

RETAIL REFRIGERATION

MAKING THE TRANSITION
TO CLEAN COLD

PROFESSOR TOBY PETERS
UNIVERSITY OF BIRMINGHAM

FOREWORD

The UN's Sustainable Development Goals ('Global Goals') can broadly be divided into two groups: resource challenges, and social challenges. But in reality they are highly interdependent. Any innovation aiming to address one of the Global Goals will necessarily affect and be affected by the others.

Addressing any of the challenges individually will be difficult enough; delivering all of them together even more so. Historically, increasing affluence and living standards in the developed economies have resulted in unsustainable resource depletion, pollution and environmental degradation. Those pressures are now being stoked exponentially by population growth and rising incomes in developing countries. But the time to debate the trade-offs between environment, business and society is over; it was always a false and unsustainable choice. On the contrary, with the right approach, we can find that the interconnectedness of the Global Goals will produce not a vicious circle but a virtuous spiral.

Nowhere is this truer than with cooling. Artificial cooling is a pillar of our way of life. It impacts to a greater and lesser extent all the Global Goals and will only becoming increasingly important with population growth, changing demographics, urbanisation and climate change all driving the need for more cooling¹. It is estimated that cooling currently accounts for 7% of total greenhouse gas emissions, and left unchecked will almost double to 13% by 2030.

Refrigeration is vital to our food chain and to food retailers' very existence: without it, they would have no business. Demand for refrigeration is set to increase over the coming decades. Reducing the damage refrigeration does to the climate is not simply a matter of obeying new rules, but also fundamental to good corporate citizenship. It is also integral to the food industry's responsibilities under the UN's Sustainable Development Goals.

ARTIFICIAL COOLING IS A PILLAR OF OUR WAY OF LIFE. IT IMPACTS TO A GREATER AND LESSER EXTENT ALL THE GLOBAL GOALS AND WILL ONLY BECOMING INCREASINGLY IMPORTANT WITH POPULATION GROWTH, CHANGING DEMOGRAPHICS, URBANISATION AND CLIMATE CHANGE ALL DRIVING THE NEED FOR MORE COOLING.

PROFESSOR TOBY PETERS



The fate of hydrofluorocarbon (HFC) refrigerants in Europe has now been sealed by the EU F-gas Regulation, which will reduce their supply by almost 80% by 2030. The phase down trajectory is steep: in 2018, the HFC supply will effectively fall to 48% below its level in 2015. This gives food retailers a sharp incentive to replace F-gases with natural refrigerants, which are far less damaging to the environment. But it tackles only part of the problem: 75% of cooling emissions come from energy consumption rather than refrigerant leaks². Since the ultimate goal is zero net energy supermarkets – which produce more energy than they consume over the course of a year – phasing out HFCs can only be the first step.

Broaden the agenda, however, and supermarkets have a once in a lifetime opportunity to develop refrigeration strategies that simultaneously advance business and environmental goals. Strategic choices about system architecture and/or deeper integration with local energy networks could allow supermarkets to make use of negatively-priced excess renewable power, or develop new revenue streams by providing waste heat – or excess cold – to district heating networks, while at the same time supporting three internationally agreed goals: the Paris Climate Agreement; the Montreal Protocol's Kigali Amendment; and the Sustainable Development Goals.

Regardless of the demands of recent regulatory changes in the EU and US, supermarkets must focus not only on their choice of refrigerant, but also on a broader set of criteria to make progress towards zero net energy supermarkets. These include total thermal demand; total system energy efficiency; preventing refrigerant leakage; maintenance; and decommissioning and end-of-life disposal. If supermarkets do adopt this approach, they can materially help to meet societal needs; support sustainable communities; improve energy efficiency, and combat climate change.

Not a bad day's work for a fridge.





CONTENTS

1: EXECUTIVE SUMMARY	6	5.3: ASDA: MISTRAL AIR COOLING	26
2: POLICY BACKGROUND	12	5.4: SUPERMARKET REFRIGERATION AND DISTRICT HEATING	27
3: CLEAN COLD AND NATURAL REFRIGERANT SYSTEMS	14	5.5: TOWARDS THE ZERO NET ENERGY SUPERMARKET	27
4: COMMERCIAL REFRIGERATION: STORE SIZE, COOLING ARCHITECTURE AND TECHNOLOGY CHOICES	17	6: MEASURE TWICE, CUT ONCE	28
5: CASE STUDIES	24	7: KIGALI, DEVELOPING COUNTRIES AND NATURAL REFRIGERANTS	30
5.1: WAITROSE: WATER-COOLED PROPANE INTEGRALS	24	8: CONCLUSIONS	31
5.2: COLRUYT: REMOTE PROPANE SYSTEM	25	9: RECOMMENDATIONS	32
		ENDNOTES	34

Note: This report focuses primarily on the shift to low GWP refrigerants in commercial refrigeration, and puts it in the context of the broader move towards clean cooling. It does not consider other energy efficiency measures – such as improved set-point management, or adding doors to display cabinets.

1: EXECUTIVE SUMMARY

The Kigali Amendment was signed in October 2016, just ten days after the world ratified the Paris Climate Agreement, and mandated a clear timetable by which countries would phase down the production and use of HFCs. US Secretary of State John Kerry declared the HFC deal the 'single most important step we can take to limit the warming of the planet', while others hailed it a 'huge win for the climate'.

The Kigali Amendment is indeed a major achievement. The United States Environmental Protection Agency estimates that an average supermarket using the hydrofluorocarbon (HFC) refrigerant R404A leaks about 25% of its refrigerant charge annually, resulting in approximately 1,556 tonnes of CO₂ equivalent emissions (1,556tCO₂e) – or the collective annual energy used by 165 homes³. So the global impact of supermarket emissions is clearly huge. Left unchecked, the impact of refrigerant gas leakage could rise to a fifth of global greenhouse gas emissions by 2050⁴.

Kigali extends the 1987 Montreal Protocol to include HFCs and sets a firm timetable for their withdrawal. So it both maintains the Montreal Protocol's protection of the ozone layer and starts to tackle the climate emissions of a group of greenhouse gases that can be thousands of times more potent than carbon dioxide. According to one estimate, the deal could save 70 billion tCO₂e by 2050, avoiding almost 0.5°C of warming.

This may sound enormous but the total impact of cooling is far greater. According to one estimate, greenhouse gas emissions from cooling account for 7% of global emissions, double that of aviation and shipping combined. Within this, academics at London South Bank University estimate that F-gas leakage causes around 25% of the total 25% of the total emissions from cooling, whereas energy consumption causes 75% – three times more⁵.

So while Kigali is a big step forward, it is far from solving the problem of refrigeration emissions. Cleaning up the cooling sector means confronting its efficiency and energy sources as well as refrigerant leaks. Together these make up its 'total equivalent warming impact', or TEWI. The ultimate goal must be to make supermarkets zero net energy – meaning they produce as much energy as they consume over the course of a year – which will require far more than a change of refrigerant.

Artificial cooling is essential for everyday life – whether in the preservation, processing, transportation and retailing of food; the production and distribution of lifesaving medicines; the processing, moving and storing of vast quantities of data created by the modern digital world; and comfortable environments at home, in vehicles and at work – where they increase productivity.

We can – and should – use clever building design to reduce the energy intensity of cooling demand, but the use of artificial cooling will remain essential – there is no other practical way of preserving fresh food, for example. To provide safe food and minimise wastage, temperature management must be ensured throughout the entire cold chain for perishable food commodities from field to fork: in Europe 70% of our food is chilled or frozen at some point on the journey from producer to consumer. The UN's Food and Agriculture Organisation (FAO) estimates that global food production needs to rise 70% to feed an additional 2.3 billion people by 2050. Since around a third of all food is currently lost post-harvest, refrigeration will have a vital role to play in this context. In India, where post-harvest food losses are high, just 4% of food currently goes through a cold chain⁶.



Photo courtesy of UNEP/IIISD/ENB/ Kiara Worth <http://enb.iisd.org/ozone/resumed-oweg38-mop28/>

THE NEED FOR A HOLISTIC APPROACH

Conventional cooling technologies are energy intensive, which makes supermarkets the most electricity-intensive type of commercial building, and causes the bulk of their greenhouse gas emissions. Making refrigeration sustainable, therefore, demands a holistic approach that not only expedites the move from HFCs to natural refrigerants, but also considers energy. If large scale operators of refrigeration systems fail to consider the long-term impacts of this transition on energy consumption and their long-term business planning, they may solve one problem but fail to take advantage of all the opportunities.

For example, designers, manufacturers, contractors and operators of refrigeration systems must consider the skills required to not only install new technology, but to maintain it in the future. Today, cooling employs more than 12 million people globally and this will need to increase rapidly, ahead of the demand curve, if an increasingly environmentally friendly industry is to be sustained. A lack of qualified engineers is already seen as a challenge during the shift to natural refrigerants, but it also has the potential to be a significant limiting factor if we fail to consider long-term maintenance to reduce leaks and maintain energy efficiency when specifying technologies.

There are undoubted challenges, but food retailers have an opportunity. By making strategic system and equipment choices today, they can not only reduce costs, take advantage of negatively-priced excess renewable power, and open up new sources of revenue (see district heating box), but also simultaneously support three internationally agreed goals: the Kigali Amendment; the Paris Climate Agreement; and the Sustainable

Development Goals. By considering the long-term pros and cons of different technologies, supermarkets can help to meet societal needs; create sustainable industries; improve energy efficiency; and phase-down HFC refrigerants – all of which helps combat climate change.

Conversely, if we respond to the Kigali Amendment without considering the full challenges and opportunities that the industry faces, in the scramble to hit tight regulatory deadlines food retailers may lock themselves into new refrigeration systems that will fail to produce the best results for their business or the environment. By focusing solely on the refrigerant gas rather the refrigeration system as a whole, they may risk losing the flexibility to protect themselves against future retail trends or new regulatory demands beyond refrigerant gases.

RESPONSIBILITY AS GLOBAL LEADERS

We also need to recognise that where the EU and US lead, developing countries may follow. And since cooling demand is growing fastest in developing countries – driving the global commercial refrigeration equipment market from \$37 billion in 2015 to \$61 billion by 2021⁷ – there the impact of any missteps would be greatly amplified. It is therefore vital that the refrigeration industry develops clean cold systems and pathways not only to forestall a dramatic increase in cooling emissions in developing countries, but also allow those countries to leapfrog truly sustainable solutions.

As part of the Kigali Agreement, parties to the Montreal Protocol also agreed to begin examining opportunities to increase the energy efficiency of cooling appliances to achieve additional GHG mitigation while also delivering additional sustainable

development benefits, such as improved air quality and public health energy security. The importance of sustainable refrigeration for developing countries has also been recognized through the launch of 'Cooling for All', funded by the Kigali Cooling Efficiency Program and led by the broader Sustainable Energy for All initiative led by Ban Ki Moon, the former UN secretary general. Cooling for All is intended to support faster progress on the Kigali HFC phase-down, but also to broaden the focus to meeting growing cooling demand within a clean energy transition. 'With populations rising, growing cooling needs risk creating a significant increase in energy demand, that if not managed through super-efficient technologies or clean sources, will cause further climate change impacts and a rise in emissions. We can't keep cooling down by warming the planet up'⁸.

It is not entirely clear what the Trump administration's intention to withdraw from the Paris Agreement in 2020 means for the Kigali Amendment. President Trump has never clarified the issue, and in any case much of the industry was at Kigali and supports the Amendment. Honeywell, Chemours, Trane, and Carrier have invested tens of millions of dollars developing new, compliant refrigerant gases, and would probably oppose any proposed roll-back of US regulation⁹.

The recent ruling by a panel of the United States Court of Appeals for the District of Columbia Circuit that the Environmental Protection Agency (EPA) does not have the authority to regulate HFCs under the Clean Air Act is clearly worrying, however. The decision supports the plaintiffs' contention that the EPA is trying to shoehorn climate change policy into a treaty that was meant to address ozone depletion. This increased uncertainty in the US makes the EU's continued leadership on sustainability all the more important.

EXECUTIVE SUMMARY CONTINUED...

HOW ARE EUROPEAN RETAILERS RESPONDING?

In Europe, rapid change is being driven by the EU F-gas Regulation, which will reduce the supply of HFCs by almost 80% by 2030. The phase down trajectory is steep: in 2018 HFC supply will effectively fall to 48% below its level in 2015. This gives food retailers a sharp incentive to replace F-gases with natural refrigerants, and the industry is now shifting from HFCs such as R404A, with a global warming potential (GWP) almost 4,000 times greater than CO₂, to natural refrigerants such as CO₂ and hydrocarbons with GWPs in low single digits.

CO₂ systems are described as 'remote', meaning the cooling equipment is generally housed in a plant room, and cold is piped to cabinets in the store in the form of high pressure CO₂. In most hydrocarbon systems, each display cabinet in the shop contains its own cooling equipment, which – like all domestic fridges – uses a refrigerant such as propane or butane, and heat is removed from the store to an external heat exchanger or chiller by a pipe containing water or brine. There are also a few remote propane systems, such as that operated by Colruyt in Belgium (see case study p.25).

So far most supermarkets seeking to phase-down HFC refrigerants have chosen CO₂ systems, and from discussions with industry, commentators and a review of published case studies, only a handful such as Waitrose in the UK and Lidl in Germany¹⁰ have opted for water-cooled hydrocarbon integral systems. By early 2017, it is thought there were almost 9,000 CO₂ transcritical systems in European supermarkets and around 700,000 hydrocarbon integral units¹¹. The number of stores wholly converted to hydrocarbon integrals with water-cooled loops is much smaller, estimated at around 500 today, but is growing¹².

Yet the capital cost of CO₂ systems is 5% – 10% higher¹³ than that of the HFC systems they replace, and the energy and emissions claims made for some installations are equally challenged by industry experts. Trials by one leading UK supermarket found that a CO₂ transcritical system emitted around 14% more greenhouse gas overall as measured by TEWI (total equivalent warming impact, which includes both direct emissions from refrigerant leaks, and indirect emissions from energy consumption) compared to a well-maintained remote HFC system.

CO₂ systems also depend on high pressure engineering, which means they require far greater skill to install and maintain. Skills capacity is however already a recognised challenge in Europe. By contrast, water-cooled propane integral systems are cheaper to buy and efficient to run, and evidence suggests they can produce greater financial and emissions savings. They also operate at low pressure and are easier to install and maintain.

In cooler climates, some supermarkets have integrated new CO₂ or propane systems with their central heating systems, so that waste heat from the fridges displaces large amounts of fossil fuel. In some CO₂ systems it has been claimed this raises efficiency to 45%. This is an important demonstration of how the shift to natural refrigerants creates an opportunity to integrate thermal energy loads, and make progress towards the goal of zero net energy buildings. Others have gone one step further and linked their refrigeration system into a district heating network (see case studies).

Yet the evidence so far suggests commercial refrigeration in the EU faces an imminent crisis, partly because food retailers have not yet done enough to match the phase-down target for 2018. According to one analysis, to meet the phase-down timetable food retailers should have installed 18,500 low GWP systems in 2015 alone, but so far they have installed only 9,000 CO₂ systems

in total¹⁴. The HVACR industry association EPEE warns progress is too slow and could cause severe shortages of HFCs in 2018 – when supplies will effectively fall to 48% below 2015 levels – and that prices could rise 20-fold¹⁵. Under such time and cost pressures, food retailers may be forced to make hasty decisions they come to regret.

THE PATH FORWARD

As Europe's retailers react to the phase-down of HFCs, they should view the shift to natural refrigerants in the context of a much broader debate that has emerged around clean cold technologies and the cold economy. Making cooling sustainable involves far more than replacing high GWP refrigerant gases, and the move to natural refrigerants needs to be seen in the context of the wider shift to clean, sustainable cold: reducing refrigeration energy demand; marrying thermal demands, both inside the store but also where possible through district thermal networks (see supermarket refrigeration and district heating p.27); and converting the remaining load to renewable energy.

So food retailers should use the HFC phase-down as an opportunity to review their cooling and energy architecture strategically. Instead of reaching for the nearest available refrigerant that meets the regulation, and a system architecture that is closest to today's, they should ask themselves if their intended approach opens up new opportunities or conversely might soon restrict their room for manoeuvre.

The cooling industry has wandered into blind alleys several times already because – prompted by regulation – its eyes were on the road beneath its feet rather than the skyline. Today, natural refrigerants are only one part of the cooling challenge, and further fundamental change is inevitable. It is time to forestall the unintended consequences. This time we need to get it right.

RECOMMENDATIONS

The EU and national governments need to match regulation around refrigeration with support, as it does for other sectors. It should:

- Support research and analysis by industry trade bodies and independent research organisations so that retailers can make informed and rational choices based on robust, comparative performance information. This should specifically include a matrix of measures reflecting whole of system and whole of life performance of different refrigerants, technologies, architectures and approaches. It should also evidence performance in different climates.
- Support the development of a clear roadmap for sustainable refrigeration, not just low GWP refrigerants, to guide retailers' long-term strategy. Again, this needs to be about a total system level solution, rather than simply increasing the efficiency of individual pieces of refrigeration equipment, with proper like for like assessments to inform industry.
- Provide incentives, not just penalties, for end-users to accelerate transition to low-impact, not just natural refrigeration, solutions. This need not necessarily involve subsidies or scrappage schemes. Governments could, for example, consider increasing depreciation allowances for investments in new refrigeration systems that are both low-GWP and demonstrably produce the best energy efficiency outcome for the proposed location.
- Support research and development into deeper integration of supermarket refrigeration into electricity grids and district thermal networks; a coordinated and integrated approach to total energy systems.
- Mandate certification and training in natural refrigerants, and provide enough funding to develop the skilled workforce required to support an accelerated transition.
- Increase investment into low-impact and sustainable cooling technologies and applications.

SUPERMARKETS, CLEAN COLD AND THE SUSTAINABLE DEVELOPMENT GOALS

European supermarkets are currently fixated with meeting their obligations under the EU F-gas Regulation. While the phase-down schedule is tight, they should not lose sight of their wider obligations, which are, if anything, more demanding.

In 2015 the United Nations agreed an extraordinarily ambitious plan to create a healthy, fair, sustainable and prosperous world by 2030. The Sustainable Development Goals (or Global Goals) commit 193 countries to abolish poverty and hunger; provide good healthcare, education, decent work, gender equality and access to clean water for all; and to promote affordable clean energy, sustainable cities, infrastructure, climate action, economic growth and responsible consumption.

AN 'EXTRAORDINARY, URGENT AND OPTIMISTIC PLAN FOR A NEW GENERATION'

Unlike their predecessors, the Millennium Development Goals, the Global Goals apply to developed countries as well as developing¹⁶. The 17 Goals and 169 targets are intended to be met 'for all the nations and people and for all segments of society' so that 'no one will be left behind'. In essence, rather than the traditional approach of driving rich countries to help the poorer nations of the world, they are [to quote Project Everyone Founder Richard Curtis] an 'extraordinary, urgent and optimistic plan for a new generation'.

Yet awareness of the Global Goals is 'shockingly low' in Britain according to a recent parliamentary inquiry. The government appears to view the Goals as something it can help developing countries achieve but which need not apply at home. Very few companies audit themselves against all 17 of the Goals – just 1% plan to do so according to a survey by PWC. At the same time, the UN concludes in its latest annual assessment that global progress is patchy and needs to accelerate.

CLEAN COLD AND THE GLOBAL GOALS

A report published by the University of Birmingham Energy Institute was the first to point out that achieving all 17 of the Global Goals will depend to a greater or lesser extent on developing clean cooling technologies – and for many of the Goals, clean cold will be vital.

Some of the links between cooling and the Global Goals are complicated and indirect, but many are starkly obvious. Refrigeration is critical to ending poverty and hunger (Goals 1 and 2), for example, since most of the world's poor are farmers with no access to cold chains to transport their crops to market and minimise post-harvest food losses. If developing countries had the same level of cold chain as developed, they could save 200 million tonnes of food per year, or 14% of their food supply, according to the International Institute of Refrigeration (IIR)¹⁷, and the farmers' income would rise. Reducing food waste would in turn reduce waste of water (Goal 6), fertilizer and energy, so reducing carbon emissions (Goal 13). Refrigeration would also improve health (Goal 3) by expanding the food supply and improving food safety, and because 2 million people die each year from vaccine preventable diseases due to poor non-existent cold chains.



CLEAN COLD AND THE GLOBAL GOALS

2: POLICY BACKGROUND

THE KIGALI AMENDMENT TO THE MONTREAL PROTOCOL –EXCERPTS FROM UNITED NATIONS OVERVIEW

'Back in the 1920s, coolants and fridges were discovered to be very toxic, causing severe health complications to humans. CFCs were the solution to address this, but decades later, CFCs were also found to be the root cause of a hole in the stratosphere – commonly referred to as the ozone hole. The ozone layer is the natural shield against the sun's harmful ultraviolet rays, which can cause severe health risks such as skin cancer. This damage to the ozone layer prompted governments to moot an environmental agreement to govern the production and use of harmful substances that damage the ozone layer.'

'The Montreal Protocol on Substances that Deplete the Ozone Layer was designed to reduce the production and consumption of ozone depleting substances in order to reduce their abundance in the atmosphere, and thereby protect the earth's fragile ozone layer. The protocol was agreed on September 16th in 1987 and entered into force on January 1st in 1989.'

CLIMATE CHANGE AND PHASING DOWN HFCs

'A unique feature of the protocol is an adjustment provision that enables the Parties to the Protocol to respond quickly to new scientific information, in a bid to accelerate the reductions required on chemicals already covered by the Protocol. These adjustments are then automatically applicable to all countries that ratified the Protocol. Developing countries are given more time to comply with the phase out decisions, and also they receive funding from the Multilateral Fund to facilitate compliance with the Protocol's provisions.'

'In Kigali, delegates reached a deal on a timetable that would mandate countries to phase down the production and usage of hydrofluorocarbons (HFCs), introduced to replace CFCs. Following seven years of continuous consultations, parties to the Montreal Protocol struck a landmark legally binding deal to reduce the emissions of powerful greenhouse gases in a move that could prevent up to 0.5°C of global warming by the end of this century, while continuing to protect the ozone layer. HFCs are man-made chemicals that are primarily used in air conditioning, refrigeration and foam insulation. While their impact on ozone depletion is far less than CFCs, HFCs are powerful greenhouse gases that can be thousands of times more potent than carbon dioxide in contributing to climate change.'

'The new deal includes specific targets and timetables to replace HFCs with more planet-friendly (natural) alternatives, provisions to prohibit or restrict countries that have ratified the protocol or its amendments from trading in controlled substances with states that are yet to ratify it, and an agreement by rich countries to help finance the transition of poor countries to alternative safer products. Notably, African countries opted to phase down the chemicals faster than required, citing the grave threats the region faces due to climate change.'

'The final deal divided the world economies into three groups, each with a target phasedown date. The richest countries, including the United States and those in the European Union, will reduce the production and consumption of HFCs from 2019. Much of the rest of the world, including China, Brazil and all of Africa, will freeze the use of HFCs by 2024. A small group of the world's hottest countries such as Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates have the most lenient schedule and will freeze HFCs use by 2028.'

'As pressure mounts on governments worldwide for less talk and more action to address climate change, the Kigali Amendment was indeed, a commendable move that adds momentum to a series of new global climate change agreements, including the Paris agreement which officially entered into force on 4 November, 2016.'

By linking the two worldwide challenges of ozone depletion and climate change, the Kigali Amendment and resulting decisions form a new narrative for international environmental governance.



AS PRESSURE MOUNTS ON GOVERNMENTS WORLDWIDE FOR LESS TALK AND MORE ACTION TO ADDRESS CLIMATE CHANGE, THE KIGALI AMENDMENT WAS INDEED, A COMMENDABLE MOVE THAT ADDS MOMENTUM TO A SERIES OF NEW GLOBAL CLIMATE CHANGE AGREEMENTS...

ENERGY EFFICIENCY – THE NEXT STEP²⁰

As part of the Kigali Agreement, parties to the Montreal Protocol also agreed to begin examining opportunities to increase the energy efficiency of cooling appliances to achieve additional GHG mitigation while also delivering additional sustainable development benefits, such as improved air quality and public health energy security.

'During the negotiation of the Kigali Amendment, ensuring energy efficiency in refrigeration and air-conditioning equipment was considered another important means of achieving climate co benefits..... The Technology and Economic Assessment Panel has been tasked to review energy efficiency opportunities in the refrigeration and air-conditioning and heat-pump sectors related to a transition to climate-friendly alternatives. In addition, parties have been invited to submit, on a voluntary basis, any relevant information on energy efficiency innovations in those sectors. The Panel will prepare a report on the matter for consideration by the parties at their 29th Meeting in November in Montreal.'

A key recommendation is to increase knowledge of energy efficiency opportunities in the refrigeration and air-conditioning sectors during the transition to low-GWP and zero-GWP alternatives, with co-benefits for the climate and for energy provision. A second highlighted the need for capacity-building and training of service and maintenance personnel in a field of rapidly changing technology.

However as we are seeing in the U.S with the [August 2017] ruling by a panel of the United States Court of Appeals for the District of Columbia Circuit holding that the Environmental Protection Agency does not have the authority to regulate HFCs under the Clean Air Act, this is indeed being viewed in some quarters as an attempt to shoehorn climate change policy into a treaty that was meant to address ozone depletion, and something to be fought against. It would seem therefore that even the 'win-win' of addressing climate change and ozone depletion together still potentially has some way to go before it is secured.

KIGALI COOLING EFFICIENCY PROGRAMME

In support of the Montreal Protocol, 19 impact philanthropies announced a contribution of USD \$52 million for developing nations to help in the transition to more energy-efficient cooling through a separate funding mechanism called the Kigali Cooling Efficiency Programme (K-CEP). The goal of K-CEP is to 'significantly increase and accelerate the climate and development benefits of the Montreal Protocol refrigerant transition by maximizing a simultaneous improvement in the energy efficiency of cooling.'

COOLING FOR ALL

In July 2107, the UN-backed Sustainable Energy for All launched a new initiative to identify the challenges and opportunities of providing access to affordable, sustainable cooling solutions for all – Cooling for All.

An important part of the initiative that will support greater, more informed action, will be the Cooling for All Global Panel. The panel will bring together a group of high-level leaders from government, academia, civil society, business and finance leaders who will together better understand the challenges and opportunities of providing access to cooling solutions for all across the world.

The panel, made up of leaders from business, philanthropic, policy and academia, will now work together to produce a comprehensive report that clearly addresses these challenges with evidence based recommendations. The report, due for release in 2018, will help create a pathway to ensure the poorest countries and their citizens, who are often disproportionately affected, can have sustainable access to cooling solutions.

The Global Panel is led by two co-chairs; President Hilda Heine of the Marshall Islands and Dr. Vincent Biruta, Minister of Natural Resources for the Republic of Rwanda. Global Panel members include; Achim Steiner, Administrator, United Nations Development Program; Rachel Kyte, CEO and Special Representative of the UN Secretary-General for Sustainable Energy for All; Erik Solheim, Executive Director, UN Environment; Dan Hamza Goodacre, Executive Director, Kigali Cooling Efficiency Program; Juergen Fischer, President, Danfoss Cooling; Kate Hampton, CEO, Children's Investment Fund Foundation; Veerabhadran Ramanathan, Distinguished Professor of Climate Sciences, Scripps Institution of Oceanography, University of California at San Diego; Maria Neira, Director, Public Health and the Environment Department, World Health Organisation; Tina Birmbili, Executive Secretary to the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol on Substances that Deplete the Ozone Layer; Iain Campbell, Managing Director, Rocky Mountain Institute; Kurt Shickman, Executive Director, Global Cool Cities Alliance.

The Cooling for All work is being funded by the Kigali Cooling Efficiency Program.

3: CLEAN COLD AND NATURAL REFRIGERANT GASES

Cooling is crucially important to modern life, but until now has been largely ignored in high level energy and climate debates. This is changing, however, as it becomes increasingly clear that addressing the way cooling is delivered will be crucial to achieving national and international environmental targets. The German government agency GIZ Proklima estimates that cooling causes 7% of global greenhouse gas emissions today, but forecasts this will almost double to 13% by 2030 if nothing is done²¹.

A significant proportion of the emissions from cooling are caused by leaks of hydrofluorocarbon (HFC) refrigerants – the working fluid in refrigeration equipment that absorbs, transports and rejects heat to achieve cooling. These leaks are generally assumed to cause around 25% of the total emissions of cooling, with energy consumption causing the rest, although industry data suggests that at some retailers – which must suffer far higher levels of leakage – direct emissions account for almost twice that proportion²².

Because HFCs (or 'F-gases') are pressurised during the vapour compression cycle, some leakage is likely – at least in remote systems in which refrigerant circuits are not hermetically sealed. The volumes are typically tiny, but their impact is grossly disproportionate. For example, one of the most commonly used F-gases, R404A, has a global warming potential (GWP) of 3,922, meaning that a leak of one kilogramme causes global warming equivalent to almost four tonnes of CO₂.

THE GERMAN GOVERNMENT AGENCY GIZ PROKLIMA ESTIMATES THAT COOLING CAUSES 7% OF GLOBAL GREENHOUSE GAS EMISSIONS TODAY, BUT FORECASTS THIS WILL ALMOST DOUBLE TO 13% BY 2030 IF NOTHING IS DONE.

In future, if countries keep reducing the carbon intensity of their power generation, refrigerant leakage will cause an ever greater proportion of the total greenhouse gas emissions of refrigeration. Left unchecked, F-gas leakage could cause almost 20% of global greenhouse gas emissions by 2050²³.

The world is now beginning to take action, however. In the US, the EPA's Significant New Alternatives Policy (SNAP) has labelled R404A and other common F-gases as 'not acceptable', and will affect almost all commercial refrigeration by 2022 – subject to the recent Court of Appeal ruling. In Europe, the EU F-gas Regulation, which came into force in

2015, bans most new equipment with refrigerant gases above 150 GWP from 2022, and imposes a stringent phase down of HFC supplies to 2030. Last year, the Kigali Amendment to the Montreal Protocol was agreed by 197 countries, which should phase down HFCs by 80% worldwide by 2050.

But it would be a mistake to assume that simply because stiff regulations have been introduced that commercial refrigeration is on an automatic path to sustainability. Food retailers are starting to make substantial investments in new equipment, and are pursuing a range of different technologies and strategies. With regulatory deadlines in the US and Europe now so tight, end-users may be in danger of selecting equipment that fails to deliver the best results for either the environment or their businesses in the long run.

THE IMPACTS OF THE EU F-GAS REGULATION

The EU F-gas Regulation bans most stationary refrigeration equipment with F-gases above 2,500GWP from 2020, and prohibits the installation of new commercial refrigeration equipment with F-gases higher than 150GWP from 2022²⁴. Servicing existing equipment with a charge size of 40tCO₂e or more with new refrigerant above 2,500 GWP is also banned from 2020²⁵, although recycled or reclaimed F-gases can continue to be used until 2030. Existing equipment may continue to operate on recycled high-GWP F-gases such as R404A, or fresh supplies of F-gases below the 2,500 GWP, such as R407F (1825 GWP) or R448A (1387 GWP). But this will become increasingly difficult because of the effect of the regulation's other main provision: the F-gas phase down.

The phase down will reduce supplies of HFCs in Europe to just 21% of 2015 levels by 2030. The annual quotas step down in a series of three year plateaux (see Figure 1), and the cut in 2018 is particularly steep because it includes imported pre-charged equipment for the first time.

Manufacturers and importers receive a quota for F-gases measured in their CO₂ equivalence. This means supplier A could sell x quantity of an F-gas with 4,000 GWP, or 2x of an F-gas with 2,000 GWP, or 4x of an F-gas with 1,000 GWP. It is intended to force manufacturers to develop lower GWP alternatives to existing F-gases, and to raise the price of HFCs to encourage customers to abandon them in favour of natural refrigerants with GWPs in low single digits.

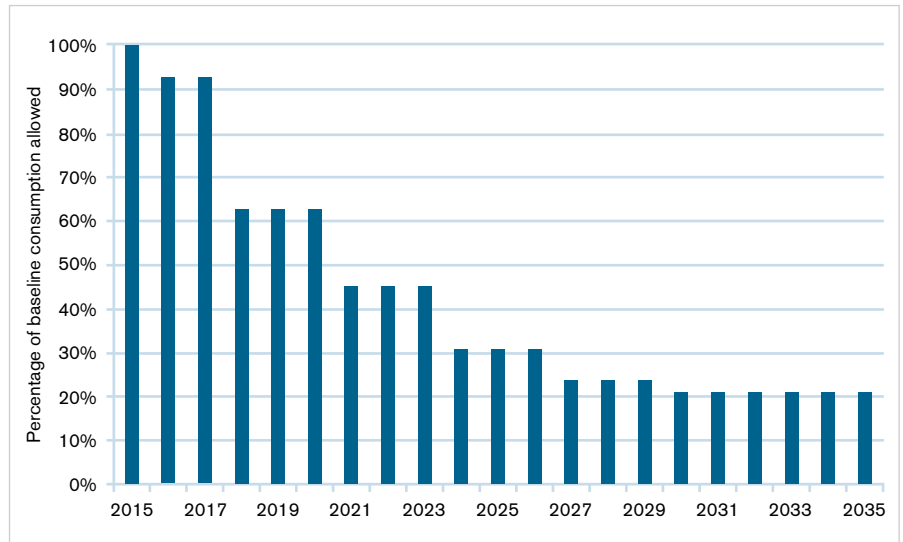


Figure 1: EU HFC Phase Down Steps

The evidence so far suggests that the F-gas Regulation has not yet galvanised the industry sufficiently to keep pace with the phase down:

- The price of HFCs has risen five-fold since the start of 2017²⁷, which suggests manufacturers are running short of quota and are therefore increasing prices.
- To meet the phase-down timetable, food retailers should have installed 18,500 low GWP systems in 2015 alone²⁸, but so far they have installed only 9,000 CO₂ systems in total²⁹. The HVACR industry association EPEE has recently warned that progress is too slow and could cause severe shortages of HFCs next year – when supplies will effectively fall to 44% below 2015 levels – and that prices could rise 20-fold³⁰. If HFC prices do spike by this much, it may galvanise the industry, but it might also force retailers into hasty technology choices they later regret.

Some parts of the industry are inevitably better prepared than others. Industry commentators and consultants confirm that even at this late stage many smaller end-users are still installing new R404A equipment³¹. Shecco, an organisation that promotes natural refrigerants, says progress is slower in southern and eastern Europe than elsewhere.

The shortfall in HFC supplies could bite even harder than expected because the European economy is growing faster than when the phase-down – which assumes roughly static refrigerant volumes through to 2030 – was designed³².

Therefore it is imperative that as an industry the retail sector plans effectively for the rapid phase out of HFC systems, both to ensure that environmental targets are met, and because without effective planning, opportunities to adopt the systems with the most positive long-term impact will be lost.

Figure 1: The EU HFC phase down. The chart shows that HFC supply in Europe in 2018 falls nominally to 37% below the initial baseline, but this understates the severity of the squeeze. From 2017 pre-charged imported equipment is included in the quota system for the first time, meaning more demand for quota but no additional supply. That means the effective reduction in 2018 is nearer to 48% than 37%. In other words, in 2018 HFC supply in Europe will fall to scarcely more than half its 2015 level. Source: Gluckman Consulting.

ENERGY EFFICIENCY

Both academic reports and interviews with retailers indicate that the refrigeration market has historically been driven primarily by customer appeal and purchase price, with less consideration given to energy efficiency and life-cycle costs. A study based on interviews with UK grocery store managers found that energy efficiency has become an increasing priority in recent years, though managers prioritise systems that meet regulatory requirements and avoid those they perceive as having negative effects on customer appeal (Ochieng et al. 2014). This is perhaps understandable, because although supermarkets are large energy users, energy and refrigeration account for a relatively small proportion of their expenditures.

The phase-down of HFCs therefore presents a timely opportunity to catalyse and secure improvements in the energy efficiency of appliances and equipment and better align to the objectives set out in the Europe 2020 Strategy's flagship initiative resource-efficient Europe as well as the UN's Sustainable Development Goals³³.

Among commercial buildings, supermarkets are the most electricity intensive due to their high refrigeration loads, and taking a holistic look at the impacts of new refrigeration technologies provides an opportunity to achieve long-term environmental benefits well beyond reducing the damage caused by F-gas leakage.

SUPERMARKET COLD THERMAL STORAGE

Supermarkets can significantly reduce their energy costs by exploiting the potential of cold thermal energy storage, as Whole Foods has done at its store in Los Altos in California. The company has installed a thermal battery made by Axiom Energy, which stores energy in a brine solution that freezes at -15°C . The supermarket's refrigeration system produces cold to freeze the brine in a shipping container at night when power is cheaper, which then provides cold to cool the display cabinets during the day. Axiom says this reduces the store's electricity bill by 40%, a major saving since refrigeration accounts for 60% of a supermarket's energy costs. It also makes the store more resilient in case of a power failure. Unlike electric batteries, Axiom's thermal batteries are built to last 25 years⁶⁰.

(See page 27 for further information)



System Integrator

The heart and brain of the Refrigeration Battery is the System Integrator. It uses heat exchangers and a secondary heat transfer loop to exchange cooling between the central refrigeration system and Axiom Thermal Storage Tanks.



Thermal Storage Tanks

Typically sited adjacent to the building or below ground, the Thermal Storage Tanks are filled with a saltwater solution that freezes at -5°F and stores cooling for later use.

4: COMMERCIAL REFRIGERATION: STORE SIZE, COOLING ARCHITECTURE AND TECHNOLOGY CHOICES

While stores will often undergo a refit every five to seven years, commercial refrigeration equipment has a lifespan of around 15 years, and companies are naturally reluctant to retire it early. As a result, many supermarkets are refilling their existing systems with a medium-GWP HFC's such as R407F (1825 GWP) or R448A (1387 GWP), and replacing equipment with natural refrigerant systems only when they reach the end of their working life. But this can only be a stop-gap solution. Other companies are considering new gases known as HFOs, which have GWPs of less than 150, but these are expensive, and many fear they are vulnerable to further tightening of regulations in future (see HFO refrigerants p.23).

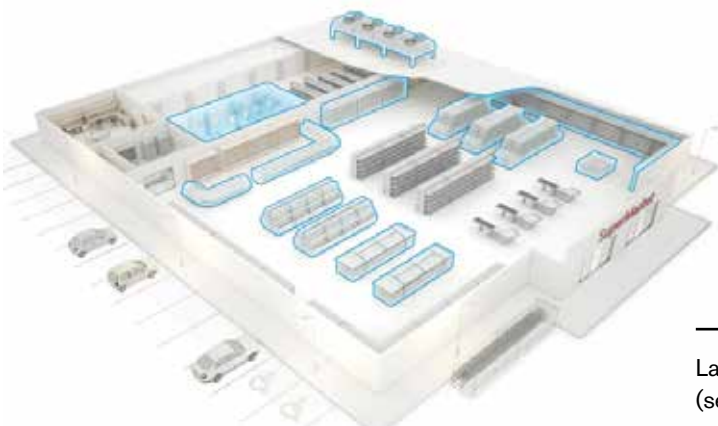
The two main natural refrigerant choices today are CO₂ and hydrocarbons such as propane. Among European supermarkets, CO₂ has received more investment so far: 9,000 CO₂ systems have been installed in Europe to date, and Shecco forecasts this number will now grow at 6,000 per year³⁴.

The refrigeration manufacturer Carrier claims that in five years' time, two thirds of commercial refrigeration market will be CO₂, and the rest split between HFCs and HFOs³⁵. Propane predominates in drinks vending machines and ice cream freezers found in bars and corner shops worldwide, and so far only a handful of supermarket chains such as Waitrose, Co-op and Iceland in the UK, and Lidl in continental Europe, have decided to convert all the refrigeration in their stores to systems using propane. The commercial cooler and freezer manufacturer AHT estimates there were some 700,000 hydrocarbon integral units in European supermarkets by the end of 2016. This figure includes units that provide only a small part of a store's cooling, where the majority is provided by another technology. The number of stores that have converted wholly to hydrocarbons is much smaller, estimated at 500 today, but is growing.

The dominance of CO₂ among supermarkets seems to reflect the legacy cooling architecture of the larger store formats, which have traditionally favoured centralised or 'remote' systems (see remote and integral refrigeration systems p.17).

Additionally propane is flammable, and existing safety standards for 'type approved' equipment limits the charge of hydrocarbon in each refrigerant circuit to 150g, which is too little to refrigerate a full sized supermarket cabinet. This means retailers wanting to install hydrocarbon integrals must either buy cabinets with several circuits each to ensure type approval; or buy single circuit cabinets with a higher charge and comply with a more onerous set of EU and local safety standards (see Waitrose case study p.24). So hydrocarbon integrals can provide refrigeration for an entire store, and provide significant benefits according to chains that have done so, but they do present retailers with a different concept in system architecture.

In many cases, however, the legacy architecture may not deliver the greatest environmental benefits, financial savings or operating advantages. The combination of legacy mindset and regulatory deadlines may lead commercial refrigeration into a blind alley.



Layout of a remote refrigeration system
(see box, p.18)

REMOTE AND INTEGRAL REFRIGERATION

Food retailing is typically segmented into three store formats – hypermarkets, supermarkets and convenience stores – and historically the choice of refrigeration system has been strongly influenced by store size.

In larger formats – supermarkets and hypermarkets – most companies use centralised direct expansion (DX) systems to chill their products. Supermarkets tend to have one DX system for low-temperature refrigeration (ice cream, frozen foods) and one or two DX systems for medium temperature refrigeration (meat, prepared foods, dairy, refrigerated drinks). The cooling equipment is typically housed in a separate plant room, from which high pressure F-gas is pumped as a liquid through long bespoke networks of pipes to the refrigerated displays and freezers in the store. Having cooled the cabinets by phase-change from a liquid to a vapour, pulling in the exhausted heat of the units, the refrigerant is now in gaseous form. It is compressed to condense and release its heat through a heat exchanger outside, and then returns back to the plant room. These are known as ‘remote’ systems.

‘Integral’ refrigeration describes stand-alone display cabinets and freezers that each contain their own cooling system – just like a domestic fridge, although some may not have doors. Integral units predominate in the drinks vending machines and ice cream freezers found in bars and corner shops worldwide. Most supermarkets have some integrals, even if their main system is remote. But integrals can also be used to provide refrigeration for entire stores provided the heat generated is removed to an external chiller or heat exchanger through a simple pipe containing water or brine. These are referred to as water cooled integral systems, and need no plant room.

CO₂

Modern CO₂ systems were developed and demonstrated in Nordic countries in the early years of this century in response to national taxes on HFCs, and because CO₂ works better as a refrigerant gas in cooler climates. By the time the F-gas Regulation was introduced, CO₂ systems had been demonstrated in northern Europe often as cascade systems combining CO₂ with traditional refrigerants, and manufacturers were developing new technologies such as transcritical, booster and parallel compressor systems allowing systems to operate with higher levels of efficiency and in warmer climates.

In terms of layout, CO₂ systems closely resemble the HFC remote systems they replace. They are made up of a plant room containing the cooling equipment, and long pipes that transfer the cold to the store’s display cabinets, which contain a heat exchanger and controls but no cooling equipment of their own. The main difference in operational terms is that CO₂ only works under extremely high pressure. The new generation of ‘transcritical’

systems operate at over 100 times atmospheric pressure (100 bar) or 1500psi.

The main advantage of the CO₂ system is the total elimination of HFCs from the system with associated environmental and economic benefits, including elimination of the cost of refrigerants. One of the main reasons food retailers have favoured CO₂ is that it has GWP of 1 and is therefore thought immune from future regulation. One supermarket executive has said: ‘We would like to go straight to a final solution. By using CO₂ or other natural refrigerants, we are also avoiding [the risk] that in two or three years’ time, there may be another update of the F-Gas Regulation, limiting other gases and decreasing even more the GWP³⁷.’

Another benefit of CO₂ systems is that they reject heat at high temperatures which can be recycled to produce space heating or hot water if needed. CO₂ systems produce most heat in the northern summer, however, when it is needed least, and in hotter climates, where it may not be needed at all.

That said, where the heat can be recycled, it can provide much of the space or water heating required by a supermarket – reducing heating energy costs substantially. Many in the industry believe CO₂ should be the first choice for large format supermarkets. And the rate of CO₂ growth is accelerating: the number of CO₂ stores in the EU, Norway and Switzerland has tripled to 9,000 over the past three years, representing 8% of the grocery market. Yet CO₂ systems also have some disadvantages:

- Higher capital cost: CO₂ systems are reported to be 5-10% more expensive than HFCs for larger stores, and even more for smaller systems such as those used in convenience stores³⁸.
- The high capital cost of CO₂ systems is mainly due to their centralised plant room cooling equipment, which makes them prohibitively expensive for smaller store formats with only a few display cabinets. This issue may become more challenging for CO₂ since well-established trends in retailing mean average store size in Europe is forecast to shrink 35% in the next decade³⁹.

- The efficiency of the system is reduced when operated in higher ambient temperatures.
- Operating at extremely high pressure, CO₂ systems are prone to leak unless well maintained, which reduces efficiency and raises power consumption.
- Because of their high pressure and complexity, CO₂ systems demand skilled engineers to install and maintain them, at a time when the engineering workforce is greying.

The biggest single question mark hanging over CO₂ systems, however, is their emissions performance. Some announcements of CO₂ installations claim emissions savings of 30-40%, but industry and academic experts suggest

this can only be true if the CO₂ system is compared to an old and badly maintained system that is inefficient and leaky. Independent data is limited but two studies support the idea that CO₂ systems can perform worse in terms of energy consumption and their overall emissions impact:

- Analysis by ASDA of metered data from its stores shows that its CO₂ transcritical system consumed more energy than its well-maintained HFC system running on R407F (1825 GWP) (see Figure 2 below). The CO₂ transcritical system emitted around 14% more greenhouse gas than the HFC system, as measured by TEWI (total equivalent warming impact, which includes both direct emissions from refrigerant leaks, and indirect emissions from energy consumption).

- A desk study by an independent refrigeration research institute for Emerson compared several technology options for a supermarket in Moscow⁴⁰. It compared a CO₂ cascade system and a water-cooled integral system running on conventional HFCs to a conventional system running on R404A. It found the integral HFC system consumed 12% less energy than the CO₂, and reduced TEWI by 16% more against the conventional system (the HFC system saved 41%, the CO₂ system saved 25%).

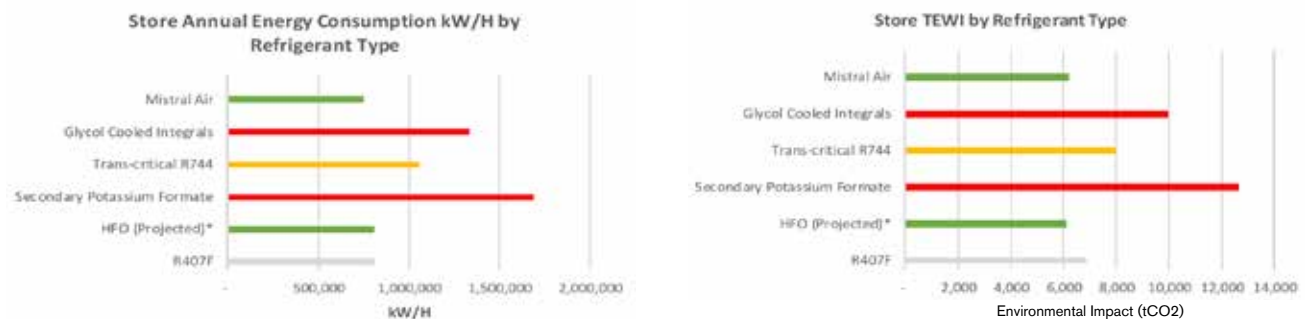


Figure 2: Energy and TEWI performance of various cooling systems. ASDA stresses that its results reflect its own specifications and technical standards, and should not be compared to similar systems trialled by others. They are, however, like-for-like comparisons based on metered data. Source: ASDA⁴¹

These are just two studies, but they do reinforce the importance of retailers conducting thorough system energy analysis before choosing a low-GWP technology. It also highlights the need to recognise the importance of auditing the efficiency of the total system, including pipework and the associated maintenance to minimise leakage, not just the refrigeration components.

SKILLS AND TRAINING

Compared to HFCs, natural refrigerants present some additional hazards, including high pressure (CO₂), flammability (hydrocarbons) and toxicity (ammonia). It is therefore vital that maintenance engineers are properly trained before working on such systems. Extraordinarily, however, in Europe there is no legal requirement for engineers to be certified in natural refrigerants as they are for F-gases.

Research conducted by Gluckman Consulting for the European Commission in 2016 suggests a significant skills gap in natural refrigerants. Of the 160,000 certified F-gas engineers registered by national governments, it appears that only tiny percentage has been trained in ammonia, CO₂ or hydrocarbons.

The authors acknowledge their results may be depressed by under-reporting; since there is no requirement to certify, there is no requirement to report. But they conclude that levels of training for natural refrigerants appear low nonetheless.

Source: European Commission⁴²

	Ammonia	CO ₂	Hydrocarbons: small hermetic systems	Hydrocarbons: larger systems (split systems, chillers)	HFO's
Training available in country (% of Member States)	71%	52%	48%	35%	20%
Proportion of certified fluorinated gas personnel trained in alternative refrigerants	2.3%	2.2%	0.7%	0.05%	0%

A survey published this year by Shecco, which promotes natural refrigerants, found almost 200 organisations offering training in Europe, and that 71% of end-users were planning to increase training over the coming year. But it also found that significant barriers exist, with end-users citing the high cost of training, lack of courses and the fact that training is not compulsory.

Marek Zgliczynski, who chairs the IEC committee considering hydrocarbon charge limits, has called for mandatory training on flammability to allow the safe and rapid expansion of natural refrigerants. This is clearly correct, but there should also be mandatory training for CO₂, where pressures in transcritical systems can reach as high as 100 bar or around 1,500psi.

Setting up a rigorous certification process for natural refrigerants looks all the more important following reports of loopholes in the F-gas certification system. Recent reports suggest that some F-gas suppliers may be failing to check engineers' certificates at the point of sale, which is their legal responsibility, and that 'alternative' forms of identification are beginning to circulate⁴³.

Without significant investment in certification and the training that underpins it, the transition to natural refrigerants could be hampered and the long-term maintenance of systems undermined.

This could be a particular problem for CO₂ systems because of their complexity compared to integral systems and the rapid increase in demand. When choosing a system retailers therefore need to consider not only the skills needed for installation, but also those needed to maintain the equipment and ensure performance and efficiency standards long term.

HYDROCARBONS

Propane (R290) was first used as a refrigerant in the early 1900s, but was fell out of favour after the invention of non-flammable chlorofluorocarbon (CFC) refrigerants in the 1930s. In the 1980s, when CFCs were found to be destroying the ozone layer, the refrigeration industry started to look at propane again.

Hydrocarbons such as propane and isobutane now predominate in domestic fridges – there are thought to be some 2 billion domestic fridges and freezers with hydrocarbon refrigerants worldwide⁴⁴ – and in stand-alone vending machines and freezers. In 2014, it was estimated that there were 2.7 million hydrocarbon bottle coolers and ice-cream freezers worldwide, and more than 2 million in Europe⁴⁵. More recently *Refrigerants Naturally!*, an alliance of Coca Cola, Pepsico, Redbull and Unilever, which is supported by Greenpeace, says it has installed 5.5 million natural refrigerant units worldwide, which it claims has avoided 33mtCO₂e⁴⁶.

But hydrocarbons can also be used to provide refrigeration throughout an entire store in several different configurations:

- Water-cooled integral system (see remote and integral box p.17) in which each display contains perhaps three refrigeration circuits that each contain less than 150g of hydrocarbons, giving the system 'type approval' (see charge limit reform p.23).
- Water-cooled integral system in which each display contains a single refrigeration circuit of more than 150g (eg 800g), but conforms to more onerous EU safety measures under EN378 (see Waitrose case study p.24).

- Remote propane system in which the propane never enters the store but is used to cool a secondary refrigerant such as brine (see Colruyt case study p.25).

This 'water-cooled hydrocarbon integral' approach has so far been adopted by only a few supermarket chains such as Waitrose in the UK. But all supermarkets have some integrals and integrals predominate in small stores⁴⁷. By one estimate, there are now 700,000 hydrocarbon integrals in European supermarkets⁴⁸, and around 500 stores that have converted wholly to hydrocarbon integrals over the past ten years.

Despite its relatively limited uptake to date, water-cooled hydrocarbon integral systems have several potential benefits:

- Hydrocarbons tend to have GWPs in low single digits (propane's GWP is 3), are considered a natural refrigerant, and systems running on hydrocarbons have a good safety record.
- Hydrocarbons are efficient refrigerants and operate well in warmer climates.
- The refrigeration circuits are hermetically sealed in the factory, and operate at low pressure, meaning leakage rates are low; important for overall system efficiency.

- The integral units are small and modular, so in the event of equipment failure, the contents of only one display case are likely to be at risk.
- The units are self-contained and essentially 'plug and play', making the systems quick to install or move, and require little maintenance.
- The system is simple to install, and installers require no refrigeration certification.

The biggest benefit of water cooled integrals may be a reduction in TEWI due to energy efficiency. According to Emerson, which manufactures components for integral units, this approach can halve a supermarket's refrigeration TEWI compared to a standard remote HFC system. As Table 1 shows, this results from a combination of lower energy consumption and zero impact from direct emissions: leakage rates are lower, and propane has a GWP of just 3. Their data shows that the TEWI reduction is 8% greater than that of CO₂, and almost double that of a remote system running on HFC/HFO blends. This analysis has not been independently tested, but if the numbers are even broadly correct, they suggest water-cooled integrals offer greater overall emissions reduction than other low-GWP technologies.

TEWI, tCO ₂	Remote HFC	Remote HFO	Remote CO ₂ Boost	Integral HC
Refrigerants	R404A/ R404A	R448A/ R448A	R744/R744	(R290)
MT Power	1250	1240	1475	1256
LT Power	335	369	205	215
MT Leak	1075	395	0	0
LT Leak	260	93	0	0
TEWI	2920	2097	1680	1471
Saving		28%	42%	50%

Table 1: TEWI comparison of supermarket refrigeration systems.

Source: Emerson⁴⁹

Another advantage of water cooled integrals – in smaller store formats at least – appears to be financial. An analysis conducted by the independent refrigeration research institute ILK Dresden for Emerson illustrates that in a discount store with ten display cases, integral systems would be €29,000 cheaper to install, and over ten years would save a further €12,000 on energy and €6,500 on maintenance (see tables pp.21-22)⁵⁰. The lower capital cost was an important factor for the subject of the study, a major European discount chain that is converting its stores to water cooled integrals.

Hydrocarbons also have some distinct disadvantages, however:

- Hydrocarbon refrigerants are highly flammable (classified as A3), and this is a competitive disadvantage, although the problem is largely one of perception, since the safety record of hydrocarbon systems is good. Hydrocarbons compete with CO₂, which is not flammable, and a new class of HFO refrigerant gases that are only mildly flammable (A2L) and have GWPs low enough to meet the F-gas Regulation – such as Honeywell’s Solstice L40X (R455A), which has a GWP of 148. Some HFOs are not yet produced in large quantities, and most are currently more expensive than the HFCs they are intended to replace.

- Existing safety standards for ‘type approved’ equipment limits the charge of hydrocarbon in each refrigerant circuit to 150g, which is too little to refrigerate a full sized supermarket cabinet. This means manufacturers are forced to build integral cabinets with up to three circuits each to secure type approval, or to build single circuit cabinets but comply with a more onerous set of EU safety standards. Both options can increase cost. It is widely expected, however, that the charge limit will be raised from 150g to 500g by international agreement in early 2018 (see charge limit reform p.23).

Investment ten years, annuity method €	CO ₂	R290 Integral	Savings
Machine room and ventilation	7,513	–	–
Cold energy production, rack, unit	45,104	1,407	43,697
Dry cooler/gas cooler	9,965	16,998	7,033
Display cases	60,948	73,843	12,895
Refrigeration distribution, piping	7,034	11,254	4,220
Control system	6,448	6,448	–
Other positions for technology installation	3,282	2,139	1,143
Total cost	140,294	112,089	20,692
Planning (simplified assumption)	2,000	1,000	1,000
Total cost including planning	142,294	113,089	29,205

Table 2: Comparative costs of remote CO₂ and propane integral systems in discount store. Source Emerson.

Ten-year life cycle cost and savings, average ten display case per store (k€)	System A CO ₂ Remote	R290 Integral	Savings
Investment	142	113	29
Energy	149	140	9
Service, maintenance, insurance	35	29	6
Decommissioning	6	4	2
Three days earlier opening	–	–	2
Cost of shut down due to refurbishment	–	–	2
Loss of performance due to leaks	–	–	1
Ten years saving per store	333	286	51

Table 3: Comparative total costs of remote CO₂ and propane integral systems in a discount store. Source: Emerson.

- While hydrocarbons are highly efficient refrigerants – good at absorbing and rejecting heat with little energy input – water-cooled hydrocarbon integral systems lose efficiency through the plate heat exchanger heat transfer in each cabinet, and cooling loop pumping energy rises with store size.

- While CO₂ struggles to scale down in size, hydrocarbon integrals struggle to scale up, because most of the capital cost is contained in the display cabinets – so increasing store size typically worsens the business case. The supermarket chains that have opted for water-cooled integrals so far tend to have smaller store formats. Those that have opted for CO₂ tend to be larger – although not the very largest (ASDA, for instance, has opted for the Mistral

system with air as a secondary refrigerant, see case study). Waitrose, however, has installed water-cooled integrals in stores of all sizes – large and small (see case study p.24).

It is perhaps not surprising that commercial claims about the TEWI savings of various natural refrigerant gases are inconsistent or incompatible. More worryingly, there appear to be no independent high-level studies comparing the energy and TEWI of refrigeration systems on a like-for-like basis, let alone comparing wider criteria such as system architecture and integration with local energy networks. Given the speed with which European retailers are required to replace HFC systems, filling this gap should be an urgent priority.



Photo courtesy of Emerson

CHARGE LIMIT REFORM

In Europe, integral cabinets are currently limited to 150g of hydrocarbon per refrigeration circuit to win 'type approval', meaning the unit is considered safe by design. Above this level commercial fridges with a single circuit containing a larger hydrocarbon charge can also be manufactured and installed – Waitrose units have between 600g and 800g, for example – but only under a more onerous set of EU safety standards (EN378) that require additional leak simulation testing and an on-site risk assessment.

150g is too little to cool a full-sized supermarket cabinet, however, and manufacturers have built integrals with up to three circuits each to provide sufficient cooling and secure type approval, but this increases complexity and cost.

The International Electrotechnical Committee, one of three related organizations (IEC, ISO, ITU) that develop international standards is expected to approve an increase in the hydrocarbon charge limit from 150g to 500g in early 2018, combined with more stringent safety measures, meaning that integrals containing up to 500g per circuit will be able to win type approval without compromising safety. This should allow manufacturers to simplify their designs and reduce costs, so improving the economics of the water-cooled hydrocarbon integral approach.

Marek Zgliczynski, chairman of the IEC committee co-ordinating the reform, says the change is necessary to help speed up the implementation of the Kigali Amendment and the shift to natural refrigerants, particularly in developing countries⁵¹.



Courtesy of Honeywell Refrigerants

HFO REFRIGERANTS

Hydro-fluoro-olefins (HFOs) have been developed recently as refrigerant gases to provide similar performance to HFCs but with lower GWPs. Most are rated 'mildly flammable', with GWPs ranging from 140 to 700 (although some are as low as 6). They can be used on their own or blended with HFCs to produce non-flammable refrigerants with GWPs of 600-1,400.

HFOs have been trialled in both remote and integral commercial refrigeration systems:

- Waitrose installed a chilled water plant using HFO R1234ze with a GWP of 7 at its store in Bromley, and found that compared to an identical plant using propane it consumed 22% less energy. The company has not pursued the technology, however, since its standard system can in many cases operate without a water chiller (see case study, pp.24), and where one is needed, it prefers to use a natural refrigerant.

- The French supermarket company Groupe Auchan has installed a remote CO₂/HFO blend cascade system at a new hypermarket on the outskirts of Paris, using a Honeywell refrigerant marketed as Solstice N13 (R450A). This is a blend of HFO R1234ze and R134a that is non-flammable and has a GWP of 604. Compared to the company's standard system (R134a, glycol water and CO₂), the company expects electricity consumption to be similar, but estimates emissions savings of 90tCO₂e/year⁵³.

HFOs are more expensive than HFCs, although the EU HFC phase-down may soon change this. But a persistent concern among end-users is that HFOs remain vulnerable to future regulatory tightening.

5: CASE STUDIES

WAITROSE: WATER-COOLED HYDROCARBON INTEGRALS⁵⁴

Waitrose was an early-adopter of hydrocarbon integrals. Ten years ago, when many supermarkets were considering CO₂ systems, Waitrose was more concerned about leakage. 'If we were struggling to control leaks with R404', recalls the company's refrigeration manager, 'how much worse could [high pressure] CO₂ be?'

Waitrose opted for integrals running on propane or propene, and has now converted 133 of its 292 stores, including 37 of its 50 convenience stores. Most of Waitrose's stores measure up to 2,300m² (25,000ft²), but the company has extended the system both to its largest store (3,700m² / 40,000ft²), and some of its smallest (280m² / 3,000ft²).

The third generation system that Waitrose has installed comprises hydrocarbon integrals for store cabinets with a water cooling loop connected to an external dry air cooler – reducing the power needed to cool the water.

Compared to its previous remote system running on R404A, each converted store saves 7% of its electricity and 60% of its gas, since the waste heat from the cooling loop is used to provide space heating. This reduces operating costs by £65,000 per store per year, and the capital cost of each new system saves the company around £85,000. The hydrocarbon leakage rate is 2.9% and each store reduces total carbon emissions by around 700tCO₂e per year from energy efficiency and reduced leakage. The system is also considered 99.6% reliable.

THE THIRD GENERATION SYSTEM THAT WAITROSE HAS INSTALLED COMPRISES HYDROCARBON INTEGRALS FOR STORE CABINETS WITH A WATER COOLING LOOP CONNECTED TO AN EXTERNAL DRY AIR COOLER, REDUCING THE POWER NEEDED TO COOL THE WATER.



COLRUYT: REMOTE PROPANE SYSTEM

Hydrocarbon refrigerants are used in billions of domestic fridges and integral display cabinets worldwide, and in increasing numbers of water-cooled integral systems (see Waitrose case study). They are also being trialled as the main refrigerant in some remote cooling systems, such as the system being rolled out by Colruyt Group in Belgium⁵⁵.

Colruyt decided in 2014 to eliminate all HFCs from its estate of almost 240 supermarkets and 140 smaller store formats. HFC emissions currently account for 12% of the company's total emissions.

Colruyt considered CO₂ but opted for remote hydrocarbon systems (mainly propane and some propene). The company's stores are unusual in that they contain no refrigerated display cabinets, but cold rooms where customers select fruit, vegetables and other chilled products. The cold room is kept at temperature by air cooled by remote chillers, each containing 2.5kg of

propane. Cold air is prevented from escaping through the door by an 'air curtain'. The smaller store formats need one chiller, supermarkets two, and all stores have a spare for emergencies. Frozen products are kept in standalone integral freezers.

OTHER FOOD RETAILERS THAT HAVE TRIALLED REMOTE PROPANE SYSTEMS REPORT THEY HAVE REDUCED ELECTRICITY CONSUMPTION BY 10%, HEATING DEMAND BY 100%, AND REDUCED CO₂ EMISSIONS BY 30%⁵⁷

Colruyt is rolling out the remote hydrocarbon systems across its estate and expects all stores to have been converted by 2027. Combined with its conversion to renewable electricity, this means all its emissions from cooling will have been eliminated. It is also improving store insulation and testing heat recovery in two stores so that all heating will be provided by waste heat from the cooling system.

Other food retailers that have trialled remote propane systems report they have reduced electricity consumption by 10%, heating demand by 100%, and reduced CO₂ emissions by 30%⁵⁶.



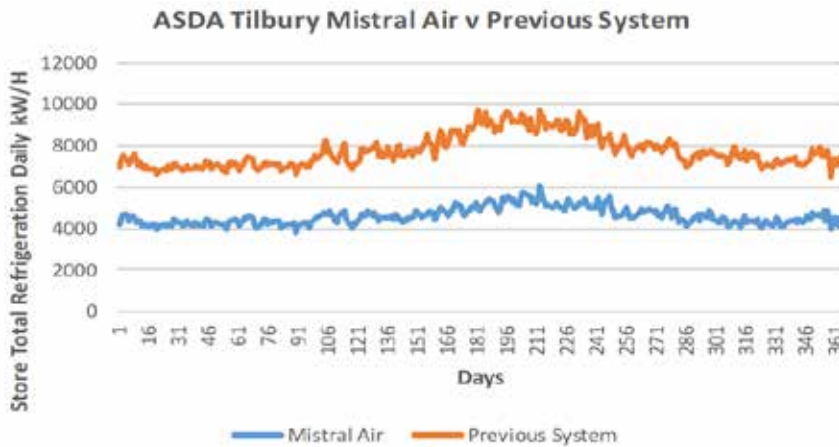
ASDA: MISTRAL AIR COOLING

The Mistral cooling system developed by ASDA replaces much of the refrigerant gas of a conventional remote system with air, and this produces big savings in energy, emissions and cost. As in a conventional system, cold is generated in a plant room. The difference is that the cold refrigerant gas is pumped not to the cabinets in the store, but rather to a large air handling unit on the roof directly above the aisles. Here the cold is transferred to air through a heat exchanger, and the cold air blown through ducting down to the cabinets below.

Despite adding an intermediate heat exchange to the process, this arrangement increases system efficiency. One reason is that it shortens the distance that the refrigerant has to be pumped; another is that each cabinet no longer needs its own individual fan; and a third is that much less cold air spills out of the cabinets, even without doors, meaning the store can save on heating. At present ASDA uses R407F (1825 GWP), but in principle the system could operate with any natural refrigerant – ammonia, CO2 or propane. In any case, the Mistral

system requires about 40% less refrigerant by weight than a conventional system.

ASDA has converted a dozen of its stores to Mistral so far, and has achieved large energy savings. The graph below shows that refrigeration energy saving (excluding heating) at its Tilbury store is 33%.



ASDA has also found the system provides several operational benefits:

- Because the display cabinets contain no refrigeration equipment, and suffer no condensation, they last much longer, nor is there any need for maintenance work on the shop floor;
- Since there is no condensation in the cabinets, there can be no leaks from drainage pipes, so no danger of water on the floor causing a slip hazard;
- Significant return on investment, in which reduced capital expenditure due to longer equipment life is even more significant than the energy savings.
- The system requires space plant room and ducting, however, and ideally a flat-roofed building, so it could prove difficult to scale down to smaller store formats.



DEEPER INTEGRATION IN ENERGY SYSTEMS

SUPERMARKET REFRIGERATION AND DISTRICT HEATING

Fridges inevitably produce waste heat, and in recent years supermarkets have begun to install equipment to recycle this to provide space heating or hot water in the store. Doing so reduces the natural gas burned for heating and so reduces cost and carbon emissions (see Waitrose case study p.24). But this may only represent a fraction of the potential gains that could be achieved by integrating supermarket refrigeration more closely into local energy systems.

One idea is to use waste heat from supermarket refrigeration not only in store but also through a district heating network to warm other buildings nearby. Twenty Danish supermarkets have adopted this approach, and one reports that it has reduced its gas bill by \$31,000 per year and carbon dioxide emissions by 34%. It is a neat way of decarbonising local heat: the supermarket's cooling is electrically driven and needs to happen in any case, and waste heat is an inevitable by-product, so in a sense low carbon electricity is converted into low carbon heat with cooling provided along the way. It also gives the supermarket an additional source of income.

RENEWABLE INTEGRATION AND GRID BALANCING

Storing energy thermally rather than in electrical batteries allows us to make use of waste and renewable sources of heat and cold that would otherwise go unexploited, and also to convert 'wrong time' energy – such as wind or nuclear power generated at night when demand is low – into low carbon peak time thermal energy services. TES can have more than 30% lower capital cost and up to 90% lower maintenance cost than a battery-electric storage system.

Supermarket refrigeration could also help raise the amount of renewable power that can be absorbed by electricity grids. That's because while wind turbines and solar panels are intermittent producers, fridges are intermittent consumers.

Supermarket refrigeration systems are typically designed to match the cooling load on the hottest day in ten years, and may have spare capacity of up to 70%⁵⁷ that could be used to absorb excess wind or solar power and store it as cold and heat. By one estimate, if all of Germany's spare cooling compressor capacity were used in this way it could absorb 30% of Europe's wind output⁵⁸.

LOAD-SHIFTING

The TES system runs during off-peak hours and enough energy is stored to meet the cooling demands during the on-peak hours of operation, thus allowing for a much smaller refrigeration system to meet the load and eliminating expensive electrical consumption during on-peak hours.

The TES system is allowed to operate 24 hours a day and the stored energy is used during periods where electrical demand charges apply, eliminating such charges and reducing energy costs.

So in times of excess renewable production – which in some markets increasingly produce negative wholesale electricity prices – supermarket cooling systems could be used to produce and store both cold and heat for later use. It is frustrating to note that this idea was proposed in the Netherlands a decade ago, but has yet to make serious commercial inroads worldwide⁵⁹.

If supermarkets were already supplying heat to a district heating network, their returns would be improved by being able to absorb and store low or negative cost power. This arrangement would also allow more renewable energy to be absorbed by the grid than would otherwise be possible; decarbonise greater amounts of cooling and heat load; and improve resilience.

TOWARDS THE ZERO NET ENERGY SUPERMARKET

The ultimate aim must be to make supermarkets zero net energy (ZNE) buildings – those that produce more energy than they consume over the course of a year. There are now 53 certified ZNE buildings in the US, but none of them is a supermarket⁶¹.

The problem is that refrigeration consumes so much energy, and cold air spillage from display cabinets, which often means the store has to be heated to compensate, even if the temperature outside is warm.

The first step towards ZNE supermarkets is to recover the waste heat given off by refrigeration to provide space and water and heating and the next to integrate with district heat networks (see case studies pp. 24-25). But to become ZNE, supermarkets will also have to develop significant amounts of renewable energy onsite.

Although no supermarkets have yet achieved ZNE status, one retail store with significant amounts of refrigeration has done so: Walgreens in Evanston, Illinois, which opened in 2013.

The store combines 850 rooftop solar panels, two small wind turbines and a ground-source heat pump to produce 220,000kWh per year. The HVAC system is integrated with the ground-source heat pump to store energy underground until needed, and with the CO2 refrigeration system, from which it recovers waste heat for space and water heating. The store's refrigeration load is much smaller than that of a supermarket, but it does suggest that ZNE supermarkets are achievable.

6: MEASURE TWICE, CUT ONCE.

The fate of HFCs in Europe has now been sealed by legislation and international agreement, giving supermarkets an imperative to act. Some argue that it is economically sensible to delay replacing existing equipment by increasing leakage tightness as much as possible and bear the rising cost of HFCs or retrofit with a lower GWP refrigerant (but still several hundred times higher than a natural refrigerant) in order to sweat current assets for as long as possible. Others see value in holding back while their competitors take the risks associated with early adoption of new technologies.

But the reality is that doing nothing puts the business at risk from shortages of refrigerant supply from 2018. And perhaps more importantly, it is a short-sighted corporate decision and out of step with the urgency of our wider responsibilities under the Paris Agreement and the Sustainable Development Goals:

- The most sustainable companies now exceed their peers in stock market value and financial performance;
- Climate change is itself an operational risk: rising temperatures will increase the operating costs of businesses with heavy refrigeration loads, and such companies have greater than average self-interest in mitigating climate change.

Given the significant financial implications, and the inherent conservatism of the sector, the challenge is to translate a 'needs must' approach into a value creation opportunity. Regulatory compliance should be taken as a chance to assess the wide range of system architecture and technology options available.

Retailers who seize this opportunity could maximise the corporate, economic and environmental benefits today and for the life of the system. A study of UK supermarkets found that several major chains have steadily reduced their energy intensity and GHG emissions over the past decade through voluntary corporate goals and investments in technologies expected to have a positive financial return (Sullivan and Gouldson 2013). But now is the time for step-change decisions.

The potential for those food retailers prepared to think more broadly about the role refrigeration plays in their business is enormous. With integration in to district heating or thermal networks they could not only cut costs and emissions but also develop new sources of revenue. By considering their refrigeration systems as energy storage devices they could also take advantage of cheap or even negatively priced excess renewable energy (see supermarket refrigeration and district heating p.27).

But in commercial refrigeration, such decisions must overcome deep cultural barriers, such as the 'energy-efficiency paradox' – meaning the tendency of businesses to eschew investments that have a higher upfront cost than the alternative, but which are expected to save money in the long run due to reduced energy costs (Klemick and Wolverson 2013; Jaffe and Stavins 1994).

This paradox may have a variety of causes: return on investment, market failures, short-termist management outlook and trade-offs with other valued system attributes like reliability and customer appeal.

For retailers, the barriers most often cited are imperfect information and uncertainty about the performance of unfamiliar technologies. It requires a great deal of time and effort for users to acquire the information necessary to compare the energy performance of different products and system architectures. As a result, the market for refrigeration has historically focused primarily on purchase price and return on investment and pays less attention to the broader benefits of purchasing energy-efficient products. If retailers were properly informed, these factors could accelerate their response to the regulations.

Technologies are available to monitor the energy consumption and performance of refrigeration systems once installed. But supermarkets have expressed their concern that it is hard to obtain reliable information about new and emerging technologies, and remain doubtful about their 'real world' performance. This scepticism is increased by the high degree of variance across stores, and the view that refrigeration performance is location, layout and climate specific. 'Manufacturers advertise a certain capability at a certain set of conditions, and if you happen to be there it works as advertised, but in my case that very seldom happens. It's good baseline information, but you have to really extrapolate [from it].'

Supermarkets highlight the potential trade-offs between energy efficiency and other important technology attributes, including store-specific factors like climate and space constraints, customer appeal, reliability and maintenance, and refrigerant management. But with proper information these need not be a barrier to more efficient choices; rather a spur to invest in technologies with lower energy consumption and broader business benefits.

It is clear that robust data and reliable comparisons are essential. But if retailers are to make better informed judgments about the overall impact of their refrigeration choices on the environment and their businesses, they will need to consider more than upfront cost and the latest regulatory cattle-prod. Their choice of refrigeration system is not simply a matter of satisfying the F-gas Regulation, and will affect their profitability directly through cost, and also through such issues as safety, operation, duration of store closures, future flexibility and skills.

The choice of refrigeration system will also greatly affect supermarkets' wider responsibilities to the environment, sustainable development and the Global Goals. A report published by the University of Birmingham Energy Institute has shown how refrigeration materially impacts many of the Goals, including (SDG 1) poverty, (2) hunger, (3) health, (7) affordable and clean energy, (8) economic growth, (9) innovation and infrastructure, (11) sustainable cities and communities, (12) responsible consumption and of course (14) climate change (see supermarkets, clean cold and sustainable development goals p.10).

We suggest supermarkets consider a wider range of criteria when selecting refrigeration technologies and architectures, which address business resilience, sustainability and the Global Goals. While not complete, below is an example of the criteria that could produce better decisions today and deliver progress on wider societal challenges within an acceptable timeframe:

GLOBAL GOALS:

SUSTAINABLE CITIES

CLIMATE CHANGE

ENERGY EFFICIENCY (DISTRICT, NOT JUST INTERNALLY)

NATURAL RESOURCE MANAGEMENT

ACCESS TO AFFORDABLE, SAFE FOOD FOR ALL

MINIMISE FOOD LOSS

END OF LIFE MANAGEMENT

CREATE SUSTAINABLE AND AFFORDABLE INFRASTRUCTURE

ADVANCE ECONOMIC STABILITY AND INCLUSIVITY

BUSINESS RESILIENCE:

COMPLIANCE WITH REGULATIONS AND SAFETY

ALIGNMENT WITH SUSTAINABLE DEVELOPMENT GOALS AND TIMELINE

- RESPONSIBLE BRAND

INSTALLATION DISRUPTION/STORE CLOSURE

WHOLE OF LIFE COST AND ROI

- CAPITAL COST
- TRUE SYSTEM ENERGY / OPEX COST
- DOWNTIME/LOSS OF PRODUCT
- DECOMMISSIONING

PERFORMANCE / RELIABILITY

- SYSTEM COMPLEXITY
- RISK OF LEAKS
- TEMPERATURE CONTROL - SEASONALITY

SKILLS RISKS

FUTURE FLEXIBILITY

- STORE REFURBISHMENT
- INTEGRATION WITH RENEWABLES / OFF-GRID ENERGY SOLUTIONS INCLUDING THERMAL ENERGY STORAGE
- ABILITY TO TRIAL OR INTRODUCE NEW TECHNOLOGIES

NET ZERO ENERGY

- NEW REVENUE STREAMS, ENERGY STORAGE, FREE EXCESS RENEWABLE POWER

7: KIGALI, DEVELOPING COUNTRIES AND NATURAL REFRIGERANTS.

Nowhere is demand for refrigeration growing more strongly than in developing economies. The Kigali Amendment to the Montreal Protocol, agreed in October 2016, commits 197 countries to phase down HFCs to 15-20% of their baseline by 2050⁶². UN programmes associated with Kigali will have a profound impact not only on the speed at which HFCs are eliminated, but also the wider outcomes in terms of energy efficiency and overall emissions. It is therefore vital that they focus not only on replacing HFCs with natural refrigerants, but also on the wider objective of clean cold.

The reasons for the strength of refrigeration demand growth in developing countries have been explored in several reports from the University of Birmingham Energy Institute⁶³. In summary, the reasons comprise:

- **Need:** developing countries have far less cooling infrastructure than developed, with major impacts on food waste, food safety and health. For example, the lack of adequate 'cold chains' of refrigerated warehouses and transport causes two million vaccine preventable deaths each year, and the loss of 200 million tonnes of food – some 14% of the food supply in developing countries. This in turn causes massive waste of water and other agricultural resources. It is estimated that 420,000 people die every year from contaminated food, resulting in the loss of 33 million healthy life years. A University of Birmingham report has shown how cooling impacts all 17 of the Global Goals (see box above)⁶⁴.

- **Demographics:** developing countries are getting richer and more urban. The Asia Pacific middle class is forecast to grow six-fold by 2030 to 3 billion people⁶⁵, whose spending power could rise to \$33 trillion⁶⁶. Their lifestyles – changing diets, improved healthcare, online data and air conditioning – will be built on cold. Almost 90% of Chinese households now own a fridge but only 30% in India – where there is clearly huge pent-up demand⁶⁷. The projected rise in fridge electricity consumption in developing countries from 2005 to 2030⁶⁸ equates to the entire generating capacity of Belgium and Bulgaria combined⁶⁹, and could almost double annual indirect (energy) emissions from this source to 450mtCO₂ per year by 2030⁷⁰.

- **Climate change:** As global temperatures continue to rise the demand for cooling is bound to increase, to preserve food supplies, food safety, health and comfort.

In this context it is important to see such programmes as the Kigali Cooling Efficiency Programme (K-CEP) and Cooling for All which do not simply focus on replacing HFCs with natural refrigerants, but also the broader energy, emissions and economic outcomes.

Key challenges include:

- Hot climates demand efficient refrigerants that have no 'equator'.
- Energy matters as much as refrigerant, especially in countries such as India with carbon-intensive grid electricity; rigorous TEWI analysis is essential to achieve the greatest possible overall emissions reductions in developing countries, because that is where refrigeration demand is growing fastest.

- Store sizes are forecast to shrink in future in Europe, and this trend may be repeated elsewhere.
- Ease of maintenance in countries that may not have a large skilled engineering workforce.
- Future integration of renewable energy.

It is interesting to note that Marek Zgliczynski, chairman of the IEC committee overseeing the likely rise in charge limits from 150g to 500g for hydrocarbons and accompanying safety measures, has said the change is necessary to help speed up the implementation of the Kigali Amendment and the shift to natural refrigerants in developing countries.

8: CONCLUSIONS

‘Every three years...there is going to be a step down in the [HFC supply] quota. The cliff [comes in 2018]... In theory, it looks like R404A is still available and prices, until this year maybe, have been bearable, but are we living with a false sense of security? Do we think we are on solid ground when, in fact, the cliff is right ahead?’

It is clear from the industry that food retailers are not planning to replace high-GWP refrigeration systems quickly enough; indeed some are still buying R404A systems. Where they are converting, research suggests that many retailers may be choosing CO₂ because they believe its GWP of 1 protects them from any future tightening of regulations, and because the technology and systems architecture looks similar to their existing systems, even when the energy, TEWI and economic outcomes may be worse than for readily available alternatives.

‘The CO₂ boom is driven by phase-down fatigue. The chemical industry says it’s developing new refrigerants, but end-users have been round the track several times and heard it all before. They now want something future proof and immune from future regulatory change.’

The industry’s reaction suggests that it might have been more effective to calibrate the F-gas Regulation in terms of TEWI reduction, rather than simply refrigerant GWP or HFC supply. Such an approach might have involved a great deal of work to assess and verify the performance of each retailer’s refrigeration systems, and be vulnerable to loopholes, but it would at least have been technology neutral and forced retailers to seek the best outcome for the climate. The F-gas Regulation is here to stay, however, as are the ramifications of the Kigali

Amendment, which means it is up to retailers to conduct their own thorough energy, TEWI and business impact analysis before choosing a low-GWP refrigerant based system. Given the lifespan of the equipment, not doing so might lead them to choose a system that fails to produce the best outcome for the climate or their bottom line, as well as putting them at risk from potential skills shortages.

‘Skills would be massive challenge if there were a big surge in CO₂ transcritical demand. Not supply or installation so much, but maintenance yes. Service is the biggest challenge. There is skills shortage, don’t let anyone tell you any different.’

Another key challenge is that while there are many reports on individual technologies, and some site-specific comparative analyses produced by manufacturers or end-users, there is not yet an authoritative and wholly independent analysis benchmarking different system architectures and refrigerants.

‘I haven’t seen any like for like lifecycle comparison. It is difficult to access data. Hydrocarbons should be very efficient in comparison, but I haven’t seen a study on this. There is definitely a gap in terms of being able to compare and validate different approaches.’

The challenge facing European retailers is compounded by the fact that the industry as a whole is lagging behind the phase-down schedule. HFC prices have already risen five-fold in 2017, and could spike 20 times in 2018, when supplies will contract sharply, which could prompt hasty rather than considered decision making.

‘We assumed that, once the F-Gas regulation was announced, people would be logical in their approach and take a reasonably long-term view. Our model assumes that, in 2016, quite a chunk of retrofit would have taken place followed by another big chunk in 2017 so, by 2020 when we hit the service ban, a significant proportion of the R404A bank would have been retrofitted. The problem is that nothing much happened in 2016 because prices were low. I’m sensing acceleration certainly in the UK now, but I worry about Germany, France, and so on, who are not reacting to this opportunity as quickly.’

If commercial refrigeration is to be sustainable, we need a holistic approach that welcomes and expedites the transfer from HFCs to natural refrigerants, but does so in the wider context of the Paris Agreement and Global Goals. It is vital that supermarkets consider the impacts of this transition on energy consumption and their long-term business planning, otherwise they may have addressed one problem but created another for themselves. They may also miss emerging opportunities to add new revenue streams, and take advantage of negatively priced excess renewable power.

These issues matter not only in Europe, where the F-gas Regulation applies, but also throughout the developing world. Where mature markets lead, other Kigali signatories may follow, and since cooling demand is growing fastest in developing countries, the environmental and financial cost of any missteps would be greatly amplified.

9: RECOMMENDATIONS

It is in the interests both of retailers and the environment that companies should be motivated to bring forward investment into retrofitting and upgrading stores. It is equally essential that government recognises the role it has to play.

While refrigeration is a central pillar of our society and is energy intensive, in Britain over the past decade, research into Refrigeration and Air Conditioning (RAC) has attracted an average of just £2.2 million in public funding each year, scarcely 0.2% of total UK funding for engineering research, an order of magnitude lower, and despite the fact that cooling is responsible for 7% of all greenhouse gas emissions worldwide⁷². Across the EU as a whole, annual public RAC R&D funding has averaged £23.5 million per year or 0.22%. These levels of funding fall far short of matching the environmental and economic importance of cooling.

The EU and national governments need to match regulation around refrigeration with support, as it does for all other sectors. It should:

- Support research and analysis by industry trade bodies and independent research organisations so that retailers can make informed and rational choices based on robust, comparative performance information.

This should include a matrix of measures reflecting whole of system and whole of life performance of different refrigerants, technologies, architectures and approaches.

- Develop targets to guide a clear roadmap for sustainable refrigeration, not just low GWP refrigerants, to guide retailers' long-term strategy. This needs to be about a total system level solution, rather than just more efficient refrigerators, with proper like-for-like assessments to inform industry.
- Provide incentives, not just penalties, for end-users to accelerate transition to low-impact, not just natural refrigeration, solutions. This need not necessarily involve subsidies or scrappage schemes. Governments could, for example, consider increasing depreciation allowances for investments in new refrigeration systems that are both low-GWP and demonstrably produce the best energy efficiency outcome for the proposed location.
- Support research and development into deeper integration of supermarket refrigeration into electricity grids and district heating networks.

- Mandate certification and training in natural refrigerants, and provide enough the funding to develop the skilled workforce required to support an accelerated transition.

- Increase investment into low-impact and sustainable cooling technologies and applications.

THE EU AND NATIONAL GOVERNMENTS NEED TO MATCH REGULATION AROUND REFRIGERATION WITH SUPPORT, AS IT DOES FOR ALL OTHER SECTORS.

Segmentation by GWP	Type	Main refrigerant(s)	GWP	ASHRAE class	Pressure
NH3	Natural	R717	0	B2L	MP
CO2		R744	1	A1	HP
Hydrocarbons		R290	3	A3	MP
		R600	5	A3	MP
		Other	5	A3	MP
HFO<10	HFO	R1234yf	4	A2L	LP
		R1234ze	6	A2L	LP
		Other	6	A2L	LP
HFO B300	HFO	R454A	238	A2L	MP
		XL20	148	A2L	MP
		HDR110	145	A2L	MP
		R444B	295	A2L	MP
HFO B600	HFO	R446A	466	A2L	HP
		R454B	461	A2L	HP
		R447A	583	A2L	HP
		R513A	630	A1	LP
		R450A	547	A1	LP
HFC<700	HFC	R32	675	A2L	HP
HFC<1500	HFC	R134a	1,422	A1	LP
HFC&HFO B <1700	HFO	R448A	1,273	A1	MP
		R449A	1,397	A1	MP
		R452A	1,945	A1	MP
		R240fa	1,030	A2L	HP
	HFC	R407F	1,674	A1	MP
		R407C	1,610	A1	MP
HFC=2000	HFC	R410A	2,088	A1	HP
		4407A	2,107	A1	MP
HFC=4000	HFC	R404A	3,922	A1	MP
Others	HCFC	R22	1,810	A1	MP
	CFC	R12	10,900	A1	MP

Table 4: Properties of various refrigerant gases.

ENDNOTES

- 1 Clean Cold and the Global Goals, University of Birmingham, January 2017
- 2 *Sustaining the Future – Inspiring a Generation*, Graeme Maidment, IOR, January 2014, http://www.ior.org.uk/app/images/downloads/Maidment9thJanuary2014LSBUggmFinalVersion_USE.pdf
- 3 https://www.epa.gov/sites/production/files/documents/gc_averagestoreprofile_final_june_2011_revised_1.pdf
- 4 <http://k-cep.org/why-cooling/>
- 5 *Sustaining the Future – Inspiring a Generation*, Graeme Maidment, IOR, January 2014, http://www.ior.org.uk/app/images/downloads/Maidment9thJanuary2014LSBUggmFinalVersion_USE.pdf
- 6 <http://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/india-third-agricultural-revolution-birmingham-energy-institute.pdf>
- 7 <https://globenewswire.com/news-release/2017/04/26/971988/0/en/Commercial-Refrigeration-Equipment-Market-size-worth-61-44-billion-by-2021-Zion-Market-Research.html>
- 8 <http://www.coolingpost.com/world-news/cooling-for-all-is-new-objective/>
- 10 http://hydrocarbons21.com/articles/2659/propane_as_refrigerant_in_food_retailing
- 11 <https://www.slideshare.net/gadgetman17/shecco-market-policy-trends-for-natural-refrigerants>
- 12 <https://www.slideshare.net/gadgetman17/shecco-market-policy-trends-for-natural-refrigerants>
- 13 Shecco, personal communication
- 14 <http://publication.shecco.com/publications/view/oems-flock-to-hydrocarbons>
- 15 <http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/EPEE%20side-event%20OEWG%20Bangkok%202017.pdf>
- 16 <https://publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/596/596.pdf>
- 17 *The role of refrigeration in worldwide nutrition*, International Institute of Refrigeration, June 2009, http://www.iifir.org/userfiles/file/publications/notes/NoteFood_05_EN.pdf
- 18 http://blog.schneider-electric.com/sustainability/2017/08/03/envisioning-sustainable-future-innovation/#_ftn1
- 19 <http://www.unep.org/africa/news/kigali-amendment-montreal-protocol-another-global-commitment-stop-climate-change>
- 20 <http://conf.montreal-protocol.org/meeting/oewg/oewg-39/report/English/OEWG-39-5E.pdf?Mobile=1&Source=%2Fmeeting%2Foewg%2Foewg%2D39%2Freport%2F%5FLayouts%2F15%2Fmobile%2Fview%2Easp%3FList%3D88f7e250%2D0994%2D41cb%2D91ea%2D4dd533a420dc%26View%3Ddc9a9b2f%2D6ad7%2D431e%2Da31d%2D504804c7f615%26wdFCCState%3D1>
- 21 Green Cooling Initiative, German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, <http://www.green-cooling-initiative.org/> <https://www.giz.de/expertise/html/3372.html>
- 22 EIA, Chilling Facts VII, report [<https://eia-international.org/wp-content/uploads/EIA-Chilling-Facts-VI-FINAL.pdf>].
- 23 <http://k-cep.org/why-cooling/>
- 24 <http://www.gluckmanconsulting.com/wp-content/uploads/2014/12/IS-26-Ban-Summary.pdf>
- 25 <http://www.gluckmanconsulting.com/wp-content/uploads/2014/12/IS-2-Commercial-Refrigeration.pdf>
- 26 <http://www.gluckmanconsulting.com/wp-content/uploads/2015/07/IS-28-The-Phase-Down-Process-v2.pdf> <https://eia-international.org/wp-content/uploads/Chilling-Facts-VII-FINAL.pdf>
- 27 <http://www.coolingpost.com/uk-news/r404a-units-still-sell-despite-warnings/>
- 28 The analysis was conducted by the Environmental Investigation Agency (EIA) for its EIA Chilling Facts VII report [<https://eia-international.org/wp-content/uploads/EIA-Chilling-Facts-VI-FINAL.pdf>]. The source documents were not referenced in the report but were confirmed by personal comm. EIA compared and extrapolated from figures in studies conducted for the European Commission, upon which the phase-down was based. Preparatory Study annexes: [https://ec.europa.eu/clima/sites/clima/files/f-gas/docs/2011_study_en.pdf]; SKM Enviro, Phase Down of HFC Consumption in the EU – Assessment of Implications for the RAC Sector [https://www.epeglobal.org/wp-content/uploads/EPEE_HFC_Phase_Down_Report_-_Executive_Summary_6964-1.pdf].
- 29 Shecco, personal communication.
- 30 <http://conf.montreal-protocol.org/meeting/oewg/oewg-39/events-publications/Observer%20Publications/EPEE%20side-event%20OEWG%20Bangkok%202017.pdf>
- 31 <http://www.coolingpost.com/uk-news/r404a-units-still-sell-despite-warnings/>
- 32 <http://www.coolingpost.com/blog-posts/a2l-refrigerants-myths-and-realities-pt-1/>
- 33 Unlike its predecessors, the Millennium Development Goals, the Sustainable Development Goals are universal, applying to developed and developing countries alike. The Goals should be 'met for all nations and peoples and for all segments of society' and 'no one will be left behind'. In essence, rather than the traditional approach of driving the rich to helping the poorer nations of the world, they are [to quote Richard Curtis] an 'extraordinary, urgent and optimistic plan for a new generation'.
- 34 <https://eia-international.org/wp-content/uploads/Chilling-Facts-VII-FINAL.pdf>
- 35 <http://publication.shecco.com/upload/file/org/57fe03c438c881476264900dfko.pdf>
- 36 <https://www.slideshare.net/gadgetman17/shecco-market-policy-trends-for-natural-refrigerants>
- 37 <http://publication.shecco.com/upload/file/org/57fe03c438c881476264900dfko.pdf>
- 38 <http://publication.shecco.com/upload/file/org/57fe03c438c881476264900dfko.pdf>
- 39 Bain & Company, How to Thrive in Europe's Vexing Grocery Business, [<http://www.bain.com/publications/articles/how-to-thrive-in-europes-vexing-grocery-business.aspx>]
- 40 Energy comparison of three Refrigeration systems for a Hypermarket and Supermarket in Moscow, Dipl.-Ing. (FH) R. Paatzch, ILK Dresden for Emerson, Unpublished.
- 41 Personal communication
- 42 REPORT FROM THE COMMISSION on availability of training for service personnel regarding the safe handling of climate-friendly technologies replacing or reducing the use of fluorinated greenhouse gases <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0748>
- 43 <http://www.coolingpost.com/uk-news/new-laws-to-get-tough-on-non-compliance/> <http://www.acr-news.com/f-gas-cards>
- 44 P39 http://publication.shecco.com/upload/file/org/56c4a541a13711455727937HcLg3.pdf?utm_source=shecco+natural+refrigerants&utm_campaign=964a27d93d-AA1602_v1&utm_medium=email&utm_term=0_9db972ca57-964a27d93d-291161925
- 45 http://hydrocarbons21.com/articles/4886/first-ever-european-market-maps-480_000-hydrocarbon-plug-in-units-today
- 46 <http://www.refrigerantsnaturally.com/reductions-and-benefits/>
- 47 <http://publication.shecco.com/upload/file/org/57fe03c438c881476264900dfko.pdf>

- 48 <https://www.slideshare.net/gadgetman17/shecco-market-policy-trends-for-natural-refrigerants>
- 49 http://www.emersonclimate.com/europe/en-eu/Resources/Software_Tools/The_Right_Balance_Calculator/Pages/Calculator.aspx
- 50 Energetischer Vergleich und Lebenszykluskosten-Analyse von zwei Supermarktkältesystemen an verschiedenen Standorten; Emerson Internal Report Emerson-ILK-B-2-17-1640, Feb 2017. Unpublished.
- 51 http://www.frigoconsulting.com/media/directory/images/AE_1705.pdf
- 52 <http://www.ccacoalition.org/en/resources/lower-gwp-alternatives-commercial-and-transport-refrigeration-expanded-compilation-propane>
- 53 <http://www.ccacoalition.org/en/resources/lower-gwp-alternatives-commercial-and-transport-refrigeration-expanded-compilation-propane>
- 54 Based on interview with the refrigeration manager of Waitrose.
- 55 https://issuu.com/shecco/docs/acorp_1709
- 56 <http://www.ccacoalition.org/en/resources/lower-gwp-alternatives-commercial-and-transport-refrigeration-expanded-compilation-propane>
- 57 <http://www.globalopportunityexplorer.org/solutions/district-heating-with-supermarket-refrigeration-systems>
- 58 http://www.huffingtonpost.com/niels-b-christiansen/supermarkets-as-the-backb_b_9607946.html
- 59 <http://www.nature.com/news/2007/070205/full/news070205-9.html>
- 60 <https://www.greentechmedia.com/articles/read/axiom-exergy-brings-its-refrigeration-batteries-to-market-in-three-years>
- 61 http://verdicalgroup.com/diving-deeper-into-net-zero/supermarkets-as-the-backb_b_9607946.html
- 62 https://www.unido.org/fileadmin/user_media/Publications/UNIDO-MP-NormalCoverDesign.pdf
- 63 Doing Cold Smarter [<http://www.birmingham.ac.uk/research/activity/energy/policy/cold/doing-cold-smarter.aspx>]; Clean Cold and the Global Goals [<http://www.birmingham.ac.uk/research/activity/energy/research/clean-cold-and-the-global-goals.aspx>].
- 64 Clean Cold and the Global Goals [<http://www.birmingham.ac.uk/research/activity/energy/research/clean-cold-and-the-global-goals.aspx>].
- 65 *The emerging middle class in developing countries*, Homi Kharas, OECD Development Centre, January 2010, <http://www.oecd.org/dev/44457738.pdf>
- 66 *The emerging middle class in developing countries*, Homi Kharas, OECD Development Centre, January 2010, <http://www.oecd.org/dev/44457738.pdf>
- 67 <http://blogs.economicstimes.indiatimes.com/et-commentary/the-hidden-truth-behind-indias-low-refrigerator-ownership/>
- 68 Fridge electricity consumption is forecast to rise from 308TWh in 2005 to 581TWh in 2030. Cf *Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector – 2007*, Michael A. McNeil and Virginie E. Letschert, Lawrence Berkeley National Laboratory, http://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2007/Panel_6/6.306/paper
- 69 273TWh / 8760 hours per year = 31GW. Belgium's generating capacity is 21GW, Bulgaria's is 10GW. US Energy Information Administration, <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7>
- 70 Non-OECD average grid carbon intensity of 0.777 gCO₂/kWh [<http://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf>] multiplied by 273,000,000MWh = 212mtCO₂.

ABOUT THE BIRMINGHAM ENERGY INSTITUTE

The Birmingham Energy Institute is the focal point for the University and its national and international partners, to create change in the way we deliver, consume and think about energy. The Institute harnesses expertise from the fundamental sciences and engineering through to business and economics to deliver co-ordinated research, education and the development of global partnerships.

The Midlands region is renowned for its ability to drive technology revolution and provide a nationally leading manufacturing base. It is the home of pioneers such as Watt, Boulton and Priestly, and the internationally recognised companies of Rolls-Royce and Jaguar Land Rover.

The City of Birmingham is setting the green low carbon agenda nationally. Birmingham City Council's Green Commission launched a Vision Statement with an aim of building a leading green city and reducing CO2 emissions by 60% by 2027 against a 1990 baseline. The UK Government is committed to facilitating a cost-effective approach to meeting the UK's emissions by at least 80% of 1990 levels by 2050. The Birmingham Energy Institute is working with these stakeholders to realise this transition.

Acknowledgements

Editor: David Strahan

This report was supported by
Emerson Climate Technologies
GmbH.



UNIVERSITY OF
BIRMINGHAM

Edgbaston, Birmingham,
B15 2TT, United Kingdom
www.birmingham.ac.uk

Designed and printed by

UNIVERSITY OF
BIRMINGHAM | **creativemedia**