SINCLAIR KNIGHT MERZ
SKM ENVIROS

Examination of the Global Warming Potential of Refrigeration in the Food Chain

MAIN REPORT

- Draft Version 7b
- 30th June 2011

Examination of the Global Warming Potential of Refrigeration in the Food Chain

MAIN REPORT

- Draft Version 7b
- 30th June 2011

SKM Enviros

Victoria House
Southampton Row
London
WC1B 4EA

Tel: +44 20 7759 2600

Fax: +44 20 7759 2601

Web: www.skmenviros.com

SKM ENVIROS

Contents

Executive Summary

1) This report provides the outputs of a study into greenhouse gas emissions (GHG) from refrigeration systems in the UK food chain. The study was carried out for Defra by SKM Enviros in the period October 2010 to May 2011.

2) The objectives of the study were to quantify GHG emissions from refrigeration systems in the UK food chain, identify and quantify opportunities to reduce emissions and to make suggestions about how emission reductions can be maximised in the future.

3) The GHG emissions from refrigeration can be split into two main parts. **"Direct emissions"** are created by leakage of refrigerants that have a high global warming potential (GWP). A significant proportion of refrigerants used in the food chain are fluorocarbons (including HFCs[1] and HCFCs[2]) that have GWPs between 1,000 and 4,000 times higher than CO_2. **"Indirect emissions"** result from the energy used to operate the refrigeration systems. In nearly all cases this emission is CO_2 from electricity generation. Approximately two thirds of food chain GHG emissions are indirect.

4) The food chain consists of 6 market sectors, each using different types of refrigeration equipment. These were: (i) agriculture, (ii) food and drink manufacture, (iii) cold storage, (iv) refrigerated transport, (v) food and drink retail and (vi) food service.

Evidence Review

5) A detailed review of relevant literature and other evidence was carried out to provide Defra with an update of new evidence and actions that have occurred since the Food Industry Sustainability Strategy (FISS) and Food 2030 reports were published.

6) 27 different sources were reviewed to identify information about GHG emissions, emission reduction technologies and drivers / barriers to implementation. Section 2 and Appendix 1 provide details of the relevant evidence extracted from these sources.

7) There was good qualitative information found about emission reduction techniques, and about drivers and barriers to implementation.

8) There were significant gaps in the available evidence. In particular: (a) data about HFC and HCFC emissions from food chain market sectors, (b) quantitative data about costs of implementing emission reduction measures and (c) the degree of market penetration of emission reduction technologies.

---

[1] HFCs: hydrofluorocarbons

[2] HCFCs: hydrochlorofluorocarbons

Questionnaire Survey and Other Research

9) Research was carried out with end users of refrigeration systems in the food chain to collect new information about use of refrigerants, use of energy and to better understand progress towards emission reductions.

10) A web-based questionnaire was used to gather information from larger end users in food manufacture, dairy, brewing and cold storage. 200 questionnaires were completed and these provide valuable new evidence about refrigerant usage and the uptake of emission reduction techniques. The survey results are described in Section 3 and Appendix 2.

11) On average the survey respondents estimated that 42% of their electricity was used for refrigeration. A surprising result was the lack of sub-metering used on refrigeration systems. Despite the fact that refrigeration was such a large proportion of the electricity bill, only 27% of respondents had any sub-metering for refrigeration.

12) The majority of respondents assessed that they only have "limited" in-house skills related to refrigeration. This implies significant reliance on external contractors, in relation to both purchase of new plant and maintenance of existing systems.

13) A particularly useful output from the survey is an up-to-date picture of the use of refrigerants in food and drink manufacturing plants and cold stores. Detailed responses were received from 132 sites that have a total of 2278 individual refrigeration systems. The results are summarised in Table 3.1. 35% of systems still use R22. HFC 404A is the most popular of the HFCs and represents 48% of the quantity of HFCs in use. Ammonia only represents 6% of the number of systems, but is dominant in terms of refrigerant quantity – being 56% of the total of all refrigerants in the survey.

14) New information was also collected from supermarket operators and refrigerant manufacturers. The supermarket data helps characterise the existing use of refrigerants in the sector and also shows the significant efforts being made by most large supermarkets to reduce both direct and indirect emissions. Data from refrigerant manufacturers shows the rapid rate of change in the refrigerants market. In particular, the growing use of CO_2 and the potential for the recently introduced very low GWP HFO[3] refrigerants.

Direct and Indirect Emission Estimates

15) Data from the evidence together with new information gathered during the study was used to estimate direct and indirect GHG emissions from each of the 6 sectors of the UK food chain. The results are described in Section 4.

---

[3] HFO: hydrofluoro-olefin

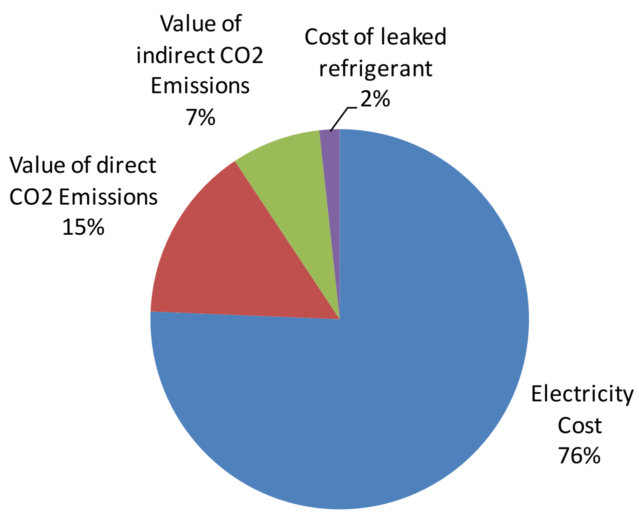
16) The overall emissions are summarised in Table ES 1. 65% of total emissions are indirect emissions from electricity use and 35% are direct emissions related to refrigerant leakage. Retail is the dominant market sector, with nearly half the total emissions. Manufacturing and food service are also important with nearly 20% each. The split between direct and indirect varies between sectors, because of the type of equipment used. For example in retail, direct emissions are 46% of the total whereas in food service direct emissions are only 18% of the total.

Table ES1: Total GHG Emissions from Food Chain Refrigeration, 2010

Refrigerant Type	Agriculture	Food & drink manufacture	Cold Storage	Transport	Retail	Food Service	Total
	ktonnes CO_2e						
Direct	50	890	180	230	3,000	450	4,800
Indirect	210	1,660	330	1200	3,530	1,990	8,920
Sub-Total	260	2,550	510	1430	6,530	2,440	13,720
% Total	2%	19%	4%	10%	47%	18%	

17) The value of emissions from food chain refrigeration has been estimated as £1.7 billion per year as illustrated in Figure ES1. This is based on the cost of electricity used, the cost of refrigerant top up plus a "notional cost" for the embedded carbon in both the electricity and leaked refrigerant (see Section 4.4).

Fig ES1: Costs of Operating Food Chain Refrigeration Systems



Emission Reduction Opportunities

18) Section 5 provides details of the numerous ways in which direct and indirect emissions can be reduced. The evidence review together with further expert input shows there are well over 100 techniques that can be considered to reduce emissions. This actually creates a barrier for investment as many end users are confused by the range of different opportunities and unable to select those that are most relevant to their circumstances and that will give them the most benefit.

19) To simplify understanding of the emission reduction techniques a set of 12 opportunity categories were introduced and reviewed. This includes 5 categories for direct emissions and 7 categories for indirect emissions. Examples of emission reduction techniques are given in Sections 5.2 and 5.3.

20) It is important to recognise that the best opportunities are highly dependent on circumstances. In particular, the maximum potential for emission reduction occurs when old plant is being replaced – that is the key opportunity to make a "step-change" emission reduction in the most cost effective way. For medium and large plants there are also good opportunities to reduce emissions from existing plant, although these are more limited and usually more costly. For small and very small systems there are relatively limited retrofit opportunities but good opportunities for new systems.

21) Section 5.4 provides details about how the emission reduction opportunities map into the 6 food chain market sectors.

Drivers and Barriers

22) Drivers and barriers are discussed in Section 6.

23) There is a very strong financial driver to reduce indirect emissions because of the high price of electricity and the availability of saving measures with short payback periods. There is no equivalent financial driver for direct emissions as the cost of the embodied carbon is an "externality" and is not included in the price of refrigerants. Inclusion of this external cost would provide a strong price signal that would stimulate reduction of direct emissions.

24) There are strong regulatory drivers to reduce emissions. The F Gas Regulation is leading to reduced direct emissions. Climate Change Agreements and the Carbon Reduction Commitment stimulate energy savings in many parts of the food chain.

25) Voluntary CSR initiatives are stimulating emission reductions especially in large food retail companies and some manufacturing companies.

26) Lack of investment capital and a requirement to achieve very high rates of return on emission reduction investments are key barriers.

27) Lack of awareness of key opportunities and lack of in-house expertise is also preventing more progress. This is exacerbated by rapid changes in technology (especially in relation to new refrigerants) and a lack of independently verified information about the cost effectiveness of individual measures.

Emission Reduction Potential

28) A detailed analysis of emission reduction potential was carried out and is described in Section 7. The analysis included:

- A "Bottom-Up" assessment that provides an overall assessment of the total GHG emission reduction potential for the whole food chain and for individual sectors. The outputs include Marginal Abatement Cost Curves (MACCs) for retrofit and new plant opportunities.
- A "Top-Down" assessment that provides a projection of the rate of emission reduction over the next 25 years, taking into account both retrofit and plant replacement measures.

29) There is potential for significant direct emission reductions. . The modelling shows that current direct emissions (4,790 kT CO_2) can be cut by at least 75% by 2035 and possibly by over 90%. The average cost of achieving these reductions should be below £25 per tonne CO_2 saved.

30) There is also good potential to reduce indirect emissions. The modelling shows that current indirect emissions (8,900 kT CO_2) can be cut by 35% by 2035 and possibly by up to 80% if the expected decarbonisation of the electricity sector is taken into account. The majority of opportunities can be implemented with negative carbon costs due to the value of energy being saved.

31) Figures ES2 and ES3 illustrate a MACC (for retrofit direct emission reductions) and a projection to 2035 (for direct savings). Further MACCs and projections are presented in Section 7.

Potential Actions

32) Various suggested next steps are described in section 8.2. Details are given about the following initiatives:

To Reduce Direct Emissions

a) An initiative to reduce the amount of R404A going into new systems and being used in existing systems.

b) Information about the performance of CO_2 systems should be collated and disseminated.

c) Consideration of how embodied carbon costs can be internalised into refrigerant costs to encourage more efforts to reduce leakage.

d) Building on the successes of the F Gas Regulation.

e) Preparation of guidance for buying new refrigeration equipment with low direct emissions.

f) Tracking development of HFOs and other new refrigerants.

g) Preparation of guidance related to R22 phase out.

To Reduce Indirect Emissions

h) Preparation of guidance for buying new refrigeration equipment with low indirect emissions.

i) Consideration of minimum efficiency standards for new systems.

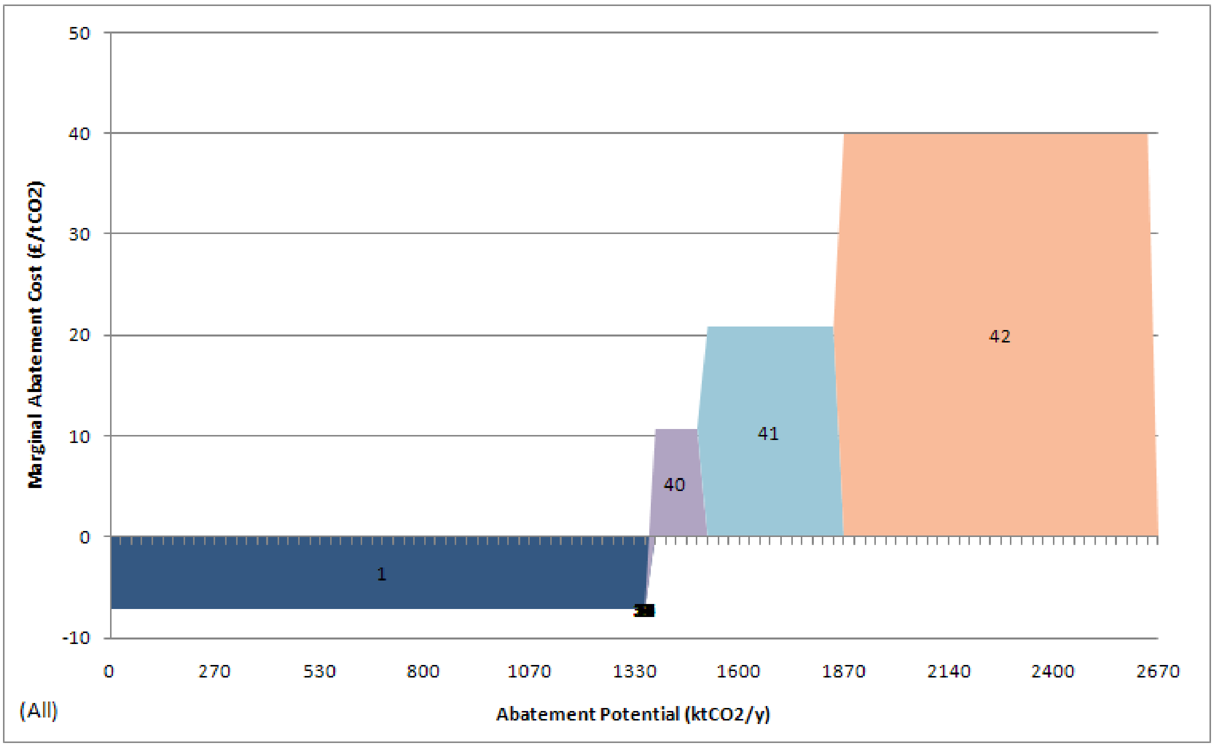
j) Energy Labels for new small systems.

k) More sophisticated performance information for new large systems.

l) Preparation of guidance on indirect emission reduction opportunities for existing plants.

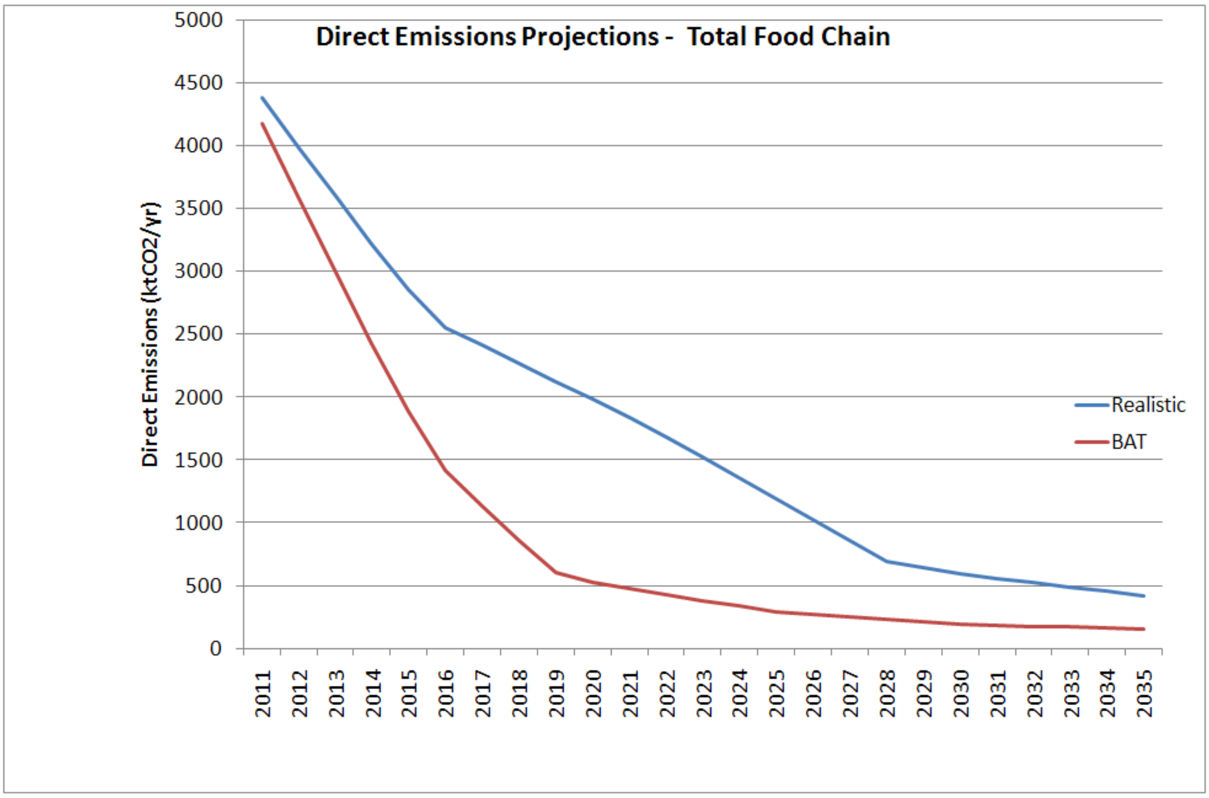
m) Encouraging use of better metering.

Figure ES2: MACC for Retrofit Direct Emission Reductions, Whole Food Chain



Key measures: 1 = Retrofit of R404A with medium GWP alternative; 40 = compliance with F Gas Regulation, 41 = management / maintenance beyond F Gas Regulation requirements; 42 = investments to reduce leakage.

Figure ES3: Projection for Direct Emission Reductions, Whole Food Chain



1. Introduction

This document is the main report from a project entitled: "Examination of the global warming potential of refrigeration in the food chain" carried out on behalf of Defra. The research work was done by SKM Enviros from September 2010 to April 2011.

The overall aim of the project is to understand the level of greenhouse gas (GHG) emissions from food chain refrigeration systems in the UK and the scope to reduce these emissions. The project provides suggestions about policy measures that can increase the uptake of cost effective GHG emission reduction technologies.

1.1. Project Background

Refrigeration is a crucial utility used throughout the food chain. It avoids wastage of food, enabling short term storage of chilled foods and longer term storage of frozen foods. Key uses include refrigeration on farms (dairy farms and post harvest), manufacturing plants, bulk storage, retail, food service and transport[4].

GHG emissions from food chain refrigeration include "direct" emissions related to leakage of refrigerants, including HFCs[5] and HCFCs[6] and "indirect" emissions related to the energy consumed by the refrigeration systems (this is mostly in the form of CO_2 emissions from power stations). Reducing both direct and indirect emissions is an important objective.

Energy efficiency is a crucial issue in relation to emission reduction from refrigeration systems. There are many opportunities for efficiency improvement and a key barrier is a lack of awareness and understanding by refrigeration users. Reducing the direct emissions of HFC and HCFC refrigerants is also a big opportunity. There are a number of emission reduction options including improved containment and use of various alternative refrigerants with a lower global warming potential (GWP).

1.2. Project Activities

The key steps in the research programme were to:

a) **Review of current evidence**. A review of existing evidence about refrigeration in the food chain, in particular energy and refrigerant use and emission reduction technologies.

b) **Quantification of emissions**. Estimate of GHG emissions from refrigeration systems in the UK food chain, with a breakdown for each step in the supply chain including farms, food processing / manufacturing, bulk storage, food retail, food service and transport.

---

[4] This project does not address food refrigeration in domestic refrigerators and freezers.

[5] HFCs: hydrofluorocarbons, refrigerants with a high global warming potential (GWP).

[6] HCFCs: hydrochlorofluorocarbons, refrigerants with a high GWP that also damage the ozone layer.

c) **Identification of emission reduction opportunities**. A comprehensive list of relevant opportunities to reduce both direct and indirect emissions was researched, to establish the potential for (a) energy saving or leak reduction, (b) the CO_2 and cost savings and (c) the likely cost of implementation.

d) **Levels of technology uptake and assessment of drivers and barriers**. Research to highlight the spectrum of progress between companies that have already taken significant steps to reduce emissions and companies that have done little or nothing in this area. Research to understand the various drivers and barriers to the uptake of the technologies identified in different sectors of the food chain.

e) **Development of MACCs for refrigeration emission reduction opportunities**. The data on the cost and benefits of each measure and on technology penetration were used to develop marginal abatement cost curves (MACCs) to illustrate the overall potential.

f) **Suggestions for next steps**. The research carried out in this project will inform Government and other Stakeholder initiatives to help stimulate emission reductions. A range of options for new or improved initiatives have been assessed.

1.3. Report Structure

The structure of this report is as follows:

Section 2, Evidence Review, provides a summary of a review of 27 references that provide important background information related to this project.

Section 3, Survey Results, provides the results of a survey of 200 food manufacturing sites using refrigeration systems and of discussions with experts in other sectors.

Section 4, Direct and Indirect Emission Estimates, provides an analysis of GHG emissions from different parts of the food chain.

Section 5, Emission Reduction Opportunities, discusses the technologies and techniques that can be used to make GHG emission reductions.

Section 6, Drivers and Barriers, provides feedback from end users.

Section 7, Emission Reduction Potential, gives outputs from an analysis of the cost effectiveness of emission reduction techniques in the food chain, including MACCs that describe the future emission reduction potential.

Section 8, Conclusions and Potential Actions, provides guidance on steps that can be taken to increase the uptake of cost effective emission reduction technologies.

This main report has been kept concise so that it quickly highlights the key outcomes from the research. Further detail is available in 2 Appendices that accompany the main report:

Appendix 1, Evidence Review, gives more details on the review of existing evidence.

Appendix 2, Survey Results, gives more details on the survey of food manufacturers.

1.4. Project Team and Steering Group

The SKM Enviros project team included:

Ray Gluckman	Project Director
Jane Galloway	Project Manager
Tim Thurnham	Technical Expert

The Defra team that defined and supervised the work programme included:

Sonia Molnar

Lucy Foster

Luke Spadavecchia

Duncan Egerton

Jacob Andresen

A steering group including the above teams plus external stakeholders met to discuss key aspects of the work. Defra and SKM Enviros would like to acknowledge the helpful input received from the external stakeholders that included:

Alison Austin	Woodside Training (expert on retail)
David Cowan	Institute of Refrigeration
Fergus McReynolds	Dairy UK
Stephen Reeson	Food and Drink Federation
Chris Sturman	Food Storage and Distribution Federation

2. Evidence Review

An important objective of this project is to provide Defra with an update of new evidence and actions that have occurred since the Food Industry Sustainability Strategy (FISS) and Food 2030 reports were published. The first step of the project was to review existing evidence about refrigeration in the food chain, in particular related to energy and refrigerant use and emission reduction technologies.

A review of the available literature has been carried out to establish the important sources of evidence created in the last few years. A starting point was the FISS report and other important Defra publications such as Food 2030. A review was then carried out of outputs from relevant projects such as the FDF Refrigeration Efficiency Initiative, the Retail Refrigeration Roadmap and the Institute of Refrigeration Real Zero project (all supported by the Carbon Trust). Discussions have been held with the project steering group and with academic institutions such as Brunel University, London South Bank University and FRPERC, to ensure that all relevant evidence has been considered. Public statements made by large companies (e.g. initiatives such as M&S “Plan A” or Cadbury’s “Purple goes Green”) and by Trade bodies (e.g. the FDF “5-Fold Plan” and BRC “A Better Retailing Climate”) have also been reviewed to provide evidence of current activities.

The Food Industry Sustainability Strategy (FISS) aims to help the Food Industry contribute to the UK’s sustainability goal. For the priority of tackling energy use and carbon emissions, the FISS encourages industry to adopt widely energy best practice. In particular, the FISS challenged industry to reduce its carbon emissions by 20% by 2010 against a 1990 baseline and commits Government and industry to a process of discussion, on the feasibility of reaching this target, the evidence base and the measures needed to achieve the target.

2.1. Sources Reviewed

27 different sources were reviewed. A full reference list is available in Appendix 1 and a summary list of the sources is given in Table 2.1. Each source was evaluated to extract information about the use of refrigeration in specific parts of the food chain. The information of particular interest to this project includes:

a) Direct emissions of GHGs from refrigerants.

b) Indirect emissions of GHGs from the energy consumed by refrigeration equipment.

c) Type of refrigeration activity and type of equipment used.

d) Opportunities to reduce direct refrigerant emissions.

e) Opportunities to reduce indirect energy related emissions.

f) Strategic thinking.

g) Drivers and barriers.

Appendix 1 contains a summary of the relevant information identified from each of the 27 references. In Section 2.2 below we evaluate the areas where there is good evidence available and those areas where there are still gaps in the evidence base.

Table 2.1 Summary of Sources Reviewed (for full references see Appendix 1)

Source	Description
1	Food 2030 Report (Defra, 2010)
2	Food Industry Sustainability Strategy (FISS) Reports (Defra, 2007)
3	Study on direct energy use in agriculture
4	Digest of United Kingdom energy statistics (DECC, 2010)
5	Climate Change Agreement data (energy data from various food manufacturing sectors)
6	Refrigeration Technology Support in the Food and Drink Sector (FDF and others, 2005)
7	Refrigeration road map for the food retail sector (IOR, BRA, CT, 2010)
8	Food and Drink Industry Refrigeration Efficiency Initiative (FDF and others, 2007)
9	Study on reducing energy inputs into refrigeration of food (FRPERC and others, 2009)
10	IOR paper on impact of refrigeration on energy use in food (Garnett, 2007)
11	Eco-efficiency study in supermarket refrigeration (SKM Enviros, 2010)
12	F Gas inventory (March Consulting, 1999)
13	F Gas inventory (AEA Technology, 2010)
14	Good Practice Guides on refrigeration (CT, various dates)
15	Supermarket CSR reports
16	Sector voluntary initiatives (e.g. FDF 5-Fold Plan) and Supermarket initiatives.
17	Study of Environmental Impacts of the Food Service Sector (Defra, 2010)
18	A Food Vision (British Frozen Food federation, 2010)
19	Industrial Energy Efficiency Accelerator Guide to the Dairy Sector (CT, Dairy UK, 2010)
20	Real Zero campaign information and literature (IOR, CT, various dates)
21	Publications on new refrigerants from various manufacturers
22	Comparative Assessment of Supermarket Refrigeration Systems (Germany, 2009)
23	Market Transformation Programme information on commercial refrigeration (Defra, 2010)
24	Study on refrigerating and freezing equipment (EC EUP study, 2010)
25	Study on commercial refrigerators and freezers (EC EUP study, 2010)
26	Eco-friendly Refrigeration Equipment in Transport (DfT, Freight Best Practice 2010)
27	Improving the Energy Performance of Commercial Refrigeration Products (Defra 2008)

2.2. Evaluation of Evidence

Table 2.2 gives a qualitative assessment of the quality of evidence reviewed in this project. The table illustrates that for some areas only limited evidence was found (shown as category "1"), whilst for others there was excellent evidence (shown as category "3").

In general there was better evidence on indirect energy related emissions than on direct emissions. There was particularly good evidence describing indirect emission reduction opportunities and strategic thinking. The weakest area of evidence related to direct emissions data. In terms of food chain sectors the best evidence was for food and drink manufacturing, cold storage and retail. There was less information available on use of refrigeration in agriculture, transport and food service.

Table 2.2 Qualitative Evaluation of Evidence

	Emissions Data		Reduction Opportunities		Strategic	
	Direct	Indirect	Direct	Indirect	Direct	Indirect
Agriculture	1	2	1	2	1	1
Food Mfr	1	2	2	3	3	3
Drink Mfr	1	2	2	3	3	3
Cold Storage	1	2	2	3	3	3
Transport	2	1	1	2	2	3
Retail	2	2	3	3	3	3
Food Service	1	2	1	3	1	2

1 Limited evidence	**2** Reasonable evidence	**3** Excellent evidence

Direct Emissions Data

The core source for direct emissions data is the 2010 UK F Gas Inventory (Source 13), but this only provides data on HFC emissions. The inventory is based on various modelling assumptions which lead to a level of inaccuracy. The inventory does not map HFC emissions into the food chain sectors being assessed in this project, with the exception of large retail and transport. The only source of data on HCFCs is from sales figures. There is virtually no data in the evidence that maps these HCFC emissions into the food chain.

Indirect Emissions Data

There is good information about total electricity consumption in key food chain sectors from Climate Change Agreement data (Source 5) and high level sources such as DUKES (Source 4). However, there is little detailed information about what proportion of electricity use is for refrigeration. Various sources can be used to make reasonable estimates of this proportion and hence establish a good estimate of indirect emissions, especially in large retail and in the industrial sectors of the food chain.

Emission Reduction Opportunities

There is a lot of good information available about both direct and indirect emission reduction opportunities, although these are not always quantified with payback periods or with sector-wide potential. The FDF Refrigeration Efficiency Initiative (Source 8) and the Retail Refrigeration Roadmap (Source 7) provide particularly good evidence about energy saving opportunities. The Retail Roadmap also gives useful information on direct emission reduction techniques, together with the excellent information available from the Real Zero project (Source 20). The Market Transformation Programme (Source 23) and data from EC EUP studies (Sources 24 and 25) provide good information on opportunities related to small equipment found in small retail and food service. Specialist studies of refrigerant alternatives in supermarket systems (Sources 11 and 22) together with data from refrigerant manufacturers (Source 21) provide good information about use of alternative refrigerants including CO_2, ammonia and the new HFO[7] fluids.

Strategic Information

There is good information about the strategic thinking being adopted in different food chain sub-sectors from a number of sources and also about the drivers and barriers that affect investment in emission reduction technologies.

2.3. Gaps in the Evidence Base

Areas where better evidence would be useful include:

a) Improved data on HFC emissions from sub-sectors of the food chain.

b) More comprehensive data on HCFC emissions generally and, emissions mapped into food chain sub-sectors.

c) Improved estimate of the proportion of electricity used for refrigeration in different food chain sub-sectors.

d) More information on the payback periods of emission reduction opportunities.

e) More information on uptake of emission reduction opportunities.

In this project we have provided new estimates that address some of these information gaps, although it must be stressed that numerous expert assumptions were needed to establish some of these estimates, because of the lack of credible source data. The survey described in Section 3 of this report has provided some very useful new information to better understand the use of refrigerants in different food chain sub-sectors, the proportion of electricity used for refrigeration and the uptake of some emission reduction techniques.

[7] HFO: hydro-fluoro-olefin, new refrigerants with very low GWP

3. Survey Results and Other Research

Research was carried out with end users of refrigeration systems in the food chain to collect new information about use of refrigerants, use of energy and to better understand progress towards emission reductions.

A key part of this research was a survey of users of industrial refrigeration systems in food and drink manufacturing plants and in cold stores. These sectors were covered because they account for a significant share of the overall emissions, there are important gaps in the evidence base and it was relatively easy to carry out a survey through the industry CCA contacts. Other sectors were not included in the survey since they were considered to be unsuitable for one or more of the following reasons:

- the gaps in the evidence base were smaller;
- telephone interviews would be needed with only a small number of companies e.g. the supermarket sector;
- conducting a survey would have been difficult in practice and costly due to the large number of small companies in the sector e.g. food service sector.

3.1. Survey of Industrial Sites

The survey was carried out on line using Survey Monkey in the period December 2010 to 10th March 2011.

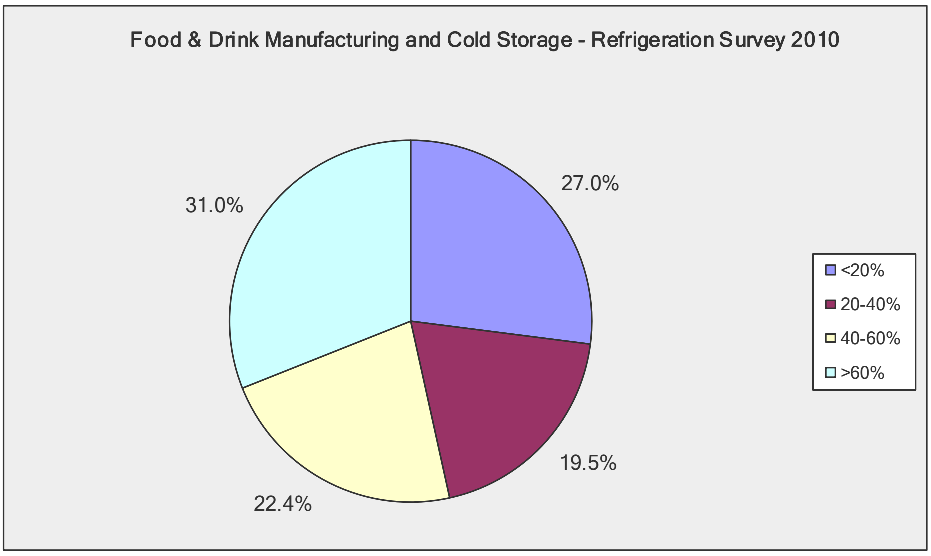
In total 198 questionnaires were completed for the survey. Subsectors for which a reasonable number of sites took part were Bakery (14%), Fruit and Vegetable (10%), Fish (9%), Red Meat (9%) and Cold/Chill Storage (15%).

Full details of the survey results are in Appendix 2. Key findings are summarised below.

Use of Energy

On average the respondents estimated that 42% of their electricity was used for refrigeration. This result stresses the importance of refrigeration in food and drink manufacturing and in cold storage.

Figure 3.1 - Percentage of Total Electricity Consumption which is for Refrigeration

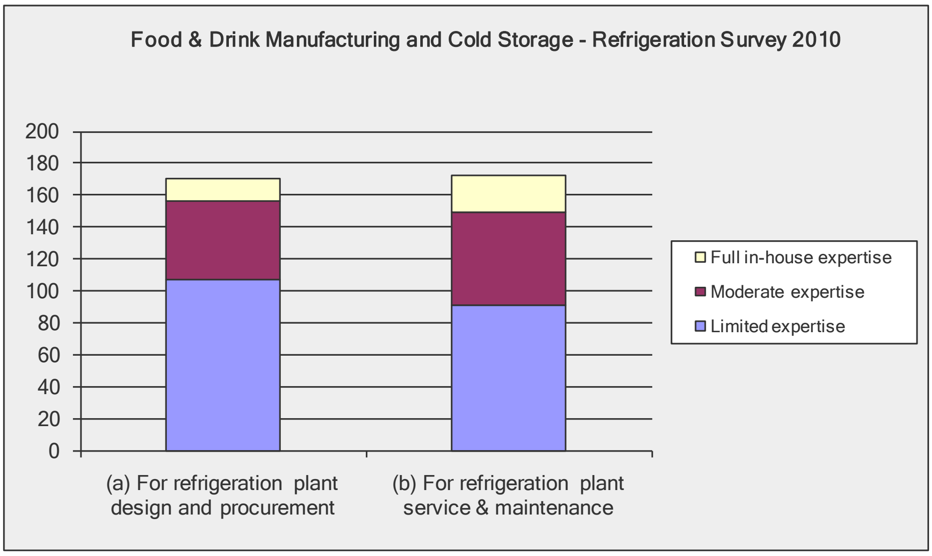


A surprising result was the lack of sub-metering used on refrigeration systems. Despite the fact that refrigeration was such a large proportion of the electricity bill, only 27% of respondents had any sub-metering for refrigeration.

Level of In-House Expertise

Many food and drink are completely reliant on refrigeration systems for their factory output – a refrigeration system failure could result in factory closure. Despite the clear importance of refrigeration the survey showed a relatively low level of in-house expertise. As shown in Figure 3.2, the majority of respondents assessed that they only have "limited" in-house skills related to refrigeration. This implies significant reliance on external contractors, in relation to both purchase of new plant and maintenance of existing systems.

Figure 3.2 - Level of In-house Refrigeration Expertise



Types of refrigerant in use in food and drink manufacturing

A particularly useful output from the survey is an up to date picture of the use of refrigerants in food and drink manufacturing plants and cold stores.

Detailed responses were received from 132 sites. The respondents were asked to select the number of refrigeration and air-conditioning systems at their site that use each type of refrigerant. Then they were asked to estimate the total quantity of refrigerant in these systems. The results are summarised in Table 3.1.

The respondents have a total of 2278 refrigeration systems at 132 sites – this is an average of 17 systems at each site. They have a total of 331 tonnes of refrigerant, which is an average of 2.5 tonnes per site and 145 kg per system. These figures show that the survey sample includes sites that make significant use of refrigeration.

A surprising result is that the most popular refrigerant, in terms of numbers of systems, is R22, which is an HCFC subject to phase out under the Ozone Regulation. 35% of systems still use R22. This shows that the food manufacturing sector still has a lot of work to do to meet the phase out deadlines[8].

All the HFCs added together represent 55% of all systems in the survey, although each system is relatively small. The HFC systems account for only 18% of the refrigerant tonnage.

Table 3.1 Use of Refrigerants

Refrigerant	Number of Systems	Quantity of Refrigerant (tonnes)	% Number of Systems	% Quantity of Refrigerant	Average Charge (kg)	% quantity of HFCs	GWP[9]	% GWP weighted quantity
HCFC 22	798	76	35%	23%	95		1,810	43%
HFC 404A	392	30	17%	9%	76	48%	3,922	37%
HFC 407C	324	15	14%	4%	46	24%	1,774	8%
HFC 410A	267	5	12%	2%	20	9%	2,088	4%
Other HFC	169	5	7%	1%	27	7%		4%
Ammonia	146	185	6%	56%	1267		0	0%
HFC 134a	114	7	5%	2%	64	12%	1,430	3%
Other HCFC	50	2	2%	1%	44			1%
CO2	10	6	0.4%	2%	600		1	0%
HCs	8	0	0.4%	0%	1		~5	0%
Total	**2278**	**331**	**100%**	**100%**	**145**			**100%**

[8] Use of virgin HCFCs for maintenance of existing systems was banned from January 2010. Only reclaimed and recycled HCFCs can currently be used – these are expected to become increasingly in short supply. Use of reclaimed and recycled HCFCs for maintenance will be banned from the end of 2014.

[9] Refrigerant Global Warming Potential (GWP) based on 4th Assessment Report of UN FCCC.

HFC 404A is the most popular of the HFCs, despite the fact that its GWP is twice as high as that of other HFC refrigerants and R22. R404A represents 48% of the quantity of HFCs in use. R407C is the second most import HFC, representing 24% of HFCs. R22 and R404A together represent 80% of the GWP weighted bank of refrigerant in the food chain.

Ammonia only represents 6% of the number of refrigeration systems in the survey, but is very dominant in terms of refrigerant quantity – being 56% of the total of all refrigerants in the survey. The data in Table 3.1 clearly shows that ammonia is mainly used in very large systems – the average charge across 146 systems is well over 1 tonne per system. This is more than 10 times the average charge of all other refrigeration types except CO_2. This reflects the fact that ammonia is the refrigerant of choice on very large food manufacturing systems such as blast freezers and large cold stores.

CO_2 was only used in 6 systems, although it is interesting to note that these are quite large (average charge of 600 kg per system).

The survey showed virtually no use of hydrocarbon (HC) refrigerants. This is because HCs are only cost effective in very small systems (< 1 kg of refrigerant) – well below the size of systems used in food manufacturing.

Uptake of Emission Reduction Measures

The survey included questions to try and estimate the current uptake of a number of emission reduction technologies. There were specific questions about 35 emission reduction techniques. In each case the respondent classified the technology into one of the following 6 categories:

33) Fully implemented – already actioned for ALL relevant systems on site

34) Part implemented – already actioned for SOME relevant systems on site

35) Likely to be implemented – possible for relevant systems on site and is likely to be actioned in next 5 years

36) Not likely to be implemented - possible for relevant systems but is not likely to be actioned in next 5 years

37) Not possible / not applicable - not possible to implement on site

38) Don't know

The emission reduction opportunities were split into the following groups:

- Leak reduction (6 opportunities)
- Cooling load reduction (6 opportunities)
- Main refrigeration plant (e.g. on compressors, heat exchangers, etc.; 9 opportunities)

- Auxiliary equipment (e.g. pumps, fans etc.; 5 opportunities)
- Plant control (4 opportunities)
- Plant maintenance (4 opportunities)

Full results for all the questions are given in Appendix 2. An example of the responses, related to the 5 opportunities on auxiliary equipment is given in Figure 3.3.

Figure 3.3 – Auxiliary Equipment Projects

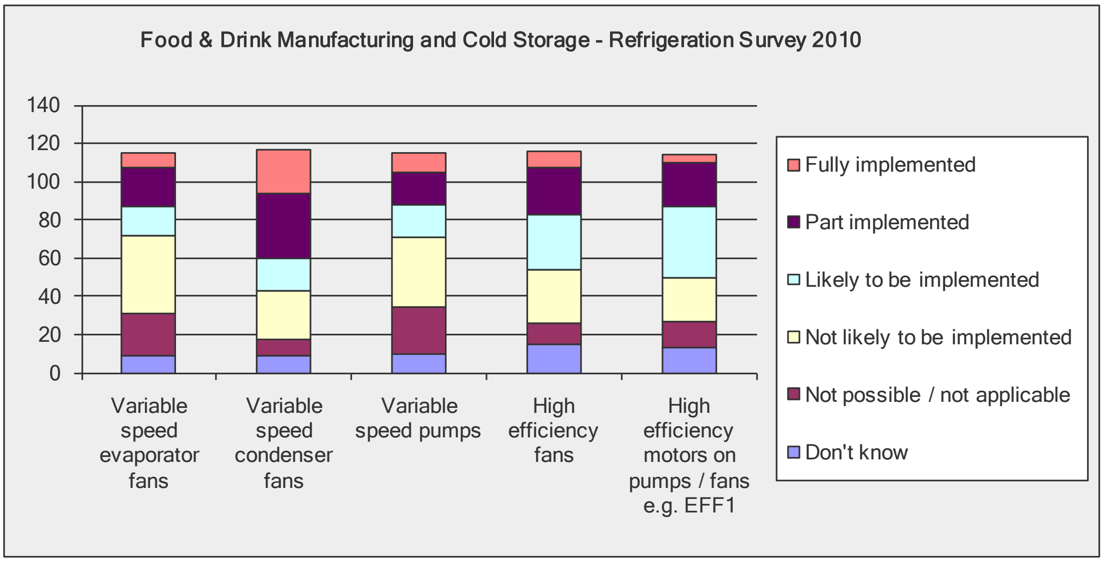


Figure 3.3 shows there is relatively poor implementation of the 5 opportunities. Only the use of variable speed drives on condenser fans was already fully or partly implemented by a reasonable proportion of respondents (40%). The other 5 technologies are not well implemented yet. It is interesting to note that variable speed evaporator fans represent a very good opportunity and yet they have been implemented by very few companies.

The overall finding from this part of the survey is that a lot of good emission reduction opportunities have yet to be widely implemented in food and drink manufacturing. The results from the survey have been used to help estimate further potential for emission reduction (see Chapter 5 of this report).

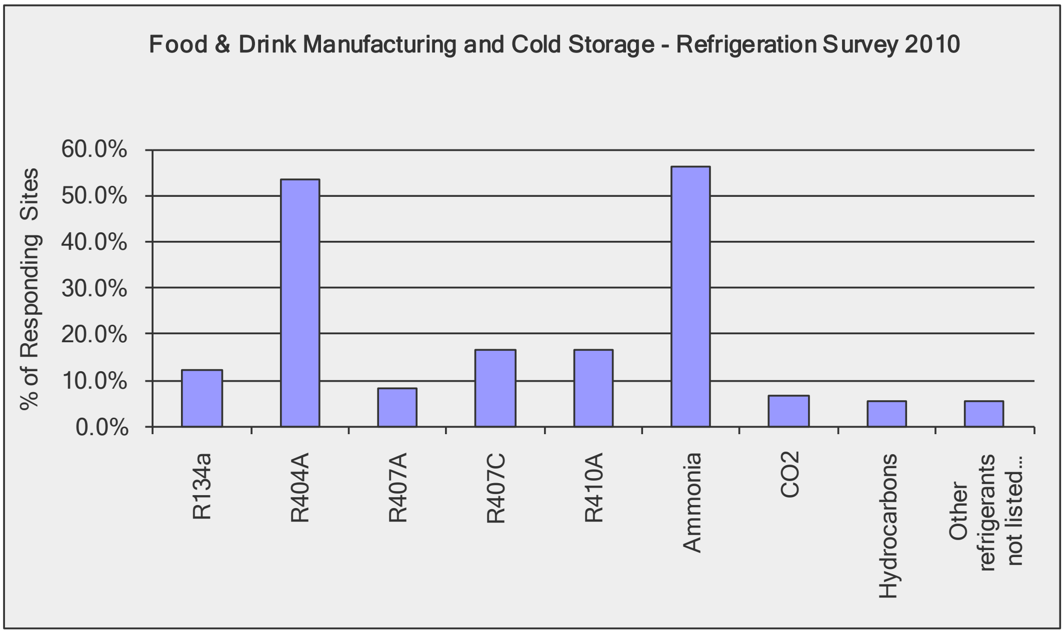
Plans for Phase Out of HCFCs

Only 7% of sites said they had no plans for phasing out R22 and other HCFCs. The majority of respondents indicated that they will keep existing equipment and use drop-in alternatives such as R442D. Surprisingly, the most popular choice of drop-in alternative refrigerant was R404A – which could indicate a lack of understanding as this is a difficult refrigerant to use in place of R22 in existing systems due to its different thermodynamic and oil compatibility characteristics (and it has twice the GWP).

Plans for New Refrigeration Systems

Nearly two thirds of respondents said they are planning to purchase some new refrigeration systems during the next 5 years. Figure 3.4 illustrates their refrigerant preferences.

Figure 3.4 – Refrigerants being Considered for New Equipment



It is encouraging to see that ammonia based systems are a popular preference for large systems, but it is concerning that R404A remains by far the most popular HFC preference given its very high GWP.

Drivers

The survey included questions about drivers that encourage emission reduction and factors taken into account when purchasing a new refrigeration plant.

The three most important drivers for improving energy efficiency, in order, were:

1) Energy Costs
2) Climate Change Agreement Targets
3) Corporate Social Responsibility Commitments

The three most important drivers for reducing refrigerant leakage, in order, were:

1) Refrigeration System Reliability
2) Energy Efficiency
3) F Gas Regulations.

The three most important factors when investing in new refrigeration plant were:

1) High Reliability
2) Low refrigerant leakage level
3) Low annual energy cost.

Barriers

Respondents were asked: "Are there any barriers which currently prevent you from either improving energy efficiency or reducing the leakage emissions from your refrigeration systems?" The two dominant responses to this question were:

1) Lack of available capital
2) Payback Criteria required for any investment

Government Support

Respondents were asked describe any support measures that Government or Trade Associations could offer which would help overcome these barriers.

- Half of the suggested support measures are associated with some sort of financial support i.e. grants, interest free loans, tax incentives, ECA and general financial assistance.
- Other popular measures were the provision of improved, impartial advice and better information, both on the incentives and grants available under various programs and on emerging technologies.

3.2. Other Research

Supermarkets

Supermarkets represent one of the largest end user categories in the food chain. Information issued by a number of supermarket companies highlights the following points:

a) R404A is the dominant refrigerant used in existing stores, used for both chilled and frozen food systems.
b) Most R22 in the supermarket sector has already been replaced. It is estimated that under 5% of pack systems in larger stores still use R22 – which is much lower than the 35% of systems identified in the survey of food and drink manufacturers. Plans for completing the R22 phase out are fully in place and nearly completed.
c) There is significant effort being made to reduce the direct emissions from new systems. Three different approaches are being adopted:

- CO_2 is being used in all / most new systems by a number of companies in place of R404A in both transcritical and cascade designs. This saves almost 100% of direct emissions.
- One company is adopting a design based on hydrocarbon integrals combined with a chilled water system and heat recovery.
- One company is specifying higher quality design and installation to reduce leak rates significantly on new systems.

d) There is also a significant effort being made to reduce leakage from existing systems in response to the F Gas Regulation.

e) Trials of medium GWP refrigerants such as R407A and R407F have been carried out. These can be retrofitted into existing plants running on the very high GWP refrigerant R404A. Results show an energy saving of 7% to 12% alongside a 50% reduction in direct emissions. Some of the supermarkets are considering more widespread use of such refrigerants and one company has a substantial retrofit programme in place.

f) Most of the supermarkets are also very actively looking at ways of reducing energy consumption. The recent Retail Refrigeration Roadmap (Evidence Source 7) was written with much input from the supermarkets.

g) The supermarket plans are often very visible via CSR programmes. Several companies have made voluntary commitments to phase down use of HFCs substantially over the next 25 years.

Refrigerant Manufacturers

Discussions were held with a number of refrigerant manufacturers to try and understand the types of new refrigerant that may emerge on the market over the next few years. There are rapid changes likely because of the recent introduction of HFO 1234yf for the mobile air-conditioning (MAC) market.

Two HFOs are coming to the market:

- HFO 1234yf is being adopted by car manufacturers in response to the MAC Directive which bans the use of refrigerants with a GWP above 150 from 2011 (in new vehicle types). HFO 1234yf has a GWP of only 5, so it saves over 99.5% of GHG emissions compared to the current MAC refrigerant HFC 134a (GWP = 1,300). This refrigerant is slightly flammable, albeit much less flammable than most other flammable refrigerants. A new flammability class ("A2L") is being introduced in the refrigeration safety codes that could make this refrigerant useful in a range of food chain applications. The refrigerant will only be available in commercial quantities at the end of 2011 and it is likely that all available output will go to the MAC sector over the next few years. Larger quantities should be available for stationary refrigeration applications by 2015.
- HFO 1234ze is already commercially available and is being used as an aerosol propellant and being considered for foam blowing applications. It has properties that

make it suitable for use in some refrigeration applications such as large water chillers. It also has a very low GWP.

Refrigerant manufacturers are considering developing blends of HFOs and HFCs to offer a non-flammable option. These blends would probably have a GWP in the range 500 to 1,000. If these are used in place of HFC 404A (GWP = 3,922) the savings in GHG emissions would be between 75% and 90%.

Summary

It is clear that the rate of change in the refrigerants market is very rapid. CO_2 is gaining a foothold, especially in supermarkets. HFOs will first be used in the MAC market, but are likely to become important in food chain refrigeration applications.

4. Direct and Indirect Emission Estimates

Using data from the evidence review, supplemented by data received via the questionnaire survey, estimates have been made of GHG emissions from refrigeration systems in different parts of the food chain.

As shown in Table 2.2, the quality of evidence related to GHG emissions was not as strong as would be desirable to make the estimates given below. The evidence for direct emissions was "limited" in all sectors except transport and retail, where the evidence was "reasonable". The evidence for indirect emissions was generally better, being "reasonable" in all sectors except transport where the evidence is "limited". Table 2.2 shows that none of the existing evidence on emissions was "excellent".

Extra evidence gathered during this study has helped improve the estimates, especially in relation to indirect (energy related) emissions. Good data from the questionnaire survey on refrigeration electricity use, together with accurate data from CCAs has provided a good estimate of electricity use in the manufacturing and cold storage sectors. Good data on energy use from supermarket companies has helped improve the estimate for electricity use in the retail sector.

Information on the confidence level of the data for each of the sectors is given in Appendix 3.

4.1. Direct Emissions

The key data sources for the direct emissions estimate are:

a) UK F Gas inventory, 2010

b) Sales data for HFCs and HCFCs from British Refrigeration Association

c) CSR data from supermarket companies

d) Discussions with supermarket, manufacturing and cold storage companies.

The estimates of direct emissions are summarised in Table 4.1 and Figures 4.1 and 4.2. The confidence level for the direct emissions estimates is "low" for all sectors except transport and retail, for which it is "medium". Information on the confidence level of the data for each of the sectors is given in Appendix 3.

Table 4.1 Direct GHG Emissions from Food Chain Refrigeration, 2010

Refrigerant Type	Agriculture	Food & drink manufacture	Cold Storage	Transport	Retail	Food Service	Total
	ktonnes CO_2e						
HFCs	20	540	80	120	2,600	240	3,600
HCFCs	30	350	100	110	400	210	1,200
Total	50	890	180	230	3,000	450	4,800

Fig 4.1: Food Chain Direct Refrigerant Emissions, 2010

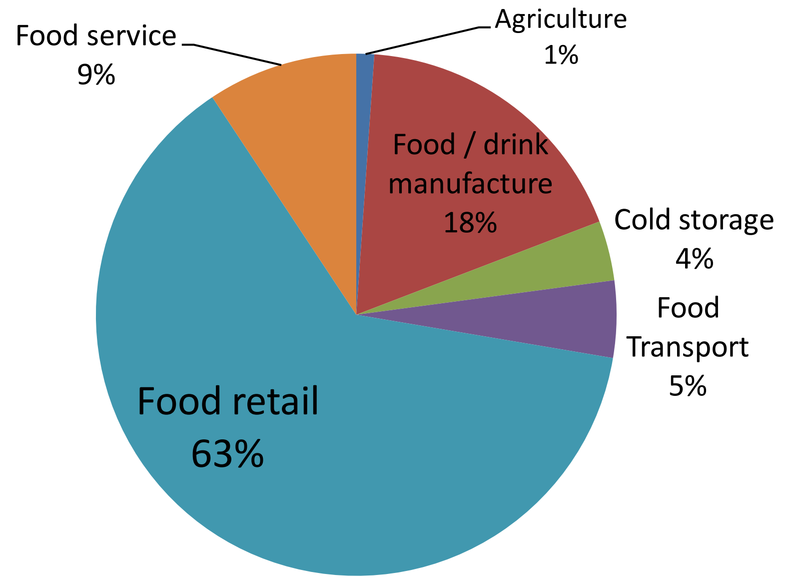
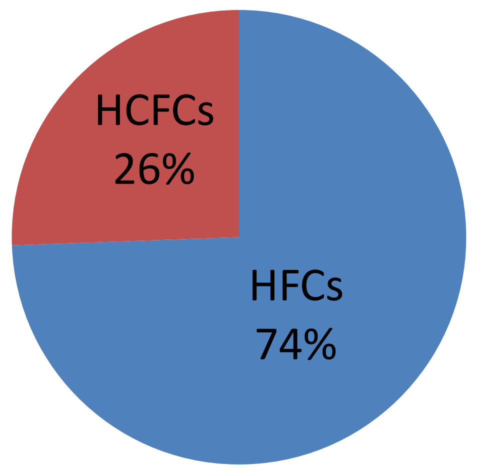


Fig 4.2: Split of Food Chain Direct Emissions, 2010



The direct emissions are dominated by those from supermarkets (63%) and larger industrial systems in food / drink manufacture (18%) and cold storage (4%). These 3 parts of the food chain represent 85% of total direct emissions. Food service emissions account for a further 9%. HFCs represent nearly three quarters of total direct emissions.

R404A is the dominant HFC refrigerant used in supermarkets and industrial systems. With its very high GWP (see Table 3.1) R404A is estimated to represent 80% of HFC emissions and 60% of total direct emissions.

4.2. Indirect Emissions

The key data sources for the indirect energy related emissions estimate are:

a) Digest of UK Energy Statistics (DUKES, 2010)

b) Electricity consumption data for Climate Change Agreement sectors

c) Defra Projects AC0401, AC0403, FO0411

d) Questionnaire data from manufacturing and cold storage companies

e) CSR data for supermarkets and discussions with supermarkets

The estimates of indirect emissions are summarised in Table 4.2 and Figure 4.3. The confidence level for the indirect emissions estimates is considered to be no more than "medium" for all sectors except transport, for which it is "low". Information on the confidence level of the data for each of the sectors is given in Appendix 3.

Table 4.2 Indirect GHG Emissions from Food Chain Refrigeration, 2010

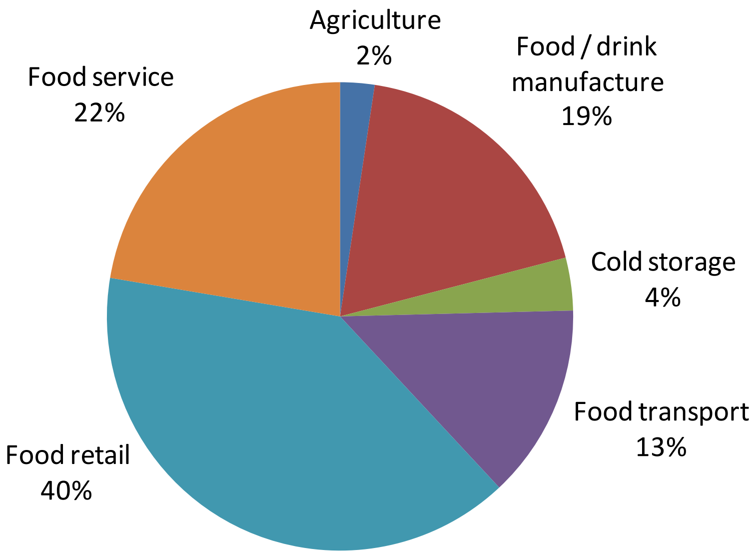
	Agriculture	Food & drink manufacture	Cold Storage	Transport	Retail	Food Service	Total
Total electricity, GWh	4,100	11,700	900	n/a[10]	27,400	14,800	58,800
% Refrigeration	11%	29%	80%	n/a	27%	20%	
Refrigeration electricity, GWh	440	3,450	680	n/a	7,360	4,160	16,100
Refrigeration indirect emissions, ktonnes CO_2e [11]	210	1,660	330	1200	3,530	1,990	8,910

[10] Note, transport refrigeration "indirect" emissions are related to the diesel fuel used to operate the refrigeration equipment on large trucks and smaller delivery vehicles. Hence it is not applicable to show electricity consumption in Table 4.2.

[11] Where indirect emissions have been calculated from electricity consumption data, an electricity emissions factor of 0.4795 kgCO2/kWh has been used (average emissions factor for 2010, 'Valuation of energy use and greenhouse gas emissions for appraisal and evaluation – June 2010' by DECC).

Supermarkets (40%) and larger industrial systems in food / drink manufacture (19%) and cold storage (4%) are important sources of indirect emissions, representing 63% of the total. However, these sectors are less dominant than they were for direct emissions, with food service (22%) and transport (13%) together representing over a third of indirect emissions.

Fig 4.3: Food Chain Refrigeration Indirect GHG Emissions, 2010



4.3. Total GHG Emissions from Food Chain Refrigeration

The total GHG emissions from food chain refrigeration are shown in Table 4.3 and figures 4.4 and 4.5.

Table 4.3 Total GHG Emissions from Food Chain Refrigeration, 2010

Refrigerant Type	Agriculture	Food & drink manufacture	Cold Storage	Transport	Retail	Food Service	Total
	ktonnes CO_2e						
Direct	50	890	180	230	3,000	450	4,800
Indirect	210	1,660	330	1200	3,530	1,990	8,920
Total	260	2,550	510	1430	6,530	2,440	13,720

Figure 4.4 shows that 65% of total emissions are indirect energy related CO_2 emissions whilst 35% is from direct refrigerant emissions.

Food retail represents just under 50% of total emissions, with industrial systems (manufacturing and cold storage) representing 22% of emissions and food service 18%.

Fig. 4.4: Split between direct and indirect emissions

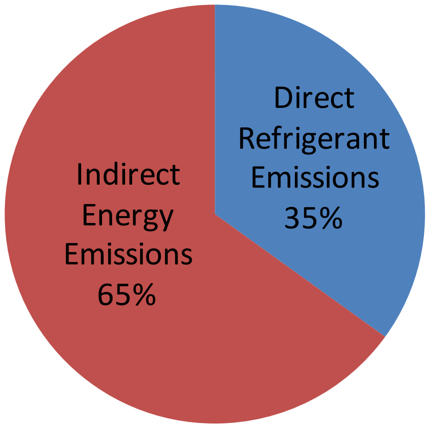
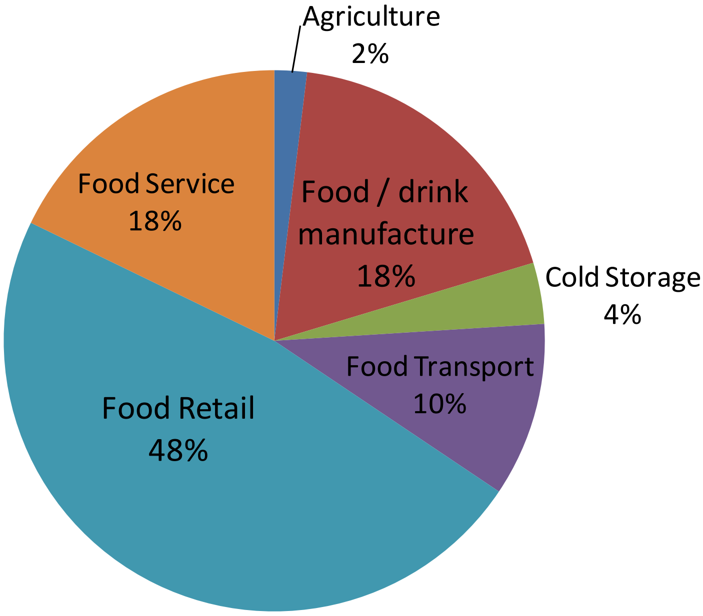


Fig. 4.5: Total Food Chain Refrigeration Emissions, 2010
Split between food chain sectors



4.4. Value of GHG Emissions

It is useful to consider the overall cost of the emissions from food chain refrigeration. There are 3 elements of cost:

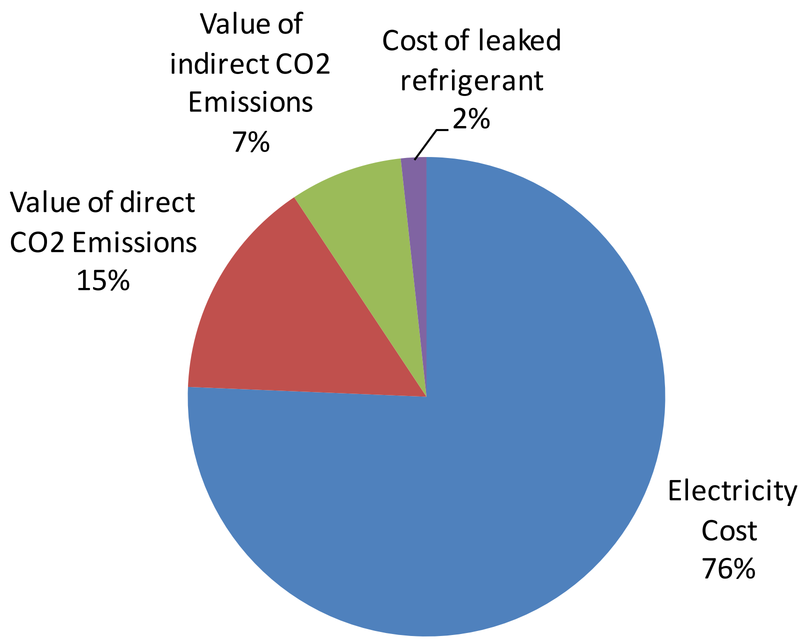
a) Direct cost of the electricity consumed. An average electricity price of 6.81 pence per kWh has been assumed[12].

b) Cost of replacing any leaked refrigeration. An average price of £15 per kg of refrigerant has been assumed.

c) Value of the CO_2 emitted. Whilst this is not a price currently paid by end users it will become of increasing importance as the UK tries to reduce GHG emissions. DECC currently uses different CO_2 prices for "traded" emissions (including that due to electricity) priced at £14.27 per tonne CO_2 and "non-traded" emissions (including direct refrigerant leakage), priced at £52.48 per tonne CO_2.

These prices have been applied to the emissions estimates to establish that the total cost of emissions related to food chain refrigeration emissions are nearly £1.7 billion per year. A split of costs is given in Figure 4.6. The dominant cost is the electricity itself. The value of CO_2 emissions is also significant, whilst the cost of replacing leaked refrigerant is a very small proportion of the total. The actual cost incurred by the food chain is 85% of the total, or just over £1.4 billion per year. This excludes the cost due to "non-traded" emissions which is a burden to society collectively but is not directly 'felt' by the food chain.

Fig 4.6: Costs of Operating Food Chain Refrigeration Systems



[12] 6.81 p/kWh is the DECC 2011 long term variable cost of electricity

5. Emission Reduction Opportunities

The evidence review included numerous good references about emission reduction opportunities. Table 2.2 showed that there is "excellent" evidence for indirect emission reduction opportunities in food manufacture, cold storage, retail and food service. There is "reasonable" evidence in the other sectors (agriculture and transport). In relation to direct emission reduction opportunities, there is "excellent" evidence in retail and "reasonable" evidence for manufacturing and cold storage. The evidence for direct emission reduction opportunities in agriculture, transport and food service is "limited", although Figure 4.1 illustrates that these 3 sectors only account for 15% of direct emissions, so the lack of better evidence is not crucial.

5.1. Categorising Emission Reduction Opportunities

A key aspect of understanding emission reduction opportunities is to recognise that their application varies considerably depending on the circumstances. In particular there are two types of circumstances that must be considered:

a) **New versus existing equipment**. If new plant is being purchased (either to replace old equipment or for a new refrigeration requirement) there are more cost effective emission reduction opportunities than those that can be applied to existing plant.

b) **Large versus small refrigeration systems**. For existing systems, there are few emission reduction opportunities that can be cost effectively applied on small and very small refrigeration systems. In such circumstances it is usually necessary to wait until equipment is being replaced before emission reductions can be made. This is not true for medium and large sized systems where there are numerous opportunities to improve existing systems.

The opportunities for direct and indirect emission reduction can be subdivided into various categories as shown in Table 5.1. The table shows 12 categories of emission reduction opportunity. Within each category there are many different types of measure – there are well in excess of 100 different techniques that could be considered for refrigeration systems in the food chain. This actually creates a barrier for investment as many end users are confused by the range of different opportunities and unable to select those that are most relevant to their circumstances and that will give them the most benefit.

In this chapter of the report we discuss each of the 12 categories and give examples of cost effective emission reduction opportunities. We also provide some sector specific guidance about which techniques are most applicable in different circumstances.

5.2. Direct Emission Reduction

Opportunity Category D1: Maintenance and management

Refrigerant leakage can be reduced by more regular manual leak checks, use of automatic leak checking systems and rapid response to repair leaks. Evidence from the IOR Real Zero project and the questionnaire survey in this project shows that there are a relatively small number of common types of leakage – these can be targeted for leak checking. Making good use of management data is crucial, especially in organisations with many refrigeration systems, where it is important to track refrigerant use and highlight which plants are causing the most leakage. It is typical that 80% of leakage comes from less than 20% of plants – concentrating on “rogue plants” can quickly lead to improvements.

The F Gas and Ozone Regulations specify mandatory leak testing and repair for all HFC and HCFC plants containing more than 3 kg of refrigerant. It has also led to higher standards of training for technicians – by July 2011 all technicians are required to hold the new F Gas qualification. Building on these mandatory requirements can help companies cut direct emissions by around 25%. It is worth noting that less direct emissions usually improves energy efficiency, giving a reduction in indirect emissions.

Table 5.1 Categories of Emission Reduction Opportunity

Type	Category	Comments
Direct	D1. Maintenance and management	Reduce leakage by more frequent leak checking / repair
	D2. Component replacement	Invest to replace leaky components
	D3. Replace refrigerant, existing plant	Replace high GWP refrigerant with lower GWP alternative
	D4. New plant, low leakage	Design new plant for low leakage
	D5. New plant, alternative refrigerant	Use lower / very low GWP alternative
Indirect	I1. Maintenance and management	Improve efficiency via better metering and management
	I2. Cooling load reduction	Invest to reduce cooling load on the system
	I3. Main refrigeration components	Invest to improve cycle efficiency and component performance
	I4. Auxiliary components	Invest to reduce auxiliary loads (e.g. pumps and fans)
	I5. Improved plant control	Control plant for higher efficiency
	I6. New plant, high efficiency	Ensure a new plant design is of high efficiency
	I7. New plant, BAT efficiency	Invest to maximise efficiency of a new plant

Opportunity Category D2: Component replacement

Management data on refrigerant emissions can quickly establish sources of regular leakage. If a simple leak repair does not solve the problem it is important to consider replacing components such as valves and joints if these are causing leakage. Sorting out problems on badly leaking plants can reduce direct emissions by a further 25%.

Opportunity Category D3: Replace refrigerant, existing plant

This opportunity specifically relates to plants that run on R404A. As discussed in Chapter 4, R404A represents 80% of all HFCs used in food chain refrigeration. It has a very high GWP (3,922) and it is not a particularly efficient refrigerant in many circumstances. Projects in some supermarkets have shown that R404A can be replaced in existing plants with either R407A or R407F. These refrigerants have a much lower GWP (2,107 and 1,825 respectively). The GWP is around 50% of that for R404A, so significant savings are achieved for equal leakage. If a refrigerant retrofit programme is combined with Opportunity D2 (investment to replace seals and leaky components), it is possible to achieve a direct emission reduction of around 75% for many types of system.

An exciting aspect of this opportunity is that R407A and R407F are both more efficient refrigerants in many types of existing system. An energy saving of 7% to 12% has been measured on trial projects. This provides a cost saving that can justify the investment and also provides indirect GHG emission reductions. A payback period between 2 and 4 years can be expected.

Opportunity Category D4: New plant, low leakage

One strategy for new plants is to continue using HFC refrigerants, but to make investments to ensure that the plant is designed for low leakage. Purchasing better quality valves, using low leakage joints and designing pipework to avoid vibration can all lead to reduced leakage. Emission reductions of at least 30% can be envisaged.

This approach should always be combined with Opportunity D3 i.e. the avoidance of using R404A. Whenever possible, R404A should not be used on any new systems; the plant can be designed to use a much lower GWP refrigerant such as R407F in most circumstances.

Opportunity Category D5: New plant, alternative refrigerant

The best way of reducing direct emissions is to use an alternative refrigerant with a zero or very low GWP. The choice of refrigerant depends on plant size:

- For large plants in food and drink manufacturing and cold storage an obvious choice is ammonia. This is already the most commonly used refrigerant on very large systems (see Table 3.1) as it is cost effective and energy efficient.
- For very small plants (under 1 kg of refrigerant) hydrocarbon refrigerants are a good choice. They are already used on most domestic refrigerators and freezers in Europe and can readily be used on small integral systems in retail and food service.
- Finding the best option for medium sized systems is more problematic. CO_2 is rapidly emerging as a strong contender – e.g. it is being used in many new supermarket systems in the UK. However it is not yet widely used in other food chain sectors. New refrigerants based on HFO / HFC blends, with GWPs between 500 and 1,000 may become available over the next few years and could be adopted in conjunction with Opportunity D4 (low leakage design).

5.3. Indirect Emission Reduction

Opportunity Category I1: Maintenance and management

There are significant opportunities to improve refrigeration plant monitoring and to make efficiency improvements linked to better operation and maintenance of existing systems. A regime of energy M&T (monitoring and targeting) using electricity meters combined with other specialist data (e.g. pressures and temperatures around the refrigeration circuit) is likely to provide very cost effective savings for many operators.

It is surprising how few refrigeration plant users have electricity sub-metering on their systems. The questionnaire survey of food and drink manufacturers and cold stores showed that only 25% of sites have any sub-meters, despite the fact that on average the survey participants used over 40% of their electricity for refrigeration.

Opportunity I2: Cooling load reduction

There are often good opportunities to reduce the amount of cooling carried out, sometimes by a significant percentage. There are various quite different opportunities in this category:

- Process cooling systems sometimes take warm products and cool them with low temperature refrigeration. It may be possible to use an “ambient free cooling system” using ambient air or cooling tower water to pre-cool the product before using refrigeration. For example, a process cooling a hot food stream from 65 ^{o}C to 5 ^{o}C should use a cooling tower water heat exchanger before refrigeration. In winter the stream could be pre-cooled to around 15 ^{o}C, reducing the refrigeration cooling load by 80%. In summer there is less pre-cooling available, but a saving of over 50% is still possible.
- Some heat exchangers, such as regenerative pasteurisers, provide a significant amount of “process free cooling”. However, they are often badly optimised and a small investment can reduce cooling load by 25%.
- Temperature set points in cold stores are sometimes set at a conservatively low level, e.g. -23^{o}C. Raising the temperature set point just 3 deg C to -20 ^{o}C reduces the cooling load and can simultaneously increase the efficiency of the refrigeration plant. This small 3 deg C adjustment will save at least 10%.
- Auxiliary loads in the cooled area, such as evaporator fans and lights, produce heat that must be removed by the refrigeration system. Improving the auxiliary load control and efficiency (see Opportunity Category I4, below) will reduce the cooling load.
- Reducing heats gains by improving insulation, (e.g. cold stores, pipework), and reducing air ingress e.g. by making better use of cold store doors, will reduce the cooling load.

Opportunity Category I3: Main refrigeration components

This is the most complex and varied of the opportunity categories. There are many ways in which a whole refrigeration cycle or individual components within the cycle can be improved in efficiency. These can provide useful savings on existing systems and more substantial improvements when a new plant is being designed. Some examples include:

- Large / better condensers (to allow lower head pressure)
- Liquid pressure amplification (to allow lower head pressure)
- Electronic expansion valves (to allow lower head pressure and less suction superheat)
- Higher efficiency compressors, selected for good efficiency across the whole operating envelop (including the range of summer and winter ambient temperatures and the range of high and low cooling loads).
- Large / better evaporators (to allow higher suction pressure)
- Heat recovery

Opportunity Category I4: Auxiliary components

End users are often surprised at the amount of power used by refrigeration system auxiliaries, such as pumps, fans and lights. Whilst compressors are the biggest user it is possible that auxiliaries will use well over 25% of the total annual energy bill.

Auxiliaries on the "cold side" of a system (e.g. evaporator fans, refrigerant pumps, lights in a cold room) are "paid for twice" – firstly to run the actual device and, secondly, to remove the heat that is created. For example a 10 kW evaporator fan in a cold store produces 10 kW of extra cooling load, which adds to the power used by the main refrigeration compressors.

Historically, many auxiliaries operate at 100% load all the time, irrespective of the cooling demand. An important way of reducing auxiliary power consumption is to control the devices to meet the actual needs of the refrigeration system load.

- A key technology is the variable speed drive, which can be used on pumps and fans in a very cost effective way. For much of the year, evaporator fans can be run below full load. A small drop in fan speed can lead to a large drop in power input (e.g. a drop from 100% to 80% speed (and flow) will reduce power input by 50%. This also means 50% less heat generated in to cold space.
- The efficiency of fans and fan motors has increased significantly in recent years. Selecting high efficiency fans and motors is an important opportunity.
- High efficiency lighting in cold stores and retail cabinets is important, together with the ability to turn lights off e.g. when parts of a store are not in use. Recent developments such as LED lighting and "light pipe" systems can provide significant reductions in full load power consumption and also the ability to control the lighting system.

Opportunity Category I5: Improved plant control

There are a number of ways in which refrigeration system control can be improved to increase energy efficiency. Projects to improve control offer some of the most cost effective "retrofit" opportunities for existing systems. Some examples include:

- Avoiding losses from head pressure control (HPC). Many plants have HPC, which prevents the condensing pressure falling below a pre-set value at times of low ambient temperature and/or low cooling load. The HPC is often set at a conservatively high level (e.g. 25°C or 30°C). This leads to high energy consumption, especially in winter. A system with "floating head pressure" is preferable and can save between 10% and 25%.

It is often possible to make savings by simply adjusting the set point on the HPC system. To get the maximum benefit it may also be necessary to modify the plant slightly e.g. by using electronic expansion valves or by using a “liquid pressure amplifier” system.

- Avoiding low compressor efficiency at part load. Most plants run at part load for a proportion of the year. The strategy for controlling compressor capacity is critical for high efficiency. Compressor control options (such as slide valves on screw compressors or inlet guide vanes on centrifugal compressors) can have very poor efficiency at part load. Changes to the capacity control algorithm can save in excess of 10%. A good approach can be to install an extra small compressor, perhaps with variable speed control, to allow “finer tuning” of the control system. This can sometimes save in excess of 25%.
- Avoiding a “one size fits all” approach to control. Various control settings are left unchanged all year round, despite widely varying operating conditions. A more sophisticated approach provides various low cost opportunities. For example, the suction pressure setting on some systems could be varied to suit cooling demand instead of being left at the “lowest common denominator” value (e.g. a supermarket system could have two suction pressure set points, one for normal operation and a higher setting for night time operation with closed night blinds; another option is a floating suction pressure controller which adapts suction pressure to cooling demand giving savings of 10 to 30%). In cold stores it is common to defrost evaporators with an unchanging timer based regime. The rate of frost build up is probably 4 times greater in summer than in winter – hence a defrost-on-demand control system can provide significant savings.
- As discussed above (Opportunity I4) there are various opportunities to control auxiliaries better such as variable speed control of fans and pumps and demand control for lighting.

Opportunity Category I6: New plant, high efficiency

The best opportunities for improving energy efficiency occur when new plant is being purchased. When the plant is “on the drawing board” various efficiency measures can be built in at no extra cost and other measures can be included with much shorter payback periods than those achieved for a similar technology applied to an existing plant.

For **small systems** there are only a few cost effective measures that can be applied to existing systems, but new plants can be 30% to 80% more efficient. A simple example is a domestic refrigerator. Table 5.2 shows the energy label banding for one size of refrigerator.

Table 5.2: Example of kWh Annual Consumption Bands in an Energy Label

A++	A+	A	B	C	D	E	F	G
<30	<42	<55	<75	<90	<100	<110	<125	>125

Replacing an old E labelled fridge with a new A label will save around 50%. Replacing an E label with an A++ label will save over 70%. This type of “step change” improvement is a one off opportunity for the life of the system – if a low efficiency plant is purchased it will not be possible to improve things until that plant is replaced, perhaps not until 10 or 20 years later.

The level of savings illustrated above applies to many types of small refrigeration system used in small retail, food service and agriculture. Selecting a high efficiency system can provide excellent savings for the life of the system.

For **large systems** in food and drink manufacture, cold storage and supermarkets it is important that new designs are carefully appraised – plant life for large systems is typically in excess of 20 years. During that time period the cost of electricity will rise considerably, hence it is important to consider all aspects of plant design. A 5-step approach to evaluating and purchasing new refrigeration plant should be adopted:

a) Firstly, try to minimise the cooling demand (e.g. use free cooling).

b) For each major load ensure that cooling is carried out at the highest possible temperature (e.g. do not combine loads at different temperatures on a single system).

c) Design the refrigeration cycle and select individual components with high efficiency at all common operating conditions throughout the year (e.g. select compressors with high efficiency at full / part load and at high / low condensing temperature)

d) Design the control system for maximum efficiency (e.g. floating head pressure, good compressor part load performance, VSD fans and pumps etc.)

e) Include energy metering and other key data (e.g. temperature and pressure data) in the specification – it is low cost to add these to a new system and they will help ensure on-going efforts can be made to operate and control the plant at high efficiency (see Opportunity Category I1: maintenance and management).

A comprehensive design review and careful specification of new plant will lead to significant energy savings achieved at a negative cost of CO_2 saved. There are many examples of good design that will reduce energy consumption (and hence create running cost savings) and result in a lower capital cost. Three Case Studies are described in Table 5.3.

Opportunity Category I7: New plant, BAT efficiency

This opportunity category is simply an extension of Category I6 described above. Whilst I6 opportunities can be achieved at negative capital cost (see Table 5.3) or with small extra investments with payback periods below 3 years, this category goes further and includes new plant design opportunities that have payback periods above 3 years. For example: (a) maximising the use of ambient free cooling in a food processing operation or (b) optimising part load performance through use of smaller compressors with variable speed drive control.

Table 5.3 Case Studies of Zero or Negative Cost Design Improvements

Design Opportunity	Description and Benefits
Splitting loads at different temperature levels to avoid "lowest common denominator" systems	Many breweries operate a single temperature level "secondary refrigerant" system, circulating glycol at, say, -5°C to the various cooling loads. A brewery was planning to replace 6 large chillers on an old glycol system and had received a budget quotation of £3 million for the new equipment. However, they realised that a significant part of the cooling load was a summer time requirement to pre-cool incoming brewing water from around 16°C to 6°C. This could be done much more efficiently with a dedicated water chiller instead of a glycol heat exchanger. This improved the efficiency of the refrigeration process by around 30% (because the evaporating temperature of the water chiller was +2°C compared to -7°C for the glycol chiller AND it reduced the overall capital cost by £0.6 million (20%), because the dedicated water chillers were much cheaper than the glycol chillers.
Using doors on retail chill cabinets	Most chilled food in supermarkets is sold via "open vertical display cases". These are relatively inefficient as cold air spills out of the cabinet continually, adding to the cooling demand and also increasing the space heating load in the supermarket. Using display cabinets with doors reduces the cooling load by around 25%, resulting in savings for both cooling and space heating. When this is done on a new system the extra cost of the doors is offset by a reduced cost for the refrigeration system, which can be 25% smaller. Hence a significant energy saving is achieved at zero capital cost. There has been some resistance to the use of doors because retailers are concerned about loss of trade. However, some trials have shown that customers actually prefer to buy products from a cabinet with doors as they believe that product quality may be improved by more consistent cooling.
Increasing the "free cooling" on a regenerative pasteuriser.	Milk pasteurisers require milk to be heated from 4°C to 72°C and then cooled down again to 4°C. Most of the heating and cooling is done in a "regenerative heat exchanger" where the incoming cold milk cools down the outgoing hot milk. A bit of steam heating is applied to bring the milk all the way to the upper temperature and a bit of refrigeration is used to bring the milk back to 4°C. A dairy was about to purchase a new refrigeration system for £250k to cope with increased output and a new pasteuriser. However, they reviewed the design of all existing pasteurisers and realised that these were not optimised to give maximum free cooling. By adding extra plates to the regenerative heat exchangers they could reduce the cooling demand by around 30%. By investing around £50k in their heat exchangers they reduced both heating and cooling demands AND they found they no longer needed to purchase the new refrigeration system.

5.4. Sector Specific Opportunities

Table 5.4 shows the overall emissions from each sector of the food chain (based on data in Table 4.3). This clearly shows that retail is the dominant sector and that the top three sectors represent about 85% of total emissions. As described in Sections 5.2 and 5.3 there are numerous opportunities for emission reductions – especially in relation to energy efficiency opportunities. In this part of the report the opportunities that are most appropriate to different food chain sectors are briefly described.

Table 5.4 Total GHG Emissions from Food Chain Refrigeration, 2010

Sector	Total Emissions (Direct + Indirect) kT CO_2	% of Total Emissions
Retail	6,530	47%
Food and drink manufacture	2,550	19%
Food Service	2,440	18%
Transport	1,430	10%
Cold Storage	510	4%
Agriculture	260	2%
Total	13,720	100%

Retail

The retail sector represents nearly 50% of all food chain emissions and over 60% of direct emissions – reductions in this sector are clearly crucial if significant overall savings are to be made. A significant proportion of these emissions are from large supermarkets, where the most commonly used design is an R404A "centralised pack system". These are large distributed systems serving many retail display cases. In small shops there is widespread use of integral systems and small split systems (with a remote condensing unit serving one or more display cases). The cooling demands in retail are a "holding load" – product is received at the correct temperature and must be kept at that temperature in bulk storage or in retail display cabinets. Life cycle of large systems is typically 15 to 20 years. Life cycle for small systems and display cases used on large systems is typically around 10 years. There are lots of good emission reduction opportunities – many of which are being actively pursued by the major food retailers. The most important opportunities include:

a) Avoiding use of R404A in all new equipment – alternatives with much lower GWP and better energy efficiency are available.

b) Retrofit of existing R404A medium temperature plants with R407A or R407F, saving around 10% of energy consumption and reducing direct emissions by over 50%.

c) Making on-going efforts to reduce leakage from existing systems, focussing on "rogue" plants that have the highest leakage levels.

d) Regular measurement of performance to identify and rectify maintenance or operational efficiency issues.

e) Developing a low GHG emission refrigerant policy for new systems e.g. use of CO_2, HCs or HFC 134a in low leakage designs.

f) Use of doors on chill cabinets.

g) Use of high efficiency auxiliary components e.g. LED lights in display cases, EC fans and fan motors.

h) Selection of high efficiency compressors.

i) Use of sophisticated control strategies to minimise head pressure, maximise suction pressure and provide good part load compressor performance.

j) For integral systems (used mainly in small shops), selection of high efficiency designs when new equipment is purchased.

Food and Drink Manufacture

The manufacturing sector represents 19% of food chain emissions. The sector includes many very large systems e.g. for blast freezers or glycol chillers – these often contain in excess of 500 kg of refrigerant. Food manufacturers also make widespread use of medium sized systems dedicated to specific cooling loads – these will typically contain between 10 and 100 kg of refrigerant. Large parts of the cooling demand are "process loads" where warm product needs to be chilled or frozen. There are also holding loads for cold raw materials and for finished products. A characteristic of this sector is the existence of a lot of HCFC equipment (especially R22) that will be subject to phase out under the Ozone Regulation. Life cycle of equipment is very long – large systems often operate for 25 to 30 years. The most important opportunities include:

a) Cooling load reduction – because of the complex process loads there are often good opportunities for free cooling.

b) Avoiding "lowest common denominator" systems – where several loads exist at different temperature levels these should not be cooled by a single system.

c) Avoiding use of R404A in all new equipment – alternatives with much lower GWP and better energy efficiency are available.

d) For large new plants, use of ammonia or CO_2 in place of HFCs or HCFCs.

e) For small new plants, consideration of low leakage designs.

f) Regular measurement of performance to identify and rectify maintenance or operational efficiency issues.

g) Making on-going efforts to reduce leakage from existing systems.

k) Selection of high efficiency compressors.

h) Use of sophisticated control strategies to minimise head pressure, maximise suction pressure and provide good part load compressor performance.

i) Heat recovery systems to utilise waste heat from refrigeration system to heat hygiene water or other process streams.

j) For systems currently on R22 or other HCFCs, avoiding an increase in emissions when dealing with HCFC phase out via use of a “drop-in” alternative refrigerant.

Food Service

The food service sector represents 18% of food chain emissions. The sector mainly includes small systems including integrals (e.g. drinks coolers, food display cases) and small split systems (e.g. cellar cooling in pubs and small walk-in cold stores). There are limited opportunities for changes to existing systems at the small end of the size range – hence it is crucial that new equipment is carefully selected. The life cycle of equipment is relatively short in this sector (9 to 15 years). Most cooling loads are “holding” of chilled or frozen products. The most important opportunities include:

a) Avoiding use of R404A in all new equipment – alternatives with much lower GWP and better energy efficiency are available.

b) Careful selection of new equipment to ensure maximum efficiency. This is a vital step as it is usually not cost effective to make retrofit improvements to existing plant.

c) Careful location of small systems to maximise efficiency (e.g. ensuring good air circulation to condensers).

d) Use of appropriate control settings to maximise efficiency (e.g. do not set storage temperature lower than is required).

e) Good maintenance e.g. to avoid condenser fouling and evaporator frost problems.

Transport

The transport sector represents 10% of food chain emissions. This is an unusual sector as the refrigeration systems are operated from “on board” power supplies on lorries, containers, rail cars etc. In general, these are small diesel engines that directly drive the on board refrigeration systems (or, in some cases driving an electricity generator which is used to power the refrigeration). Independent diesel engines are always used on medium and large sized systems, to provide cooling when the lorry is stationary and to avoid paying the tax that applies to vehicle fuel. Some small delivery vehicles have a refrigeration system that is driven off the main engine of the vehicle. Many refrigerated trailers can be plugged into a fixed electricity socket while stationary e.g. at a distribution centre. The life cycle of the vehicles themselves is relatively short for large long haul tractor lorries, which may operate up to 100,000 miles per year. Hence a life of 3 to 5 years is common. However, refrigerated trailers pulled by these tractors will have a much longer life of around 10 years.

As with food service there are few opportunities to make improvements to existing transport systems. Purchase of new equipment is crucial to ensure a step change towards best efficiency. The most important opportunities include:

a) Careful selection of new equipment to ensure maximum efficiency. This is a vital step as it is usually not cost effective to make retrofit improvements to existing plant.

b) Ensuring that trailers are purchased with best available level of insulation.

c) Use of appropriate control settings to maximise efficiency (e.g. do not set storage temperature lower than is required).

d) Good maintenance e.g. to avoid condenser fouling and evaporator frost problems.

Cold Storage

The cold storage sector represents 3% of food chain emissions. Most systems in this sector are large industrial systems. Ammonia is commonly used and there is still quite a bit of HCFC 22 in use. The loads are mainly “holding”, although at some cold store sites there are associated blast freezer facilities.

The most important opportunities include:

a) Avoiding “lowest common denominator” systems. In particular, avoid having a cold store and a blast freezer on the same system (as a blast freezer usually needs a much lower evaporating temperature than a cold store). Also avoid putting medium temperature chill storage loads on the low temperature cold store refrigeration circuit.

b) Use of variable speed drives for evaporator fans.

c) Use of automatic doors or docking stations to minimise air ingress into the store.

d) Use of defrost on demand systems for evaporator defrost.

e) Use of high efficiency light sources and good lighting control systems.

f) Regular measurement of performance to identify and rectify maintenance or operational efficiency issues.

g) Use of sophisticated control strategies to minimise head pressure, maximise suction pressure and provide good part load compressor performance.

h) Avoiding use of R404A in all new equipment – alternatives with much lower GWP and better energy efficiency are available.

i) For large new plants, use of ammonia or CO_2 in place of HFCs or HCFCs.

j) For small new plants, consideration of low leakage designs.

l) Selection of high efficiency compressors.

k) For systems currently on R22 or other HCFCs, avoiding an increase in emissions when dealing with HCFC phase out via use of a "drop-in" alternative refrigerant.

Agriculture

The agriculture sector represents 2% of food chain emissions. There are three main refrigeration uses in this sector. The most important by far is on dairy farms which have equipment to cool milk and store it at 4°C prior to dispatch to milk processing factories. Refrigeration is also used during the storage of crops such as potatoes and for rapid removal of "field heat" after harvesting of some fruit and vegetables, prior to dispatch to processing or packaging plants. In all cases there is a process cooling load followed by a chilled storage requirement. Most of the equipment used in these operations in small to medium sized.

The most important opportunities include:

a) For milk cooling, consideration of free cooling with cooling tower or ground water to pre-cool milk prior to the refrigeration unit. For crop storage, optimisation of ventilation systems to maximise the use of free cooling during mild and cold ambient conditions. Free cooling offers the possibility to save a significant proportion of the refrigeration requirement.

b) Improved insulation of milk storage tanks and crop storage buildings and reduced air leakage from crop storage buildings.

c) Careful selection of new equipment to ensure maximum efficiency. This is a vital step as it is usually not cost effective to make retrofit improvements to existing plant.

d) Use of appropriate control settings to maximise efficiency (e.g. do not set storage temperature lower than is required).

e) Good maintenance e.g. to avoid condenser fouling and evaporator frost problems.

f) Avoiding use of R404A in all new equipment – alternatives with much lower GWP and better energy efficiency are available.

g) For new plants, consideration of low leakage designs.

h) Selection of high efficiency compressors.

i) For systems currently on R22 or other HCFCs, avoiding an increase in emissions when dealing with HCFC phase out via use of a "drop-in" alternative refrigerant.

6. Drivers and Barriers

Through the literature review and the Questionnaire Survey the key drivers and barriers to reduction of GHG emissions from refrigeration in the food chain have been identified. These are discussed in this section of the report.

6.1. Drivers

There are strong drivers that can be built on by policy makers to deliver substantial reductions in GHG emissions from food chain refrigeration during the next 10 to 15 years. The drivers fall into 3 categories: financial, regulatory and CSR commitments.

Financial Driver – Indirect Emissions

The main financial driver to reduce indirect emissions is the electricity cost savings that can be achieved by reducing energy usage. As described in Sections 5 there are numerous energy saving opportunities with attractive financial return. The level of financial savings will grow over the next 15 years as the price of electricity rises in response to the Government's electricity decarbonisation objectives.

It is important that future policies maximise the potential of this driver, recognising that the largest and most cost effective opportunities are available when new plant is being purchased.

Financial Driver – Direct Emissions

Currently there is no strong financial driver to reduce direct emissions. If the "embodied value of carbon" in high GWP HFC refrigerants was included in the refrigerant price this would provide a very powerful financial driver. Table 6.1 shows the typical cost of a range of refrigerants, together with the embodied carbon value. Two CO_2 prices have been used for these calculations – the lower cost is the current "traded emissions" CO_2 price and the higher price is the "non-traded" CO_2 price (see Section 4.4). The data shows that the value of embodied CO_2 is much higher than the purchase price for HFCs. The costs are especially high for R404A. The attractiveness of using ammonia in large systems is clear in terms of both fluid purchase price and value of embodied CO_2.

Table 6.1 Cost of Embedded CO_2 in Refrigerants (Hidden costs)

Refrigerant	GWP	Typical fluid price £ per kg	Value of Embedded CO_2 £/kg	
			£14 / tonne CO_2	£52 / tonne CO_2
HFC 404A	3,784	15	53	197
HFC 410A	1,975	15	28	103
HFC 134a	1,300	10	18	68
HFO 1234yf	5	50	0.07	0.26
Ammonia	0	2	0	0

Regulatory Drivers – Indirect Emissions

The majority of food manufacturing and cold storage sites are covered by a Climate Change Agreement (CCA), and receive a discount on the Climate Change Levy (CCL), a tax collected via energy bills if they meet emissions reduction targets. CCAs have been extended by Treasury to 2023. The CCA energy efficiency targets from 2013 to 2023 are likely to be challenging (they will be negotiated with DECC in 2012) and will act as a strong driver to improve refrigeration plant efficiency.

Large retail and food service companies in the food chain are affected by the new Carbon Reduction Commitment (CRC). The CRC started in April 2010 and is a mandatory emissions trading scheme that aims to deliver energy (and carbon) savings in large, non energy intensive organisations. CRC will provide regulatory pressure to improve refrigeration plant efficiency.

The UK Government's plan to significantly decarbonise the electricity supply should lead to much lower GHG indirect emissions from refrigeration systems by 2030. The decarbonisation process will probably lead to considerably higher electricity prices, which will act as an extra financial driver for efficiency improvements as discussed above.

Regulatory Drivers – Direct Emissions

The EU F Gas Regulation aims to reduce emissions of HFCs, amongst other fluorinated greenhouse gases. It places significant responsibilities on companies that use HFC refrigerants, including record keeping, leak testing and prompt leak repair. The F Gas Regulation is being reviewed by the EC in 2011 and this could lead to tougher regulations to prevent leakage or even to ban the use of HFCs in certain refrigeration applications.

The EU Ozone Regulation is phasing out the use of HCFCs. As shown in the Questionnaire Survey (see Table 3.1) there is still substantial use of HCFCs in food manufacture and cold storage. The use of virgin HCFCs for maintenance of refrigeration plants was banned at the beginning of 2010. By the end of 2014 the use of reclaimed and recycled HCFCs will also be banned. A substantial amount of refrigeration equipment in the food chain will need to be replaced or refilled with an alternative refrigerant by the end of 2014. This represents a both an opportunity and threat to levels of GHG emissions. If replacements are done well they can give benefits of significant reductions in both direct and indirect emissions. However, if existing plants are converted to an alternative refrigerant, there is a risk of higher leakage and increased energy consumption.

The international community is discussing the possibility of an HFC phase down, via the Montreal Protocol process. Current proposals (from North America) suggest a phase down in consumption of HFCs starting in 2014 and falling to only 15% of baseline consumption[13] by 2033. If proposals of this kind go forward there will be a strong regulatory framework that would lead to significant reductions in the use of HFCs in food chain refrigeration.

---

[13] Average annual HFC + HCFC consumption in 2004 to 2006, GWP weighted.

CSR Drivers

Corporate Social Responsibility (CSR) commitments are a key driver for many large companies within the food chain. They wish to show investors and the wider public their commitment to being proactive on climate change; for example, by setting voluntary carbon reduction targets; producing corporate carbon footprint or product carbon footprints; or investing in environmental initiatives to reduce energy use and carbon emissions.

The voluntary initiatives by supermarket companies are highly visible and have very challenging targets. The large supermarkets represent a significant proportion of total GHG emissions from the food chain (nearly 40%), so the challenging CSR targets provide a powerful driver. Supermarkets are proactively trying to reduce their emissions (e.g. through pioneering use of CO_2 as a refrigerant and through comprehensive efforts to reduce energy consumption). Their CSR programmes can also work “up the supply chain” with farms, food manufacturers and transport companies to ensure that the supply chain meets the supermarket’s environmental objectives.

Parts of the manufacturing sector also have visible CSR programmes, such as the Food and Drink Federation’s “5-Fold Plan” which has challenging energy efficiency targets.

6.2. Barriers

There are a number of barriers to reducing GHG emissions due to refrigeration in the food chain, which fall into 4 categories: financial, awareness, technological and commercial.

Financial Barriers

The main financial barriers are the lack of funds for investment and the demand for short payback periods. Also, there is a reluctance to switch to more expensive new technologies. The only programme identified which provides financial incentives for investment in energy efficient refrigeration equipment is the Enhanced Capital Allowance scheme.

Purchase decisions for refrigeration plant, both small and large, are generally not made on life cycle cost or payback considerations. Equipment buyers often select the equipment that meets specifications at the lowest cost.

Lack of Awareness

A key issue is lack of awareness of the best opportunities, amongst end users of refrigeration in the food chain. The Questionnaire Survey showed a relatively low level of in-house refrigeration knowledge (see Figure 3.2) which makes it hard for end users to evaluate emission reduction opportunities. Many rely on refrigeration contractors, who are not always best placed to provide the advice required. As discussed in Section 5.1 there are well in excess of 100 different techniques that could be considered to reduce emissions. This actually creates a barrier for investment as many end users are confused by the range of different opportunities and unable to select those that are most relevant to their circumstances and will give them the most benefit. This problem is exacerbated by the rate of technology change in relation to both refrigerants and energy saving technologies.

Technological Barriers

Substantial technological barriers include shortages of technicians and engineers skilled in producing or maintaining alternative technologies, lack of information on emission reduction opportunities and little UK manufacture of novel refrigeration technologies.

There are a number of factors that influence the choice of refrigerant for new equipment. These include practical and market implications such as cost, global availability of the fluids and system components, and technical familiarity of engineers and technicians. There is some evidence that the reason for the popularity of R404A, even as a replacement for R22, is that refrigeration engineers are familiar with the refrigerant and not with the other alternatives, which have a lower GWP. The cost of retraining engineers to work with other less common alternative refrigerants currently acts as a barrier.

Purchase decisions for refrigeration plant, both small and large, are generally not made on life cycle cost or payback considerations. Frequently, this is due to a lack of expertise and resource needed to assess the energy cost and direct GHG emissions associated with alternative refrigeration plant.

Commercial Barriers

In the food service and small retail sector, energy costs are often small compared to the food products sales revenue. This increases the tendency to disregard energy issues in evaluating sales-boosting design changes such as an increase in lighting intensity.

An important commercial issue in the retail sector is the desire to keep products in easy reach of shoppers – which is why most of chilled display cabinets have no doors. The use of display case doors, particularly for chilled displays, is one of the best opportunities for indirect emission reduction. Some supermarkets are beginning to use more chill cabinet doors – trying to eliminate barriers to the use of this technology should be a key objective.

In some cases, new equipment is purchased when the old equipment fails and there is little or no time to analyse the complex range of competing options. This leads to a preference for established technologies and is a barrier to the speed of uptake of more recent technologies with lower GWP refrigerants or better efficiency.

The food service sector has a number of specific barriers related to the fragmented ownership structure of the sector. Food service seems especially constrained by lack of funds for investment, sometimes a result of separate owners and operators and a high rate of business failure in the profit sector. Also, there is no trade body that represents a significant proportion of the sector which makes it more difficult to involve food service companies in a coordinated programme to reduce CO_2 emissions.

7. Emission Reduction Potential

7.1. Introduction to Emission Reduction Opportunities

Current Emissions

In Section 4, data is presented about the GHG emissions from each part of the food chain, including a split between sectors and a split between direct and indirect emissions. Total GHG emissions from food chain refrigeration are 13,700 kT CO_2. Direct emissions of refrigerant account for 35% of these emissions, with indirect energy related emissions accounting for 65%.

Emission Reduction Categories

The numerous measures available for emission reduction have been described in Section 5. The literature review led to the identification of well over 100 emission reduction opportunities. The importance of categorisation of opportunities was stressed – without a categorisation process it is very difficult for refrigeration users to decide which opportunities apply to them and which provide the greatest emission reduction potential and cost effectiveness. Emission reduction opportunities in 12 different categories are described in Section 5.2 and 5.3. This includes 5 categories of measures to reduce direct emissions and 7 categories of measures to reduce indirect emissions, as summarised in Table 5.1.

Variable Cost Effectiveness

The large number of possible emission reduction measures makes analysis of the overall potential for emissions reduction very challenging. It is not only necessary to account for many different measures, but also recognise that the cost effectiveness of each measure can vary considerably depending on the specific size and use pattern of a piece of refrigeration equipment. An obvious example of this is that an energy efficiency measure that is cost effective on a plant running continuously (8,760 hours per year) will be much less cost effective on a plant that only runs, say, 4,000 hours per year. This is because the capital cost is the same in both circumstances, but the energy saving varies with operating hours.

Distinguishing Between Existing and New Systems

In Section 5 it was explained that the emission reduction opportunities are always larger and more cost effective when new refrigeration plant is being purchased. There are numerous reasonably cost effective opportunities that can be “retrofitted” to many types of refrigeration system, but there are also a number of constraints that prevent the maximum benefit being achieved in the retrofit situation. For example, if an old HFC plant is being replaced with new, a high GWP refrigerant such as R404A can be replaced by a zero or very low GWP option such as ammonia, resulting in a 100% reduction of direct emissions. In a retrofit situation it is impossible to use ammonia, so the potential for direct emission reduction is much more limited.

Distinguishing Between Large and Small Systems

It is also important to recognise that different opportunities apply to plants of different size and different design configuration. For example, the opportunity to use ammonia in place of R404A applies to large industrial systems but is not feasible for small and medium sized systems because of safety and cost related issues.

For most small systems (e.g. used in food service, small retail shops, road transport) there are relatively few opportunities that reduce emissions from existing plants. The crucial opportunity to reduce emissions from small systems is when new equipment is being purchased. For medium and large sized systems there are many more opportunities that can be retrofitted to existing systems in a cost effective way.

Distinguishing Between Technology-dependant and Sector-dependant Opportunities

Many of the available opportunities are "technology-dependant". That means that they are applicable to a given type of refrigeration technology, irrespective of the food chain sector. For example, reducing the condensing temperature of a system will achieve savings in all sectors. However, there are certain opportunities that are "sector-dependant". This means that they are only applicable to specific sectors of the food chain. For example, free cooling opportunities are only applicable to certain processing operations and improved design of food display cases is only applicable to food retail.

7.2. Modelling of Emission Reductions

A detailed analysis of emission reduction potential was carried out, taking into account the various opportunities described in Section 5 and the complexities described in Section 7.1. The analysis included:

- A "Bottom-Up" assessment that provides an overall assessment of the total GHG emission reduction potential for the whole food chain and for individual sectors.
- A "Top-Down" assessment that provides a projection of the rate of emission reduction over the next 25 years.

Bottom-Up Assessment

The bottom-up assessment was carried out with a complex spreadsheet model that includes the following steps:

a) Identification of the types of refrigeration technology used in each food chain sector (e.g. small integral equipment, large industrial equipment etc.). 15 equipment categories were used and these were split into sub-categories to describe the refrigerants being used (e.g. HCFCs, high GWP HFCs etc.).

b) Mapping of the sector level direct and indirect emissions (as described in Section 4) into the various equipment types.

c) Identification of the key emission reduction opportunities. Mapping of these by equipment type (for technology dependant measures) or by sector (for sector dependant measures). Assessment of average levels of emission reduction and payback period for each measure.

d) Assessment of mutual exclusivity between measures.

e) Assessment of adjustment factors for the applicability of each opportunity within each of the food chain sectors.

f) Assessment of adjustment factors for current market penetration and remaining potential.

g) Calculation of emissions savings[14] and cost effectiveness of individual measures, measures by equipment type and sector.

h) Calculation of overall potential on a sector basis.

i) Preparation of MACCs (Marginal Abatement Cost Curves).

It is important to note that the literature review (Section 2) provided little “hard data” on some of the required parameters (such as market penetration or capital cost data). Some better data was researched during the project (e.g. via the Questionnaire Survey described in Section 3) and the rest was estimated using expert judgement. It may be worthwhile doing further research to improve some of the input data. Despite the lack of certain input data, the bottom-up model provides an excellent platform for analysis of the overall saving potential. In particular, the model can be used to carry out sensitivity analysis (by varying various input assumptions) and scenario analysis (by assessing the benefits of mutually exclusive options).

A powerful feature of the bottom-up model is a set of filters that allow the output data to be presented in a number of different ways. These filters include:

- Food Chain Sectors – the assessment can be done for the whole food chain or individual sectors within the food chain.
- Retrofit / New – this splits the analysis of retrofit projects from plant replacement opportunities.
- Direct / Indirect – this splits the opportunities for direct and indirect emission reductions.
- Technology – this gives an assessment for the 15 equipment types in the model.

Outputs from the bottom-up model are given below in Section 7.3.

It is important to note that while the abatement potential shown on the MACCs is correct for each individual opportunity, there is some loss of accuracy when considering the total potential available from a number of opportunities. This is because a MACC does not take into account the effect the implementation of one opportunity will have on the potential savings for any other opportunities. Therefore the overall abatement potential shown on the

[14] Indirect emission reductions were calculated using the marginal electricity emissions factor for 2010 from ‘Valuation of energy use and greenhouse gas emissions for appraisal and evaluation – June 2010’ by DECC. This factor is 0.3939 $kgCO_2/kWh$

x-axis of the following MACCs is only an approximation which will always be higher than the actual total potential.

Top-Down Assessment

The top-down assessment uses outputs from the bottom-up model and other input data to provide a time based projection of emission reduction potential. It combines the likely take up of retrofit opportunities with a cycle of plant replacement over the next 25 years. The top-down model includes the following steps:

a) Use of data from the bottom-up model to estimate the overall potential for retrofit and new plant savings in each food chain sector.

b) Assessment of typical plant lifetime for different technology types.

c) Estimate of the rate of uptake of retrofit opportunities.

d) Assessment of 2nd and 3rd generation new plant opportunities (it is believed that new opportunities will emerge over the next 25 years that will improve the "new plant potential" during that timeframe.

e) Calculation of overall emission reduction projection over a 25 year period[15].

As with the bottom-up assessment, the literature review did not provide all the data required for the top-down model, but the outputs remain very useful for policy development. The outputs can be presented for the whole food chain or can be split by food chain sector or refrigeration technology type. Separate projections are made for direct and indirect emission reductions.

We have calculated two sets of projections for indirect emissions. The first has been calculated using the average and marginal electricity emissions factor for 2010 for all years to 2035 i.e. constant emission factors. Therefore the projected emission reductions will be conservative, since we anticipate very significant decarbonisation of the electricity sector over the next 25 years. The second set of projections has been calculated using the average and marginal electricity emissions factor for the relevant year i.e. variable emission factors. These take into account the expected decarbonisation of the electricity sector over the next 25 years.

Outputs from the top-down model are given below in Section 7.3.

---

[15] Indirect emissions for the period 2010 to 2035 were calculated using two methods. Firstly, using the average and marginal electricity emissions factor for 2010 from 'Valuation of energy use and greenhouse gas emissions for appraisal and evaluation – June 2010' by DECC for all years. The average factor used was 0.4795 $kgCO_2$/kWh and the marginal factor used was 0.3939 $kgCO_2$/kWh. Secondly, the indirect emissions were calculated using the average and marginal electricity emissions factor for the relevant year, again from 'Valuation of energy use and greenhouse gas emissions for appraisal and evaluation – June 2010' by DECC.

7.3. Outputs from Emission Reduction Modelling

Direct Emissions

Direct emissions from food chain refrigeration are likely to fall significantly during the next 25 years. As discussed in Section 6 there are strong regulatory drivers (especially the F Gas Regulation and possible phase down via the Montreal Protocol) and strong CSR drivers (especially in supermarket companies) to reduce direct emissions. The modelling shows that current direct emissions (4,790 kT CO_2) can be cut by at least 75% by 2035 and possibly by over 90%.

The costs and timescale of achieving significant reductions in direct emissions are uncertain because there is currently a rapid development of various very low GWP refrigerants (e.g. CO_2 and HFOs) – as these technologies are very "immature" it is hard to predict costs and performance in 5 to 10 years time. If the recently announced HFOs (e.g. R1234yf) prove technically and commercially successful, then the 90% emission reduction is achievable at an average cost effectiveness well below £25 per tonne CO_2.

Figure 7.1 shows the marginal abatement cost curve (MACC) for direct savings achieved via retrofittable improvements to existing systems. The x-axis shows the extent of emission reduction in kT CO_2 per year and the y-axis shows the cost of achieving reductions for various measures, in £ per tonne CO_2 avoided.

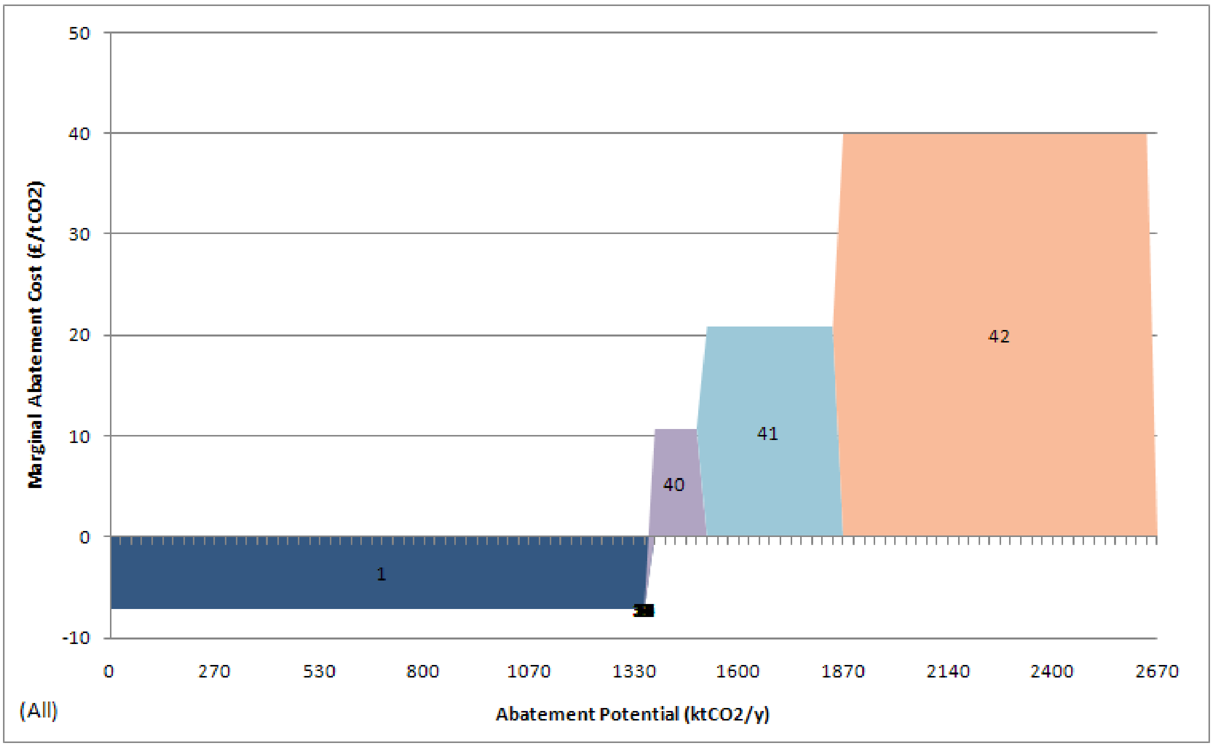
Savings of nearly 50% can be achieved on existing equipment via the 4 measures included in Figure 7.1. Over half the retrofittable savings can be achieved with a negative marginal cost, through retrofit of systems that currently use R404A with an alternative such as R407F or R407A. These alternatives have about half the GWP and they can deliver better energy efficiency. The efficiency improvement provides a financial saving, hence the low carbon cost.

Figure 7.2 shows the marginal abatement cost curve (MACC) for direct savings achieved via use of alternative refrigerants or improved designs for new systems. The overall saving potential is around 75% of current emissions. In this example it has been assumed that the cost of CO_2 systems will fall over the next 5 years (as experience is developed and components become more readily available). It has also been assumed that HFOs and HFO blends do not take a significant market share – this is a conservative assumption as HFOs are in such an early state of development. If HFOs become a proven technology there would be 3 impacts on the situation described in Figure 7.2:

- The overall emission reduction could rise from 75% to around 90% because HFOs could replace HFCs in small and medium sized systems.
- The balance between CO_2 (opportunity 41) and HFOs (opportunity 39) would swing significantly towards HFOs.
- The overall cost impact could be lower, because HFOs would be an alternative to CO_2 in many circumstances – this may cost around £10 per tonne CO_2 saved compared to CO_2 costing around £35 per tonne CO_2 saved.

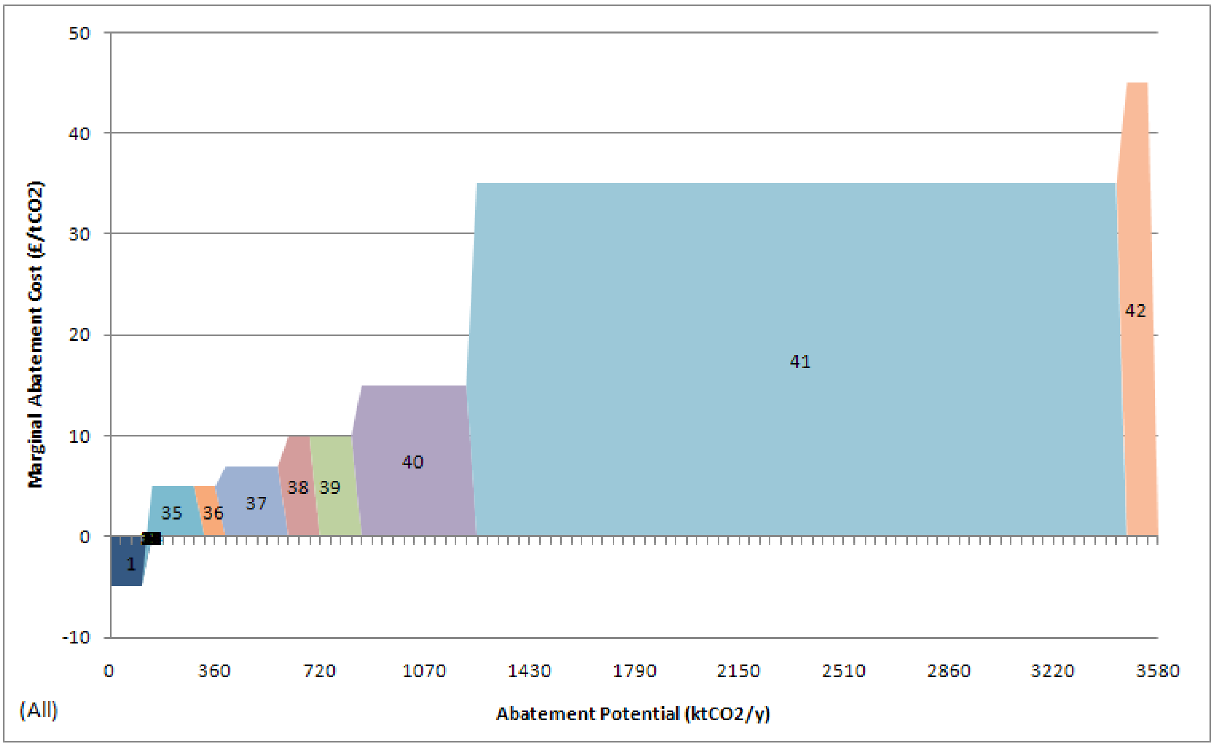
Figure 7.3 provides the results of the "top-down" direct emissions projection over the next 25 years. The projections combine the uptake of retrofittable emission reduction measures with the adoption of "new plant" measures as plant is replaced at the end of its lifecycle. The "realistic" scenario assumes a slow uptake of CO_2 and HFO technologies in 1st generation new systems, whilst the BAT scenario assumes that these technologies are dominant in 1st generation replacements.

Figure 7.1: MACC for Retrofit Direct Emission Reductions, Whole Food Chain



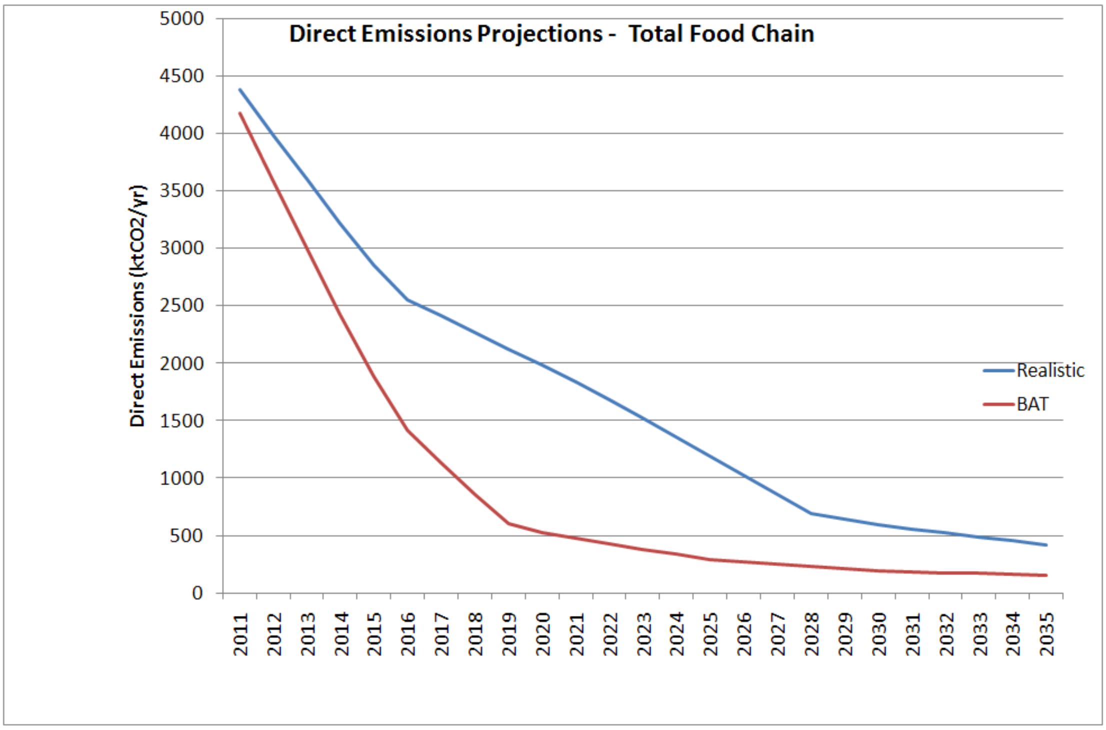
Key measures: 1 = Retrofit of R404A with medium GWP alternative; 40 = compliance with F Gas Regulation, 41 = management / maintenance beyond F Gas Regulation requirements; 42 = investments to reduce leakage.

Figure 7.2: MACC for New System Direct Emission Reductions, Whole Food Chain



Key measures: 1 = Use of medium GWP alternative in place of R404A; 35 = leak tight HFC design, 36 - 39 = use of HCs, HFOs and HFO blends; 40 = use of ammonia; 41 = use of CO_2 in large systems; 41 = use of CO_2 in small systems.

Figure 7.3: Projection for Direct Emission Reductions, Whole Food Chain

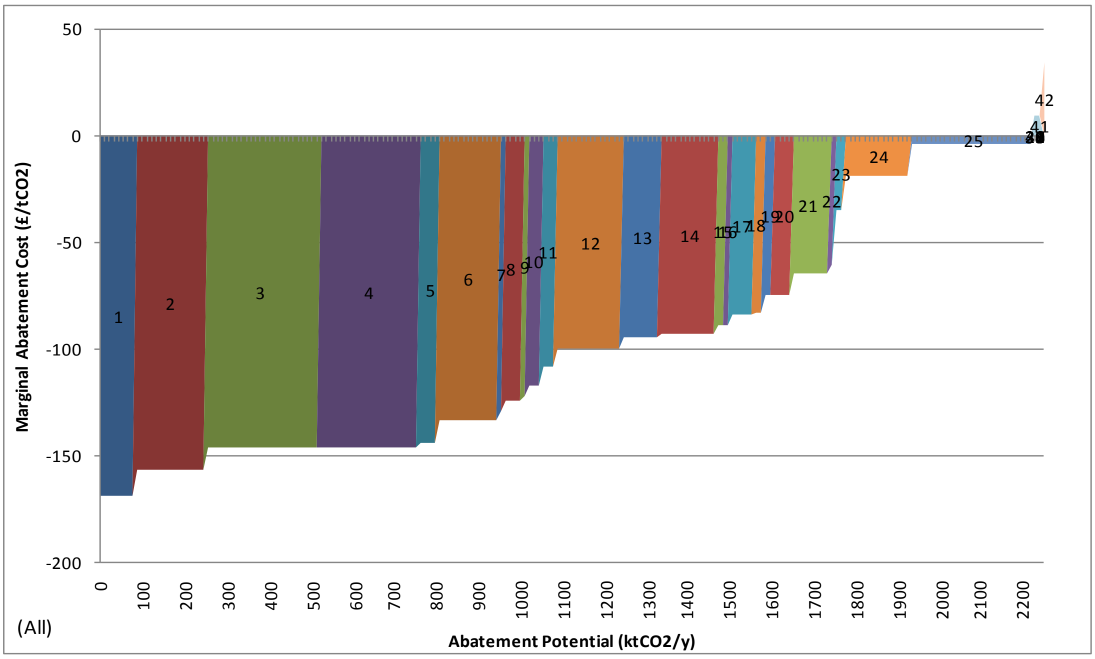


Indirect Emissions

Indirect emissions from food chain refrigeration are also likely to fall during the next 25 years, albeit that the saving potential is not as dramatic as that available for direct emissions. As discussed in Section 6 there are reasonably strong drivers towards reduced indirect emissions – in particular, high electricity prices, regulatory pressure via CCAs and the CRC plus voluntary efforts through CSR programmes. The modelling shows that current indirect emissions (8,900 kT CO_2) can be cut by 35% by 2035 and possibly by up to 80% if the expected decarbonisation of the electricity sector is taken into account. The majority of opportunities can be implemented with negative carbon costs due to the value of energy being saved.

Figure 7.4 shows a MACC for the indirect savings that can be retrofitted to existing systems. Savings of up to 25% can be achieved at negative carbon costs. As shown in the figure, the total saving is made up by the implementation of many different measures. Some of these are technology dependant (e.g. opportunity 2, lowering of head pressure control setting) whilst others are sector dependant (e.g. opportunity 13, free cooling).

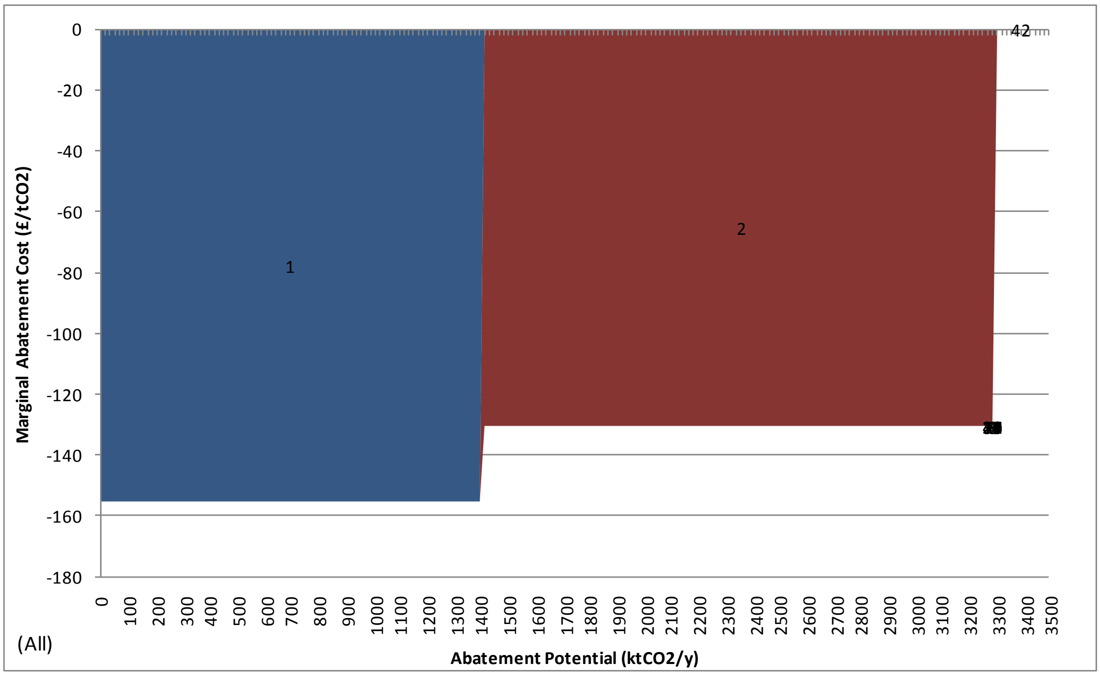
Figure 7.4: MACC for Retrofit Indirect Emission Reductions, Whole Food Chain



Example measures: 1 = Condenser fans; 2 = Head pressure control; 3 = Set point control; 4 = Improved maintenance; 5 = Cabinet anti-sweat heaters; 6 = Suction pressure control; 7 = Cabinet night blinds; 8 = M&T; 9 = Door curtains; 10 = Electronic expansion valves; 11 = Defrost controls; 12 = High efficiency motors; 13 = Free cooling; 14 = Variable speed drives

Figure 7.5 shows the MACC for indirect savings in new systems. This MACC is simplified, to consider the implementation of 2 types of new system. It is assumed that a proportion of the market makes "standard" improvements, whilst others make extra investments to achieve a BAT level of saving. In both cases these improvements are being achieved at a negative carbon cost.

Figure 7.5: MACC for New System Indirect Emission Reductions, Whole Food Chain



Key measures: 1 = Replace with new (Standard); 2 = Replace with new (BAT).

Figure 7.6: Projection for Indirect Emission Reductions, Whole Food Chain

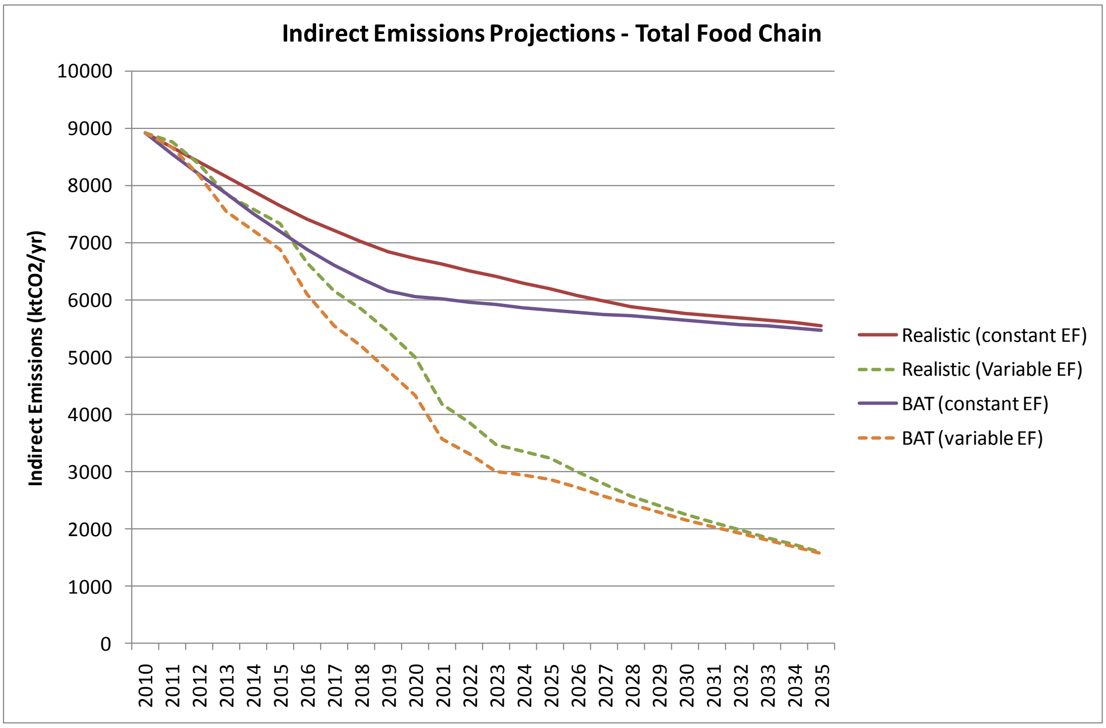


Figure 7.6 gives a projection of indirect savings to 2035 based on two scenarios:

- Constant electricity emissions factors over the whole period (using 2010 figures)
- Variable electricity emissions factors, using projected factors for the years up to 2035.

Combined Direct and Indirect MACCs

Figure 7.7: MACC for Retrofit Direct + Indirect Emission Reductions, Whole Food Chain

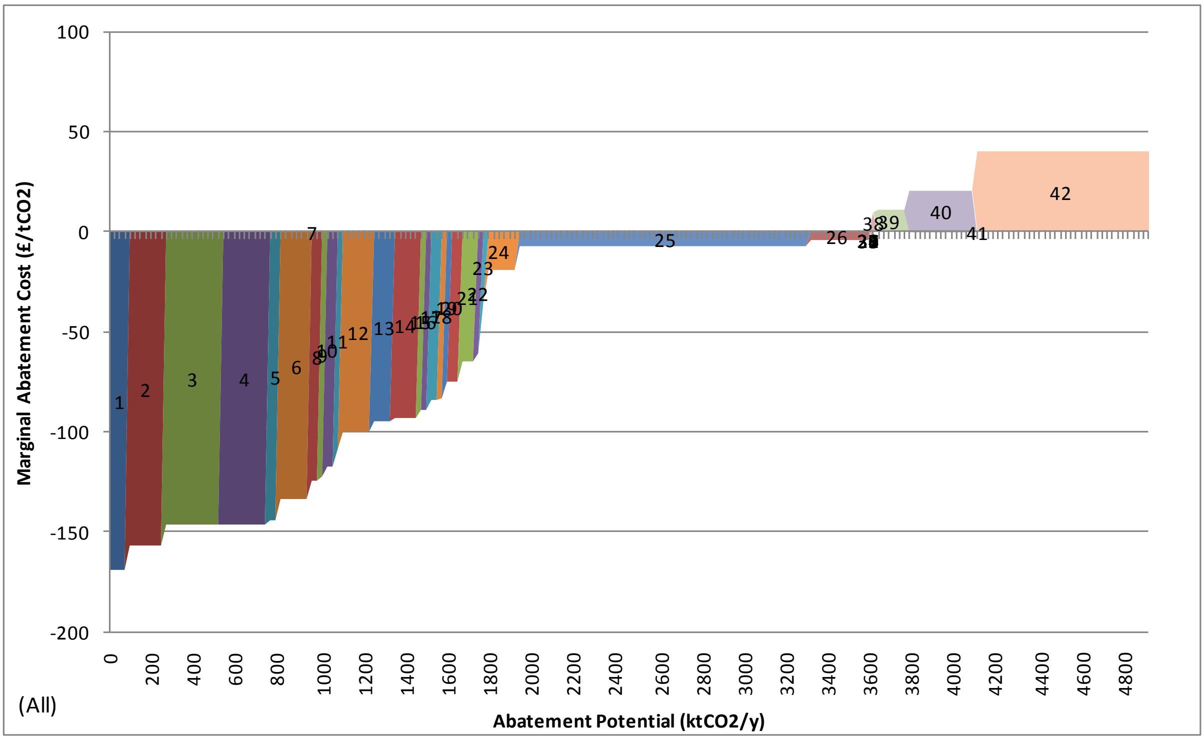
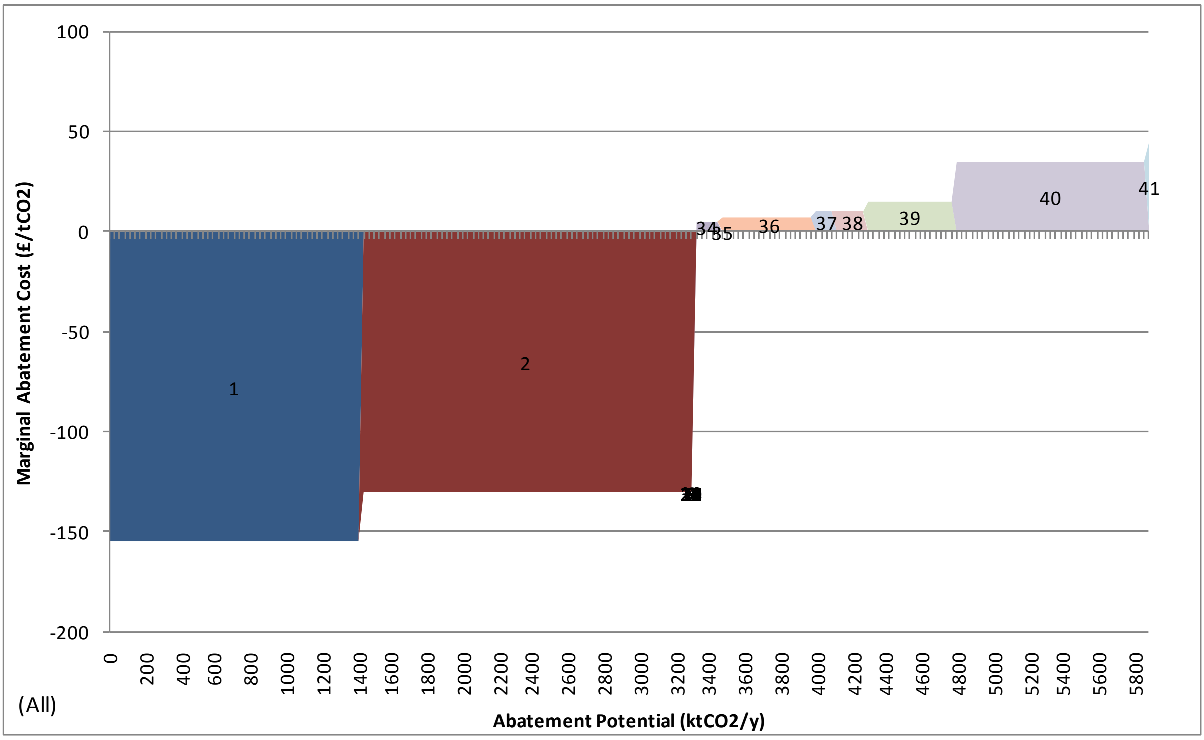


Figure 7.8: MACC for New System Direct + Indirect Emission Reductions, Whole Food Chain



8. Conclusions and Potential Actions

8.1. Study Conclusions

Quantification of Emissions

The work in this project has helped to quantify the direct and indirect emissions from food chain refrigeration. Total emissions are estimated to be 13,700 kT CO_2. 65% of emissions are related to energy use and 35% to direct refrigerant emissions.

There is a lack of detailed evidence about direct emissions in food chain market sectors and, in particular, about emissions from HCFCs that are not assessed in recent UK inventories. This limits the overall accuracy of the emissions estimates, although does not affect the valuable nature of the estimates in relation to defining future polices in this area.

Understanding Refrigerant Usage

The questionnaire survey has provided a very useful picture of refrigerants used in food and drink manufacturing and in cold storage.

The results (see Table 3.1) show that R22 is still in widespread use. This is a considerable concern as R22 and other HCFCs are being phased out under the EU Ozone Regulation.

R404A is the most popular of the HFC refrigerants and represents about 80% of GHG emissions from HFC refrigerants in the food chain. R404A has a very high GWP (3,922) – over twice as high as many other HFCs used in food chain refrigeration.

Ammonia is widely used on very large systems in manufacturing and cold storage. This shows it is a cost effective alternative for very large plants, although it is less cost effective on medium and small sized systems.

CO_2 is being used quite widely on new supermarket systems. Currently there are only a few CO_2 applications outside this sector, mostly in manufacturing and cold storage.

HFOs are being introduced in response to the EU MAC Directive (which bans refrigerants with a GWP above 150 for car air-conditioning). These have a very low GWP (~5). HFOs are not yet commercially available for food chain refrigeration applications, but could become an important option from 2015 onwards.

Opportunities for Emission Reduction

The research shows there are numerous opportunities to reduce both direct and indirect emissions in a reasonably cost effective way.

The modelling shows that current direct emissions (4,790 kT CO_2) can be cut by at least 75% by 2035 and possibly by over 90%, at an average cost effectiveness below £25 per tonne CO_2 saved. Current indirect emissions (8,900 kT CO_2) can be can be cut by 35% by 2035 and possibly by up to 80% if the expected decarbonisation of the electricity sector is taken into account. The majority of opportunities can be implemented with negative carbon costs due to the value of energy being saved.

Understanding emission reduction potential is shown to be very complex because of the large number of different opportunities and the sensitivity to site-specific circumstances. Some key factors that must be taken into account include:

- Variable cost effectiveness depending on site circumstances (e.g. operating hours).
- Different level of opportunity for existing plants and old plant being replaced with new.
- Better retrofittable opportunities on larger systems.
- Some opportunities are sector specific (e.g. free cooling).

Drivers

There is a very strong financial driver to reduce indirect emissions because of the high price of electricity and the availability of saving measures with short payback periods.

There is no equivalent financial driver for direct emissions as the cost of the embodied carbon is an “externality” and is not included in the price of refrigerants. Inclusion of this external cost would provide a strong price signal that would stimulate reduction of direct emissions.

There are strong regulatory drivers to reduce emissions. The F Gas Regulation is leading to reduced direct emissions. Climate Change Agreements and the Carbon Reduction Commitment stimulate energy savings in many parts of the food chain.

Voluntary CSR initiatives are stimulating emission reductions especially in large food retail companies and some manufacturing companies.

Barriers

Lack of investment capital and a requirement to achieve very high rates of return on emission reduction investments are key barriers.

Lack of awareness of key opportunities and lack of in-house expertise is also preventing more progress. This is exacerbated by rapid changes in technology (especially in relation to new refrigerants) and a lack of independently verified information about the cost effectiveness of individual measures.

The questionnaire survey showed that only a small proportion of industrial sites (27%) have any sub-metering for their refrigeration systems. This was despite the fact that refrigeration represented 42% of the electricity bill for these sites. This illustrates a key barrier related to an apparent lack of awareness and lack of interest in improving refrigeration system performance.

8.2. Potential Actions

It is clear that there is good potential to achieve significant emission reductions from food chain refrigeration. This potential will not be achieved unless some of the key barriers are overcome. It is suggested that Defra consider some of the following actions:

Direct Emission Reduction

1) **Efforts should be made to reduce the amount of R404A going into new systems and being used in existing systems.** End users need more information about the benefits of avoiding R404A. Detailed information about benefits of alternative refrigerants would be very helpful. This should clearly distinguish between the alternatives available for new plants and the alternatives that can be retrofilled into existing plants. Case Study material illustrating options, benefits and costs should be prepared and disseminated. This should include examples that can be targeted at specific end use sectors, especially (a) supermarkets, (b) manufacturing, (c) cold storage and (d) food service.

2) **Information about the performance of CO_2 systems should be collated and disseminated.** Whilst a number of supermarket companies have installed CO_2 systems, there is little independently verified data available about the energy efficiency of these new systems or about the practical difficulties encountered and overcome. If supermarkets are willing to provide data, it would be very useful to carry out an independent investigation of performance. The results can be used to help encourage greater uptake of CO_2 and to ensure that practical lessons about system and component design issues are shared.

3) **Consider how embodied carbon costs can be internalised.** Table 6.1 clearly illustrates the embodied cost of carbon in HFC refrigerants is far higher than the cost of the refrigerant itself. Internalising this cost would provide a powerful financial driver for emission reductions.

4) **Build on the successes of the F Gas Regulation.** The F Gas Regulation is beginning to have a significant impact on use of refrigerants and leakage reduction. The training requirements (for improved technician training) come fully into effect in July 2011. The contractor workforce is now much more aware of leakage issues than they were a few years ago. End users are becoming more aware of their obligations. It is worth considering how food chain refrigeration users can be encouraged to “go beyond” the F Gas Regulation and make every effort to reduce direct emissions. Case study material about initiatives to find and repair leaks and to make investments to reduce leakage would be beneficial.

5) **Guidance for buying new refrigeration equipment with low direct emissions.** It has been stressed several times in this report that the best time to make emission reduction investments is when old equipment reaches the end of its life and it is being replaced. Some detailed guidance about options to minimise direct emissions would be very helpful. This should be tailored to specific sectors of the food chain for ease of use and

dissemination. It could include information of low leakage design and relevant alternative refrigerants.

6) **Tracking development of HFOs and other new refrigerants.** The modelling showed direct emission reduction potential between 75% and 90% by 2035. Achieving the higher level of improvement is dependent on the availability of suitable new refrigerants to replace HFCs in small and medium systems. Very small systems can use HCs and very large systems can use ammonia – these alternatives are cost effective as they are already in widespread use. At mid-sizes HFCs remain the most cost effective option at the moment. As CO_2 technology matures it may fill some of the gap and if HFOs prove suitable they will probably have an important role. It is important that Defra keep track of the rapid developments in the refrigerants market.

7) **Guidance related to R22 phase out.** The use of R22 is still widespread, especially in food manufacture and cold storage. There is a danger that a low cost conversion of an existing to an alternative refrigerant could lead to increased leak rates and reduced energy efficiency. Guidance and case study material could help end users avoid this backwards step.

Indirect Emission Reduction

8) **Guidance for buying new refrigeration equipment with low indirect emissions.** As with direct emissions (see point 5) the best opportunity for reducing indirect emissions is when new plant is being purchased. Guidance on plant purchase aimed at individual sectors of the food chain could help end users make the step change in energy efficiency that is available. The European Commission intends to extend the mandatory energy and environmental labelling to a wider range of products, including some commercial refrigeration equipment. This will provide valuable guidance for the equipment types to be covered, but will not address other types, such as industrial plant.

9) **Consideration of minimum efficiency standards for new systems.** End users buying new refrigeration equipment do not have to comply with any efficiency standards. Through complacency or lack of awareness this often means that new systems of relatively low efficiency are being purchased. This is a significant concern:

   - for small systems there are few retrofittable improvement opportunities, so purchase of an inefficient plant cannot be corrected until the plant is replaced, say 10 to 15 years later;
   - for large systems the lifecycle is much longer (20 to 30 years) and a number of good efficiency opportunities are only cost effective when a new system is being purchased.

   It is worth considering a mechanism that could prevent this happening. The Building Regulations impose minimum efficiency standards in various ways – a similar approach applied to new refrigeration systems could be investigated.

10) **Energy Labels for new small systems.** For small refrigeration systems such as those used widely in food service, it may be possible to improve efficiency standards via an energy labelling scheme. The energy label values illustrated in Table 5.2 show the enormous variation between best and worst performing new equipment.

11) **More sophisticated performance information for new large systems.** For large equipment it would be beneficial if end users were given detailed performance information about a new plant, showing an estimate of annual performance that takes seasonal weather variations and likely cooling load variations into account. A step towards this would be to prepare some example material that illustrates this approach.

12) **Guidance on opportunities for existing plants.** In food chain sectors that use large equipment (especially manufacture, cold storage and supermarkets) there are numerous good opportunities that can be implemented on existing plants. As described in Sections 5 and 6 there is a lack of awareness about the best opportunities and some reluctance to make investments. Detailed guidance aimed at these sectors could be of value.

13) **Encouraging use of better metering.** The questionnaire survey showed how little electricity sub-metering is used on refrigeration systems. Without good data it is impossible for end users to ensure that their refrigeration systems are working at maximum efficiency. A programme to encourage greater use of both kWh sub-metering and other relevant metering (e.g. of temperature and pressure in the refrigeration system) would be very beneficial. It would need to include guidance on what to do with the data as many end users would not have the knowledge of how to run a refrigeration system monitoring and efficiency improvement programme.

Appendix 3 – Confidence Level of Data

Direct Emissions

Sector	Confidence indicator for HFC data	Confidence indicator for HCFC data
Agriculture		
Food & drink manufacture		
Cold Storage		
Transport		
Retail		
Food Service		

Indirect Emissions

Sector	Confidence indicator
Agriculture	
Food & drink manufacture	
Cold Storage	
Transport	
Retail	
Food Service	

Key

Low

Medium

High