Frost Bitten: an exploration of refrigeration dependence in the UK food chain and its implications for climate policy

Tara Garnett and Tim Jackson, Food Climate Research Network, Centre for Environmental Strategy, University of Surrey

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Abstract

This paper reports on an in-depth study of refrigeration in the UK food chain. It identifies the greenhouse gas impacts of the 'cold chain' and discusses some of the technological options for reducing these. The main thrust of the paper is to explore the social, technological and economic factors which have given rise to what must now be regarded as a potentially problematic 'refrigeration dependence' in the food chain. We explore the historical roots of this dependency and discuss some of its key features. In particular we show how interactions between refrigeration technologies, packaging, transport, food product innovations and marketing have combined to help create cultural norms and practices which are now highly energy-dependent. Reversing this trend is likely to be far from easy. While energy efficiency measures and novel technologies are essential, they do not tackle the underlying structural need for refrigeration – the kinds of foods we eat and the way we manage our lives that renders refrigeration essential. 'Defrosting' our increasing addiction to the cold chain is likely to require significant changes in where and how we grow and transport food, in where and how we shop for it, and in how and when we cook it. We highlight in particular the potential to reduce refrigeration needs along the supply chain by reducing meat and dairy consumption, by more frequent local shopping, and by a shift towards 'robust' seasonal foods.

1. Introduction

Today's food system is built upon refrigeration. Temperature control is a feature of almost every stage in the supply chain.

This paper looks at the contribution that food refrigeration makes to the UK's greenhouse gas (GHG) emissions, at how our reliance on refrigeration has come about, and at what the consequences might be as regards future consumption trends and associated emissions. Specifically we explore the relationship between technological development and societal changes, and at how they have together fostered behavioural norms that are predicated upon the existence of refrigeration.

This paper addresses too how we might be able to reduce refrigeration-related GHG emissions both by improving the greenhouse gas efficiency of the equipment itself and, as a culture, by reducing our dependence on the cold chain.

In pursuit of these aims, the next section summarises briefly the contribution of food refrigeration to greenhouse gas emissions in the UK, while Section 3 examines the scope for reducing those emissions through broadly technological means. A part of our aim in the paper is to situate the current reliance on the cold chain in a historical context and we pursue this aim in Section 4 of the paper, while Section 5 draws out some of the key factors which have shaped our current refrigeration dependence. Sections 6 and 7 address two specific issues – food waste and food safety – which are now intimately related to the cold chain. Section 8 sketches out some of the key elements in a less refrigeration-dependent food chain.

The analysis in this paper summarises the findings from a major study on food refrigeration undertaken during 2006/7.[1] The study itself draws upon a number of sources. These include published literature, close and ongoing communication with the food and refrigeration industries and on the outcomes of a one day working seminar involving representatives from government, industry, non governmental organisations and research institutions, organised to explore some of the issues that are presented in the following sections.[2]

2. Food refrigeration and its contribution to greenhouse gas emissions

Refrigeration creates greenhouse gases both because of the energy used to operate the equipment and because of the inherent global warming potential (GWP) of the refrigerant gases most commonly used.

It is hard to quantify precisely what contribution refrigeration makes to the UK's greenhouse gas emissions since the number of enterprises that use refrigerated equipment and the size and efficiency of this equipment varies very widely indeed. Roughly speaking however, we estimate that food related refrigeration contributes about 3-3.5% of the UK's greenhouse gas emissions.

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[1] Garnett T. (2007). *Food refrigeration: What is the contribution to greenhouse gas emissions and how might emissions be reduced*? A working paper produced as part of the Food Climate Research Network, Centre for Environmental Strategy, University of Surrey.

[2] Presentations are available at http://www.fcrn.org.uk/frcnresearch/seminars/refrigeration/index.htm

Data for energy use in regrigeration are available for the food manufacturing, retailing and domestic stages of the supply chain. These total about 2.4% of UK greenhouse gas emissions, and sources for this calculation are detailed in Table One.

Table 1: Emissions associated with food refrigeration life cycle stages

Refrigeration life cycle stage	**Carbon emissions million tonnes**	**Contribution to UK greenhouse gas emissions total of 179 MTCe %**	**Source**
Manufacturing stage	0.28	0.18	Estimates based on data provided by Enviros, managers of the UK food sector's Climate Change Agreements
Food retail & catering	1.46	0.97	Market Transformation Programme pers. comm Nov 2005
Domestic	1.9	1.24	*Sustainable Products 2006: Policy Analysis and Projections*, Market Transformation Programme, July 2006
Mobile refrigeration	unknown	unknown	
UK total	**3.64**	**2.39**	

Note: These figures are for energy related emissions only and do not include the global warming impacts resulting from the leakage of refrigerants. It is assumed here that these increase total GHG emissions by around 15%.[3] The non-CO_2 greenhouse gases account, in the national inventory, for around 15% of the UK's total greenhouse gas emissions. Hence we assume here that the contribution of refrigeration to total greenhouse gas emissions is the same as the CO_2 contribution of refrigeration to the UK CO_2 total

An additional half to one percent might easily be added on to take into account the hidden 'embedded' energy of foods (such as meat, fruit and vegetables) that are grown or manufactured abroad and imported, together with the additional energy and unquantified energy used by mobile refrigeration units while food is being transported within the UK.[4] Overall, therefore, the UK cold chain is responsible for something in the order of 3% of total UK greenhouse gas emissions: not a massive contribution but certainly significant in the context of food chain emissions as a whole.

3. Scope for improvements

There is in fact much scope for improving the efficiency of refrigeration in the UK. Energy savings of between 20%[5] [6] and 50%[7] are generally considered possible

[3] *Sustainable Development: Achievements and Challenges in the Refrigeration Sector*. Bulletin of the International Institute of Refrigeration, no. 2002-5, http://www.iifiir.org/en/doc/1045.pdf

[4] Estimates of the carbon trade balance suggest that including the carbon embodied in traded goods may add up to 20% to the UK carbon footprint. (Druckman, A, P Bradley, E Papathanasopoulou and T Jackson 2007. Measuring progress towards Carbon Reduction in the UK. Paper presented at the International Ecological Footprinting Conference. Cardiff, May 2007.) Since the food sector is more generally dependent on imports this trade balance is likely to be higher.

[5] Robert Heap, Cambridge Refrigeration Technology, comment made at FCRN refrigeration seminar, Manchester, September 2006

through the proper specification, use and maintenance of equipment. Some improvements can be achieved by better maintaining and operating existing equipment with further savings by specifying cleaner and more appropriate equipment to replace older technologies. There is plenty of information and advice available in the UK and overseas from bodies such as the Carbon Trust,[8] the Institute of Refrigeration[9] and the International Institute for Refrigeration.[10]

In essence the four key elements of a more efficient system include minimising the load, minimising the temperature difference, checking the controls and maintaining the system properly.[11]

Various UK and EU level policies and incentives seek to influence energy use. The EU's Energy Using Products (EuP) Directive, still in its initial stages, is developing design requirements to address the environmental effects of energy-using products throughout their life cycle. Within the UK, the sector has negotiated a Climate Change Agreement (CCA), which commits participants to reducing energy use by between 12% (from a 2005 baseline) by 2011, with – as an intermediary target – a 5% reduction by 2008.

The CCA covers only commercial cold-storage enterprises where the refrigeration element is the main purpose of their business - where coldness is the product for sale. Businesses where refrigeration is used during the process of selling or producing something else (such as food) are not eligible for a CCA and as such have little incentive to improve their energy efficiency. Recognising this, Government is currently considering and seeking consultation on the merits of a new scheme, the Energy Performance Commitment (EPC). The EPC aims to cut carbon emissions from large commercial and public sector organisations including supermarkets, hospitals, hotel chains and so forth by 1.2 million tonnes per year by 2020.[12]

Further gains can be achieved through the development and implementation of newer technologies. One particularly promising technology is trigeneration – systems that produce combined heat, power and coolness – and current trials such as those ongoing at Brunel University suggest that such technologies are twice as efficient as existing ones. [13] At their cleanest, these systems could even use biomass as a fuel source.

The global warming effect of refrigeration arises not just from the energy required to operate it, but also from the refrigerants used. The latter, for commercial systems, account for about 15% of greenhouse gases emitted.[14] Hydrofluorocarbons, which are currently the standard refrigerant fluid, can have a very high global warming potential; a switch to refrigerants such as hydrocarbons, which have a zero global warming potential can thus lead to overall greenhouse gas reductions provided the

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[6] John Hutchings, Director, Cold Storage and Distribution Federation, personal communication, December 2005

[7] See for example *How to improve energy efficiency in refrigerating equipment*, International Institute of Refrigeration, November 2003, http://www.iifiir.org/en/doc/1015.pdf

[8] http://www.carbontrust.co.uk/default.ct

[9] http://www.ior.org.uk/

[10] http://www.iifiir.org/

[11] *Energy Efficient Technology*, presentation given by Robert Heap, Cambridge Refrigeration technology, FCRN seminar, Manchester, September 2006

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[13] Doug Marriott, Doug Marriott Associates, comment made at FCRN seminar, Manchester September 2006 and personal communication

[14] *Sustainable Development: Achievements and Challenges in the Refrigeration Sector*. Bulletin of the International Institute of Refrigeration, no. 2002-5, http://www.iifiir.org/en/doc/1045.pdf

refrigeration system has been designed properly and with their use in mind. Further efforts are needed to improve the design of such HFC-free systems. Regulations tightening the use of F-gases (other forms of fluorocarbon refrigerant, also with high global warming potential) will also come into force over the next few years. While the F-gas regulation does not prohibit their use, they place tighter controls on leakage and require business to use only qualified people to carry out associated work.

One of the obstacles to improving energy efficiency is that current business thinking favours short-term gains over longer-term savings both in energy and money.[15] It can be the case that even when the long-term advantages are quantified and set out, the desire to cut costs in the short term, or to buy a familiar product ('let's go for the same as last time') is overwhelming. Traditional or long-standing industry purchasing relationships also have a part to play – a product is bought from the same supplier time and again because it offers familiarity and predictability. Those responsible for maintaining and servicing the equipment may also have a stake in the continued use of less efficient equipment since this is where their expertise lies. Hence less efficient products continue to be manufactured and used even where better alternatives are readily available.

Collaborative action by the various players in the cold chain - including the manufacturers of the relevant technology, those responsible for servicing it and of course the end users themselves - need to be taken to break out of this systemic inertia. Another approach that offers potential is for end users to contract out the business of 'coldness' to Energy Service Companies (or ESCOs).

A retailer using an ESCO, for example, would not so much buy refrigeration equipment, as a cooling service. It could specify certain parameters and then leave the ESCO to specify, provide, maintain, monitor and improve on the refrigeration equipment. Since the ESCO, under the terms of its contract, would be picking up the energy bills, it would be in their interests to ensure that both the equipment and the management of that equipment were as efficient as possible.

The commercial sector includes not only those who operate refrigeration equipment but those who retail it to householders. As such they have the ability to 'edit' people's choices – they can simply choose not to stock inefficient appliances.[16] Since all stores in any case need to make decisions as to what to stock and what not to, environmental considerations simply need to be incorporated into these decision-making processes.

Future years are likely to see general improvements in the overall efficiency of the refrigeration stock in the UK, although the level of improvement will depend very much upon the strength of supporting policies. According to projections published by the Government-funded Market Transformation Programme (MTP),[17] overall energy use by commercial refrigeration could rise by 6% or fall by 8% compared with a 2000 baseline, depending on the framing policy context. For domestic refrigeration, energy use is projected to fall whatever the policy scenario although there is a twofold difference between the best and worst cases.

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[15] Point emphasised repeatedly at FCRN refrigeration seminar, Manchester, September 2006

[16] On the concept of 'choice editing' see SDC/NCC 2006. *I will if you will*. Report of the UK Round Table on Sustainable Consumption. London: Sustainable Development Commission.

[17] *Sustainable Products 2006: Policy Analysis and Projections*, Market Transformation Programme, July 2006

Taking the domestic and commercial projections together, the MTP anticipates an absolute decline in refrigeration-related emissions. Importantly however, the MTP projections do not take into account refrigeration energy used by goods in transport, nor do they look at refrigeration energy used by processing plants overseas. Very importantly, in our view, the MTP projections do not consider cultural trends and changes in marketing, lifestyle, food innovation and the environment which could substantially alter their conclusions. Cold chain technology is embedded in each life cycle stage of today's food system; its ubiquity means that new food products and technologies emerge that are predicated on refrigeration and as such exacerbate and increase our refrigeration dependence.

4. A brief history of food refrigeration

Having examined the greenhouse gas impacts of the cold chain and the technological potential for improvement, we now turn our attention to the history of food refrigeration technologies and practices, with the aim of identifying some of the key elements on which our current refrigeration dependence has been built.

We have in fact have been extending the natural life of our food one way or another for a very long time.[18] Salting, preserving in sugar or vinegar, smoking, drying and fermentation are all age-old methods which are still used today and which enable food to be stored or transported safely before consumption. More recent years have seen us take enthusiastically to canning. This, developed in the early 1800s (the first factory in the UK was set up in 1813),[19,20] allowed the UK to import cheap beef and mutton from Australia. It has indeed been argued that the can played an integral role in the expansion and maintenance of Britain's empires in the Victorian era.[21]

As for the preservation of foods by cooling, this is hardly a new technique. Indeed, most ancient cultures, including the Greeks, Roman, middle-Eastern peoples and the Chinese all harvested and stored ice for use in the summer months. There is evidence that the Chinese were cutting and storing ice by about 600 BC.[22] From the 8th century BC they were building ice houses and by the time of the Tang dynasty (13th century) huge blocks of ice were being lugged from mountains and frozen rivers and buried in caves or underground pits to act as giant refrigerators.[23] Tannahill notes that by this time chilled food and drinks were *'an almost commonplace luxury'* in China.

Moving forward in time, the American Shakers were building ice houses with walls, roofs and floors insulated with sawdust and straw during the 17th century. In the UK, things were a little slower to get started but ice houses were a fairly common feature in stately homes by the 18th century.[24]

From about the mid 19th century the ice-harvesting industry became big business onwards in the United States. Breweries were perhaps the foremost users since

[18] Some of the sources for this section include Wikipedia http://www.wikipedia.org , the *History Magazine* http://www.history-magazine.com, and the Canal Museum http://www.canalmuseum.org.uk
[19] See http://www.martinmathew.co.uk/canning.htm
[20] See http://www.open2.net/historyandthearts/history/food_timeline_html2.html
[21] Naylor, S. (2000). Spacing the can: empire, modernity and the globalisation of food. *Environment and Planning A*. volume 32 pp1625-1639
[22] Tannahill, R. *Food in History*, Penguin 1988
[23] Tannahill, R. *Food in History*, Penguin 1988
[24] Tannahill, R. *Food in History*, Penguin 1988

refrigeration enabled them to make a uniform product all year round. The meat-packing companies were, understandably, also major users.

The use of ice for domestic purposes also gained popularity during this period. For the American middle classes, its ready availability enabled them to keep their foods cool with the aid of an ice box. This was a wooden box whose hollow walls were lined with tin or zinc and packed with various insulating materials such as cork, sawdust, straw or seaweed. A large block of ice was held in a tray or compartment near the top of the box. Cold air circulated down and around storage compartments in the lower section. The ice was delivered to customers via a fleet of horse-drawn ice delivery carts.[25]

Demand for ice was also growing in the UK and, with our milder climate, was such that it soon outstripped our ability to harvest it domestically. Hence ice began to be imported, initially from the US, and then from Norway, which quickly became our major supplier.[26] Major customers included the food industry (particularly the brewing and fish industries) and the associated transport sector. Ice was used to preserve goods travelling by rail, road and sea. While some domestic households followed the US example with the use of ice boxes, their use was by no means as common here as it was there.

The late 18th and early 19th centuries also saw considerable experimentation – both in the US and in Europe – with various mechanical cooling techniques. The first ice-making machines were patented in the 1830s, using coolants such as ethyl ether and liquid ammonia, and this enabled the technology (and its ensuing benefits) to become much more widespread. By the late 1870s, mechanical refrigeration was being deployed successfully to ship cheap frozen meat from Australia and New Zealand to the UK.

This had a major impact on the UK's consumption of meat. Oddy[27] notes that from the 1890s onwards, London relied mostly on foreign meat supplied by chains of frozen-meat retailers which in turn triggered the demise of local slaughterhouses. At the national level, by 1895 a third of the meat consumed in Britain was imported.[28]

Responding to this influx of frozen meat, cold-storage capacity in the London area expanded ninefold in the twenty years between 1888 to 1908. Most West-End butchers had refrigerators by the early 1890s but meat sold by street hawkers and in open-air markets continued to be the mainstay of working-class districts.

As chilling techniques developed, they were used to ship fruits from overseas. From the 1890s onwards, Californian peaches and pears began arriving in London in ships fitted with cool chambers – but the greatest trade was in apples. Other fruit, like bananas, ripened on the voyage, though a subsidised refrigerated service from

[25] Sources include Wikipedia http://www.wikipedia.org, the *History Magazine,* http://www.history-magazine.com, and the Canal Museum http://www.canalmuseum.org.uk

[26] Blain, B. (2006). *Melting Markets: The Rise and Decline of the Anglo-Norwegian Ice Trade, 1850-1920,* London School of Economics, Working Papers of the Global Economic History Network No. 20/06, http://www.lse.ac.uk/collections/economicHistory/GEHN/GEHNPDF/GEHNWP20-BB.pdf#search=%22history%20of%20refrigeration%20in%20the%20Uk%20domestically%20available%20%22

[27] Oddy, D. J. (2006). *Food quality in London, 1870-1938*, XIV International Economic History Congress, Helsinki, 2006, see http://www.helsinki.fi/iehc2006/papers1/Oddy.pdf

[28] Victorian Agriculture, University of Guelph, http://www.uoguelph.ca/ruralhistory/research/crowley/victorianAgriculture.html

Jamaica that began in 1901. With the increase in imports and the fall in prices, bananas were soon affordable for and very popular with the working classes.[29]

The First World War gave further impetus to the development of cold storage infrastructure – by 1918, Britain had 1.1 million cubic metres of cold-store capacity and over 230 refrigerated ships.[30] Since then, of course, cold-storage capacity has increased dramatically: we now have about 10 million cubic metres of frozen storage capacity and an unknown volume for chilled goods.[31] Since 1920 the world wide shipping of refrigerated foodstuffs has grown twenty-fold.[32]

At the domestic level, the refrigerator rapidly became a mainstream household fixture in the US and by the late 1940s over 60% of households had a fridge.[33] In the UK however, take-up was much slower, and the domestic refrigerator remained the preserve of a few wealthy families. It was not until after the Second World War that refrigerators entered the mainstream market. Indeed, even as late as 1970, over 40% of the population still did not have a fridge, as Table 2 shows, while just a tiny minority owned a freezer.

Table 2: Ownership of refrigeration appliances, UK 1970-1995

	1970	**1980**	**1990**	**1995**
	Figures show % of households owning a refrigeration appliance			
Fridge-freezers	0	19	51	58
Refrigerators	58	72	52	46
Chest freezers	3	16	16	16
Upright freezers	0.5	11	21	22

Source: Table presented in *DECADE: Domestic Equipment and Carbon Dioxide Emissions – Transforming the UK Cold Market*, Environmental Change Unit, University of Oxford, 1997

Today, however, virtually every household owns some combination of fridge and freezer.[34]

5. Refrigeration dependence: shaping forces

The growing use of refrigeration went hand in hand with a number of social, economic and technological developments. One should note that the extent to which these developments helped *engender* and to which they simply *reflected* our dependence upon refrigeration is not always clear, nor indeed is there likely to be a clear-cut distinction between cause and effect.

Growing incomes and working women
The economic growth which followed the Second World War meant that average incomes rose and more women entered the workforce. By 1971[35] nearly 60% of

[29] Oddy, D. J. (2006). *Food quality in London, 1870-1938*, XIV International Economic History Congress, Helsinki, 2006, see http://www.helsinki.fi/iehc2006/papers1/Oddy.pdf
[30] Thevenot, R. (1979). *A History of Refrigeration Throughout the World* , International Institute of Refrigeration, Paris
[31] John Hutchings, Cold Storage and Distribution Federation, personal communication, 2006
[32] Robert Heap, Cambridge Refrigeration Technology, personal communication, November 2006
[33] Bowden, S. and Offer, A. (1994). Household appliances and the use of time: the United States and Britain since the 1920s, *Economic History Review*, XLVII, volume 4. pp. 725-748
[34] *Assumptions underlying the energy projections for domestic cold appliances* Version 2.1, Market Transformation Programme, 18/09/06

working-age women were economically active and of course the figure is higher still today at 74%. The result at the household level was more money to spend but less time to shop for food. Since shopping trips had to be made less frequently, this created a greater need for an effective means of longer-term safe food storage; prior to this, perishables could be bought daily. The implications of this are discussed below.

The post-war period was also characterised by a rapidly intensifying love affair with all things technological. With the growing ownership of televisions, and the introduction of commercial advertising, people were exposed to vigorous advertising not just of cold (and other) appliances, but also of frozen food. [36] In the early days of the domestic freezer, the appliance was very expensive, owned by a tiny minority of the population and viewed largely as a handy means of storing seasonal gluts, whole sheep and so forth rather than for processed food. The vast majority of those initially buying frozen food would have stored it in the ice compartment of the fridge or bought and cooked it straight away. However, from about the 1970s onwards the UK saw the development and rapid expansion of the supermarket format and with it an extensive and reliable commercial infrastructure for storing and distributing frozen food. This proved the turning point for the freezer[37] and ownership levels rose rapidly.[38] As such the domestic freezer's ubiquity reflects not just the growth in national supermarkets and in national distribution systems, but it has also helped foster their further development. The domestic freezer is now the final point in a long and temperature-controlled supply chain.

Marketing, supermarkets and the supply chain
How did all of the necessary infrastructure develop? Cox *et al*[39] argue that it was the frozen food manufacturers themselves who were key to the development and widespread uptake not just of the frozen foods themselves but also of the technological infrastructure. This in turn produced a snowballing effect; the technology prompted the development of further frozen goods, and vice versa.

Unilever, a pioneer in the frozen food industry, had, towards the end of the Second World War acquired the frozen food company Birds Eye. The company already owned subsidiaries producing fish, meat and vegetable products[40] and it already operated its own retail chain of fishmongers. However, in order to make a success of the frozen food concept they needed to see higher levels of sales than could be managed via their stores alone. In the 1950s, very few shops had the freezers essential to storage of such food, so in 1957 Birds Eye persuaded two manufacturers of refrigerated equipment to design and market 'open-top' display cabinets for retail use.

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[35] This is when the Labour Force Survey begins: see *Employment by age and sex – First Release dataset*, Office of National Statistics (data for earlier years are unfortunately not available): http://www.statistics.gov.uk/downloads/theme_labour/LMS_FR_HS/WebTable01.xls
[36] Cox, H., Mowatt, S. and Prevezer, M. *From frozen fishfingers to chilled chicken tikka: Organisational responses to technical change in the late twentieth century*, Centre for International Business Studies, South Bank University, Paper 18-99, ISSN No. 1366-6290
[37] Although one observer (Robert Heap, Cambridge Refrigeration Technology, personal communication, December 2006) notes the fact that buying half a sheep, say, was cheaper than buying smaller cuts and therefore acted as a major incentive for purchasing a freezer
[38] Shove, E. and Southerton, D. Defrosting the Freezer: From Novelty to Convenience. A Narrative of Normalization, *Journal of Material Culture*, Vol. 5, No. 3, 301-319 (2000)
[39] Cox, H., Mowatt, S., and Prevezer, M. *From frozen fishfingers to chilled chicken tikka: Organisational responses to technical change in the late twentieth century*, Centre for International Business Studies, South Bank University, Paper 18-99, ISSN No. 1366-6290
[40] Including canned peas, potted and canned meats and so forth

In return, the company agreed to sell only to those retailers who installed such devices. Later, Birds Eye developed a policy of leasing refrigerated cabinets to some of its more important retail customers on condition that the equipment was used only for stocking Birds Eye products or other foods which were not direct rivals. Meanwhile, according to Cox *et al*, consumers were bombarded with an array of Birds Eye brand marketing and in-store inducements. Thus, in pioneering the mass consumer market for frozen foodstuffs, Birds Eye actually needed to create the infrastructure before households could be offered the product in sufficient quantities to make manufacturing worthwhile.

As the use of frozen food by caterers increased, smaller firms producing unbranded goods entered and so broadened the market. This increase encouraged other companies to come in too, specialising in the provision of processing, storage and distribution services for these manufacturers. As the role of independent suppliers expanded, so the freezing capacity of these large storage and distribution companies began to rival those of the proprietary branded manufacturers. The result of all this activity was an increase both in frozen food sales and in sales of the domestic freezers need for storing the food.

Hence the frozen food concept spawned the freezer infrastructure, which in turn catalysed further frozen food developments, which in turn extended the infrastructure. To put it more simply still, infrastructure generates further infrastructure. This observation may be worth bearing in mind when one considers how the food industry might further develop and what the energy implications of such developments might be.

Cox *et al* note that the growth in ready-meals has also been enabled by the retailers' information technology (IT) capacities. The short shelf life of chilled meals requires responsive logistics systems, which are themselves underpinned by and dependent on sophisticated IT. In short, the cold chain – and the environmental impacts arising from it – is about more than the refrigeration technology itself. It is about a nexus of transport, packaging, retail and IT infrastructure within which refrigeration technology is situated. How these and perhaps new technologies and infrastructures interact and develop in future years, and what the environmental implications might be, is impossible to say. It is likely, however, that new developments *will* arise. As such, 'straight' projections of the type undertaken by the MTP, above, while useful, are unlikely to tell the whole story.

Shopping trips

How often we shop for food and how much we buy at any one time will clearly influence our need for refrigeration. Perishable food bought to be eaten within a day of purchase may not need refrigerating, in contrast with perishable food that is bought to last the week. And if many days' worth of perishable food is being bought, then a big fridge will be needed to contain it all.

Up until the 1970s food was purchased daily or at least very frequently, usually by women. However, the rise in female employment highlighted above, together with the growing dominance of the supermarket chains, led to a shift to the weekly, and by now car-dependent shop. Data on shopping patterns going back to the immediate post-war period are unfortunately not available but more recent data from 1989[41] show that while the overall number of shopping trips has declined, the number undertaken by car has increased, as has the average distance travelled. Hence car based travel and food refrigeration have developed symbiotically.

[41] Department for Transport, personal communication October-November 2006

Another change in our shopping patterns is the almost total demise of daily food deliveries. When daily deliveries were the norm, there was less need for households to own a refrigerator. The onus of (cold) storage was pushed higher up the supply chain and placed on manufacturers and distributors. Cieraad highlights this relationship between deliveries and daily refrigeration needs.[42] She notes that post-war sales of refrigerators were very low in the Netherlands, where daily deliveries were the norm - in contrast with Finland where the home delivery system did not exist, and where sales of refrigerators were much higher.

In the UK the daily doorstep milk delivery was the norm even as late as the 1980s but thereafter declined steeply. In 1980, doorstep milk deliveries represented almost 90 per cent of household milk sales, but by 2002 this share had dropped to just over 20 per cent.[43] By the 1980s most people had a fridge and so by this stage, the daily delivery was not needed to ensure freshness. With a fridge, milk could be stored for days. Since milk was sold more cheaply in the supermarkets that people were already visiting, it made sense to buy perishables at the same time.

Another factor in the decline of the daily delivery was the growing number of women entering the workforce. If there was no-one at home to receive deliveries, the delivery could not be made.[44] With milk, which was typically delivered very early in the morning, this was not such an issue but it could have played a part in the decline in bread and other deliveries which were still common in the 1950s and 1960s.

Now, we are again seeing a rise in the popularity of home deliveries, mediated via the Internet. The difference this time is that the foods come from one retailer only and so the householder needs to ensure he/she is in for just one delivery, just once a week. In order to enable deliveries to be made even when no-one is at home, the industry has been exploring the possibility of installing the infrastructure such as secure boxes to enable drops to be made even when the customer is out. [45]

Housing design and indoor temperatures

Food has always needed to be stored in cool-ish conditions. A feature of most middle class homes (and an aspiration of working class homes) until about the 1960s was a larder – a cool separate room for keeping food. Plans for Joseph Rowntree's model 'garden village' built at the turn of the century for instance, show that houses were designed with larders.[46]

A few years later on, the Government-commissioned Tudor Walters Report of 1918[47] recommended that every house should contain, among other things, a scullery and a larder.[48] In practice many private house builders built homes with larders little bigger

[42] *The Milkman always Rings Twice… The Effects of Changed Provisioning on Dutch Domestic Architecture*, Irene Cieraad, forthcoming

[43] *Arla Foods amba / Express Dairies: Merger Inquiry*, Competition Commission, August 2003 http://www.competition-commission.gov.uk/rep_pub/reports/2003/fulltext/483c3.pdf accessed 23 October 2006

[44] *The Milkman always Rings Twice… The Effects of Changed Provisioning on Dutch Domestic Architecture*, Irene Cieraad, forthcoming

[45] Cairns, S. (2005). Delivering Supermarket Shopping: More or Less Traffic? *Transport Reviews*, Vol. 25, No. 1, 51–84

[46] See http://www.jrf.org.uk/centenary/homes.html

[47] Often called the 'homes fit for heroes' report, this was commissioned by the Government in 1917 to set standards and to produce model plans and specifications for the building industry in preparation for the house-building programme which was to start at the end of the First World War.

[48] See http://www.homeownersales.co.uk/1900.html

than cupboards.[49] Nevertheless the fact that even the cost-cutters of the building world included a larder of sorts in their designs suggests that such a space was considered essential.

The post World War Two era saw a boom in house building and between 1948 and 1958 one household in six moved to a new-build house or flat,[50] and even as late as this period larders were still a feature of these new-build homes, and were used.[51]

However, in 1961 Parker Morris[52] published his Government-commissioned report, *Homes for Today and Tomorrow*. This set new standards for social housing that sought to meet the changing needs of the modern family. In addition to generous minimum space standards,[53] Parker Morris concluded that there should be more living and circulation space, mainly split into an area for quiet and leisure activity, and an area for eating; the latter could be an enlargement of the kitchen. The formal Sunday-best parlour no longer featured. Tellingly, nor does the larder.[54] The report also placed great emphasis upon better, whole-home heating (in 1970 only 31% of homes had central heating).[55] This was the standard which helped de-specialise the hitherto separate functions of the various rooms. If all rooms are to be used at all times, then they all need to be warm. [56]

Homes with central heating and hence higher general ambient temperatures, with little demarcation between cooking and living areas and with no provision for a separate food storage area are likely to pose problems when it comes to keeping food cool. Whether the Parker Morris standards took for granted the widespread ownership of the refrigerator or whether they indirectly helped spur on the rise in uptake is unclear. Low-income groups who were eligible for social housing were perhaps those least likely to be able to afford one but, in the absence of alternative arrangements, the new housing design might have rendered its purchase necessary. On the other hand this correlation may be too simplistic – the role of marketing and the changing cultural and economic factors also, as discussed, played a very important part.

It is of course also the case that most of the population did *not* live in new-build accommodation but in older homes that were less likely to have central heating and more likely to have separate food storage space. One might suggest however that societal changes in our living arrangements helped contribute to a situation which was favourable to the uptake of the domestic refrigerator.[57]

The introduction of central heating also raised indoor temperatures. Research shows that average internal temperatures have risen considerably from a mean of 12°C in

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[49] See http://www.pre-war-housing.org.uk/internal-planning-services-and-fittings.htm
[50] Lyon P, Colquhoun A, Kinney D. (2004). UK food shopping in the 1950s: the social context of customer loyalty, International Journal of Consumer Studies, 28, 1, pp. 28–39
[51] Personal communications with people living and growing up in 1950s-built houses
[52] Parker Morris (1961). *Homes for Today and Tomorrow* (The Parker Morris Report). London: Ministry of Housing & Local Government, HMSO
[53] Ironically, homes built for private buyers were far less spacious
[54] Brierley, E. S. (2004). The Social and Environmental influence of the Parker Morris Report, *Journal of Applied Psychology* (ISSN 1454-8062)
[55] *Domestic Energy Factfile 2003*, Building Research Establishment, 2003, Bracknell, UK. See http://projects.bre.co.uk/factfile/BR457prtnew.pdf
[56] Brierley, E. S. (2004) The Social and Environmental influence of the Parker Morris Report, *Journal of Applied Psychology* (ISSN 1454-8062)
[57] Bowden, S. and Offer, A. (1994). Household appliances and the use of time: the United States and Britain since the 1920s, *Economic History Review*, XLVII, volume 4. pp. 725-748

1970 to 18°C in 2004. [58] Note that the figures given are the mean temperature for all rooms; the living area (which, as noted, may also be the kitchen) is normally a couple of degrees warmer. In all then, the average temperature of today's kitchen is likely to be much warmer than it was in the past. Some evidence suggests that the average internal temperatures are continuing to increase.[59] [60]

The supermarkets

One survey shows supermarkets, per square metre, to be more energy intensive than other food shops.[61] It may of course be possible that if one were to measure energy use per volume of *food turnover*, the conclusion would be different. Whatever the balance, it is clear that refrigeration accounts for the major share of supermarkets' intensive energy use. [62] [63][64] This heavy use of refrigeration reflects both the type of foods that supermarkets sell and the decisions made as to whether or not they need to be displayed in a refrigerated unit. Meat is arguably one product that really does need to be stored cool and refrigeration use by butchers' shops and supermarkets are compared, one finds that both use fairly similar amounts of refrigeration per square metre. However, when it comes to fruit and vegetables it is interesting to note that greengrocers use almost no refrigeration whereas in supermarkets, many fruits and vegetables are displayed in refrigerated cabinets.

What is more, most supermarkets are now open seven days a week. Some larger stores are even open for 24 hours. This means that there is relatively little opportunity for the lights to be dimmed and the covers to be put on refrigerated display cabinets, both energy-saving measures.[65] The consequences are inevitably more energy use.

It may also be the case that the availability of more brands and more variations on particular product types means that more (refrigerated) shelf space is required on which to display them. In other words, more choice leads to larger stores and a larger chilled food area, which in turn leads to greater refrigeration requirements.

Changing food tastes

Although the basic raw ingredients of our diet – meat, dairy products, fruit, vegetables, cereals, fats and sugars – have not changed much since the 1950s, within those food categories we seem to have developed a taste for the more perishable foodstuffs, salads being an example here.[66] We are also choosing to eat many foods in processed form; potatoes, say, which have been processed and then frozen or chilled. Other changes such as the massive increase in consumption of chilled soft and alcoholic drinks in the home have also increased refrigeration

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[58] Fawcett, T. (2005). Investigating carbon rationing as a policy for reducing carbon dioxide emissions from UK household energy use, Doctoral Thesis, University College London

[59] Fawcett, T. (2005). Investigating carbon rationing as a policy for reducing carbon dioxide emissions from UK household energy use, Doctoral Thesis, University College London

[60] 17 million UK homes exposed to winter 'gremlins'/ Energy Saving Trust/ICM Poll, 18 January 2006

[61] Elsayed, M. A., Grant, J.F., Mortimer N. D. (2002). *Energy use in the United Kingdom: non-domestic building stock: 2002 catalogue of results*. Final report for the Global Atmosphere Division of Defra. Contract reference number EPG 1/1/53 Report reference number SCP 4/12

[62] See http://www.johnlewispartnership.co.uk/Display.aspx?MasterId=81f00253-1639-4749-a590-d2cd32540b62&NavigationId=613

[63] See http://www.jsainsburys.co.uk/files/reports/cr2005/index.asp?pageid=59

[64] The figure includes 'catering' but this is likely to be relatively unimportant

[65] The argument has been put that the lights will in any case be on and the refrigeration display cabinets open to allow to staff to restock. However, it is perfectly possible for shelves to be stocked during the course of a shorter day

[66] *UK household purchased quantities of food and drink* – 1974-2004-5, Family Food 2004-5, Defra http://statistics.defra.gov.uk/esg/publications/efs/datasets/default.asp

dependence.[67] In addition, our definition of which foods need refrigerating (such as pickles and jams) may also have expanded.

It is very important to emphasise that the domestic refrigerator is only the final stage in the cold chain. Today all fruits and vegetables, including those that we might not store refrigerated at home (potatoes, onions, bananas) are temperature controlled at most other stages in the supply chain. In other words, a focus only on the domestic stage obscures the fact that temperature control earlier on in the supply chain is now universal for all fresh and some other products. This would not have been the case for all foods in the 1950s.

In future years, our changing, warming climate is also likely to increase demand for refrigeration. Foods such as eggs which today are usually retailed on open shelves may need to be refrigerated in coming years. Moreover, in hot weather our preference for chilled and frozen foods is also likely to grow.

6. Refrigeration and food waste

The great thing about refrigeration is that it stops food from going bad. Since wasted food represents a waste of all the embedded energy used to grow, process and transport it, the added energy requirements of refrigeration need to be balanced against the 'wasted' CO_2 that would result if the food were to spoil.

As a starting point, there is probably a relationship between appropriate refrigeration and less waste given two *identical* sets of purchases and an *identical* period of time before it is eaten. Refrigerated food lasts longer and as such is less likely to go rotten and need to be thrown away. Temperature control along the whole of the supply chain also enables producers (e.g. farmers or hobby gardeners) to manage seasonal gluts that cannot all be eaten in one go. Foods can be frozen and consumption can then be spread over a period of weeks or even months.

Indeed one Brazilian study[68] compared two food stores; one without a refrigerated unit (store A) and one with (store B). The authors found waste in the un-refrigerated Store A to be as high as 28%, while for refrigerated Store B waste levels were about a third of this, at 10%.

However it does not necessarily follow that in the less refrigerator-dependent past, households wasted more food, nor that in a (hypothetical) less refrigerator-dependent future, waste levels will inevitably increase. As discussed above, the *way* in which food is shopped for and managed affects the need for temperature control. Our attitudes to wasting food and subsequent behaviours are also critical. Food is cheaper now, relatively speaking, than it has ever been before.[69] Research suggests that while the relationship between income and food waste is a complex one there does overall appear to be some correlation. In other words, if one can afford to waste food, then one does, refrigerator or no refrigerator.[70] And while we are certainly full of

[67] *UK household purchased quantities of food and drink* – 1974-2004-5, Family Food 2004-5, Defra http://statistics.defra.gov.uk/esg/publications/efs/datasets/default.asp

[68] Fehr, M., Calçado, M. D. R., Romão, D. C. (2002) The basis of a policy for minimizing and recycling food waste, Environmental Science & Policy 5 (2002) 247-253

[69] Table 4.2: Household expenditure as a percentage of total expenditure 1982 to 2004-05 in *Family Spending: 2005 edition*, Office of National Statistics

[70] Sibrián, R., Komorowska, J., Mernies, J. (2006). *Estimating household and institutional food wastage and losses: Measuring food deprivation and food excess in the total population*, Food and Agriculture Organization

guilt about food this guilt now centres on bodily aesthetics. We are happy to waste food if it makes us thinner. Tellingly, while in the past children were urged to eat everything on their plates because 'wasting food is a sin', now magazines urge their body-obsessed readers to '*Master the "skill" of leaving uneaten food on your plate*.'[71]

The relationship between changing technology and changing consumer behaviour, may also have implications for food waste. Today's ability to store food acts as a kind of safety net – the food can always keep longer, goes the thinking – except that suddenly one finds it has gone off. In the days when there was no safety net it was necessary to think ahead and plan more systematically. Food that needing eating *was* eaten. One might speculate too that as cooking skills decline there is less of a tendency to, say, make scones out of sour milk or soup out of wilting vegetables.

The extension of store opening hours may also have had a 'safety net' effect with possible consequences for food waste. For example, if one finds one has run out of eggs but the shops are shut, then dinner will simply have to be eggless. Something will be produced out of what is available in the kitchen. However, today, where some retail outlet is open whatever the hour, a quick trip to the shops will solve the egg shortage and the omelette can be made. Food, then is not prepared out of what there is but out of almost anything one could conceivably want – this links to the earlier point made about availability and variety. Other foods that are available in the home but which do not appeal can be left uneaten even if they are nearing the end of their storage life. In other words, it may be that a sense of eating things because they 'need eating' is disappearing. One might speculate – but it is speculation only – that variety and round-the-clock availability – has contributed to a shift in our attitudes to, and behaviours affecting, food waste.

In conclusion then, while refrigeration has the technical capacity to reduce food waste, the changing attitudes and behaviours which have gone hand in hand with the uptake of refrigeration may have had a counterbalancing effect. Hence while refrigeration has the technical capacity to reduce food waste, the changing attitudes and behaviours that have gone hand in hand with the uptake of refrigeration may have had a counterbalancing effect.

7. Food safety

Another issue that clearly needs addressing in the context of refrigeration dependency is food safety. No one wants to become ill or die of food poisoning. But is a food system which uses less refrigeration inherently more risky?

As with waste, while the short answer is yes, the long answer may be more nuanced. Temperature control is certainly very important in ensuring our food is safe to eat. However the presence of refrigeration has in turn shaped the development of the sorts of foods we choose to eat, of the way we shop and of the way we cook. Refrigeration is now essential because the foods we now consume and the frequency with which we shop are predicated on refrigeration. In short, refrigeration has made itself indispensable. It is worth noting too that refrigeration has enabled other food safety problems to arise. It has facilitated the development of longer supply chains which themselves have given rise to international incidence of certain

[71] See for example some websites with links to US Government health bodies:
http://www.shapeup.org/atmstd/sud10v3/sud10s6.php
http://health.howstuffworks.com/usda-diet-strategies-for-dining-out-ga1.htm;
http://www.diet-blog.com/archives/2006/10/10/10_questions_to_ask_before_changing_your_diet.php
http://www.fns.usda.gov/TN/Resources/POC_topic9.pdf

forms of food poisoning. Salmonella (in eggs and poultry) and more recently the extremely widespread Sudan Red colouring safety alert are fairly recent examples.

Refrigeration is not always used to preserve the safety of our food; often it is used to preserve its quality. For some foods refrigeration is used, and considered necessary so as to ensure our food conforms to certain quality standards as much as to preserve its safety. The question then arises as to how refrigeration is 'necessary' in order to maintain food safety standards and how far it is simply used to preserve food in the condition which we have now come to consider as 'normal'. The distinction between 'necessary' and 'cosmetic' refrigeration is of course a difficult and subjective one and will differ between stakeholders.

8. Towards a less refrigeration-dependent food system

What then, might a lower refrigeration system look like? And what policies and commercial or institutional practices either exist or could be developed that would foster a shift in this direction?

There is no doubt that a less refrigeration-dependent supply chain would require significant changes, *if waste is to be avoided and food to remain safe*. In particular, it would require changes in where and how we grow and transport food, in where and how we shop for it, and in how and when we cook it. This section briefly explores what some of the features of a less refrigeration-dependent food system might be.

It is important here to delineate the distinction between reducing refrigeration energy *use* and reducing refrigeration *dependence*. The former entails the use of cleaner and alternative technologies and better management practices to reduce energy requirements for a given quantity of food storage. The latter, on the other hand, requires changes in our way of living and consuming so that there is less need to store food under refrigerated conditions.

One way of reducing dependence is by changing the balance of foods we eat. Less reliance on meat and dairy products would be an important start here since these tend to be the foods that are most critically dependent on refrigeration.[72]

Importantly, livestock production is in any case a highly greenhouse gas intensive process, accounting for the largest share of food emissions by food category. Hence a reduction in our production and consumption of these foods will not just reduce refrigeration needs but could lead to far more substantial overall savings in GHG emissions. Given the centrality of livestock farming to the rural economy and culture this is a highly problematic issue but it nevertheless needs to be addressed.

As regards fruit and vegetables, a shift towards the consumption of more seasonal and more 'robust' (i.e. less perishable) produce could also lower emissions since it would reduce reliance on refrigerated imports. Robust produce tends to be less critically refrigeration (and packaging) dependent.

In general, foods lower down the food chain such as cereals and pulses tend to be less refrigeration-dependent than those further up. While such foods may require long cooking times – a possible trade-off here – the technologies exist (microwave ovens and pressure cookers being domestic examples) to minimise energy use.

[72] *Defra food refrigeration – energy mapping exercise*, Mark Swain, University of Bristol, presentation given at FCRN seminar, Manchester, September 2006

We may have to accept 'good enough' quality food; food which is perfectly safe to eat but which may, for example, be softer in texture (as for some fruits) or blemished. This of course flies in the face of current retailing practices.

A less refrigeration dependent system might be one where we shop more frequently for food. More regular trips to the shops, provided they are on foot, can make it possible for people to have smaller fridges. The domestic fridge is the end point in a complex, temperature-controlled supply chain. The more refrigeration-dependent foods we put in our fridges, the more refrigeration further up the supply chain this represents. Our refrigerators – how big they are and what and how much we put in them – serve as a marker of refrigeration-dependence elsewhere in the supply chain. Moreover they tend to be determined not just by how much capacity is needed but also by the space that is allocated to them in fitted kitchen designs.[73]

It is possible, however, that a shift by the public to daily shopping patterns could have an effect on retailers' delivery systems – they may need to deliver lower volumes more frequently in smaller and less efficient vehicles. However since the total volume of foods the public purchases over the course of a week is unlikely to change, this is by no means certain. This is an issue that needs to be looked at more closely since from a transport emissions perspective too, a shift away from car-based shopping is desirable.

9. Conclusions

To conclude, refrigeration has yielded enormous benefits. It has made our food safer to eat and helps to reduce waste. However even in these areas, these gains have not been unalloyed. As perhaps with all technologies, refrigeration has created opportunities for new problems to emerge even in some of the areas where it also assists.

The interactions among refrigeration, packaging, food transport, food product innovations and various socio-economic developments have helped create cultural norms and practices which are highly energy-dependent. Technology and behaviour thus feed on and are intimately related to one another.

As such, refrigeration serves as a symbol, or marker of unsustainable energy use and behaviours in the food system. Policies need to address, therefore, not just refrigeration energy *use*, but also refrigeration *dependence*. While energy efficiency measures and novel technologies are important and indeed essential, they do not tackle the reasons *why* we need to use refrigeration: that is, what it is about the foods we eat and the way we manage our lives that renders refrigeration necessary; nor do efficiency measures address how refrigeration has catalysed additional developments in the food supply chain which have damaging consequences for greenhouse gas emissions.

[73] Chris Foster, University of Manchester, personal communication, December 2006