/reclaimed before 2010 will be stockpiled for future use. To explore the impacts of and need for stockpiling of recycled/reclaimed R-22 prior to 2010, this analysis considers two scenarios:

- No Stockpiling: No stockpiles of recycled/reclaimed R-22 are accumulated by 2010. Any recycled/reclaimed refrigerant is re-used prior to 2010.
- With Stockpiling: Stockpiles of recycled/reclaimed R-22 are accumulated by 2010, in preparation for the phaseout. Accumulated stockpiles are saved for re-use in 2010 and beyond; in other words, new manufacturing is required to keep up with demand prior to 2010.

The stockpiling scenario is applied to the amount of recovered refrigerant available for reuse at equipment end of life (EOL) in the EU-25 plus Bulgaria and Romania in each year prior to 2010. It is assumed that 10 percent of recovered R-22 is recycled and stockpiled during the period 2000-2006.[12] From 2006 to 2010, the percentage of recovered R-22 that is recycled/reclaimed and stockpiled increases exponentially to 50 percent. The maximum recycling/reclamation level is assumed to be only 50 percent because not all recovered R-22 is recyclable or reclaimable, as a result of the technical difficulty and cost associated with reclaiming contaminated and/or mixed refrigerants. The estimate of 50 percent was also supported by data on recovery, recycling, reclamation and destruction of ODS reported by Member States under Article 16(6) of the Regulation (EC) No 2037/2000 in years 2002 through 2004.

2.2.3 Analysis of R-22 Supply Beyond 2009

This analysis assesses the supply of recycled/reclaimed R-22 *needed* to meet service demand in each year beyond 2009, and then explores whether that supply is likely to be available—both with and without stockpiles. To assess needed supply, this analysis assumes that no banking of virgin R-22 occurs prior to 2010.

Thus, in the *without stockpiles* assessments, the only R-22 supply available in each year after 2009 is that which is recovered and then recycled/reclaimed from equipment retired after 2009. In the *with stockpiling* assessments, stockpiles accumulated before 2010 are assumed to be used to satisfy annual demand starting in 2010, with additional supplies recovered from equipment retired after 2009 to be used to augment that supply annually, as needed.

Once the annual amounts of recovered refrigerant *needed* from retired equipment is known for both supply scenarios, these amounts can be compared to the annual amounts of recovered refrigerant *potentially available* from retired equipment in a given year, to gauge whether supply shortfalls are likely to be experienced. For example, where no stockpiling prior to 2010 is assumed, if it is determined that the annual supply of recycled R-22 needed to satisfy demand in 2010 is equivalent to 90 percent of the R-22 recovered from retired equipment in that year, it may be inferred that there will likely be a shortfall of supply, since a 90 percent recycling/reclamation rate is technically difficult to achieve.

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[12] This assumed percentage of recovered HCFCs being recycled/reclaimed is broadly based on data received from reclamation companies in the United Kingdom on the amount of HCFCs that are recycled/reclaimed, compared to the total projected amount of recovered refrigerant available for reuse, as determined by this analysis.

Inferences can also be made about the ability of the supply generated in the EU-15 and the EU-10 plus Bulgaria and Romania to sustain demand, taking into account the level of trade of recycled refrigerant among Member States. For example, if, when the EU regions are considered separately, a shortfall of supply is predicted in the EU-10 plus Bulgaria and Romania, but excess supply is projected in the EU-15, it may be conjectured that in the absence of significant sales of recycled HCFCs from the EU-15 to the EU-10, the EU-10 will experience a supply deficit. Additionally, in such a scenario, it is possible that unless reclamation facilities in the EU-15 are aware of the demand for recycled R-22 in the EU-10 and able to access those markets, recycled/reclaimed HCFCs in excess of EU-15 demand could be destroyed, causing a shortfall of supply in the EU-10. These types of considerations will be discussed qualitatively.

2.2.4 Consideration of the Supply of HCFC Blends

While HCFC blends make up a small portion of overall HCFC demand (i.e., an estimated 10%, mostly in the commercial refrigeration sector) and, therefore, are not the focus of this study, important deductions can be made regarding the expected supply of recycled/reclaimed HCFC blends, and implications can be drawn about the continued use of equipment containing these blends beyond 2010.

In practical terms, it is likely that the supply of HCFC blends will be extremely limited after 2010, because blends cannot easily be recycled or reclaimed. In particular, specific technologies and patent rights are required to reconstitute HCFC blends, which many local recycling/reclamation facilities do not have. Moreover, even for facilities possessing appropriate technologies and legal rights, blends may be too contaminated (and therefore, too costly) to reclaim. Therefore, once the production of virgin HCFC blends is banned in 2010, very little supply will be available to service/maintain existing equipment, regardless of the policy scenario selected (to phaseout the use of recycled HCFCs).

2.3 Methodology to Estimate Cost of Undue Abandonment of Equipment

This section presents the methodology used to determine the net present value of the social cost associated with the undue abandonment of equipment (i.e., the early retirement of equipment with remaining productive life as a result of a regulatory restriction) in each of the three phaseout scenarios.

The social cost of undue abandonment is comprised of several components:

- The value associated with the lost years of productive life for unduly abandoned equipment;
- The marginal cost associated with prematurely incurring equipment disposal costs (i.e., incurring disposal costs before the year of natural equipment retirement); and
- The marginal cost of purchasing equipment at a potentially higher real price at the time of policy-imposed equipment abandonment versus the time of natural equipment retirement.[13]

This analysis attempts to quantify only the costs associated with the lost years of productive life for unduly abandoned equipment. The costs associated with equipment disposal are assumed to be small and highly variable across the EU; therefore, the cost of prematurely incurring those minimal disposal costs (i.e., the incremental cost associated with realizing those costs before the year of natural equipment retirement) is not quantified in this analysis. Similarly, any incremental differences between the real prices of new equipment purchased at the time of policy-imposed equipment

[13] Retail costs of alternative technologies may decrease over time as economies of scale develop for certain new technologies and/or research and development efforts lead to reduced production costs.

abandonment versus at the time of natural equipment retirement are not quantified in this analysis, as such potential marginal costs are difficult to predict and are highly uncertain.[14]

To calculate the value of the lost years of productive life of unduly abandoned equipment, the upfront capital costs of the HCFC equipment serve as a starting point. The price of the equipment (i.e., capital cost) at the time of purchase is assumed to represent its discounted present value to its owner over its useful life, and the cost is annualized over its lifetime using a 7 percent discount rate. Figure 7 shows the assumed present value cost of each type of equipment, as well as the lifetime of the equipment, and the calculated annualized cost.

Figure 7: Present Value Cost, Lifetime, and Annualized Cost of Equipment

Equipment	Present Value Cost of Equipment (€)[a]	Lifetime of Equipment (Years)[b]	Annualized Cost of Equipment (€)
Small Commercial Refrigeration	€ 1,000	12	€ 126
Large Commercial Refrigeration	€ 150,000	15	€ 16,469
Refrigerated Transport	€ 40,000	9	€ 6,139
Industrial Refrigeration	€ 250,000	20	€ 23,598
Small Stationary AC	€ 1,500	10	€ 214
Large Stationary AC	€ 1,500	10	€ 214

[a] Average prices of HCFC-containing equipment are based on estimates obtained through Internet research and personal communication with representatives of Trane® in February 2006.
[b] Estimates of equipment lifetime by end use are provided in step 0 of the section on *Methodology for Creating HCFC Refrigerant Consumption Model*.

Using the annualized costs shown in Figure 7, the net present value in 2006 of the costs associated with the undue loss of productive life are calculated for each phaseout scenario, using a 7 percent discount rate. In other words, the annualized cost stream from the year of supply shortfall[15] through the end of the equipment's productive life is discounted back to 2006. For the purposes of this analysis, the discounted value of that annualized cost stream across all end uses represents the net present value of the social cost of undue abandonment of equipment.

In general, the cost burdens to equipment owners of undue abandonment estimated in this report are designed to be conservative (i.e., estimated taking the higher cost where there is a cost range) estimates for several reasons:

- *Retirement immediately following phaseout date is assumed.* This analysis assumes that all refrigeration and AC equipment are phased out 1 January 2012, 2015, or 2020 to coincide with the ban on the use of recycled/reclaimed R-22 to service that equipment. In practice, however, equipment is likely to continue to operate after 1 January without additional servicing/refilling with R-22, although such equipment may operate sub-optimally and/or be topped off with other fluids for which the systems were not designed (which may lead to operational inefficiencies). Indeed, some equipment owners may not need to prematurely replace or retrofit their HCFC equipment for several months or years following the phaseout date—if at all, which would result in lower costs than estimated here.[16]

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[14] It should be noted that equipment replacement costs must be incurred regardless of when HCFC systems are retired, due to a prohibition on those systems as part of an existing regulatory decision (Article 5(c)(iv) of EC Regulation No. 2037/2000); therefore, such costs are not included in this social cost analysis.
[15] To determine the year in which supply shortfalls will be experienced by end use, it is assumed that available supply (in both the upper and lower bound scenarios) is consumed proportionally among end uses, based on market share.
[16] In such cases, however, benefits may also be slightly overestimated in this analysis, since any HCFC equipment that remains in service beyond the phaseout date may leak, which would lead to reduced emission savings.

- *No re-sale of equipment is assumed.* To the extent that old equipment is sold for reuse instead of being retired, the cost burden to equipment owners, as well as the projected benefits, will be reduced. Indeed, under Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE), old refrigeration/air conditioning equipment may be exported to certain countries outside the EU. However, because the Commission does not wish to promote the export of HCFC equipment to other countries—which would simply displace, not eliminate, the source of ODS emissions from equipment now in the EU—this analysis does not assume that any used equipment is sold.

- *No retrofits are assumed*. According to refrigerant manufacturers, a variety of feasible HFC options now exist as drop-in replacements for a wide variety of refrigeration/AC applications. However, as a result of the limited information provided in industry survey responses regarding retrofits, and the lack of robust performance and economic data available in the literature regarding retrofits and their feasibility by end use, this analysis assumes that no retrofits occur. To the extent that retrofits are feasible and do occur, this analysis overestimates the costs associated with the premature retirement of equipment.

2.4 Benefits of Undue Abandonment of Equipment

This section presents the methodology used to estimate the benefits associated with the premature retirement of refrigeration and air conditioning equipment (i.e., the early retirement of equipment with remaining productive life as a result of a regulatory restriction). These benefits are primarily in-service-life annual emissions of HCFCs that are avoided as a result of the early retirement of equipment. Annual avoided emissions (in ODP tons) for each type of equipment are estimated by applying the annual leak rate to the charge size for each year through the end of the equipment's productive life. The charge sizes and leak rates used in this analysis are shown in Figure 6.

Any emissions occurring when the equipment is taken out of service (i.e., end of life emissions) are not included in this analysis. This is because end of life emissions will be experienced regardless of whether the equipment is phased out sooner, as a result of a regulatory action, or later, when the equipment has reached the end of its useful life; thus, end of life emissions are not avoided by this regulation *per se*, and are not considered a benefit. Results of the cost analysis are presented in Section 5.

The benefits calculations also implicitly assume that once refrigerant is no longer needed to meet demand within the EU-25, it is destroyed, rather than reclaimed and sold outside of the EU-25 and eventually emitted.

3. Analysis of Alternative Refrigerants and Technologies

If the European Commission is to successfully phaseout HCFCs, there must be feasible alternatives available to replace them. This chapter qualitatively analyzes the alternatives to HCFCs, assessing their technical, economic, and environmental feasibility.

Alternative refrigerants and technologies that can replace HCFC-based systems are discussed by end use. Detailed descriptions of the alternative refrigerants and the replacement technologies discussed in this chapter are provided in Appendix A. Figure 8 presents a summary of the feasible alternative refrigerants and technologies by end use. The feasibility of alternatives in new equipment is reported as either:

- Feasible now and widely available (✓);
- Feasible now but new market entrant (M); or
- Potentially feasible in the future, pending additional research and development (P).

In general, alternatives (replacement refrigerants or novel technologies) that are new market players are associated with higher costs; however, these costs generally decrease over time as technological advances are made and as the market share increases. Figure 8 also indicates which feasible alternatives are limited to only specific new applications within an end use, and which may be feasible as a retrofit option. New technologies are continually entering the market, which will further facilitate the transition to alternatives.

Figure 8: Feasibility of Alternative Refrigerants and Technologies by End Use[a]

Alternative	Small Retail Food	Large Retail Food		Refrigerated Transport	Industrial Process Refrigeration	Small AC		Large AC (Chillers)
	Stand-Alone Equipment	Large Supermarket Systems	Cold Storage			Unitary AC (Commercial & Residential)	Window AC Units	
Alternative Refrigerants								
R-32					✓			
R-134a	✓	✓	L	✓	✓		✓	✓
R-236fa					P			
R-245fa					P			P
R-365mfc					P			
R-404A	✓	✓R	✓	✓	✓		✓	
R-407C		✓R	✓	✓L		✓	✓	✓
R-407D		R		RL				
R-410A			M	✓L	✓	✓	✓	✓
R-417A	✓R	✓R	✓R		✓R	✓R	✓R	
R-422A	✓R	✓R	✓R		✓R			
R-422D	✓R	✓R	✓R		✓R	✓R	✓R	
R-507A		✓R	✓	✓L	✓		✓	
Propane (R-290)	✓L		M	✓L	✓	P	✓	✓L
Isobutane (R-600a)	✓L			✓L				✓L
Propylene (R-1270)				✓L	✓			✓L
Ammonia (R-717)	✓L		✓	✓L	✓L			✓L
CO_2 (R-744)	✓L	P	ML	P	✓	P		P
Alternative Technologies								
Secondary Loop		✓	✓L		✓			
Cascade		M	M	M	M			
Distributed		✓						

[a] New technologies are always entering the market that could further facilitate the transition to alternatives.
✓ = Feasible now in new equipment
M = New market entrant (associated with higher costs, at least in short-term)
P = Potential for use in future
L = Limited application (in new equipment or as retrofit, as specified)
R = Retrofit is feasible or potentially feasible
Note: blank spaces represent lack of actual or potential feasibility in new or existing systems.

3.1 Small Retail Food

Currently feasible alternatives used in the small retail food end use include HFCs, namely R-134a (for low/medium-temperature applications) and R-404A (for low-temperature applications). Other HFC refrigerants have recently entered that market that may be feasible in both new and retrofit equipment, including ice machines and stand alone refrigerator/freezer cases. According to one gas manufacturer, R-422A is feasible as a drop-in replacement for use in low-temperature applications, while R-417A and R-422D are feasible in medium-temperature applications. In certain cases, R-422A and R-422D may be feasible in both medium- and low- temperature applications (DuPont, 2006a).

In some applications, natural refrigerants—such as hydrocarbons (HCs), ammonia, and CO_2—may also be feasible. For example, soft-drink vending machines using CO_2 as a refrigerant have been developed and are in use in Europe.

However, equipment using natural refrigerants has not been developed for all small applications in the retail food sector. Indeed, several small beverage companies and ice cream manufacturers are still evaluating the use of ammonia, CO_2, and hydrocarbons (i.e., HC-600a, HC-290 and HC-based blends) (CIAA/ECSLA/EuroCommerce 2005, IPCC/TEAP 2005). There are a number of factors limiting the use of natural refrigerants in this end use, including safety of use in public areas, and cost (IPCC/TEAP 2005, Reisch 2005). Available equipment using ammonia and hydrocarbons (HCs) are more expensive than HFC equipment, with ammonia systems estimated to cost two to three times more than similar HFC equipment. Similarly, equipment containing propane is estimated to cost 5% to 10% more (CIAA/ECSLA/EuroCommerce 2005, Goetzler and Dieckmann 2001). In addition, the inclusion of engineering controls to reduce safety hazards may increase the cost of equipment using natural refrigerants (IPCC/TEAP 2005).

Despite these challenges, some small retail food equipment using HCs is estimated to consume less energy than equipment using HFCs, which reduces annual costs (IPCC/TEAP 2005).

Summary Analysis of Alternatives for Small Retail Food Equipments

For small retail food equipment, feasible alternatives exist, though in some small applications, only HFCs are viable. Moreover, a variety of new HFC refrigerants may provide viable drop-in replacements for a variety of medium- and low- temperature applications. While HFCs may currently be the most attractive alternative, their use results in greenhouse gas (GHG) emissions. Moreover, their long-term viability may be in question, as future EC regulations may further restrict their use. Natural refrigerants, such as hydrocarbons and CO_2, do provide greener options for some applications, though cost barriers and safety concerns may be a factor. Over time, as technological advances are made and more systems are commercialized using natural refrigerants, and potential safety concerns associated with the use these refrigerants are addressed, it is likely that their technical and economic feasibility will increase.

3.2 Large Retail Food

3.2.1 Large Retail Food (Parallel) Systems

Feasible alternative refrigerants for large supermarket systems include HFCs, such as R-134a, R-404A, R-407C, and R-507A, which can be used in conventional direct expansion (DX) retail food systems. R-404A and R-507A are the most commonly used refrigerants in low- and medium-temperature systems. R-404A and R-507A are more efficient than R-22 in low-temperature applications, but slightly less so in medium-temperature applications (IPCC/TEAP 2005, UNEP 2001). In addition, a variety of new HFC refrigerants, including R-417A, R-422A, and R-422D, are reportedly feasible as drop-in replacement for R-22 in DX systems (for low- and medium-temperature applications) (DuPont 2006a). Indeed, as part of a pilot project, the German REWE Group has successfully converted its first refrigeration unit to R-422D, and intends to convert many more systems over the next three years to fully phaseout R-22 in its supermarkets by 2010 (DuPont Press

Club 2006). According to one gas manufacturer, R-422D requires virtually no business disruptions for the conversion process, has a 30% lower GWP than R-404A and R-507, and an energy efficiency similar to or greater than R-22, as shown in Figure 9 (DuPont 2006b).

Figure 9: Energy Consumption and LCCP of Alternative Refrigerants/Technologies for Large Retail Food Systems, Relative to HCFC DX Systems (tCO2-eq)[a]

Alternatives	Energy Consumption[b]	LCCP Reduction
Technologies		
CO_2 Direct Systems	0% to 10%	35% to 60%
Distributed Systems	0% to +10%	
Secondary Loop (HFC, HC, or ammonia primary refrigerant)	0% to +20%	
Cascade Systems	Similar	
Refrigerants in DX Systems		
R-134a	-	35% to 60%
R-404A (low temp)	Slightly less[c]	-
R-404A (medium temp)	Slightly more[c]	-
R-417A	-	-
R-422A	-	-
R-422D (low temp)	Up to 14% less[d]	-
R-422D (medium temp)	Similar[d]	-
R-507A (low temp)	Similar	-
R-507A (medium temp)	Similar	-

- = No information available.
[a] Unless otherwise noted, source is IPCC/TEAP (2005).
[b] Positive energy consumption indicates that the alternative refrigerant consumes more energy than the baseline refrigerant.
[c] Source: UNEP (2001).
[d] Source: DuPont (2006b).

According to a variety of industry sources, R-404A, R-407C, R-407D, R-417A, R-422A, and R-507A are also technically feasible as retrofits for existing R-22 DX systems, but the cost for such retrofits may be very high in some circumstances (DuPont 2005, Gartland 2005, Spletzer and Rolotti, 2004). According to various industry experts, the cost of converting R-22 to R-407c/R-417a or R-404a/R-507A may be on the order of €15,000 to €75,000, depending on store size (Honeywell Genetron Refrigerants 2004, Hill Phoenix 2005a, Hussman 2005).

CO_2 is potentially feasible in new DX systems. Several DX systems using CO_2 are currently being tested in Europe for both low- and medium-temperature applications. CO_2 direct systems cost about 10% to 20% more than R-404 DX systems (IPCC/TEAP 2005).

Certain alternative technologies are available that use HFCs but could reduce refrigerant emissions and minimise emissions of GHGs (see Appendix A for a description of alternative technologies). For example, distributed systems have a 75% lower charge size than DX systems, and can reduce leakage by an estimated 5% to 7% (due to shorter refrigerant tubing and fewer fittings). However, distributed systems consume up to 10% more energy than conventional DX systems, which leads to higher indirect GHG emissions associated with electricity generation (some distributed systems do not use more energy, however). Despite the sometimes higher energy consumption to run the equipment, this technology still results in significant Life Cycle Climate Performance (LCCP)[17] reductions compared to R-22 DX systems (IPCC/TEAP 2005).

In addition, secondary loop systems, which can use HFCs or natural refrigerants (i.e., CO_2, ammonia, or hydrocarbons), also represent viable alternatives. Secondary loop systems can reduce charge size

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[17] LCCP measures direct refrigerant emissions and indirect greenhouse gas (GHG) emissions associated with energy consumption, accounting for cradle to grave emissions.

by between 75% and 85% (compared to conventional DX systems), and bring annual leakage rates down to about 5% (whereas DX systems tend to be significantly higher). Thus, if HFCs are used as the primary refrigerant in a secondary loop system, greenhouse gas emissions can be reduced relative to a DX system. Or, if natural refrigerants are used as the primary refrigerant in these systems, direct GHG emissions can be avoided entirely. However, these systems may consume up to 15% more energy than DX systems, resulting in higher indirect GHG emissions (IPCC/TEAP 2005). Regarding cost, additional insulation requirements may lead to increased installation costs, while the use of safety equipment needed for systems using toxic or flammable primary refrigerants (e.g., sensors to detect high levels of refrigerant in occupied space and measures to deal with possible leakage) may increase capital and annual costs (Horton and Groll 2001). According to IPCC/TEAP (2005), the following one-time costs (relative to state-of-the-art conventional DX systems) are associated with secondary loop systems in full supermarket systems using the following primary refrigerants:

- Ammonia: 20% to 30% more expensive;
- HC: 20% to 30% more expensive; and
- HFC: 10% to 25% more expensive.

Finally, cascade systems (described in Appendix A) can use HFC/CO_2, ammonia/CO_2, or HC/CO_2, with CO_2 being used in the low-temperature stage. The HFC/CO_2 cascade system can reduce direct GHG emissions associated with refrigerant leakage by 50% to 90% without imposing any energy penalties, and these systems cost about the same as R-404 DX systems. The HC-290/CO_2 system is estimated to have similar energy requirements as a typical HFC DX system. Insufficient data are available from the literature to describe the emission reduction potential and energy usage of the other cascade systems, which are not yet widely available on the market. (IPCC/TEAP 2005)

Several not-in-kind technologies are also being evaluated for large retail food systems (e.g., Stirling cycle and thermoacoustic refrigeration), and may one day be feasible for wide-scale use (IPCC/TEAP 2005).

Summary Analysis of Alternatives for Large Retail Food (Parallel) Systems

For large supermarket systems, viable HCFC alternatives exist in the form of HFCs and natural refrigerants. New HFC refrigerants are also feasible retrofit options. Because the use of HFC refrigerants results in GHG emissions, and given that future EC regulations may further restrict the use of these gases, natural refrigerants may provide the greatest long-term viability as HCFC replacements in this end use. Currently, these systems may be more expensive, however, as technological advances are made and market shares increase (reaching an economy of scale), it is likely that the cost of such equipment will decrease.

3.2.2 Cold Storage

The primary feasible alternatives for cold storage systems include ammonia and a variety of HFCs. Ammonia is already the primary refrigerant used in cold storage applications; in some European countries, ammonia may be used in up to 80% of systems.

In terms of HFCs, R-404A, R-407C and R-507A are the most commonly used HFCs, and R-410A is expected to gain market share as a result of its lower compressor size requirements relative to other refrigerants. Some use of R-134a in cold storage applications has been reported, but to a very limited extent (IPCC/TEAP 2005). In addition, R-417A, R-422A, and R-422D are reportedly feasible for both new and retrofit equipment, to replace R-22 in medium- and/or low-temperature food storage applications (DuPont 2006a).

In cold storage, R-410A is less efficient than both R-404A and R-507A and, in applications requiring temperatures as low as -40°C, it performs at a similar efficiency level as ammonia. In applications requiring temperatures ranging from -40°C to -51.6°C, R-410A is less efficient than ammonia. (IPCC/TEAP 2005)

In addition, CO_2 and HC DX and secondary loop systems are in use to a limited extent, though their feasibility has not been demonstrated on a wide-scale. CO_2 could be used for low-temperature applications, particularly in cascade systems with ammonia in the upper stage. Such systems are beginning to enter the market, although the efficiency of CO_2 has been questioned. The market penetration of CO_2 in the cold storage end use for large sites is growing and expected to continue to do so, but its use remains limited in smaller sites (CIAA/ECSLA/EuroCommerce 2005, IPCC/TEAP 2005). According to information received through an industry survey, the capital costs of ammonia/CO_2 systems are estimated to be 60% higher than HCFC systems, while maintenance costs are estimated to be 25% higher (ECSLA 2005). Regarding HCs, potential safety hazards have prevented this alternative from penetrating to a significant degree in the cold storage market; however, market share is expected to increase, as several manufacturers have already developed a variety of HC products in this end use. (CIAA/ECSLA/EuroCommerce 2005, IPCC/TEAP 2005)

Figure 10 presents a summary of the relative energy consumption and LCCP of alternative refrigerants and technologies in the cold storage end use.

Figure 10: Relative Energy Consumption and LCCP of Alternative Refrigerants and Technologies in Cold Storage[a]

Alternative Refrigerant	Baseline	Energy Consumption[b]	LCCP
Alternative Technologies			
CO2/ammonia cascade (-40°C to -55°C)	R-410A/ammonia cascade	Similar	-
HFC/CO_2 cascade	HFC DX system	Similar	-
CO_2/ammonia cascade	HCFC system	-5%[c]	-
R-290/CO_2 cascade	DX system	Similar	-
Alternative Refrigerants			
R-404A	R-22	-5% to -10%[c]	-
R-407C	R-22	-	-
R-410A	R-22	-40%	-
R-417A	R-22	-	-
R-422A	R-22	-	-
R-422D	R-22	Up to -14% (low temp)[d] Similar (medium temp)[d]	
R-290	R-404A	-	- 2%
R-290	R-410A	-	+4%
HCs	HFCs	Similar or less	
Ammonia	HCFCs	-5%[c]	-

- = No information available
[a] Unless otherwise specified, information is based on IPCC/TEAP (2005).
[b] Negative energy consumption indicates that the alternative refrigerant consumes less energy than the baseline refrigerant.
[c] Source: ECSLA (2005).
[d] DuPont (2006a).

Summary Analysis of Alternatives for Cold Storage Systems

Ammonia and HFCs are viable in cold storage applications, with R-410A being the most efficient of the HFCs, and even more efficient than R-22. Several HFC options are reportedly feasible as drop-in replacements for low- and medium-temperature food storage applications. CO_2 and HCs are also feasible in certain applications, though their market penetration has been limited to date.

3.3 Refrigerated Transport

Feasible alternatives for refrigerated transport include HFCs (R-134a, R-404A, R-407C, R-410A, R-507A), as well as natural refrigerants (IPCC/TEAP 2005). The feasibility of alternatives varies by specific application, as explained below.

HCFC use in refrigerated containers (used to store goods during train, truck, and ship transport) can be replaced by R-134a, R-404A, and R-407C. Historically, systems had leak rates of about 20%, although newer systems are designed to be more leak-resistant. Another possible alternative is a CO_2 compression system, although this technology is still under development. (IPCC/TEAP 2005)

In refrigerated transport vessels ("reefers") and fishing vessels (used for perishable foods), alternatives include R-134a, R-404A, R-407C, R-410A, R-507A, ammonia, and CO_2/ammonia cascade systems. HCs are also a feasible option for gas tankers, which are built according to explosion-proof standards. In general, however, the most promising natural alternative to HCFCs and HFCs is ammonia, which may be associated with slight cost increases (IPCC/TEAP 2005). In addition, there may be potential for the use of R-407D as a retrofit in ship holds (Landon 2000).

In road transport refrigeration units (designed to be mounted on vans, trucks, or trailers) where only cooling is needed, R-134a is the most commonly used alternative. In cases where both freezing and general cooling is required, R-404A and R-410A are used. Other potentially feasible alternatives include HCs, liquid CO_2, and eutectic plates. HC/CO_2 compression systems, which have been field-tested and commercialized, are also new market players (IPCC/TEAP 2005).

According to one industry survey respondent, for semi-trailers, rigid trucks and vans, a combination of R-404A/R-134a is feasible as a retrofit. In semi-trailers and rigid trucks, such a retrofit costs 20% more than HCFC systems (capital cost) and consumes 5% less energy than HCFCs. In vans, R-404A/R-134a costs 30% more than HCFC systems and consumes approximately the same energy as HCFC systems. (Transfrigoroute International 2005)

In refrigerated railcars, the primary refrigerant used in Europe is R-134a. R-404A and R-410A are also feasible. Other potentially feasible alternatives include: solid CO_2, HC/CO_2 compression systems, and a combination of stationary HC or ammonia with liquid CO_2, ice slurry, or eutectic plates. Solid CO_2 systems are not very energy efficient and changes must be made to system designs to make this alternative a safe and feasible option. (IPCC/TEAP 2005)

Summary Analysis of Alternatives for Refrigerated Transport Equipment

Viable alternatives to HCFCs exist in the refrigerated transport end use. HFCs, particularly R-134a and R-404A, are the primary alternative to HCFCs in all applications of refrigerated transport, although these alternatives will lead to GHG emissions, which may not be sustainable in the long-term. Although natural refrigerants are feasible for some applications, such as refrigerated transport vessels, fishing vessels, and refrigerated railcars, extensive research and development would be needed to expand the market share of these refrigerants into other segments of this end use (i.e., road transport refrigeration units, semi-trailers, rigid trucks, and vans). There are a number of potentially feasible alternatives in refrigerated railcars that could become significant market players with additional investment (e.g., solid CO_2, HC/CO_2 compression systems, and a combination of stationary HC or ammonia with liquid CO_2, ice slurry, or eutectic plates).

3.4 Industrial Process Refrigeration

Feasible alternatives for industrial process refrigeration (IPR) include ammonia and a variety of HFCs—including R-32, R-134a, R-404A, R-410A, R-417A, R-422A, R-422D, and R-507A. R-417A, R-422A, and R-422D are reportedly also feasible as drop-in replacements for equipment used in low- and medium-temperature food processing applications (DuPont 2006a). Ammonia is the primary refrigerant used in IPR and is particularly important for humidity control of chemicals, industrial process air conditioning, refrigeration in construction, ice rinks, and wind tunnels. Ammonia systems are the least expensive in the IPR end use and comprise up to 80% of the current market share in several European countries (IPCC/TEAP 2005). However, ammonia is not always technically feasible for specific processes (e.g., confectionary), and its use is restricted in normally-occupied spaces (CIAA/ESCLA/EuroCommerce 2005).

Of the HFC options, R-134a (used in wind tunnels) is optimal for use in large systems for higher temperatures, while R-32 is optimal for lower temperature applications. R-410A is feasible for freeze drying and refrigeration in construction, but requires equipment specially designed for its use. R-404A and R-507A are the primary alternatives for use in the temperature range from -50°C to -30°C. R-404A is commonly used for separation of gases, humidity control of chemicals, industrial processing air conditioning, refrigeration in construction, ice rinks, and wind tunnels. R-507A is most commonly used for the separation of gases, solidification of substances, humidity control of chemicals, refrigeration in construction, and wind tunnels. (IPCC/TEAP 2005)

Other natural refrigerants (CO_2 and HCs) are feasible. CO_2 can be used in the following applications: freeze drying, separation of gases, solidification of substances, humidity control of chemicals, refrigeration in construction, and ice rinks. It is increasingly used for in the low-temperature stage of cascade systems (IPCC/TEAP 2005). Although CO_2 is less expensive than other refrigerants when the system size is increased, the energy consumption of CO_2 systems is higher than that of R-22 (CIAA/ECSLA/EuroCommerce 2005, IPCC/TEAP 2005). HCs (R-290 and R-1270) may be used in any temperature range for evaporating temperatures down to -170°C. (IPCC/TEAP 2005)

R-236fa, R-245fa, and R-365mfc are potentially feasible pending additional R&D for high-temperature heat pump applications; however, the physical characteristics of these refrigerants require high condensing temperatures and make it unlikely that they will comprise a significant market share (IPCC/TEAP 2005).

Figure 11 presents the relative energy consumption of alternative refrigerants in industrial process refrigeration equipment.

Figure 11: Relative Energy Consumption of Alternative Refrigerants in IPR[a]

Alternative	Baseline	Energy Consumption
R-410A	R-22	Similar
	R-404A	Slightly more
	R-507A	Slightly more
	Ammonia	Similar
R-422D	R-22 (medium temp)	Similar[b]
	R-22 (low temp)	Up to 14% more efficient[b]
CO_2	R-22	Higher
	R-410A	Similar
	Ammonia	Similar
R-290 (propane)	HFCs	Similar
R-1270	HFCs	Similar

[a] Unless otherwise specified, information is based on IPCC/TEAP (2005).
[b] DuPont (2006).

Summary Analysis of Alternatives for Industrial Process Refrigeration Equipment

A wide variety of feasible alternatives exist for the range of industrial process applications, including ammonia, HFCs (i.e., R-32, R-134a, R-404A, R-410A, R-417A, R-422A, R-422D, R-507A), CO_2, and HCs. In general, these alternatives are comparable to HCFCs in terms of energy consumption. Furthermore, several HFCs are reportedly feasible as retrofit options. In short, this end use is expected to have a smooth transition away from HCFCs due to the current availability of alternatives.

3.5 Small Air Conditioning

3.5.1 Commercial and Residential Unitary Air Conditioning

Currently, the only feasible alternatives for unitary AC are HFCs, primarily R-407C and R-410A (IPCC/TEAP 2005, Calm and Domanski 2004). According to one industry representative, R-410A operates more efficiently than R-407C (Carrier 2006). According to one gas manufacturers, R-417A and R-422D are also feasible for use in both new and existing unitary AC units (DuPont 2006a).

CO_2 and HCs (e.g., propane) may also one day be feasible, but extensive research and development is still needed to design systems to address potential safety hazards[18] (CIAA/ECSLA/EuroCommerce 2005, IPCC/TEAP 2005). It is anticipated that the cost of CO_2 unitary air conditioning will be significantly more than conventional systems (up to 30% more than R-22 systems), due to modifications that are required to improve safety (ADL 2002, IPCC/TEAP 2005, Sand et al. 1997).

Figure 12 presents a summary of the energy consumption and LCCP of alternative refrigerants in unitary AC relative to R-22.

Figure 12: Energy Consumption and LCCP of Alternative Refrigerants in Unitary AC Relative to R-22

Alternative Refrigerant	Energy Consumption[a] (Source)	LCCP (Source)
R-134a	+5% to +10% (Sand et al 1997)	-1% (ADL 2002)
R-407C	Similar (Sand et al 1997, ADL 2002)	Similar (ADL 2002)
R-410A	-4% to -7% (Sand et al 1997)	Similar (Minor 2004)
R-417A	-	-
R-422D	-	-
R-290	+12% to +23% (Goetzler and Dieckmann 2001, Sand et al. 1997)	-3% to -8% (ADL 2002)
CO_2	Similar (ADL 2002)	Slight reductions (IPCC/TEAP 2005)

- = No information available
[b] Positive energy consumption indicates that the alternative refrigerant consumes more energy than the baseline refrigerant.

In addition, based on theoretical calculations, the use of CO_2 in unitary AC may result in slight LCCP reductions compared to R-407C and R-410A (IPCC/TEAP 2005).

[18] There are restrictions on the use of HC systems containing a charge greater than 0.15 kg (CIAA/ECSLA/EuroCommerce 2005).

Summary Analysis of Alternatives for Commercial and Residential Unitary Air Conditioning Equipment

HFC refrigerants represent viable alternatives to HCFCs in this end use, although their long-term sustainability as greenhouse gases is questionable. With additional research and development to limit safety hazards, climate-friendly alternatives, such as propane and ammonia, may also become viable.

3.5.2 Window Air Conditioning Units

Feasible alternatives for window AC units include HFCs (R-134a, R-404A, R-407C, R-410A, R-417A, R-422D, R-507A) and propane. R-407C and R-410A are the primary alternatives currently used to replace R-22 (IPCC/TEAP 2005). Calm and Domanski (2004) have also reported R-404A as an alternative for R-22 in window AC units, and other data indicate that R-407A is feasible in this end use; however, these alternatives do not appear to be big players on the European market. Similarly, R-417A and R-422D are technically feasible as a retrofit to R-22 window units (DuPont 2006a); however, it is likely that the cost of retrofitting will be more expensive than the cost of a new unit (Hundy and Pham 2001). Propane is a potential alternative for R-22, however, there are safety concerns associated with its use (Hickman 2004).

Figure 13 presents the energy consumption and LCCP of alternative refrigerants in window AC units relative to R-22.

Figure 13: Energy Consumption and LCCP of Alternative Refrigerants in Window AC Relative to R-22

Alternative Refrigerant	Energy Consumption[a] (Source)	LCCP (Source)
R-134a	Greater (Hundy and Pham 2001)	-
R-407C	0% to +5% (Minor 2004)	Similar (Minor 2004)
R-410A	0% to -7% (Calm and Domanski 2004, Minor 2004)	-
R-290	Similar (Hickman 2004)	-

- = No information available
[b] Positive energy consumption indicates that the alternative refrigerant consumes more energy than the baseline refrigerant.

Summary Analysis of Alternatives for Window Air Conditioning Units

Currently, R-407C and R-410A are the primary alternatives to HCFCs in window air conditioning units. Other alternatives include R-134a, R-404A, R-417A, R-422D, R-507A, and propane. The most promising alternatives, R-407C and R-410A, have similar energy consumption to R-22, making them attractive alternatives. It is important to note that while HFCs are currently the major alternatives, further investment into the development of equipment using natural refrigerants will need to be increased if future EC greenhouse gas regulations restrict the use of HFCs. With additional research and development to limit safety hazards, climate-friendly propane may also become viable.

3.6 Large Air Conditioning (Chillers)

Feasible alternatives for chillers include HFCs (R-134a, R-407C, R-410A) and, in some applications, HCs and ammonia. Specific alternatives vary by application, as described below.

Historically, centrifugal chillers have used R-22 and R-123.[19] Now, centrifugal chillers use R-134a as the primary alternative for R-22 for capacities ranging from 350 to 14,000 kW. Another alternative being investigated for use in centrifugal chillers is R-245fa. Its use does, however, require compressors to be redesigned, and no manufacturer has indicated plans to produce them (IPCC/TEAP 2005). In addition, HC refrigerants are used in centrifugal chillers in petrochemical plants; however, due to the large charge sizes associated with centrifugal chillers, the flammability risk prevents HC centrifugal chillers from being used in any other applications. The alternatives to R-123 are R-134a and R-245fa. Compared to R-123, R-134a is less efficient and has a higher total equivalent warming impact (TEWI). Although R-245fa consumes a similar amount of energy as R-123, it has a higher cost due to the manufacturing processes entailed. (Calm, 2004)

Positive displacement chillers (e.g., screw, scroll, and reciprocating chillers) primarily use HFCs as alternatives to HCFCs, although ammonia and HCs may also be used in some applications. The most common refrigerant in screw chillers is R-134a, though R-410A is also a market player; R-134a, R-410A and R-407C are used most in for scroll chillers; and R-407C is most common for reciprocating chillers, with R-134a used to a lesser extent (IPCC/TEAP 2005, Calm and Domanski 2004). In addition, ammonia is feasible in screw and reciprocating chillers, although it only accounts for a small portion of the market (due to safety hazards, which impose limitations on the possible charge size and location of the chiller). Similarly, although their cost is 10% to 20% higher than that of equivalent HCFC or HFC systems, a small number of HC reciprocating chillers are sold each year in Europe. Safety guidelines limit the charge size of HC chillers, depending on application, and require protective measures to be taken, including proper placement and/or gas tight enclosure of the chiller, use of a low-charge system design, fail-safe ventilation systems, and gas detector alarm systems. Alternatively, HC chillers may be located outdoors to minimize health risks. (IPCC/TEAP 2005)

Figure 14 summarizes the relative energy consumption and LCCP of alternative refrigerants in chillers.

Figure 14: Relative Energy Consumption and LCCP of Alternative Refrigerants in Chillers

Alternative Refrigerant	Baseline	Energy Consumption[a] (Source)	LCCP (Source)
General			
R-134a	R-22	0% to +7% (Calm and Domanski 2004, Minor 2004)	-
CO_2	R-22	Greater (Calm and Domanski 2004)	-
Centrifugal Chillers			
R-134a	R-22	Similar (ADL 2002, Calm and Domanski 2004)	-10% (ADL 2002)
	R-123	+9% to +20% (Calm 2004)	Slight increase (Soffientini et al. undated)
R-245fa[b]	R-22	-7% to -11% (ADL 2002)	-9% (ADL 2002)
	R-134a	-2.5% (Soffientini et al. undated, Spatz 2003)	Slight reductions (Soffientini et al. undated, Spatz 2003)
	R-123	Similar (Calm 2004)	Slight increase (Soffientini et al. undated)
Screw Chillers			
R-134a	R-22	-	+ 6% (ADL 2002)
R-410A	R-22	-	Similar (IPCC/TEAP 2005)

[19] The use of R-123 is not modelled in this report given that its use is reportedly negligible as a percent of overall HCFC consumption (i.e., less than 1 percent).

Alternative Refrigerant	Baseline	Energy Consumption[a] (Source)	LCCP (Source)
Ammonia	R-22	Same (Sand et al 1997)	Slight increase (IPCC/TEAP 2005)
	R-134a	Same (Sand et al 1997)	-
Scroll Chillers			
R-407C	R-290	-	Similar (IPCC/TEAP 2005)
Reciprocating Chillers			
R-290	R-22	-5% (IPCC/TEAP 2005)	-
	R-407C	-	Similar (IPCC/TEAP 2005)

- = No information available
[a] Positive energy consumption indicates that the alternative refrigerant consumes more energy than the baseline refrigerant.
[b] Calculations performed were based on theoretical efficiencies as R-245fa is not currently in use.

Summary Analysis of Alternatives for Chillers

Currently, chillers use HFCs (primarily R-134a) as alternatives to R-22 and R-123. However, as a result of the low GWP and high efficiency of R-123 centrifugal chillers, the R-134a models have a greater climate impact than their ODS counterpart. If future EC regulations restrict the use of HFCs, further investment will be required to facilitate the technical and economic feasibility of chillers using natural refrigerants. Currently, safety hazards associated with the use of natural refrigerants (HCs and ammonia) exist, although their use is slowly increasing. As research continues, these safety hazards are expected to decrease with improved engineering of chillers.

4. Summary of Modelling Results for Servicing Demand, Supply, and Avoided Emission Benefits

The methodology detailed in Section 2 was used to model projected servicing demand for R-22, supply of recovered R-22, and costs and benefits of early retirement by end use and by Member State.

This section summarizes the demand for and supply of recovered R-22 for servicing existing equipment between the phaseout date for virgin R-22 and the phaseout date for recycled R-22. It also examines the extent, costs, and benefits of the early retirement of equipment that would be precipitated by the enforcement of each of the phaseout scenarios. Analysis of these results is provided in Section 5.

4.1 Servicing Demand Summary

Figure 15 presents the total R-22 servicing demand (in metric tonnes) projected in 2005 through 2019, by country for the EU-25, Bulgaria, and Romania. Figure 16 presents total servicing demand for R-22 by end use for the EU-25 plus Bulgaria and Romania, and Figure 17 through Figure 19 present this information by region (for the EU-15, EU-10, and Bulgaria and Romania). Finally, Figure 20 shows R-22 demand by end use for the entire EU-25+2 graphically. Appendix B shows the estimated number of units remaining in service at the end of each year (from 2005 through 2019) by end use and by country.

As shown in Figure 15, total servicing demand in the entire EU-25+2 for all end uses is projected to decrease substantially by 2019. Estimated R-22 servicing demand in the EU-15 accounts for about 96 percent of total EU-25+2 demand in 2005 and decreases over time to 83 percent in 2019. The percent of total servicing demand associated with EU-10 countries increases from about 3 percent to 6 percent from 2005 to 2019, and the percent associated with Bulgaria and Romania gradually increases from 1 percent in 2005 to 11 percent in 2019.

Figure 20 shows servicing demand (in metric tonnes) by end use for years 2011, 2014, and 2019, the last year in which the use of recycled R-22 would be permitted under each of the phaseout scenarios. As shown, the highest R-22 demand in 2011 is estimated to be for servicing large stationary air conditioning equipment, followed by large commercial refrigeration, industrial refrigeration, small stationary air conditioning, small commercial refrigeration, and refrigerated transport. By the end of 2019, industrial refrigeration equipment, having the longest lifetime (assumed to be 20 years), is projected to account for over 90 percent of the servicing demand. Because of their shorter equipment lifetimes, servicing demand for small commercial refrigeration, refrigerated transport and small stationary air conditioning end uses are projected to have declined to zero by 2019, as shown in Figure 20.

Figure 15: Total Year-End R-22 Servicing Demand Projected by Country for the EU-25+2, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	2,562	2,295	2,028	1,761	1,494	1,228	963	697	496	302	107	86	64	43	21
Belgium	3,060	2,741	2,422	2,103	1,784	1,467	1,150	833	593	360	128	103	77	51	26
Bulgaria	55	55	55	51	46	42	37	33	28	24	19	15	12	9	7
Cyprus	135	123	111	99	87	75	63	50	39	31	23	16	10	3	2
Czech Rep.	35	32	29	26	22	19	16	13	10	8	6	4	3	1	1
Denmark	2,146	1,922	1,698	1,475	1,251	1,029	806	584	416	253	90	72	54	36	18
Estonia	26	24	22	20	17	15	13	11	9	7	6	4	2	1	1
Finland	1,634	1,464	1,293	1,123	953	783	614	445	316	192	68	55	41	27	14
France	1,967	1,758	1,548	1,339	1,129	938	746	555	429	310	191	153	114	76	38
Germany	882	760	637	515	393	318	243	174	106	38	30	23	15	8	0
Greece	1,604	1,436	1,268	1,100	932	765	598	430	306	186	66	53	40	26	13
Hungary	114	104	93	83	73	63	53	43	33	26	19	14	8	3	2
Ireland	1,409	1,262	1,114	966	818	671	524	377	268	163	58	46	35	23	12
Italy	7,947	7,109	6,270	5,431	4,592	3,758	2,924	2,090	1,485	903	321	257	193	128	64
Latvia	35	32	29	26	23	20	16	13	10	8	6	4	3	1	1
Lithuania	83	75	68	61	53	46	38	31	24	19	14	10	6	2	2
Luxembourg	269	241	213	184	156	128	100	71	51	31	11	9	7	4	2
Malta	69	62	56	50	44	38	32	26	20	16	12	8	5	2	1
Netherlands	558	503	448	393	339	284	230	176	132	89	46	37	28	19	9
Poland	531	484	436	389	341	294	246	199	154	122	90	64	38	12	10
Portugal	1,483	1,328	1,173	1,019	864	710	557	403	287	174	62	50	37	25	12
Romania	285	285	285	262	238	215	192	168	145	121	98	76	60	44	32
Slovakia	32	29	26	24	21	18	15	12	9	7	5	4	2	1	1
Slovenia	69	62	56	50	44	38	32	26	20	16	12	8	5	2	1
Spain	3,388	3,018	2,647	2,277	1,906	1,537	1,168	800	557	339	120	96	72	48	24
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	4,590	4,107	3,624	3,140	2,657	2,176	1,696	1,216	864	525	187	149	112	75	37
EU-25+2	*34,970*	*31,311*	*27,651*	*23,964*	*20,277*	*16,674*	*13,072*	*9,476*	*6,808*	*4,272*	*1,796*	*1,416*	*1,043*	*670*	*350*

Figure 16: Total Year-End R-22 Servicing Demand (EU-25+2) by End Use, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Small Commercial Refrigeration	1,952	1,683	1,413	1,140	867	594	321	55	40	25	10	6	3	0	0
Large Commercial Refrigeration	7,646	6,884	6,123	5,359	4,596	3,832	3,069	2,306	1,542	779	36	26	16	6	4
Refrigerated Transport	195	152	110	66	22	16	10	4	3	1	0	0	0	0	0
Industrial Refrigeration	4,596	4,292	3,988	3,683	3,377	3,072	2,766	2,461	2,155	1,850	1,544	1,239	933	628	322
Small Stationary A/C	6,021	5,170	4,319	3,460	2,601	1,788	976	164	23	16	8	0	0	0	0
Large Stationary A/C	14,560	13,130	11,699	10,256	8,814	7,371	5,929	4,486	3,044	1,601	199	145	90	36	24
All End Uses	*34,970*	*31,311*	*27,651*	*23,964*	*20,277*	*16,674*	*13,072*	*9,476*	*6,808*	*4,272*	*1,796*	*1,416*	*1,043*	*670*	*350*

Figure 17: Projected Year-End R-22 Servicing Demand for EU-15 by End Use, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Small Commercial Refrigeration	1,796	1,538	1,281	1,023	766	508	251	0	0	0	0	0	0	0	0
Large Commercial Refrigeration	7,515	6,762	6,008	5,255	4,501	3,748	2,994	2,240	1,487	733	0	0	0	0	0
Refrigerated Transport	152	114	76	37	0	0	0	0	0	0	0	0	0	0	0
Industrial Refrigeration	4,474	4,176	3,877	3,578	3,279	2,980	2,682	2,383	2,084	1,785	1,486	1,188	889	590	291
Small stationary A/C	5,724	4,901	4,078	3,255	2,432	1,656	880	104	0	0	0	0	0	0	0
Large Stationary A/C	13,841	12,453	11,065	9,677	8,288	6,900	5,512	4,124	2,736	1,348	0	0	0	0	0
All End Uses	*33,502*	*29,943*	*26,384*	*22,825*	*19,267*	*15,793*	*12,319*	*8,851*	*6,307*	*3,866*	*1,486*	*1,188*	*889*	*590*	*291*

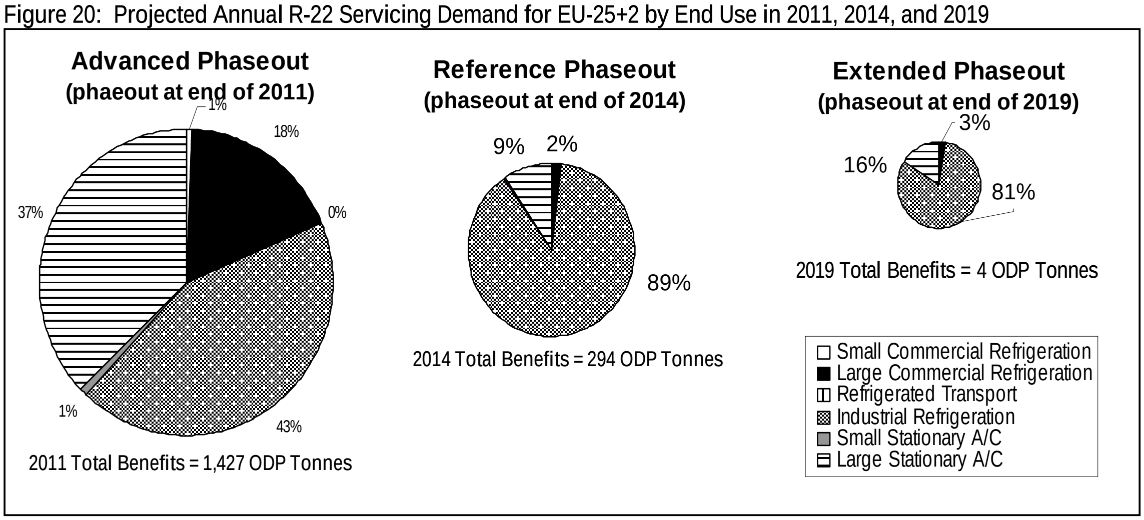
Figure 18: Projected Year-End R-22 Servicing Demand for EU-10 by End Use, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Small Commercial Refrigeration	122	109	97	85	73	61	49	36	24	12	0	0	0	0	0
Large Commercial Refrigeration	102	94	87	79	71	63	55	47	39	31	24	16	8	0	0
Refrigerated Transport	32	27	23	18	14	9	5	0	0	0	0	0	0	0	0
Industrial Refrigeration	94	89	84	78	73	68	63	57	52	47	42	37	31	26	21
Small Stationary A/C	228	199	171	142	114	85	57	28	0	0	0	0	0	0	0
Large Stationary A/C	551	509	466	424	382	339	297	254	212	170	127	85	42	0	0
All End Uses	*1,128*	*1,027*	*927*	*826*	*726*	*625*	*525*	*424*	*328*	*260*	*193*	*137*	*82*	*26*	*21*

Figure 19: Projected Year-End R-22 Servicing Demand for Bulgaria and Romania by End Use, 2005-2019 (Metric Tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Small Commercial Refrigeration	35	35	35	32	29	25	22	19	16	13	10	6	3	0	0
Large Commercial Refrigeration	28	28	28	26	24	22	20	18	16	14	12	10	8	6	4
Refrigerated Transport	12	12	12	10	9	7	6	4	3	1	0	0	0	0	0
Industrial Refrigeration	28	28	28	26	25	23	22	20	19	17	16	15	13	12	10
Small Stationary A/C	70	70	70	62	55	47	39	31	23	16	8	0	0	0	0
Large Stationary A/C	168	168	168	156	144	132	120	108	96	84	72	60	48	36	24
All End Uses	*340*	*340*	*340*	*312*	*285*	*257*	*229*	*201*	*173*	*145*	*117*	*91*	*72*	*54*	*38*

Figure 20: Projected Annual R-22 Servicing Demand for EU-25+2 by End Use in 2011, 2014, and 2019



4.2 Supply of Recovered R-22 Summary

Figure 21 presents the projected year-end annual supply of recycled R-22 by country and year from 2010 to 2019, as well as the inventory of recycled R-22 estimated to be stockpiled over the years 2000-2009 if stockpiling is assumed to occur in preparation for the 1 January 2010 prohibition on the use of newly produced R-22 in refrigeration and AC equipment.

As described in Section 2.2, the projected annual supply presented in Figure 21 assumes that 50 percent of the potential annual supply in the EU-25+2 is available for reuse (i.e., through recycling/reclamation). Potential annual supply is estimated by multiplying the number of units of equipment retired in a given year by the charge size at end of life and the recovery rate (assumed to total 75 percent of the original charge). Projected annual supply is less than the potential annual supply since not all recovered R-22 is recyclable or reclaimable, either as a result of technical difficulty/cost associated with reclaiming contaminated/mixed refrigerants, or inadequate infrastructure to support reclamation.

From 2010 through 2019, year-end supply of recycled R-22 from the EU-15 is expected to account for the vast majority of recycled R-22 supply in the EU-25+2—between 80 and 99 percent of all year-end supply. Moreover, 99 percent of the recycled R-22 projected to be stockpiled between 2000 and 2009 is expected to be generated and held by EU-15 countries.

Figure 21. Total Estimated Year-End Supply of Recycled R-22 Projected by Country, 2010-2019 (Tonnes)

Country	Assumed Stockpiled R-22 (2000-2009)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	5,703	2,176	2,176	2,176	1,223	1,102	1,102	50	50	50	50
Belgium	6,811	2,599	2,599	2,599	1,462	1,316	1,316	60	60	60	60
Bulgaria	19	12	12	12	12	12	12	11	8	8	6
Cyprus	63	29	29	29	28	20	20	13	13	13	1
Czech Rep.	16	7	7	7	7	5	5	3	3	3	0
Denmark	4,845	1,847	1,847	1,847	1,049	948	948	42	42	42	42
Estonia	10	5	5	5	5	4	4	3	3	3	0
Finland	3,641	1,390	1,390	1,390	781	702	702	32	32	32	32
France	4,384	1,659	1,659	1,659	634	507	507	89	89	89	89
Germany	4,019	463	463	423	423	423	18	18	18	18	18
Greece	1,469	546	546	546	349	329	329	31	31	31	31
Hungary	53	24	24	24	24	17	17	11	11	11	1
Ireland	3,240	1,243	1,243	1,243	672	595	595	27	27	27	27
Italy	7,370	2,752	2,752	2,752	1,701	1,595	1,595	150	150	150	150
Latvia	17	8	8	8	7	5	5	3	3	3	0
Lithuania	39	18	18	18	17	12	12	8	8	8	1
Luxembourg	626	239	239	239	114	114	114	5	5	5	5
Malta	32	15	15	15	14	10	10	6	6	6	1
Netherlands	1,020	363	363	363	276	275	275	22	22	22	22
Poland	250	113	113	113	111	77	77	50	50	50	6
Portugal	1,346	499	499	499	325	308	308	29	29	29	29
Romania	88	56	56	56	56	56	56	55	38	38	25
Slovakia	15	7	7	7	7	5	5	3	3	3	0
Slovenia	32	15	15	15	14	10	10	6	6	6	1
Spain	3,344	1,279	1,279	1,279	705	599	599	56	56	56	56
Sweden	1,671	0	0	0	0	0	0	0	0	0	0
UK	10,566	4,068	4,068	4,068	2,096	1,855	1,855	88	88	88	88
EU-15	*60,054*	*21,124*	*21,124*	*21,084*	*11,811*	*10,667*	*10,262*	*700*	*700*	*700*	*700*
EU-10	*528*	*240*	*240*	*240*	*235*	*163*	*163*	*106*	*106*	*106*	*12*
Bulgaria & Romania	*107*	*68*	*68*	*68*	*68*	*68*	*68*	*66*	*46*	*46*	*31*
EU-25 + 2	60,690	21,432	21,432	21,392	12,113	10,898	10,493	873	853	853	744

4.3 Summary of Annual Supply and Demand Projections

In summary, Figure 22 presents the annual supply and demand projections for recycled/reclaimed R-22 in the EU-25+2. Figure 23 through Figure 25 present these projections by region, first for the EU-15, followed by the EU-10, and Bulgaria and Romania. The figures indicate that under the assumptions presented in Sections 2.1 and 2.2, annual supply exceeds demand in most years from 2010-2019 for the EU-25+2 as a whole, though this is not the case for all regions. Further analysis is presented in Section 5.

Figure 22. Annual Supply and Demand for Recycled/Reclaimed R-22 in the EU-25+2, 2010-2019 (Tonnes)

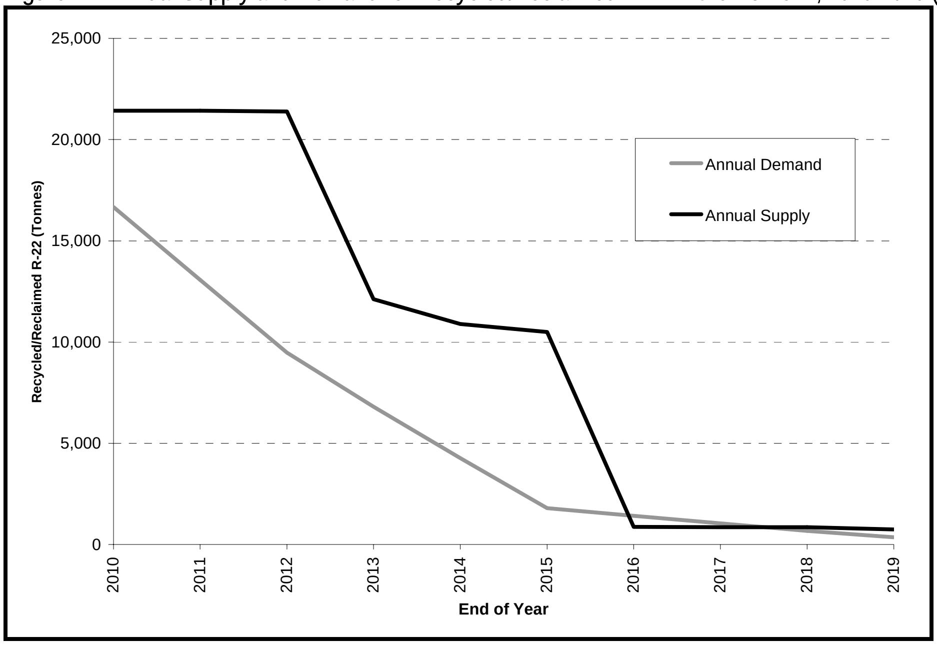


Figure 23. Annual Supply and Demand for Recycled/Reclaimed R-22 in the EU-15, 2010-2019 (Tonnes)

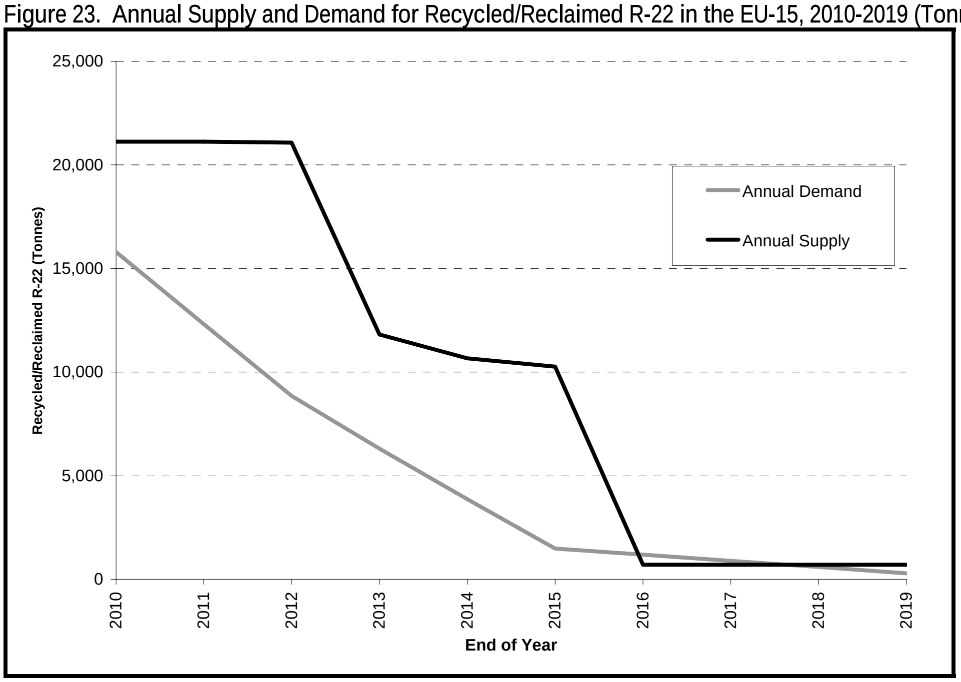


Figure 24. Annual Supply and Demand for Recycled/Reclaimed R-22 in the EU-10, 2010-2019 (Tonnes)

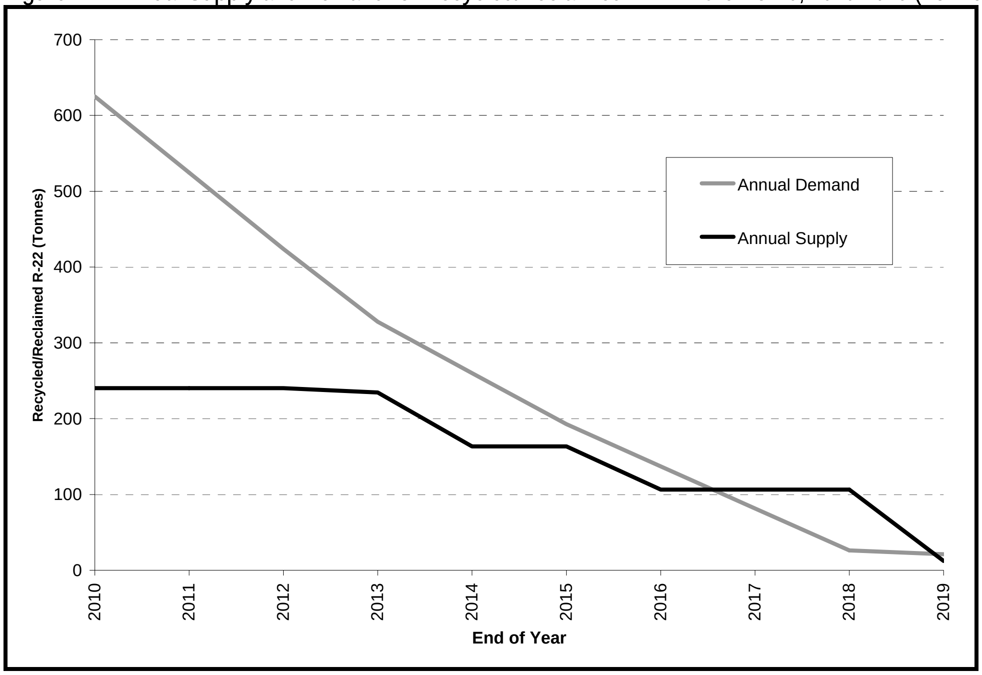
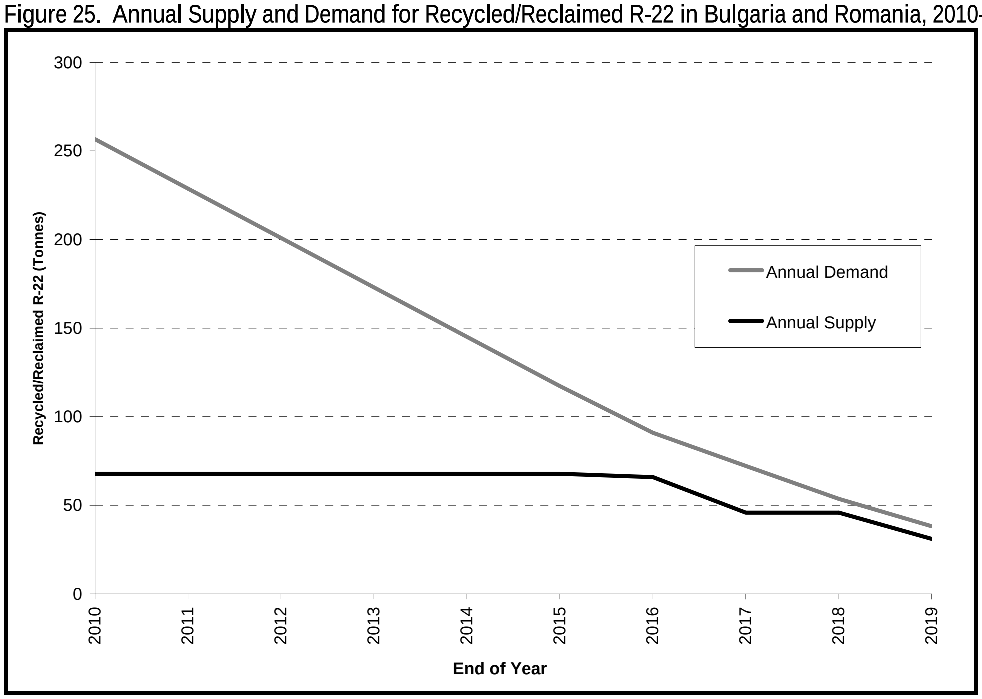


Figure 25. Annual Supply and Demand for Recycled/Reclaimed R-22 in Bulgaria and Romania, 2010-2019 (Tonnes)



4.4 Benefits Summary

Prohibiting the use of recycled R-22 to service refrigeration and AC equipment will result in environmental benefits associated with avoided emissions of R-22. Figure 26 shows the avoided ODP-weighted emissions of R-22, by country, in each year from 2012 through 2022. 2030 is the year in which it is projected that all R-22 equipment in the EU-25+2 would reach the end of its natural lifetime, therefore, benefits can be realised until that date. However, because very few HCFC equipment will remain in service beyond 2022, total emissions savings from 2022 to 2030 are less than 1 ODP tonne. Annual emissions avoided in years 2012, 2015, and 2020 are presented in bold typeface, since these are the first years for which HCFC emissions would be avoided in the advanced, reference, and extended phaseout scenarios, respectively.

Figure 27 through Figure 30 show year-end avoided emissions of R-22 by end use and region for each year from 2012 through the last year in which emissions savings are greater than 1 ODP tonne. As shown, the use of recycled R-22 in small stationary AC and small commercial refrigeration is projected to naturally decline to zero by the end of 2015, such that minimal avoided emission benefits are realized for those end uses in the reference and extended phaseout scenarios. Other end uses, such as industrial refrigeration, have longer natural lifetimes, so phaseout scenarios will lead to avoided emissions that would have otherwise been realized well into the future.

The avoided emissions shown in Figure 26 through Figure 30 are average annual in-service-life avoided emissions; any emissions occurring when the equipment is taken out of service (i.e., end of life emissions) are not included in this analysis This is because end of life emissions will be experienced regardless of when the equipment is phased out—be it sooner, as a result of a regulatory action, or later, when the equipment has reached the end of its useful life.

Figure 26. Total Estimated Year-End Avoided Emissions of R-22 Projected by Country, 2012-2022 (ODP Tonnes)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Austria	38	27	17	6	5	4	2	1	0	0	0
Belgium	46	33	20	7	6	4	3	1	0	0	0
Bulgaria	2	2	1	1	1	1	1	0	0	0	0
Cyprus	3	2	2	1	1	1	0	0	0	0	0
Czech Rep.	1	1	0	0	0	0	0	0	0	0	0
Denmark	32	23	14	5	4	3	2	1	0	0	0
Estonia	1	0	0	0	0	0	0	0	0	0	0
Finland	24	17	11	4	3	2	2	1	0	0	0
France	31	24	17	10	8	6	4	2	0	0	0
Germany	10	7	4	2	1	1	0	0	0	0	0
Greece	24	17	10	4	3	2	1	1	0	0	0
Hungary	2	2	1	1	1	0	0	0	0	0	0
Ireland	21	15	9	3	3	2	1	1	0	0	0
Italy	115	82	50	18	14	11	7	4	0	0	0
Latvia	1	1	0	0	0	0	0	0	0	0	0
Lithuania	2	1	1	1	1	0	0	0	0	0	0
Luxembourg	4	3	2	1	0	0	0	0	0	0	0
Malta	1	1	1	1	0	0	0	0	0	0	0
Netherlands	10	7	5	3	2	2	1	1	0	0	0
Poland	11	8	7	5	4	2	1	1	0	0	0
Portugal	22	16	10	3	3	2	1	1	0	0	0
Romania	9	8	7	5	4	3	2	2	1	0	0
Slovakia	1	1	0	0	0	0	0	0	0	0	0
Slovenia	1	1	1	1	0	0	0	0	0	0	0
Spain	44	31	19	7	5	4	3	1	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0
UK	67	48	29	10	8	6	4	2	0	0	0
EU-25 +2	521	375	236	99	78	57	37	19	2	1	1

Figure 27. Total Estimated Year-End Avoided Emissions of R-22 Projected by End Use for EU-15 Countries, 2012-2019 (ODP Tonnes)

	2012	2013	2014	2015	2016	2017	2018	2019
Small Commercial Refrigeration	0	0	0	0	0	0	0	0
Large Commercial Refrigeration	123	82	40	0	0	0	0	0
Refrigerated Transport	0	0	0	0	0	0	0	0
Industrial Refrigeration	131	115	98	82	65	49	32	16
Small Stationary A/C	6	0	0	0	0	0	0	0
Large Stationary A/C	227	151	76	0	0	0	0	0
All End Uses	487	348	214	82	65	49	32	16

Figure 28. Total Estimated Year-End Avoided Emissions of R-22 Projected by End Use for EU-10 Countries, 2012-2021 (ODP Tonnes)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Small Commercial Refrigeration	2	1	1	0	0	0	0	0	0	0
Large Commercial Refrigeration	3	2	2	1	1	0	0	0	0	0
Refrigerated Transport	0	0	0	0	0	0	0	0	0	0
Industrial Refrigeration	3	3	3	2	2	2	1	1	1	1
Small Stationary A/C	2	0	0	0	0	0	0	0	0	0
Large Stationary A/C	14	12	9	7	5	2	0	0	0	0
All End Uses	23	18	14	11	8	4	1	1	1	1

Figure 29. Total Estimated Year-End Avoided Emissions of R-22 Projected by End Use for Bulgaria and Romania, 2012-2020 (ODP Tonnes)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Small Commercial Refrigeration	1	1	1	1	0	0	0	0	0
Large Commercial Refrigeration	1	1	1	1	1	0	0	0	0
Refrigerated Transport	0	0	0	0	0	0	0	0	0
Industrial Refrigeration	1	1	1	1	1	1	1	1	0
Small Stationary A/C	2	1	1	0	0	0	0	0	0
Large Stationary A/C	6	5	5	4	3	3	2	1	1
All End Uses	11	10	8	6	5	4	3	2	1

Figure 30. Total Estimated Year-End Avoided Emissions of R-22 Projected by End Use for EU-25+2, 2012-2022 (ODP Tonnes)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Small Commercial Refrigeration	3	2	1	1	0	0	0	0	0	0	0
Large Commercial Refrigeration	127	85	43	2	1	1	0	0	0	0	0
Refrigerated Transport	0	0	0	0	0	0	0	0	0	0	0
Industrial Refrigeration	135	119	102	85	68	51	35	18	1	1	1
Small Stationary A/C	9	1	1	0	0	0	0	0	0	0	0
Large Stationary A/C	247	168	90	11	8	5	2	1	1	0	0
All End Uses	521	375	236	99	78	57	37	19	2	1	1

5. Analysis of Modelling Results for Reference, Advanced, and Extended Phaseout Scenarios

Using information gathered from the consumption model (described in Section 2), the projected demand, supply, costs, and benefits of the reference, advanced, and extended phaseout scenarios were estimated, as presented in Section 4. These scenario outcomes are described in more detail in Sections 5.1, 5.2, and 5.3, below. Section 5.4 summarizes and compares these results.

5.1 Reference Scenario

The reference scenario follows the existing EC Regulation: the use of virgin R-22 for servicing refrigeration and air conditioning equipment is banned as of 1 January 2010, and the use of recycled R-22 in the same applications is banned as of 1 January 2015.

5.1.1 Supply and Demand: Reference Scenario

Annual servicing demand for the EU-25+2 by the end of 2014—the last year of HCFC servicing allowed under the reference scenario is shown in Figure 17 through Figure 19. Overall, the EU-15 countries are projected to account for the large majority of demand—approximately 90 percent. By end use, large stationary refrigeration, industrial process refrigeration, and large commercial refrigeration together represent over 99 percent of the total servicing demand (see Figure 20).

As shown in Figure 22, annual supply of recycled/reclaimed R-22 throughout the EU-25+2 is projected to be more than adequate to meet the total annual demand through 2014. However, while annual supplies in the EU-15 will greatly exceed annual demand in that region (see Figure 23), the reverse is projected for the EU-10 and Bulgaria/Romania (see Figure 24 and Figure 25). Indeed, in the EU-10 and Bulgaria/Romania, supply shortfalls are expected immediately following the phaseout of new production (in 2010)—highlighting the need for recycled/reclaimed R-22 supplies from EU-15 and/or for pre-2010 stockpiling to meet projected demand.

This analysis projects that over the period 2010 through 2015, the EU-15 will generate a surplus of recycled HCFC refrigerant (see Figure 43). If it is assumed that all countries stockpile recycled R-22 before 2010, some of the excess supply (1% or 1,074 metric tonnes) generated by the EU-15 countries during the period of 2010-2014 would be required to meet the supply shortfall in the EU-10, Bulgaria and Romania, with a larger amount of the excess supply generated by the EU-15 countries (4% or 1,700 metric tonnes) required if no stockpiling were to occur prior to 2010. If reclamation facilities in the EU-15 are not aware of the demand in the EU-10/Bulgaria/Romania, or if industries in the EU-10 are not aware of the available supply in the EU-15, information asymmetry among these countries/regions could present informal barriers to trade, which could in turn produce unnecessary supply shortfalls in some eastern European countries.

In the absence of trade of recycled HCFC refrigerant among EU-15 and eastern European countries, and if no stockpiling is assumed to occur prior to 2010, EU-10 countries and Bulgaria and Romania will experience a supply deficit by the end of 2010 (see Figure 44 and Figure 45). Indeed, in Bulgaria and Romania, even if recycled R-22 is stockpiled prior to 2010, demand is projected to be greater than the total potential annual supply if they do not purchase recycled R-22 from the EU-15. For EU-10 countries, even if stockpiling of R-22 takes place prior to 2010, a refrigerant recovery rate of over 70 percent would need to be achieved in order to satisfy demand without the help of EU-15 supplies. Given the less-developed infrastructure for recycling/reclamation in the EU-10, however, a 70 percent recovery/recycling rate may not be feasible. In Bulgaria and Romania, even with higher rates of recycling/reclamation it will not be possible to meet demand without obtaining recycled R-22 from elsewhere in the EU.

5.1.2 Extent and Cost of Early Retirement: Reference Scenario

Prohibiting the use of recycled R-22 for servicing refrigeration and air conditioning equipment as of 1 January 2015 is projected to result in the undue abandonment (i.e., replacement or abandonment before the end of the equipment's useful lifetime as a result of a regulatory action) of almost 41,500 pieces of equipment. The early retirement of these units is projected to result in a total cost to industry in the EU-25+2 of approximately €370 million (net present value in 2006), as shown in Figure 31 (please refer to Figure 7 for assumed capital cost by equipment type). Italy is projected to bear the greatest of these costs, followed by the UK and France. These calculations assume that recycled R-22 supplies are traded freely among the EU-15, EU-10, and Bulgaria and Romania such that no countries experience a supply shortfall prior to 2015. Should a supply shortfall materialise in EU-10, or Bulgaria and Romania, however, additional equipment abandonment will occur in these countries.

Figure 31. Projected Equipment Abandoned Early and
Cost of Early Abandonment by Country (Millions of 2006 **€**), Reference Scenario

Country	Total Number of Equipment Abandoned Early	NPV of Cost of Undue Abandonment (Millions of 2006 €)
Austria	671	€ 22
Belgium	801	€ 26
Bulgaria	4,176	€ 6
Cyprus	381	€ 4
Czech Rep.	99	€ 1
Denmark	562	€ 19
Estonia	81	€ 1
Finland	428	€ 14
France	1,192	€ 39
Germany	188	€ 5
Greece	413	€ 14
Hungary	322	€ 3
Ireland	362	€ 12
Italy	2,006	€ 66
Latvia	100	€ 1
Lithuania	234	€ 2
Luxembourg	69	€ 2
Malta	194	€ 2
Netherlands	290	€ 10
Poland	1,502	€ 15
Portugal	388	€ 13
Romania	24,810	€ 23
Slovakia	91	€ 1
Slovenia	194	€ 2
Spain	753	€ 25
Sweden	0	€ 0
UK	1,167	€ 39
Total (EU-25 +2)	*41,474*	*€ 368*

Figure 32 presents the projected number of equipment retired prematurely and the associated costs by end use. As can be seen, the number of refrigeration and AC units projected to be unduly abandoned as a result of the 2015 ban on the use of recycled R-22, as well as the costs associated with early abandonment, are not evenly distributed across end uses and regions. For example, of the total equipment projected to be retired early, approximately 29 percent are small commercial refrigeration units, yet this end use accounts for less than 1 percent of the total costs. By contrast, 88 percent of the costs are associated with the undue abandonment of industrial refrigeration units, which represent about 23 percent of the total number of units projected to be retired early. This is because small commercial refrigeration equipment are larger in number but smaller in size and cost, whereas industrial refrigeration equipment are fewer in number but larger in size and cost.

Figure 32. Projected Total Equipment Abandoned Early and Cost of Early Abandonment by Region and End Use, Reference Scenario

	Small Commercial Refrigeration	Large Commercial Refrigeration	Refrigerated Transport	Industrial Refrigeration	Small Stationary A/C	Large Stationary A/C	*All End Uses*
EU-15 Countries							
Total Number of Equipment Abandoned Early	0	0	0	9,290	0	0	*9,290*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	€ 0	€ 0	€ 306	€ 0	€ 0	*€ 306*
EU-10 Countries							
Total Number of Equipment Abandoned Early	0	394	0	261	0	2,543	*3,198*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	€ 6	€ 0	€ 12	€ 0	€ 15	*€ 33*
Romania and Bulgaria							
Total Number of Equipment Abandoned Early	11,889	206	0	100	15,269	1,520	*28,986*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 1	€ 5	€ 0	€ 6	€ 2	€ 15	*€ 29*
EU-25 + 2							
Total Equipment Abandoned Early	11,889	600	0	9,652	15,269	4,064	*41,474*
Percent of Total Equipment	*29%*	*1%*	*0%*	*23%*	*37%*	*10%*	*100%*
Total NPV of Undue Abandonment (Millions of 2006 **€**)	€ 1	€ 12	€ 0	€ 324	€ 2	€ 30	*€ 368*
Percentage of Total Cost	*<1%*	*3%*	*0%*	*88%*	*<1%*	*8%*	*100%*

Twenty-two percent of all equipment projected to be unduly abandoned under the 2015 reference phaseout scenario is installed in EU-15 countries; however, EU-15 countries are projected to bear about 83 percent of the total cost of early retirement. Eight percent of all equipment projected to be abandoned is located in EU-10 countries, and those countries are expected to bear 9 percent of the total cost. Finally, Bulgaria and Romania together are projected to prematurely retire 70 percent of all equipment (mainly small applications) facing undue abandonment, but are projected to only bear about 8 percent of the total cost. These estimates of undue abandonment assume that equipment will need to be abandoned as soon as the use ban (for servicing and maintenance) comes into effect, which is unlikely to be the case; rather, some equipment may be retrofit or may continue to operate without the need for servicing. Therefore, these levels of undue abandonment and associated costs should be considered an upper bound.

5.1.3 Benefits of Early Retirement: Reference Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing of refrigeration and AC equipment as of 1 January 2015 is projected to result in a total of 294 ODP tonnes of HCFC emissions avoided between 2015 and 2030. As shown, the majority of those avoided emissions will be realized as a result of equipment retirement in the EU-15 countries. Additionally, the large majority of the total projected avoided emissions are expected to be realized from the retirement of industrial refrigeration equipment.

Figure 33. Total Projected Avoided Emissions, 2015-2030 (ODP Tonnes), Reference Scenario

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2	End Use as a Percent of Total
Small Commercial Refrigeration	0	0	1	1	0%
Large Commercial Refrigeration	0	3	2	5	2%
Refrigerated Transport	0	0	0	0	0%
Industrial Refrigeration	244	10	5	260	88%

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2	End Use as a Percent of Total
Small stationary A/C	0	0	0	0	0%
Large Stationary A/C	0	14	14	28	9%
All End Uses	*244*	*27*	*23*	*294*	100%
EU Region as a Percent of Total	83%	9%	8%	100%	

5.1.4 Summary of Costs and Benefits: Reference Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing of refrigeration and AC equipment as of 1 January 2015 is projected to result in a total emission savings of **294 ODP tonnes** between 2015 and 2030, at a cost of **€368 million** (net present value in 2006). Figure 34 presents the calculated cost-effectiveness of this regulatory scenario by end use and region, in terms of ODP tonnes of avoided emissions per million euros. As shown, industrial refrigeration and large stationary AC (in EU-10 countries and Bulgaria and Romania) provide the greatest value in terms of emissions avoided per euro and refrigerated transport is the least cost-effective end use to phase out in 2015. Banning the use of recycled R-22 to service large commercial refrigeration and small and large stationary AC equipment in 2015 is also slightly less expensive in the EU-10, Bulgaria and Romania than in the EU-15 countries.

Figure 34. Cost-Effectiveness of a 1 January 2015 Phaseout of Recycled R-22 (ODP Tonnes of Avoided Emissions per Million Euros)

	EU-15	EU-10	Bulgaria and Romania	EU-25, Bulgaria and Romania
Small Commercial Refrigeration	0.80	0.83	0.72	0.72
Large Commercial Refrigeration	0.21	0.41	0.42	0.42
Refrigerated Transport	--	0.08	0.00	0.08
Industrial Refrigeration	0.80	0.85	0.90	0.80
Small Stationary A/C	0.09	--	0.26	0.26
Large Stationary A/C	0.32	0.94	0.94	0.94
Average of All End Uses	*0.80*	*0.81*	*0.79*	*0.80*

Note: "--" indicates that there are no avoided emissions nor associated costs.

5.2 Advanced Phaseout Scenario

5.2.1 Supply and Demand: Advanced Phaseout Scenario

Annual servicing demand for the EU-25+2 by the end of 2011—the last year of HCFC servicing allowed under the advanced phaseout scenario—is shown in Figure 17 through Figure 19. Of this total demand, the EU-15 countries are projected to account for the large majority—nearly 95 percent. By end use, large stationary refrigeration, industrial process refrigeration, and large commercial together represent about 90 percent of the total servicing demand (Figure 20).

As shown in Figure 22, annual supply of recycled/reclaimed R-22 throughout the EU-25+2 is projected to be more than adequate to meet the total annual demand through 2012. However, while annual supplies in the EU-15 will greatly exceed annual demand in that region during this timeframe (see Figure 23), the reverse is projected for the EU-10 and Bulgaria/Romania (see Figure 24 and Figure 25). Indeed, as explained in Section 5.1.1, supply shortfalls are expected in 2010 in the EU-10 and Bulgaria/Romania—highlighting the need for importation of recycled/reclaimed R-22 supplies from EU-15 and/or for pre-2010 (pre-phaseout) stockpiling in those countries. The situation is projected to be most apparent for Bulgaria and Romania, where, even if stockpiling occurs, shortages are still expected in the absence of imported recycled/reclaimed R-22 from the EU-15. In the EU-10, shortfalls could be avoided by stockpiling and aggressive recovery/reuse programmes.

5.2.2 Extent and Cost of Early Retirement: Advanced Phaseout Scenario

Prohibiting the use of recycled R-22 for servicing refrigeration and air conditioning equipment as of 1 January 2012 is projected to result in the undue abandonment of approximately 1.4 million pieces of equipment. The early retirement of these units is projected to result in a total cost to industry in the EU-25, Bulgaria and Romania of more than €4 billion (net present value in 2006), as shown in Figure 35 (please refer to Figure 7 for assumed capital cost by equipment type). Italy is projected to bear the greatest of these costs, followed by the United Kingdom and Belgium. The costs shown here assume that refrigerant supply will be adequate to meet demand; should shortfalls transpire in the EU-10, Bulgaria, and/or Romania (for example, if EU-15 supplies are not shared across regions), additional equipment will be retired prematurely.

Figure 35. Projected Total Equipment Abandoned Early and
Cost of Early Abandonment by Country (Millions of 2006 **€**), Advanced Phaseout Scenario

Country	Total Number of Equipment Abandoned Early	NPV of Cost of Undue Abandonment (Millions of 2006 €)
Austria	126,161	€ 371
Belgium	151,742	€ 443
Bulgaria	13,744	€ 19
Cyprus	12,772	€ 15
Czech Rep.	3,303	€ 4
Denmark	106,344	€ 323
Estonia	1,509	€ 5
Finland	80,953	€ 236
France	111,657	€ 260
Germany	8,609	€ 91
Greece	24,989	€ 133
Hungary	10,789	€ 12
Ireland	76,696	€ 201
Italy	127,792	€ 647
Latvia	3,361	€ 4
Lithuania	7,843	€ 9
Luxembourg	3,487	€ 37
Malta	6,498	€ 7
Netherlands	8,243	€ 156
Poland	50,343	€ 58
Portugal	21,745	€ 125
Romania	75,296	€ 77
Slovakia	3,053	€ 4
Slovenia	6,498	€ 7
Spain	99,016	€ 249
Sweden	0	€ 0
UK	241,313	€ 615
Total (EU-25 +2)	*1,383,756*	*€ 4,107*

As can be seen from Figure 36, the number of refrigeration and AC units projected to be unduly abandoned as a result of the 2012 ban on the use of recycled R-22 in those applications, as well as the costs associated with early abandonment, are not evenly distributed across end uses and regions. For example, of the total units projected to be replaced early, approximately 71 percent are small stationary AC systems; however, only roughly 3 percent of the costs associated with undue abandonment will be incurred by early retirement of those units.

Figure 36. Projected Total Equipment Abandoned Early and Cost of Early Abandonment by Region and End Use, Advanced Phaseout Scenario

	Small Commercial Refrigeration	Large Commercial Refrigeration	Refrigerated Transport	Industrial Refrigeration	Small Stationary A/C	Large Stationary A/C	*All End Uses*
EU-15 Countries							
Total Number of Equipment Abandoned Early	0	60,678	0	14,892	871,373	241,805	*1,188,748*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	€ 1,183	€ 0	€ 847	€ 116	€ 1,741	*€ 3,886*
EU-10 Countries							
Total Number of Equipment Abandoned Early	45,564	787	0	359	54,172	5,087	*105,969*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 7	€ 25	€ 0	€ 26	€ 7	€ 60	*€ 125*
Romania and Bulgaria							
Total Number of Equipment Abandoned Early	23,779	310	1,466	128	61,077	2,281	*89,040*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 6	€ 13	€ 11	€ 11	€ 19	€ 36	*€ 96*
EU-25 + 2							
Total Equipment Abandoned Early	69,343	61,775	1,466	15,379	986,621	249,172	*1,383,756*
Percent of Total Equipment	*5%*	*4%*	*0%*	*1%*	*71%*	*18%*	*100%*
Total NPV of Undue Abandonment (Millions of 2006 **€**)	€ 13	€ 1,222	€ 11	€ 883	€ 142	€ 1,837	*€ 4,107*
Percent of Total Cost	*<1%*	*30%*	*<1%*	*21%*	*3%*	*45%*	*100%*

Eighty-six percent of all equipment projected to be unduly abandoned under the 2012 regulatory scenario is installed in EU-15 countries, and those countries are projected to bear 96 percent of the total cost of early retirement. Eight percent of all equipment projected to be abandoned is located in EU-10 countries, and those countries are expected to bear 3 percent of the total cost. Finally, Bulgaria and Romania together are projected to prematurely retire 6 percent of all equipment facing undue abandonment, but are projected to only bear 2 percent of the total cost. Again, it should be noted that these estimates of undue abandonment assume that equipment will need to be abandoned as soon as the use ban (for servicing and maintenance) comes into effect, which is unlikely to be the case. Therefore, these levels of undue abandonment and associated costs should be considered an upper bound.

5.2.3 Benefits of Early Retirement: Advanced Phaseout Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing of refrigeration and AC equipment as of 1 January 2012 is projected to result in a total of 1,427 ODP tonnes of HCFC emissions avoided between 2012 and 2030. Ninety-one percent of these avoided emissions will be realized as a result of equipment retirement in the EU-15 countries; 6 percent is attributable to the EU-10 countries; and 6 percent is projected to result from equipment retirement in Bulgaria and Romania. More than 99 percent of the total projected avoided emissions from 2015 to 2030 are expected to be realized from the retirement of large commercial refrigeration, industrial refrigeration, and large stationary AC equipment. The benefits calculated here assume that refrigerant supply will be adequate to meet demand; should shortfalls transpire in the EU-10, Bulgaria, and/or Romania (for example, if EU-15 supplies are not shared across regions), the benefits will increase.

Figure 37. Total Projected Avoided Emissions, 2012-2030 (ODP Tonnes), Advanced Phaseout Scenario

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2
Small Commercial Refrigeration	0	4	4	8
Large Commercial Refrigeration	245	9	5	259
Refrigerated Transport	0	0	0	0
Industrial Refrigeration	588	19	8	616
Small Stationary A/C	6	2	4	12
Large Stationary A/C	454	49	30	532
All End Uses	*1,293*	*83*	*51*	*1,427*

5.2.4 Summary of Costs and Benefits: Advanced Phaseout Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing of refrigeration and AC equipment as of 1 January 2012 is projected to result in a total emission savings of **1,427 ODP tonnes** between 2012 and 2030, at an estimated cost of **€4.1 billion** (net present value in 2006)—assuming no supply shortfalls are realised. Figure 38 presents the calculated cost-effectiveness of this phaseout scenario by end use and region, in terms of ODP tonnes of avoided emissions per million euros. As shown, industrial refrigeration, small commercial refrigeration, and large stationary AC (in EU-10 countries and Bulgaria and Romania) provide the greatest value in terms of emissions avoided per euro, and refrigerated transport is the least cost-effective end use to phase out in 2012. Banning the use of recycled R-22 to service refrigeration and AC equipment is generally slightly less expensive in the EU-10 and Bulgaria and Romania than in the EU-15 countries.

Figure 38. Cost-Effectiveness of a 1 January 2012 Phaseout of Recycled R-22 (ODP Tonnes of Avoided Emissions per Million Euros)

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2	Decrease in Cost-Effectiveness (%) Relative to 2015 Phaseout
Small Commercial Refrigeration	0.71	0.59	0.63	0.60	16%
Large Commercial Refrigeration	0.21	0.36	0.37	0.21	49%
Refrigerated Transport	--	0.07	0.05	0.05	46%
Industrial Refrigeration	0.69	0.74	0.78	0.70	13%
Small Stationary A/C	0.05	0.22	0.23	0.08	68%
Large Stationary A/C	0.26	0.81	0.82	0.29	69%
All End Uses	0.33	0.66	0.54	0.35	57%

Figure 38 also shows the percent change in the cost-effectiveness of phasing out R-22 in each of the end uses in 2012, relative to a 2015 phaseout. As can be seen, the cost-effectiveness of small and large stationary AC is most affected by advancing the phaseout date to 2012, whereas the cost-effectiveness of phasing out R-22 in small commercial and industrial refrigeration only decreases by 16 and 13 percent, respectively, when the phaseout date is advanced to 2012.

5.3 Extended Phaseout Scenario

5.3.1 Supply and Demand: Extended Phaseout Scenario

Annual servicing demand for the EU-25+2 by the end of 2019—the last year of HCFC servicing allowed under the extended phaseout scenario—is shown in Figure 17 through Figure 20. Of this total demand, the EU-15 countries are projected to account for the large majority—approximately 83 percent. By end use, large stationary refrigeration, industrial process refrigeration, and large commercial together represent about 99 percent of the total servicing demand (Figure 20).

As shown in Figure 22, total annual supplies of recycled/reclaimed R-22 in the EU-25+2 are not expected to be sufficient to satisfy total annual demand in 2016 and 2017. However, pre-2010 stockpiling can alleviate this deficit, as can post-2010 stockpiles recovered from retired equipment—especially from the EU-15, where all of the excess R-22 supply from retired equipment exists.

Indeed, at the regional level, the EU-15 is expected to satisfy its annual demand with its annual recovered supplies from 2010 through 2016 (see Figure 23), but the reverse is true for the EU-10 (i.e., it is expected to only be able to satisfy its annual demand beginning in 2016) (see Figure 24). Bulgaria and Romania are not expected to be able to satisfy their annual demand in any year from 2010 to 2020 (see Figure 25). Therefore, in the earlier years (2010-2015), the EU-10 and Bulgaria/Romania are vulnerable to shortfalls in the absence of pre-2010 stockpiling and/or cross-border trade in R-22 supplies from the EU-15.

In the absence of trade of reclaimed HCFC refrigerant among EU-15 and Bulgaria/Romania, and if no stockpiling occurs prior to 2010, Bulgaria and Romania are projected to experience a supply shortfall by the end of 2010. Indeed, in Bulgaria and Romania, even assuming stockpiling prior to 2010, it is expected supply shortfalls will occur between 2010 and 2020, if they do not purchase reclaimed R-22 from the EU-15—even if HCFC refrigerant is fully recovered from all retired equipment.

Without supply availability from the EU-15 (or imports from non-EU countries) and no pre-2010 stockpiling, EU-10 countries will need to recover/recycle HCFC about 80 percent of recoverable refrigerant from all retired equipment in order to satisfy their own demand. Given the less-developed infrastructure for recycling/reclamation in this region, however, an 80 percent recycling rate is most likely not feasible. If there were pre-2010 stockpiling in EU-10 countries, but no trade with EU-15 countries, 65 percent of recoverable R-22 refrigerant from retired units in EU-10 countries would need to be recycled/reclaimed in order to meet demand. This requisite recycling rate is 15 percent higher than the maximum assumed for eastern European countries (i.e., 50 percent); thus, it is anticipated that with pre-2010 stockpiling, the EU-10 may be able to satisfy demand through supply generated locally.

5.3.2 Extent and Cost of Early Retirement: Extended Phaseout Scenario

Prohibiting the use of recycled R-22 for servicing refrigeration and air conditioning equipment as of 1 January 2020 is projected to result in the undue abandonment (i.e., replacement or abandonment before the end of the equipment's useful lifetime as a result of a regulatory action) of 440 pieces of equipment. The early retirement of these units is projected to result in a total cost to industry in the EU-25, Bulgaria and Romania of approximately €4 million (net present value in 2006), as shown in Figure 39 (please refer to Figure 7 for assumed capital cost by equipment type). The costs calculated here assume that refrigerant supply will be adequate to meet demand; should shortfalls transpire in the EU-10, Bulgaria, and/or Romania, the number of units retired prematurely and associated costs will increase.

Figure 39. Projected Total Equipment Abandoned Early and
Cost of Early Abandonment by Country (Millions of 2006 €), Extended Phaseout Scenario

	Total Number of Equipment Abandoned Early	NPV of Cost of Undue Abandonment (Millions of 2006 €)
Austria	0	€ 0
Belgium	0	€ 0
Bulgaria	71	€ 0
Cyprus	12	€ 0
Czech Rep.	3	€ 0
Denmark	0	€ 0
Estonia	3	€ 0
Finland	0	€ 0
France	0	€ 0
Germany	0	€ 0
Greece	0	€ 0

	Total Number of Equipment Abandoned Early	NPV of Cost of Undue Abandonment (Millions of 2006 €)
Hungary	10	€ 0
Ireland	0	€ 0
Italy	0	€ 0
Latvia	3	€ 0
Lithuania	7	€ 0
Luxembourg	0	€ 0
Malta	6	€ 0
Netherlands	0	€ 0
Poland	46	€ 1
Portugal	0	€ 0
Romania	272	€ 2
Slovakia	3	€ 0
Slovenia	6	€ 0
Spain	0	€ 0
Sweden	0	€ 0
UK	0	€ 0
EU-25 + 2	*440*	*€ 4*

As can be seen from Figure 40, the number of refrigeration and AC units projected to be unduly abandoned as a result of the 2020 ban on the use of recycled R-22 in those applications, as well as the costs associated with early abandonment, are not evenly distributed across end uses and regions. For example, 95 percent of the costs and 92 percent of the total number of units projected to be retired prematurely are associated with the undue abandonment of large commercial refrigeration and industrial refrigeration units.

Figure 40. Projected Total Equipment Abandoned Early and Cost of Early Abandonment by Region and End Use, Extended Phaseout Scenario

	Small Commercial Refrigeration	Large Commercial Refrigeration	Refrigerated Transport	Industrial Refrigeration	Small Stationary A/C	Large Stationary A/C	*All End Uses*
EU-15 Countries							
Total Number of Equipment Abandoned Early	0	0	0	0	0	0	*0*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	*€ 0*
EU-10 Countries							
Total Number of Equipment Abandoned Early	0	0	0	98	0	0	*98*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	€ 0	€ 0	€ 2	€ 0	€ 0	*€ 2*
Romania and Bulgaria							
Total Number of Equipment Abandoned Early	0	34	0	55	0	253	*342*
NPV of Cost of Undue Abandonment (Millions of 2006 €)	€ 0	< € 1	€ 0	€ 1	€ 0	€ 1	*€ 2*
EU-25 + 2							
Total Equipment Abandoned Early	0	34	0	153	0	253	*440*
Percent of Total Equipment	0%	8%	0%	35%	0%	58%	*100%*
Total NPV of Undue Abandonment (Millions of 2006 €)	€ 0	< € 1	€ 0	€ 3	€ 0	€ 1	*€ 4*
Percent of Total Cost	0%	5%	0%	80%	0%	14%	*100%*

None of the equipment projected to be unduly abandoned under the 2020 phaseout scenario is installed in EU-15 countries, and therefore none of the costs are expected to be borne by EU-15 countries. Twenty-two percent of all equipment projected to be abandoned is located in EU-10 countries, and those countries are expected to bear 42 percent of the total cost. In the EU-10, only HCFC-containing equipment in the industrial refrigeration end use is expected to still be in use by 2020. Finally, Bulgaria and Romania together are projected to prematurely retire 78 percent of all equipment facing undue abandonment, and are projected to bear 58 percent of the total cost. Because these countries will not be subject to EC HCFC phaseout regulations until 2007, a small number of equipment in all but the refrigerated transport and small AC end uses will remain in use by 2020. Again, it should be noted that these estimates of undue abandonment assume that equipment will need to be abandoned as soon as the use ban (for servicing and maintenance) comes into effect, which is unlikely to be the case. Therefore, these levels of undue abandonment and associated costs should be considered an upper bound.

5.3.3 Benefits of Early Retirement: Extended Phaseout Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing refrigeration/AC equipment as of 1 January 2020 is projected to result in a total of 4 ODP tonnes of HCFC emissions avoided from 2020 to 2030. Forty-one percent of these avoided emissions will be realized as a result of equipment retirement in the EU-10 countries, and 59 percent is projected to result from equipment retirement in Bulgaria and Romania. Eighty-two percent of the total projected avoided emissions from 2015 to 2030 are expected to be realized from the retirement of industrial refrigeration equipment. The benefits calculated here assume that refrigerant supply will be adequate to meet demand; should shortfalls transpire in the EU-10, Bulgaria, and/or Romania, the amount of avoided emissions will increase.

Figure 41. Total Projected Avoided Emissions, 2020-2030 (ODP Tonnes), Extended Phaseout Scenario

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2
Small Commercial Refrigeration	0	0	0	0
Large Commercial Refrigeration	0	0	0	0
Refrigerated Transport	0	0	0	0
Industrial Refrigeration	0	2	2	3
Small Stationary A/C	0	0	0	0
Large Stationary A/C	0	0	1	1
All End Uses	*0*	*2*	*2*	*4*

5.3.4 Summary of Costs and Benefits: Extended Phaseout Scenario

Prohibiting the use of recycled/reclaimed R-22 for servicing of refrigeration and AC equipment as of 1 January 2020 is projected to result in a total emission savings of **4 ODP tonnes** between 2020 and 2030, at an estimated cost of **€4 million** (net present value in 2006)—assuming that supply is adequate to meet demand. Figure 42 presents the calculated cost-effectiveness of this phaseout scenario by end use and region, in terms of ODP tonnes of avoided emissions per million euros. As shown, industrial refrigeration and large stationary AC provide the greatest value in terms of emissions avoided per euro, and small stationary AC and refrigerated transport are the most expensive end uses to phase out in 2020. Figure 42 also shows the percent change in the cost-effectiveness of phasing out R-22 in each of the end uses in 2020, relative to a 2015 phaseout.

Figure 42. Cost-Effectiveness of a 1 January 2020 Phaseout of Recycled R-22 (ODP Tonnes of Avoided Emissions per Million Euros), Extended Phaseout Scenario

	EU-15	EU-10	Bulgaria and Romania	EU-25 + 2	Percent Change in Cost-Effectiveness Relative to 2015 Phaseout
Small Commercial Refrigeration	--	--	--	--	NA
Large Commercial Refrigeration	--	--	0.53	0.53	28%
Refrigerated Transport	--	0.10	--	0.10	23%
Industrial Refrigeration	--	1.07	1.15	1.11	38%
Small Stationary A/C	--	--	--	--	NA
Large Stationary A/C	--	--	1.19	1.19	27%
All End Uses	--	*1.07*	*1.10*	*1.09*	*36%*

Note: "—" indicates that there are no avoided emissions or associated costs since no equipment in that end use will be prematurely abandoned under this phaseout scenario.

5.4 Summary of Analysis

5.4.1 Summary of Supply and Demand

Figure 43 through Figure 46 present annual supply and demand assuming no stockpiling of recycled R-22 by region (EU-15, EU-10, Bulgaria/Romania) and for all of the EU (EU-25+2).[20] [Note: these figures are the same as those shown in Figure 22 through Figure 25, but with the phaseout dates indicated to allow for easier interpretation of the implications associated with each policy scenario.] As shown in Figure 43, even if EU-15 countries do not stockpile recycled R-22 prior to 2010, the annual supply of R-22 expected to be generated in the EU-15 is sufficient to meet annual demand in those countries under any of the three phaseout scenarios. This is not true for the EU-10 countries and Bulgaria and Romania, however, as shown in Figure 44 and Figure 45. Regardless of whether Bulgaria and Romania stockpile used R-22 prior to 2010, in the absence of significant trade of reclaimed R-22 from the EU-15 to those countries, Bulgaria and Romania are projected to experience a supply deficit by the end of 2010 that is expected to persist through the 2012, 2015, and 2020 phaseout dates. Similarly, if the EU-10 countries do not purchase reclaimed R-22 from the EU-15, those countries are projected to experience persistent supply shortages starting in 2010 if they do not stockpile recycled R-22 prior to 2010. Even if stockpiling does occur, shortfalls will be experienced in most years through 2030.

Figure 46 shows, however, that there may be excess supply of recovered HCFC refrigerant in the EU-25+2 to more than satisfy the demand in the EU-10 and Bulgaria and Romania, even without pre-2010 stockpiling. Thus, as long as there is trade of recovered HCFC refrigerant between the EU-15 and the EU-10 and Bulgaria and Romania, all countries are expected to have sufficient supply of R-22 to satisfy their demand under any of the three phaseout scenarios.

It should be noted that, while the figures below compare annual demand to annual recycled supplies of R-22, the unused recycled supplies can be carried over from one year to the next, as can any recycled quantities stockpiled before 2010. Therefore, the later the phaseout date, the greater the risks of supply shortfalls. While none of the phaseout scenarios are projected to result in supply shortfalls—assuming robust trade among the EU 25+2—a supply shortfall would entail the premature abandonment of equipment. In the case of such an R-22 supply shortfall, an expedited phaseout will not result in incremental costs or benefits because recycled R-22 is not available for reuse regardless of policy action (since a use ban is irrelevant if no supplies are available).

[20] As explained in Section 2.2.1 and 2.2.2, the recovery/recycling rate assumes that 75% of the original refrigerant charge is recoverable from equipment at end of life, and that (from 2010 to 2019) 50% of all refrigerant recovered from retired equipment is recycled/reclaimed. To the extent that actual recovery/recycling rates are higher or lower than these estimates, actual supply of recycled R-22 will vary proportionally relative to what is estimated in this analysis.

However, this analysis projects that no premature equipment abandonment will occur as a result of insufficient recycled supplies of R-22; therefore, in each of the policy scenarios assessed, all costs and benefits associated with premature equipment abandonment are attributed to the policy decision, as summarized in Section 5.4.2.

Figure 43. Projected Annual and Cumulative Supply and Demand for the EU-15 Assuming No Stockpiling, 2010-2019 (Tonnes)

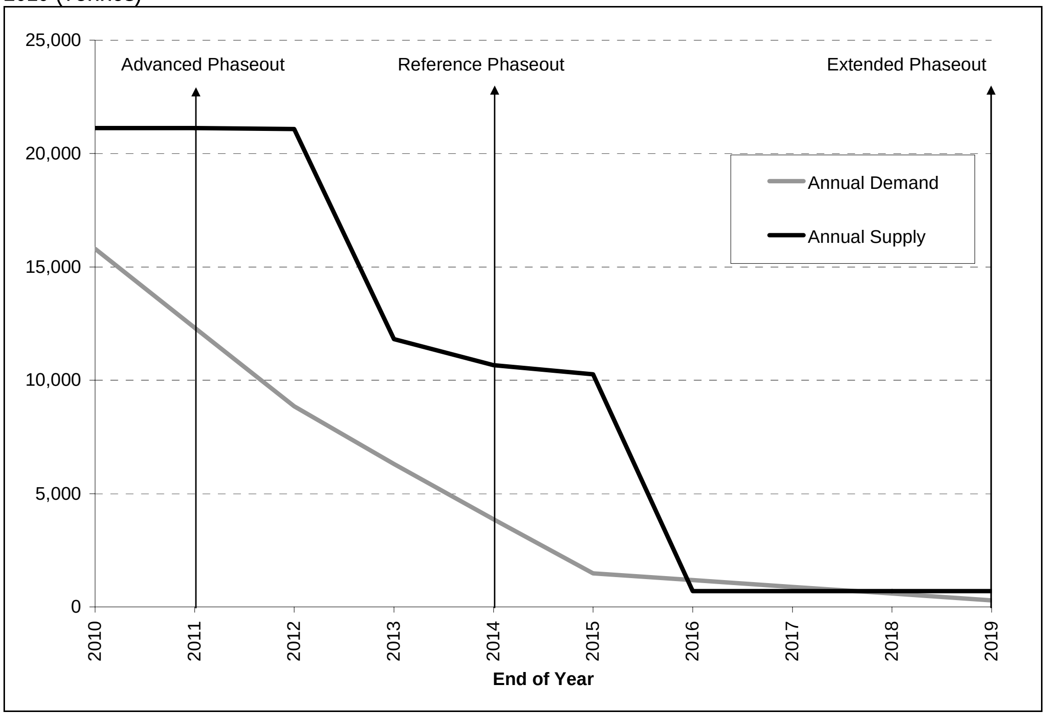


Figure 44. Projected Annual and Cumulative Supply and Demand for the EU-10 Assuming No Stockpiling, 2010-2019 (Tonnes)

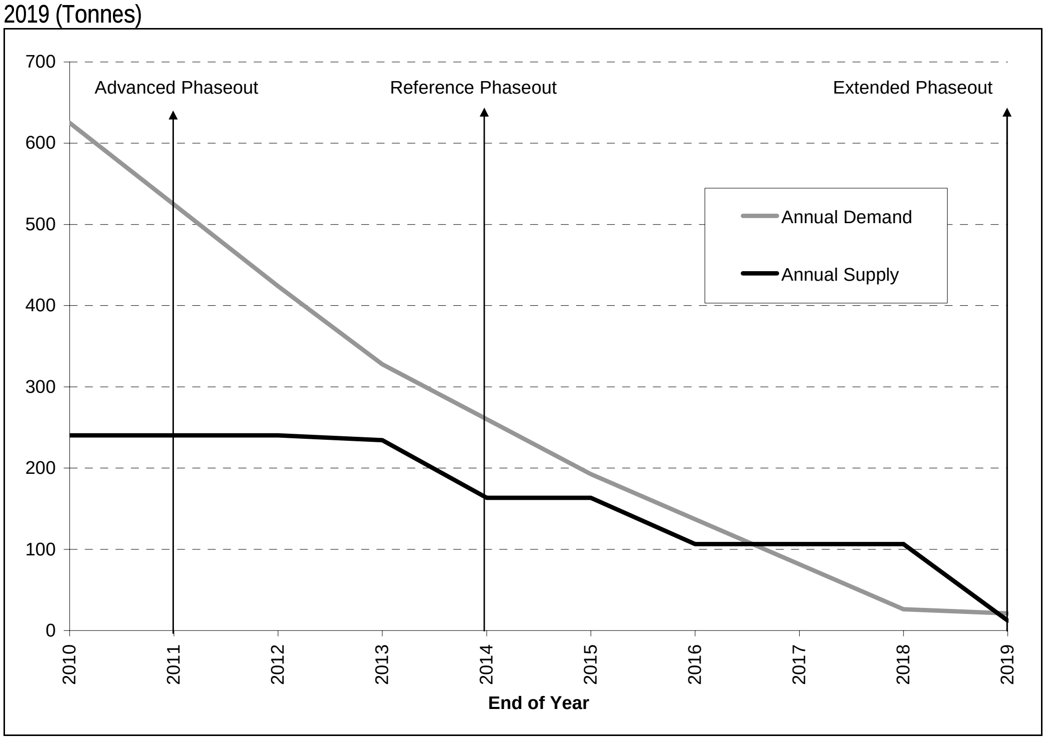


Figure 45. Projected Annual and Cumulative Supply and Demand for Bulgaria and Romania Assuming No Stockpiling, 2010-2019 (Tonnes)

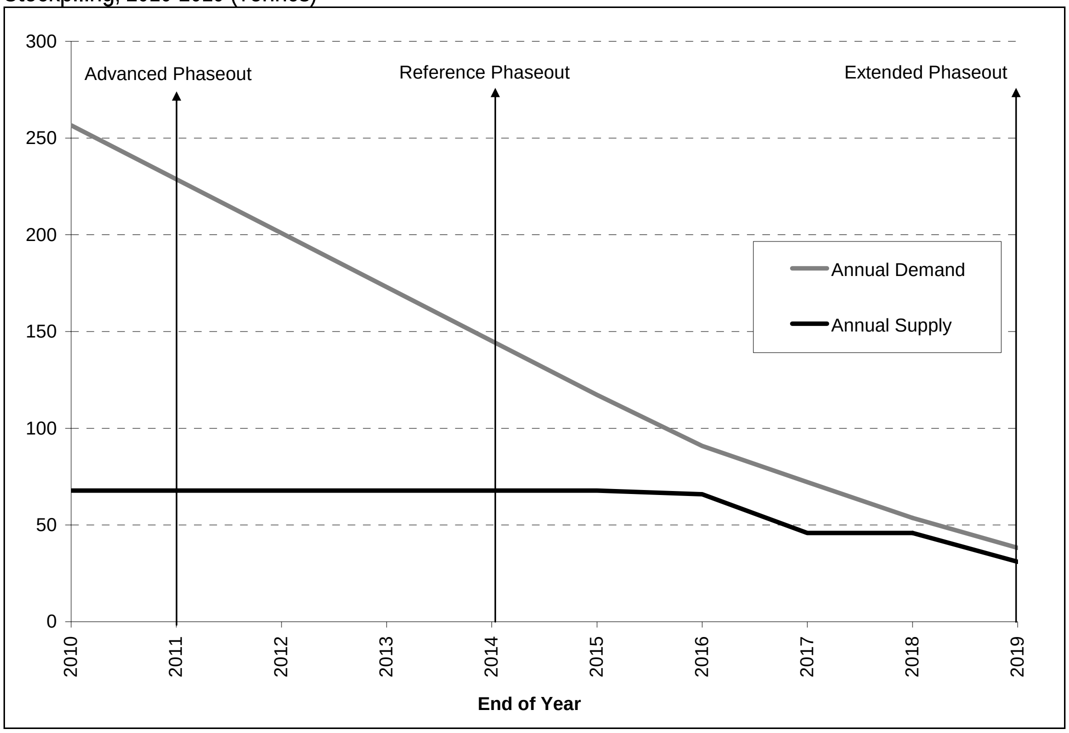
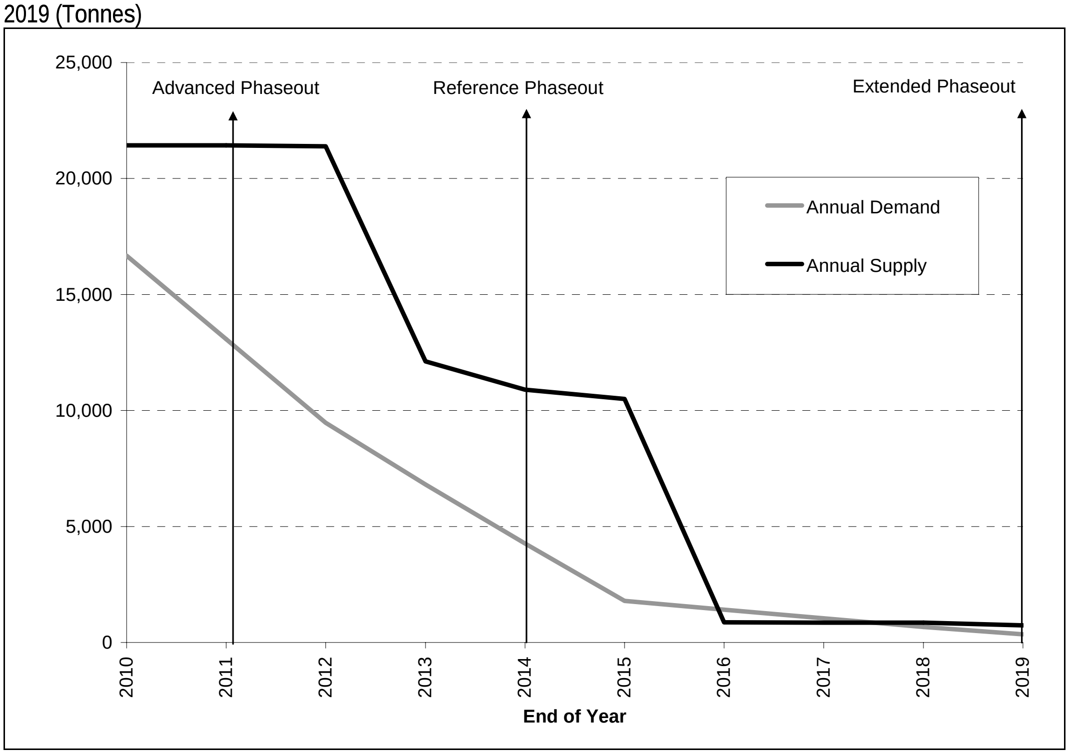


Figure 46. Projected Annual and Cumulative Supply and Demand for the EU-25 + 2 Assuming No Stockpiling, 2010-2019 (Tonnes)



5.4.2 Summary of Costs and Benefits

In addition to the supply and demand of recycled/reclaimed R-22, it is important to also consider the relative costs and benefits of each phaseout scenario. Figure 47 presents a summary of the costs and benefits associated with the premature retirement of refrigeration and AC equipment under each of the phaseout scenarios. As shown, the advanced phaseout scenario generates the highest cost for industry in the EU-25 and Bulgaria/Romania, but also generates the greatest benefits. The cost-effectiveness ratio is lowest for this scenario, however. The extended phaseout scenario is the most cost-effective, and generates significantly lower costs, as well as benefits, than the reference and advanced scenarios.

> **Cost Calculations in Perspective**
>
> A variety of assumptions were used in this analysis, which in aggregate may yield total costs of early abandonment that are overestimated. For example, as a result of the lack of robust data available in the literature and through industry surveys regarding retrofits and their feasibility by end use, this analysis assumes that no retrofits occur. Thus, to the extent that retrofits are feasible and do occur, this analysis overestimates the costs associated with the premature retirement of equipment. Similarly, this analysis assumes that the servicing ban will imply a use ban, since the precise point at which the lack of servicing will prohibit use is unclear. See Section 2.3 for a description of other conservative assumptions applied to the methodology for estimating costs.

Figure 47. Summary of Costs and Benefits for Each Phaseout Scenario[a]

	Costs (Million €)	Benefits (ODP Tonnes)	Cost Effectiveness (ODP Tonnes Avoided per Million €)
Advanced Scenario - 2012 Phaseout	€ 4,107	1,427	0.35
Reference Scenario - 2015 Phaseout	€ 368	294	0.80
Extended Scenario - 2020 Phaseout	€ 4	4	1.09

[a] Retrofits (drop-in replacements) would significantly decrease costs.

Figure 48 shows benefits by end use and phaseout scenario. As shown, the benefits associated with avoided ODS emissions decrease significantly as the phaseout date is extended. The composition of avoided emissions by end use also changes. Benefits associated with industrial refrigeration represent over 80 percent in the reference and extended phaseout scenario, but only 43 percent in the advanced phaseout scenario. Large stationary AC decreases from 37 percent of total benefits in the advanced phaseout scenario to 9 percent and 16 percent in the reference and extended phaseout scenarios, respectively. Other end uses, such as small commercial refrigeration, small stationary AC, and refrigerated transport represent small portions of total benefits under all phaseout scenarios.

Figure 48. Comparison of Benefits by End Use and Phaseout Scenario

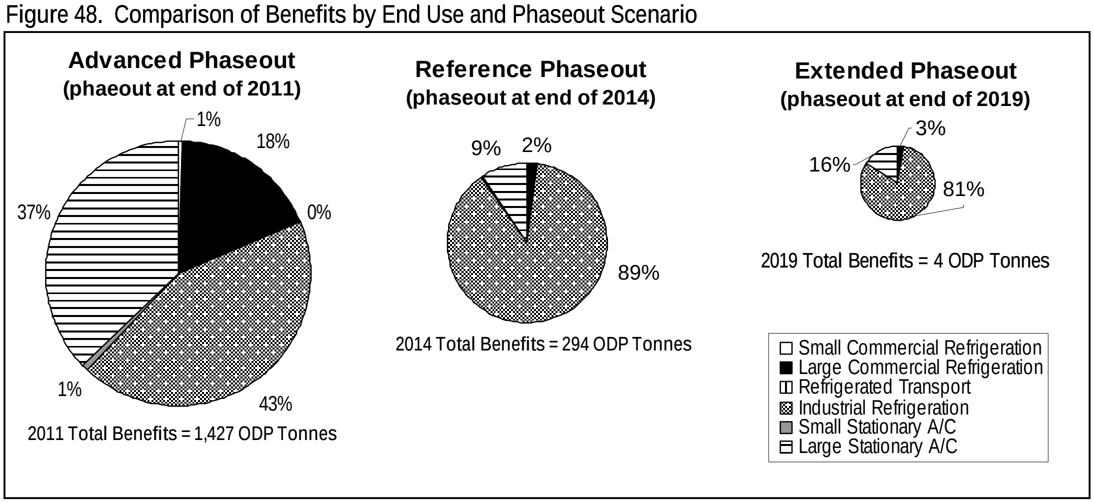
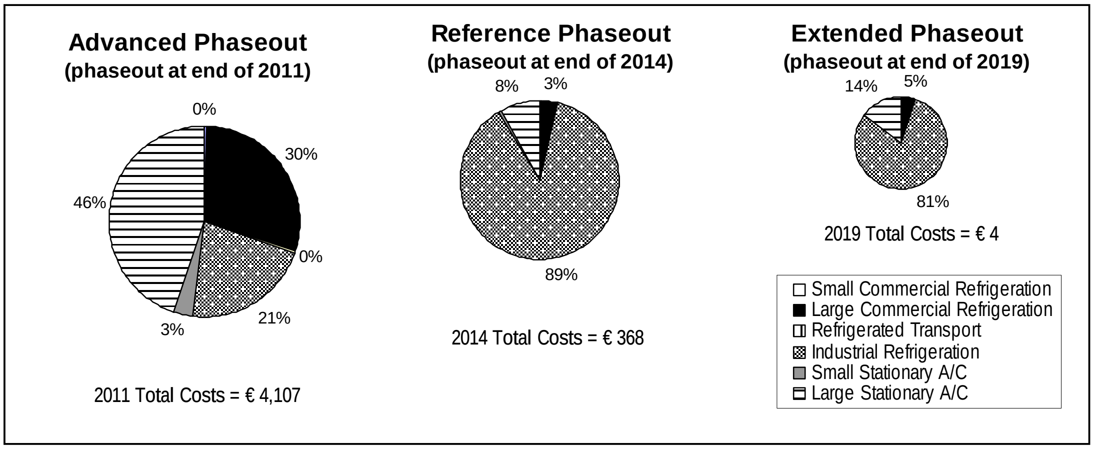


Figure 49 shows costs by end use and phaseout scenario. As shown, costs associated with large commercial refrigeration equipment are minimal in the 2020 phaseout scenario, while the end use represents a large portion of costs in the 2012 phaseout scenario (about 5 percent of total). Other end uses, such as small commercial refrigeration, small stationary AC, and refrigerated transport represent very small portions of total cost under all phaseout scenarios.

Figure 49. Comparison of Costs by End Use and Phaseout Scenario



6. Sensitivity Analysis

The estimates of servicing demand, supply of recycled R-22, benefits associated with avoided ODS emissions, and cost of undue abandonment associated with the reference, advanced, and extended phaseout scenarios, as presented in Sections 5.1, 5.2, and 5.3, are the product of a series of assumptions—related to charge size, leak rates, lifetime, and capital cost. These estimates were developed based on data provided by Member States and industry parties (for which data reliability is unknown), as well as expert opinion from refrigeration and AC industry professionals. Any adjustments to these assumptions impact the level of demand, supply, benefits, and costs associated with each of the regulatory scenarios.

To examine the change in demand, supply, benefits, and costs as a result of adjustments to the lifetime, leak rate, charge size, and capital cost of each type of equipment, sensitivity analyses have been conducted on these parameters. In general, demand, supply, benefits, and costs are most sensitive to changes in the lifetime of equipment. An increase in the lifetime of equipment leads to:

- increased demand because equipment will be requiring service for more years;
- increased cumulative supply 2010-2019, because equipment that would have retired prior to 2010 is now retiring (and thus creating recycled/reclaimed supply) during this time period;
- increased benefits, because early retirement will result in the avoidance of additional years' emissions; and
- increased costs because more years of useful life would be assumed for the prematurely retiring equipment.

A decrease in lifetime has the inverse effect.

Supply and costs are also somewhat sensitive to changes in the leak rate; an increase in the leak rate of equipment leads to a decrease in the supply of recycled R-22 and also a decrease in the cost of undue abandonment. This is because the consumption model calculates the number of pieces of equipment using service consumption divided by charge size and leak rate for each end use; for any given service consumption value, an increased leak rate implies fewer pieces of equipment, which yields a lower cost of undue abandonment of such equipment, and less recycled refrigerant available at end-of-life from that equipment.[21] Additionally, the cost of undue abandonment is sensitive to changes in the charge size of equipment and the unit cost of equipment.

The sensitive parameters are summarized below for each model output—servicing demand, supply, benefits, and costs.

Servicing Demand

Servicing demand is sensitive to changes in assumptions about the lifetime of equipment; for example, assuming a 20 percent increase in the lifetime of all equipment in the consumption model results in a 33 percent increase in total servicing demand over the period 2005-2019. This reflects an important area of uncertainty, given that lifetimes for some types of equipment can range significantly. For example, for industrial refrigeration equipment—the most important end use explored in this analysis—the IPCC estimates that equipment lifetimes can range from 10 to 20 years (IPCC, 2000).

Conversely, demand is only marginally sensitive to changes in the charge size or leak rate of equipment. Increasing the leak rate, for instance, in the consumption model leads to minimal increases in servicing demand.

[21] Supply is dependant on number of equipment and charge size.

Supply of Recycled R-22

Supply of recycled R-22 is sensitive to changes in assumptions about the leak rate or lifetime of equipment. For instance, assuming a 20 percent increase in the leak rate of all equipment results in a 17 percent decrease in cumulative supply over the period 2010-2019. By comparison, a 20 percent decrease in the lifetime of all equipment is projected to result in a 41 percent decrease in the cumulative supply of recycled R-22 from 2010-2019.

The relationship between the recovery rate and supply is linear – a 50% decrease in the assumed amount recoverable at equipment end of life will reduce supply by 50%.

Supply of recycled R-22 is not sensitive, however, to changes in the charge size of equipment.

Benefits Associated with Avoided ODS Emissions

Benefits associated with avoided ODS emissions are sensitive to changes in the lifetime of equipment because assuming a shorter lifetime can cause the benefits associated with some end uses to fall to zero. This is because a shorter assumed lifetime for these end uses would mean that they would reach the end of their useful lifetimes before the regulated phaseout dates come into effect.

Benefits are, however, only marginally sensitive to changes in the charge size and leak rate of equipment.

Cost of Undue Abandonment

Cost of undue abandonment is sensitive to changes in the lifetime of equipment because assuming, for example, a longer lifetime can cause costs for some end uses that were zero under the baseline lifetime assumptions to become positive. This is because longer assumed lifetimes for these end uses would mean that they do not reach the end of their useful lifetimes before the regulated phaseout dates come into effect.

The cost of undue abandonment also exhibits sensitivity to changes in the charge size and leak rate of equipment. For instance, a 20 percent increase in the charge size results in a 17 percent decrease in the cost of undue abandonment. This is because the consumption model calculates the number of pieces of equipment using service consumption divided by charge size and leak rate for each end use; for any given service consumption value, a larger charge size implies fewer pieces of equipment. Moreover, changes in assumptions about the unit capital cost of equipment have a direct relationship with the total cost of undue abandonment. For example, a 20 percent increase in the unit cost of all equipment leads to a 20 percent increase in total cost of undue abandonment.

7. Conclusion and Recommendations

This study collected and compiled available data from EU-25 Member States, as well as Bulgaria and Romania, to develop a top-down consumption model to estimate the supply and demand for recycled HCFCs from refrigeration/AC equipment, by country and by year. Based on the model output, the costs and benefits of equipment abandonment under the following three phaseout scenarios were projected:

- Reference scenario: existing measures in the Regulation are maintained (i.e., phaseout of recycled/reclaimed HCFCs occurs in 2015);
- Advanced phaseout scenario: recycled/reclaimed HCFC consumption is prohibited to service equipment beginning in 2012;
- Extended phaseout scenario: recycled/reclaimed HCFC consumption is allowed to service equipment until 2020.

In addition to the model, a separate analysis was conducted to assess the feasibility of available HCFC alternatives that qualitatively explored the economic and environmental impacts of HCFC replacement.

The major findings of this report, including those related to the availability of alternatives, the supply of recycled/reclaimed HCFCs, projected undue equipment abandonment, and costs and benefits, are summarised below. To substantiate the results of this analysis, it is recommended that the data output from the top-down consumption model estimates developed for this report be compared to estimates generated through a bottom-up modelling exercise on a sector or country basis, if possible.

Alternatives

- Alternatives to HCFCs are available for all equipment types. Although not explored quantitatively in this analysis, feasible drop-in alternatives also exist in a variety of end uses (e.g., medium- and low-temperature retail food systems and residential and commercial AC units, food processing and storage applications). However, in some end uses, only alternatives with high GWPs (i.e., HFCs) are currently available. The affected applications include some small commercial refrigeration, certain refrigerated transport applications, and small and large stationary air conditioning systems (chillers, window AC, and unitary AC). An earlier phaseout of HCFCs will entail a greater dependence on HFCs, as less time will be available to develop/advance non-GWP or low-GWP alternatives that are safe, reliable, energy-efficient, and cost-effective. Further, industry has raised concerns that an expedited phaseout (pre-2015) would impose disproportionate economic and technical burdens on the competitiveness of European companies, particularly small and medium-sized enterprises (SMEs).

Supply

- In terms of available supply of recycled/reclaimed HCFCs, it is critical that pre- and post-2010 recovery and stockpiling of R-22 occur in order to avoid shortfalls, regardless of the phaseout scenario selected, even with aggressive stockpiling efforts. The EU-10 however, and especially Bulgaria and Romania, will require additional supply from the EU-15 to meet on-going needs. Additional reclamation capacity from the EU-15 may be needed to help the EU-10 and Bulgaria and Romania maximise refrigerant reuse. A mechanism and proper infrastructure will also be needed to facilitate trade in recycled R-22 between the EU-15 and the EU-10, Bulgaria, and Romania.
- Should a supply shortfall materialise in the EU-10, Bulgaria, or Romania, additional equipment abandonment may occur in these countries beyond what is projected in this analysis. Or, at a minimum, equipment in those countries may operate sub-optimally and/or be topped off with other

fluids for which the systems were not designed, leading to operational inefficiencies and potentially, health or safety hazards.

Undue Abandonment

- In the 2015 reference phaseout scenario, less than 10 percent of all equipment projected to be abandoned is located in EU-10 countries, and those countries are also expected to bear under 10 percent of the total cost. The EU-15 countries, while not projected to hold the majority of prematurely retired equipment (22 percent), are projected to bear the majority of the total cost of early retirement (about 83 percent). Finally, Bulgaria and Romania together are projected to prematurely retire 70 percent of all equipment facing undue abandonment, but are projected to only bear about 8 percent of the total cost. These latter countries bear the brunt of undue equipment abandonment but not of costs because their inventory consists largely of small units. By comparison, the EU-15 bears the majority of costs because their inventory tends to be in the large end use sectors (e.g., industrial process refrigeration, large commercial refrigeration, and large stationary AC), which have a high economic value on a per unit basis. However, the estimates of undue abandonment projected in this analysis likely *over*estimate actual abandonment levels, given that (a) no retrofits are assumed to occur and (b) equipment may continue to operate at sub-optimal levels without additional servicing/refilling with R-22 (in lieu of actual retirement).

Costs and Benefits

- Compared to the reference scenario, advancing the phaseout date to 2012 would result in five times greater benefits (1,427 vs. 294 ODP tonnes) but 11 times greater costs (€4,107 vs. €368). The EU-15 would bear the majority of these costs. The economic impact of the advanced phaseout would be 3 times greater than the reference scenario for the EU-15, 4 times greater for the EU-10, and 3 times greater for Bulgaria and Romania. Extending the phaseout date to 2020 yields virtually no costs (€4 million) or benefits (4 ODP tonnes). Indeed, for the EU-15, the extended phaseout is expected to actually yield zero costs or benefits, since equipment in all end uses is expected to be naturally phased out by that date. It should be noted that the actual cost of each phaseout scenario is likely to be *lower* than estimated in this analysis, given that no drop-in replacements (with zero ODP refrigerants) have been assumed to occur. To the extent that low-cost retrofits do occur, the cost effectiveness of each phaseout scenario will increase. Hence, the costs of undue abandonment will be significantly lower, but the ODP-weighted benefits will be the same as those presented in the analysis. Further, the actual costs and benefits of each scenario may be lower if equipment continues to operate beyond the phaseout date without servicing.

- The majority of both costs and benefits are projected to come from industrial refrigeration, large commercial refrigeration, and large stationary air conditioning end uses—large systems with high costs and refrigerant charge sizes/leak rates. In the 2012 phaseout scenario, the large commercial refrigeration and large stationary AC end uses are projected to represent a higher percentage of total costs than total benefits. Conversely, phasing out HCFCs in the industrial refrigeration end use in 2012 will lead to a greater share of total benefits than total costs (43% and 21%, respectively). However, it is still more cost-effective to phaseout industrial refrigeration equipment in 2015 than 2012 (0.8 tonnes per million Euro in 2015 compared to 0.7 tonnes in 2012).

Based on the above conclusions, **it is recommended that the phaseout date for the EU-25+2 be maintained at 1 January 2015** and that appropriate infrastructure be established to facilitate trade in recycled supplies of HCFCs across EU countries. This conclusion is supported by the following rationale:

- A 2012 phaseout date will lead to higher costs and benefits compared to the reference scenario. Incremental costs, however, are greater than incremental benefits in 2012 compared to 2015. Moreover, many components of European industry would not be prepared for an advanced phaseout date, which could lead to economic hardships beyond those estimated in this report. For example, possible plant closures and impacts on competitiveness have not been considered in the cost calculations. Conversely, business decisions have been made with Regulation (EC) No. 2037/2000 in mind, so that a 2015 phaseout date should not lead to undue burden. Further, a 2012 phaseout date may lead to greater dependence on f-gases, which may be lessened by 2015 with an additional three years for research and development activities.

- A 2020 phaseout date is not recommended because it will lead to virtually no environmental benefits and will postpone industry action (to phaseout HCFC equipment) that has been under preparation for years. Moreover, this study has confirmed the wide availability of alternatives for each end use. Therefore, there is no reason to postpone the phaseout date of 2015 agreed upon in 2000.

One exception to this recommendation that should be considered is the **phaseout of industrial process refrigeration equipment on an advanced schedule**. This is because an advanced phaseout in this end use could yield significant ODS emission reductions (estimated at over 615 ODP tonnes in 2012) and the relative cost-effectiveness for achieving such benefits is quite high (about 0.7 tonnes per million Euro in 2012 assuming a cost of € 883 million). In addition, many non- or low-GWP alternatives are available in this sector, especially for the larger equipment types. However, prior to this type of policy decision being adopted, additional research should be conducted to validate the estimates derived in this analysis. For example, the data from the top-down consumption model developed for this report could be compared to a bottom-up model developed on a sector or country basis and supported by an engineering cost assessment.

Industry input should also be solicited. Indeed, if an expedited (i.e., pre-2015) phaseout is to occur in the IPR sector, industry consultation should begin immediately, as it is recommended that industry be given no less than a five-year lead time to assess and implement alternatives. Because industrial process refrigeration equipment tend to be large, custom-designed systems, companies will require this time to fully analyse safety, space constraints, and energy issues in order to select the refrigerant type and/or system design that is most appropriate for their particular application/facility, and to install the alternative selected.

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Appendix A: Description of Alternative Refrigerants and Technologies

This Appendix describes the alternative refrigerants and technologies available in place of HCFCs. For each alternative, a brief description of the alternative is provided, as well as a summary of any legislative barriers and safety considerations that may affect its penetration in EU markets.

A.1 Alternative Refrigerants

Alternative refrigerants to HCFCs include HFCs and HFC blends, ammonia, carbon dioxide (CO_2), and hydrocarbons (HCs).

A.1.1 HFCs and HFC Blends

There are a variety of HFCs and HFC blends available for use as alternatives to HCFCs in the refrigeration and air conditioning sector. The most common HFCs and HFC blends used in refrigeration/AC applications and their attributes are presented in Figure 50.

Figure 50: Global Warming Potential, Atmospheric Lifetime and Composition of HFCs and HFC Blends

HFC Blend	Global Warming Potential (GWP)[a]	Atmospheric Lifetime (years) [a]	Composition[b]
R-32	550	5	HFC-32
R-134a	1,300	13.8	HFC-134a
R-236fa	9,400	220	HFC-236fa
R-245fa	950	7.2	HFC-245fa
R-365mfc	N/A	N/A	N/A
R-404A	3,784	N/A	44% HFC-125, 52% HFC-143a, 4% HFC-134a
R-407C	1,653	N/A	23% HFC-32, 25% HFC-125, 52% HFC-134a
R-407D	1,503	N/A	15% HFC-32, 15% HFC-125, 70% HFC-134a
R-410A	1,975	N/A	50% HFC-32, 50% HFC-125
R-417A	2,249	N/A	47% HFC-125, 50% HFC-134a, 3% R-600
R-422A	3,044	N/A	85.1% HFC-125, 11.5% HFC-134a, 3.4% R-600a
R-422D	~ 2,675[c]	NA	N/A
R-507A	3,850	N/A	50% HFC-125, 50% HFC-143a

N/A = Not available.
[a] IPCC (2001).
[b] Calm and Hourahan (2001).
[c] DuPont (2005a).

Applicable End Uses

HFCs are feasible alternatives for all end uses. The most commonly used HFCs are R-134a, R-404A, R-407C, R-410A, and R-507A.

Legislative Barriers to Use

Current and potential future legislation on HFCs and other fluorinated gases (f-gases) may undermine the long-term feasibility of these substitutes. In particular, the Regulation of the European Parliament and of the Council on certain fluorinated greenhouse gases, adopted by the European Parliament and the Council on 17 March 2006, contains several components that will affect practices and/or costs associated with the use of HFCs. For example, Article 3 of the Regulation establishes a schedule for leak inspections of refrigeration and air conditioning applications and heat pumps charged with more than 3 kg of f-gases. In addition, the Regulation requires the recovery of f-gases and the training and certification of technicians servicing equipment using f-gases, and prohibits the sale of non-refillable containers of f-gases. Future regulations to ban the marketing of refrigeration equipment containing HFCs, as was proposed in COM (2003) 492,[22] could impose further barriers to the use of HFCs.

In addition, a number of Member States have passed their own, more stringent regulations regarding the use of HFCs. For example, Denmark has adopted legislation banning the use of HFCs in most applications as of 2006, and Luxembourg has banned the use of HFCs in large equipment (EPEE 2002, Thompson and Wolf 2004). Similarly, in 2008, Austria will ban the use of HFCs in air conditioning appliances, except for those intended for export (EPEE 2003). In addition, several Member States have imposed taxes on HFCs: Denmark taxes emissions of CO_2 resulting from HFC consumption; Norway taxes emissions of HFCs as well as imports of bulk HFCs and products containing HFCs; and France taxes HFCs according to their GWP values (EPEE 2002, EPEE 2003, Thompson and Wolf 2004).

Safety Considerations

Nearly all HFC refrigerants are non-flammable and have no identified toxicity at concentrations less than or equal to 400 ppm. The only exception is R-245fa, which is toxic at concentrations below 400 ppm; however, R-245fa is currently not in use, although it holds potential feasibility for use in chillers (Calm 1992, Calm and Hourahan 2001, IPCC/TEAP 2005, Trane 2005).

A.1.2 Ammonia

Ammonia (R-717) has excellent thermodynamic properties and can be used in many types of systems. In addition, it has the advantage of having a strong odour, which makes refrigerant leaks easier to detect, and is lighter than air, facilitating dispersion in the event of a release (UNEP 1999a).

Applicable End Uses

Ammonia is feasible for use in small retail food, cold storage, refrigerated transport, industrial process refrigeration, and chillers. Indeed, a significant portion of the worldwide industrial sector already uses ammonia (Pearson undated). Ammonia is used in secondary loop systems (described further in Section A.2.1) in large supermarket systems, cold storage, and industrial process refrigeration. HCFC retrofits are generally not feasible in part because ammonia cannot be used with heat exchangers, motor windings, piping, or any other components using copper (Calm and Domanski 2004).

Legislative Barriers to Use

Due to safety considerations (discussed below), building and fire codes may restrict the use of ammonia in some countries (Sand et al. 1997). In general, northern European countries, such as Germany, Belgium, Netherlands, Luxembourg, and Scandinavia, have few restrictions limiting the use of ammonia, but safety regulations in southern Europe do significantly limit its use (de Larminat 2000).

Safety Considerations

Ammonia has a number of safety issues—it is toxic, corrosive to skin, and flammable at 16% to 25% in air, which creates a problem in confined spaces (Calm and Domanski 2004, Sand et al. 1997). However, these risks can be mitigated through the use of safety devices and appropriate equipment design. For example, systems can isolate the refrigerant charge to reduce safety hazards, and/or be built with an emergency diffusion system and a series of safety relief valves to prevent over-pressurization and possible failure of the system and its pressure vessels (EPA 2004).

A.1.3 Carbon Dioxide (CO_2)

Carbon dioxide systems have been developed for numerous types of systems. Carbon dioxide has zero ODP and a GWP of 1.

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[22] The Proposed Regulation of the European Parliament and of the Council on Certain Fluorinated Greenhouse Gases COM (2003) 492 proposed a marketing ban on industrial and commercial refrigeration equipment containing HFCs beginning in 2010.

Applicable End Uses

Carbon dioxide is feasible in some small retail food applications and industrial process refrigeration. CO_2 is potentially feasible in large supermarket systems, cold storage, refrigerated transport (road, rail and container refrigeration), unitary AC, and chillers. CO_2 may also be used in secondary loop systems in large supermarket systems, cold storage and IPR, and in cascade systems with ammonia or R-404A in large supermarket systems, cold storage, industrial process refrigeration, and refrigerated transport (IPCC/TEAP 2005, Fleming 2003).

One factor limiting the use of CO_2 is the technical difficulties associated with developing efficient CO_2 systems (Fleming 2003). Such systems are most efficient and cost-effective for low temperature applications (Metro Group 2005).

Safety Considerations

Exposure to high levels of CO_2 can affect the central nervous system and may cause asphyxiation. In addition, CO_2 systems operate at high pressure presenting a potential hazard. Safety devices are needed to avoid these hazards (EPA 2004).

A.1.4 Hydrocarbons (HCs)

Hydrocarbon refrigerants currently used include isobutene (HC-600a), propane (HC-290), and propylene (HC-1270) (IPCC/TEAP 2005). HCs have zero ODP and relatively low GWPs (of approximately 20).

Applicable End Uses

Hydrocarbons are feasible for use in some small retail food applications, refrigerated transport, industrial process refrigeration, window AC, and centrifugal chillers (CIAA/ECSLA/EuroCommerce 2005, EPA 2004, IPCC/TEAP 2005). HCs are also used in secondary loop systems in large supermarket systems, cold storage, and industrial process refrigeration, and are potentially feasible for use in unitary AC equipment (IPCC/TEAP 2005). They are generally compatible with the materials used in R-22 systems and often use the same or similar lubricants; however, safety issues must be addressed somehow (Calm and Domanski 2004).

Legislative Barriers

Hydrocarbons are not allowed for use on ships by the International Maritime Organization (IMO) due to their flammability (UNEP 2001).

Safety Considerations

Hydrocarbons have relatively high flammability compared to other refrigerants, which causes safety concerns (EPA 2004, Calm 1992). Increased safety precautions often require design changes, such as the relocation of electrical components to reduce the likelihood of accidents from potential leaks (Kruse 1996, Paul 1996).

A.2 Alternative Technologies

The major alternative technologies explored in this analysis are secondary loop systems, cascade systems, and distributed systems. These technologies are used in large supermarket systems, cold storage, industrial process refrigeration and refrigerated transport.

A.2.1 Secondary Loop Systems

Secondary loop systems require a primary refrigerant and a secondary liquid. The secondary liquid, usually a brine solution, is pumped throughout the store removing heat from the display equipment. The primary refrigerant is isolated from the equipment cooled by the system and is cooled by passing through a heat exchanger (EPA 2004). Secondary loop systems have shorter piping runs allowing for smaller refrigerant charges and reduced leak rates contributing to TEWI reductions relative to traditional direct expansion (DX) systems[23] (Environment Canada 1998).

As a relatively new technology, this system has never used HCFCs. Rather, these systems use a variety of refrigerants as the primary refrigerant, including HFCs (e.g., R-404A, R-410A, R-507A), ammonia, or hydrocarbons. As of 2001, about 50 European supermarkets used ammonia secondary loop systems (UNEP 2001). Several full supermarkets using HC secondary loop systems have been installed in European countries (IPCC/TEAP 2005).

Applicable End Uses

Secondary loop systems can be used in retail food, cold storage, and industrial process refrigeration applications.

Safety Considerations

As discussed in Sections A.1.2, A.1.3, and A.1.4, there are safety considerations associated with the use of ammonia, CO_2, and HCs; however, secondary loop systems are designed to limit the potential safety hazards by reducing the charge size and restricting the refrigerant to a small portion of the system. Safety is also ensured because the ammonia is isolated from public areas.

Legislative Barriers to Use

There are no legislative barriers to the use of secondary loop systems, *per se*. However, there are a number of potential barriers associated with the use of HFCs as described in Section A.1.1.

A.2.2 Cascade Systems

A cascade system uses two refrigeration systems connected in series to achieve temperatures of around -85°C. These systems use two different refrigerants, one in each "stage' (system) to economically achieve the high compression ratios necessary to obtain the proper evaporating and condensing temperatures. The high stage condenser is usually fan cooled by the ambient air, and the low stage condenser is cooled by the evaporator of the high stage (Environmental Stress Systems, Inc. 2005). Cascade systems have been developed using HFC/CO_2, ammonia/CO_2, and HC/CO_2 (IPCC/TEAP 2005). These systems are entering the market for large supermarket systems, cold storage, industrial process refrigeration, and refrigerated transport applications.

Safety Considerations

As discussed in Sections A.1.2, A.1.3, and A.1.4, there are safety considerations associated with the use of ammonia, CO_2, and HCs; however, cascade systems are designed to limit the potential safety hazards by reducing the charge size of the system.

Legislative Barriers to Use

There are no legislative barriers to the use of cascade systems, *per se*. However, there are a number of potential barriers associated with the use of HFCs as described in Section A.1.1.

A.2.3 Distributed Systems

Distributed systems are comprised of multiple smaller rooftop units connecting to cases and coolers, thus using significantly less piping than traditional DX systems (Powell 2003; Baxter and Walker 2003). The compressors (typically scroll compressors) are located in the store near the display cases that they serve and are connected to the cooling units on the roof by a water loop (EPA 2004).

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[23] In a direct expansion (DX) system, the compressors are mounted together and share the suction and discharge refrigeration lines that run throughout the space feeding cases and coolers. The compressors and condensers are located, either in the back of the building or on its roof, in a separate machine room, to reduce noise and regulate heat rejection. In supermarkets, compressor racks operate at various suction pressures to support display cases operating at different temperatures (Baxter and Walker 2003; Powell 2003).

Distributed systems are used in retail food applications with HFCs, namely R-134a, R-404A and R-507 (ADL 2002; Environment Canada 1998; IPCC/TEAP 2005).

Safety Considerations

There are no safety considerations associated with the use of distributed systems.

Legislative Barriers to Use

There are no legislative barriers to the use of distributed systems, *per se*. However, there are a number of potential barriers to the use of HFCs as described in Section A.1.1.

Appendix B: Number of Units Remaining in Service by End Use and by Country (2005-2019)

Figure 51 through Figure 56 present model estimates of the number of units remaining in service in 2005 through 2019, by end use and by country for the EU-25, Bulgaria and Romania. Specifically, data is presented for the following six end uses modelled: small commercial refrigeration, large commercial refrigeration, refrigerated transport, industrial process refrigeration, small stationary air conditioning, and large stationary air conditioning.

Figure 51. Small Commercial Refrigeration: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	212,473	182,119	151,766	121,413	91,060	60,706	30,353	0	0	0	0	0	0	0	0
Belgium	253,754	217,504	181,253	145,003	108,752	72,501	36,251	0	0	0	0	0	0	0	0
Bulgaria	4,386	4,386	4,386	3,987	3,588	3,190	2,791	2,392	1,993	1,595	1,196	797	399	0	0
Cyprus	18,350	16,515	14,680	12,845	11,010	9,175	7,340	5,505	3,670	1,835	0	0	0	0	0
Czech Rep.	4,746	4,271	3,797	3,322	2,848	2,373	1,898	1,424	949	475	0	0	0	0	0
Denmark	177,944	152,524	127,103	101,682	76,262	50,841	25,421	0	0	0	0	0	0	0	0
Estonia	1,803	1,623	1,442	1,262	1,082	901	721	541	361	180	0	0	0	0	0
Finland	135,444	116,095	96,745	77,396	58,047	38,698	19,349	0	0	0	0	0	0	0	0
France	166,832	142,999	119,165	95,332	71,499	47,666	23,833	0	0	0	0	0	0	0	0
Germany	63,943	53,286	42,629	31,972	21,314	10,657	0	0	0	0	0	0	0	0	0
Greece	117,449	100,670	83,892	67,114	50,335	33,557	16,778	0	0	0	0	0	0	0	0
Hungary	15,500	13,950	12,400	10,850	9,300	7,750	6,200	4,650	3,100	1,550	0	0	0	0	0
Ireland	114,723	98,334	81,945	65,556	49,167	32,778	16,389	0	0	0	0	0	0	0	0
Italy	569,817	488,415	407,012	325,610	244,207	162,805	81,402	0	0	0	0	0	0	0	0
Latvia	4,829	4,346	3,863	3,380	2,897	2,414	1,932	1,449	966	483	0	0	0	0	0
Lithuania	11,267	10,141	9,014	7,887	6,760	5,634	4,507	3,380	2,253	1,127	0	0	0	0	0
Luxembourg	21,967	18,829	15,691	12,553	9,415	6,276	3,138	0	0	0	0	0	0	0	0
Malta	9,336	8,402	7,469	6,535	5,602	4,668	3,734	2,801	1,867	934	0	0	0	0	0
Netherlands	153,714	131,755	109,796	87,837	65,877	43,918	21,959	0	0	0	0	0	0	0	0
Poland	72,327	65,094	57,862	50,629	43,396	36,163	28,931	21,698	14,465	7,233	0	0	0	0	0
Portugal	110,078	94,352	78,627	62,902	47,176	31,451	15,725	0	0	0	0	0	0	0	0
Romania	39,209	39,209	39,209	35,644	32,080	28,515	24,951	21,387	17,822	14,258	10,693	7,129	3,564	0	0
Slovakia	4,386	3,947	3,509	3,070	2,631	2,193	1,754	1,316	877	439	0	0	0	0	0
Slovenia	9,336	8,402	7,469	6,535	5,602	4,668	3,734	2,801	1,867	934	0	0	0	0	0
Spain	213,809	183,265	152,721	122,177	91,632	61,088	30,544	0	0	0	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	369,878	317,039	264,199	211,359	158,519	105,680	52,840	0	0	0	0	0	0	0	0
EU-25+2	2,877,299	2,477,471	2,077,642	1,673,851	1,270,060	866,268	462,477	69,343	50,191	31,040	11,889	7,926	3,963	0	0

Figure 52. Large Commercial Refrigeration: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	16,632	14,969	13,306	11,642	9,979	8,316	6,653	4,990	3,326	1,663	0	0	0	0	0
Belgium	19,863	17,877	15,891	13,904	11,918	9,932	7,945	5,959	3,973	1,986	0	0	0	0	0
Bulgaria	102	102	102	94	87	80	73	65	58	51	44	36	29	22	15
Cyprus	182	168	154	140	126	112	98	84	70	56	42	28	14	0	0
Czech Rep.	47	43	40	36	33	29	25	22	18	14	11	7	4	0	0
Denmark	16,130	14,517	12,904	11,291	9,678	8,065	6,452	4,839	3,226	1,613	0	0	0	0	0
Estonia	219	202	185	169	152	135	118	101	84	67	51	34	17	0	0
Finland	10,602	9,542	8,482	7,422	6,361	5,301	4,241	3,181	2,120	1,060	0	0	0	0	0
France	12,855	11,570	10,284	8,999	7,713	6,428	5,142	3,857	2,571	1,286	0	0	0	0	0
Germany	8,115	7,213	6,311	5,410	4,508	3,607	2,705	1,803	902	0	0	0	0	0	0
Greece	7,520	6,768	6,016	5,264	4,512	3,760	3,008	2,256	1,504	752	0	0	0	0	0
Hungary	154	142	130	118	106	94	83	71	59	47	35	24	12	0	0
Ireland	8,980	8,082	7,184	6,286	5,388	4,490	3,592	2,694	1,796	898	0	0	0	0	0
Italy	36,486	32,838	29,189	25,540	21,892	18,243	14,594	10,946	7,297	3,649	0	0	0	0	0
Latvia	48	44	40	37	33	29	26	22	18	15	11	7	4	0	0
Lithuania	112	103	94	86	77	69	60	52	43	34	26	17	9	0	0
Luxembourg	1,720	1,548	1,376	1,204	1,032	860	688	516	344	172	0	0	0	0	0
Malta	92	85	78	71	64	57	50	43	36	28	21	14	7	0	0
Netherlands	21,436	19,293	17,149	15,005	12,862	10,718	8,575	6,431	4,287	2,144	0	0	0	0	0
Poland	716	661	606	551	496	441	386	331	276	220	165	110	55	0	0
Portugal	7,048	6,344	5,639	4,934	4,229	3,524	2,819	2,115	1,410	705	0	0	0	0	0
Romania	380	380	380	353	326	299	272	244	217	190	163	136	109	81	54
Slovakia	43	40	37	33	30	27	23	20	17	13	10	7	3	0	0
Slovenia	92	85	78	71	64	57	50	43	36	28	21	14	7	0	0
Spain	13,690	12,321	10,952	9,583	8,214	6,845	5,476	4,107	2,738	1,369	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	23,283	20,955	18,627	16,298	13,970	11,642	9,313	6,985	4,657	2,328	0	0	0	0	0
EU-25+2	206,550	185,892	165,235	144,543	123,851	103,159	82,467	61,775	41,083	20,390	600	434	269	103	69

Figure 53. Refrigerated Transport: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	6,577	4,932	3,288	1,644	0	0	0	0	0	0	0	0	0	0	0
Belgium	7,854	5,891	3,927	1,964	0	0	0	0	0	0	0	0	0	0	0
Bulgaria	1,059	1,059	1,059	927	794	662	530	397	265	132	0	0	0	0	0
Cyprus	1,284	1,101	917	734	550	367	183	0	0	0	0	0	0	0	0
Czech Rep.	332	285	237	190	142	95	47	0	0	0	0	0	0	0	0
Denmark	5,508	4,131	2,754	1,377	0	0	0	0	0	0	0	0	0	0	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	4,192	3,144	2,096	1,048	0	0	0	0	0	0	0	0	0	0	0
France	72,599	54,449	36,300	18,150	0	0	0	0	0	0	0	0	0	0	0
Germany	1,732	1,155	577	0	0	0	0	0	0	0	0	0	0	0	0
Greece	2,027	1,521	1,014	507	0	0	0	0	0	0	0	0	0	0	0
Hungary	1,085	930	775	620	465	310	155	0	0	0	0	0	0	0	0
Ireland	3,551	2,663	1,775	888	0	0	0	0	0	0	0	0	0	0	0
Italy	9,836	7,377	4,918	2,459	0	0	0	0	0	0	0	0	0	0	0
Latvia	338	290	241	193	145	97	48	0	0	0	0	0	0	0	0
Lithuania	789	676	563	451	338	225	113	0	0	0	0	0	0	0	0
Luxembourg	680	510	340	170	0	0	0	0	0	0	0	0	0	0	0
Malta	654	560	467	373	280	187	93	0	0	0	0	0	0	0	0
Netherlands	2,606	1,955	1,303	652	0	0	0	0	0	0	0	0	0	0	0
Poland	5,063	4,340	3,616	2,893	2,170	1,447	723	0	0	0	0	0	0	0	0
Portugal	1,900	1,425	950	475	0	0	0	0	0	0	0	0	0	0	0
Romania	2,852	2,852	2,852	2,495	2,139	1,782	1,426	1,069	713	356	0	0	0	0	0
Slovakia	307	263	219	175	132	88	44	0	0	0	0	0	0	0	0
Slovenia	654	560	467	373	280	187	93	0	0	0	0	0	0	0	0
Spain	3,691	2,768	1,845	923	0	0	0	0	0	0	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	11,449	8,586	5,724	2,862	0	0	0	0	0	0	0	0	0	0	0
EU-25+2	148,618	113,423	78,227	42,542	7,435	5,446	3,456	1,466	978	489	0	0	0	0	0

Figure 54. Industrial Process Refrigeration: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	2,012	1,878	1,744	1,610	1,475	1,341	1,207	1,073	939	805	671	537	402	268	134
Belgium	2,403	2,243	2,082	1,922	1,762	1,602	1,442	1,281	1,121	961	801	641	481	320	160
Bulgaria	31	31	31	29	27	26	24	23	21	19	18	16	14	13	11
Cyprus	70	66	62	58	54	50	46	42	39	35	31	27	23	19	15
Czech Rep.	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
Denmark	1,685	1,573	1,460	1,348	1,236	1,123	1,011	899	786	674	562	449	337	225	112
Estonia	19	18	17	16	15	14	13	12	11	10	9	7	6	5	4
Finland	1,283	1,197	1,112	1,026	941	855	770	684	599	513	428	342	257	171	86
France	3,577	3,339	3,100	2,862	2,623	2,385	2,146	1,908	1,669	1,431	1,192	954	715	477	238
Germany	659	612	565	518	471	424	377	330	283	235	188	141	94	47	0
Greece	1,240	1,158	1,075	992	910	827	744	662	579	496	413	331	248	165	83
Hungary	59	55	52	49	46	42	39	36	33	29	26	23	20	16	13
Ireland	1,086	1,014	941	869	797	724	652	579	507	435	362	290	217	145	72
Italy	6,018	5,617	5,216	4,815	4,413	4,012	3,611	3,210	2,808	2,407	2,006	1,605	1,204	802	401
Latvia	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
Lithuania	43	40	38	36	33	31	28	26	24	21	19	17	14	12	9
Luxembourg	208	194	180	166	153	139	125	111	97	83	69	55	42	28	14
Malta	35	33	31	29	28	26	24	22	20	18	16	14	12	10	8
Netherlands	870	812	754	696	638	580	522	464	406	348	290	232	174	116	58
Poland	274	259	244	228	213	198	183	167	152	137	122	107	91	76	61
Portugal	1,163	1,085	1,008	930	853	775	698	620	543	465	388	310	233	155	78
Romania	143	143	143	135	128	120	113	105	98	90	83	75	68	60	53
Slovakia	17	16	15	14	13	12	11	10	9	8	7	6	6	5	4
Slovenia	35	33	31	29	28	26	24	22	20	18	16	14	12	10	8
Spain	2,258	2,108	1,957	1,807	1,656	1,505	1,355	1,204	1,054	903	753	602	452	301	151
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	3,502	3,269	3,035	2,802	2,568	2,335	2,101	1,868	1,634	1,401	1,167	934	700	467	233
EU-25+2	28,726	26,825	24,925	23,016	21,107	19,198	17,288	15,379	13,470	11,561	9,652	7,742	5,833	3,924	2,015

Figure 55. Small Stationary Air Conditioning: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	5,215,795	4,483,886	3,751,977	3,020,068	2,288,159	1,556,250	824,341	92,432	0	0	0	0	0	0	0
Belgium	6,230,477	5,356,332	4,482,187	3,608,041	2,733,896	1,859,750	985,605	111,460	0	0	0	0	0	0	0
Bulgaria	23,361	23,361	23,361	20,765	18,170	15,574	12,978	10,383	7,787	5,191	2,596	0	0	0	0
Cyprus	52,195	45,671	39,146	32,622	26,098	19,573	13,049	6,524	0	0	0	0	0	0	0
Czech Rep.	13,500	11,812	10,125	8,437	6,750	5,062	3,375	1,687	0	0	0	0	0	0	0
Denmark	4,366,564	3,753,831	3,141,099	2,528,366	1,915,634	1,302,901	690,169	77,436	0	0	0	0	0	0	0
Estonia	6,489	5,678	4,867	4,056	3,244	2,433	1,622	811	0	0	0	0	0	0	0
Finland	3,338,264	2,869,862	2,401,461	1,933,059	1,464,657	996,255	527,854	59,452	0	0	0	0	0	0	0
France	5,764,329	4,954,734	4,145,140	3,335,546	2,525,951	1,716,357	906,762	97,168	0	0	0	0	0	0	0
Germany	2,668,248	2,001,186	1,334,124	667,062	0	0	0	0	0	0	0	0	0	0	0
Greece	838,524	720,913	603,302	485,691	368,081	250,470	132,859	15,248	0	0	0	0	0	0	0
Hungary	44,089	38,578	33,067	27,556	22,044	16,533	11,022	5,511	0	0	0	0	0	0	0
Ireland	3,186,272	2,739,445	2,292,618	1,845,792	1,398,965	952,138	505,311	58,484	0	0	0	0	0	0	0
Italy	4,621,927	3,973,156	3,324,386	2,675,615	2,026,845	1,378,074	729,304	80,533	0	0	0	0	0	0	0
Latvia	13,736	12,019	10,302	8,585	6,868	5,151	3,434	1,717	0	0	0	0	0	0	0
Lithuania	32,050	28,043	24,037	20,031	16,025	12,019	8,012	4,006	0	0	0	0	0	0	0
Luxembourg	604,599	518,228	431,856	345,485	259,114	172,743	86,371	0	0	0	0	0	0	0	0
Malta	26,555	23,236	19,917	16,597	13,278	9,958	6,639	3,319	0	0	0	0	0	0	0
Netherlands	30,940	26,657	22,375	18,093	13,810	9,528	5,246	964	0	0	0	0	0	0	0
Poland	205,730	180,014	154,297	128,581	102,865	77,149	51,432	25,716	0	0	0	0	0	0	0
Portugal	716,332	615,801	515,270	414,739	314,208	213,677	113,147	12,616	0	0	0	0	0	0	0
Romania	114,061	114,061	114,061	101,388	88,714	76,041	63,367	50,694	38,020	25,347	12,673	0	0	0	0
Slovakia	12,475	10,916	9,356	7,797	6,238	4,678	3,119	1,559	0	0	0	0	0	0	0
Slovenia	26,555	23,236	19,917	16,597	13,278	9,958	6,639	3,319	0	0	0	0	0	0	0
Spain	3,100,057	2,668,804	2,237,550	1,806,297	1,375,044	943,790	512,537	81,283	0	0	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	10,933,160	9,397,609	7,862,057	6,326,505	4,790,953	3,255,401	1,719,849	184,297	0	0	0	0	0	0	0
EU-25+2	52,186,284	44,597,070	37,007,855	29,403,371	21,798,887	14,861,465	7,924,043	986,621	45,807	30,538	15,269	0	0	0	0

Figure 56. Large Stationary Air Conditioning: Number of Units Remaining In Service (Year End)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	92,222	83,000	73,777	64,555	55,333	46,111	36,889	27,667	18,444	9,222	0	0	0	0	0
Belgium	110,140	99,126	88,112	77,098	66,084	55,070	44,056	33,042	22,028	11,014	0	0	0	0	0
Bulgaria	753	753	753	699	645	592	538	484	430	376	323	269	215	161	108
Cyprus	1,336	1,233	1,130	1,028	925	822	719	617	514	411	308	206	103	0	0
Czech Rep.	346	319	292	266	239	213	186	159	133	106	80	53	27	0	0
Denmark	77,235	69,512	61,788	54,065	46,341	38,618	30,894	23,171	15,447	7,724	0	0	0	0	0
Estonia	96	89	81	74	66	59	52	44	37	30	22	15	7	0	0
Finland	58,788	52,909	47,030	41,152	35,273	29,394	23,515	17,636	11,758	5,879	0	0	0	0	0
France	29,085	26,176	23,268	20,359	17,451	14,542	11,634	8,725	5,817	2,908	0	0	0	0	0
Germany	29,142	25,904	22,666	19,428	16,190	12,952	9,714	6,476	3,238	0	0	0	0	0	0
Greece	22,744	20,469	18,195	15,921	13,646	11,372	9,098	6,823	4,549	2,274	0	0	0	0	0
Hungary	1,128	1,042	955	868	781	694	608	521	434	347	260	174	87	0	0
Ireland	49,794	44,815	39,835	34,856	29,877	24,897	19,918	14,938	9,959	4,979	0	0	0	0	0
Italy	110,345	99,310	88,276	77,241	66,207	55,172	44,138	33,103	22,069	11,034	0	0	0	0	0
Latvia	352	325	297	270	243	216	189	162	135	108	81	54	27	0	0
Lithuania	820	757	694	631	568	505	442	379	315	252	189	126	63	0	0
Luxembourg	9,535	8,581	7,628	6,674	5,721	4,767	3,814	2,860	1,907	953	0	0	0	0	0
Malta	680	627	575	523	471	418	366	314	261	209	157	105	52	0	0
Netherlands	1,281	1,153	1,025	897	769	640	512	384	256	128	0	0	0	0	0
Poland	5,265	4,860	4,455	4,050	3,645	3,240	2,835	2,430	2,025	1,620	1,215	810	405	0	0
Portugal	21,316	19,185	17,053	14,922	12,790	10,658	8,527	6,395	4,263	2,132	0	0	0	0	0
Romania	2,795	2,795	2,795	2,595	2,395	2,196	1,996	1,796	1,597	1,397	1,198	998	798	599	399
Slovakia	319	295	270	246	221	196	172	147	123	98	74	49	25	0	0
Slovenia	680	627	575	523	471	418	366	314	261	209	157	105	52	0	0
Spain	41,404	37,264	33,123	28,983	24,842	20,702	16,562	12,421	8,281	4,140	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UK	160,542	144,488	128,434	112,380	96,325	80,271	64,217	48,163	32,108	16,054	0	0	0	0	0
EU-25+2	828,141	745,612	663,084	580,301	497,519	414,737	331,955	249,172	166,390	83,608	4,064	2,963	1,861	760	507