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CO_2: Creating a Sustainable Future with Natural Refrigerants

Kirkland Kaldor-Bull

George Alexander Foundation International Fellowship 2014

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THE GEORGE ALEXANDER FOUNDATION

International Specialised Skills Institute

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I. EXECUTIVE SUMMARY

In 2013, Heating, Ventilation, Air-Conditioning and Refrigeration (HVAC&R) accounted for 22.3 per cent of the total electricity consumption and 11.7 per cent of Greenhouse Gas (GHG) emissions in Australia. The industry accounts for two per cent of Australian Gross Domestic Product. Australians spend $26 billion annually on HVAC&R, $535 million of which is spent on refrigerant gas.[1]

The introduction of synthetic chlorofluorocarbon (CFC) refrigerant gases in the late 1920s resulted in significant environmental impacts that were not revealed until the discovery of a hole in the ozone layer in 1985. The Montreal protocol was established to phase out the offending refrigerant gases in 1987. As a replacement to the ozone depleting CFC's, the industry developed hydrofluorocarbons (HFC). These alternative synthetic gases are potent greenhouse gases and are now being targeted for replacement due to their high contribution to global warming.

In 1993, Professor Gustav Lorentzen proposed the revival of Carbon Dioxide (CO_2) as an environmentally friendly natural refrigerant replacement to the offending synthetic gases. CO_2 has differing properties to synthetic gases that allow for superior performance for certain applications. Whilst CO_2 gas operates at higher pressure than other refrigerants, it is non-flammable, widely available, very cheap and can offer higher system performance. Spurred on by legislation, CO_2 technology has matured in Europe and Japan to a point where it can outperform traditional refrigerants in many climates including Australia.

The result of these developments has been the transformation of much of the HVAC&R industry in Europe, particularly in commercial refrigeration. In heat pump applications, CO_2 domestic water heaters now hold 98% of the market share in Japan. Many food retailers in Europe are now taking advantage of the performance benefits that state of the art CO_2 systems provide. Manufacturers who have evolved to produce CO_2 systems are unanimously reporting a major shift of orders from synthetic gas systems to natural CO_2 systems. There are over 2885 pure CO_2 commercial systems now operating in Europe.[2]Thanks to the market advancement in Europe, hardware is now widely available and costs have been continuing to reduce. The capital cost of a new CO_2 system in many cases has reached parity with synthetic gas systems whilst a retrofit CO_2 system is now in the order of 10 per cent more expensive compared to a HFC equivalent.[3] Reductions in operating costs can rapidly payback the extra capital expenditure.

Whilst CO_2 has been used in cascade with synthetic refrigerants in Australia, we are yet to embrace transcritical CO_2 technology that completely eliminates the use of harmful synthetic gases. The major barriers in Australia are both a lack of awareness and widespread technical know-how. Realising the potential benefits of CO_2 properties requires specialised knowledge of system design and use in the appropriate area of application.

This Fellowship was undertaken to help address and further identify the current barriers to the widespread implementation of this technology in Australia. This report documents the findings of the Fellowship and provides recommendations for developing the industry in Australia.

1 Expert Group 2013, Cold Hard Facts 2.

2 Shecco Publications 2014, Guide 2014: Natural Refrigerants Continued Growth & Innovation In Europe.

3 Figure based on commonly agreed estimates from interviewed industry professionals.

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II. ABBREVIATIONS/ACRONYMS

CFC	Chlorofluorocarbon
CHF2	Cold Hard Facts 2
CO_2	Carbon Dioxide
COP	Coefficient Of Performance
GAF	George Alexander Foundation
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HVAC&R	Heating, Ventilation, Air-Conditioning and Refrigeration
ISS Institute	International Specialised Skills Institute
kW	Kilowatt
ODP	Ozone Depletion Potential

III. DEFINITIONS

Cold Hard Facts 2 (CHF2):

A report on the HVAC&R industry prepared for the Australian Government,

Department of Sustainability, Environment, Water, Population and Communities, Environment Quality Division, Ozone and Synthetic Gas Team.

Coefficient of Performance (COP)

The ratio of the heat extraction rate divided by the power consumed by the refrigeration compressor(s) and necessary ancillaries. The COP is dimensionless and is used to express the system efficiency.

Compressor

A device in the air conditioning or refrigeration system that compresses refrigerant gas, and circulates that refrigerant through to its phases of condensation and evaporation in order to produce the refrigeration effect.

Compressor rack

The machine assembly that accommodates the main high pressure components of a refrigeration system in a single structure.

Cascade system

A refrigeration system that uses two or more refrigerants connected via heat exchangers to achieve the desired cooling effect. Typically achieved using one or more synthetic refrigerants.

Global Warming Potential

A relative measure of the ability of a gas to contribute to global warming. Carbon dioxide is used as the reference gas, representing the base unit of one for comparison.

Greenhouse Gas

Gases that absorb and emit thermal radiation in the atmosphere. Naturally occurring greenhouses gases help to maintain earth surface temperatures at habitable levels. Manmade greenhouse gas emissions contribute to global warming which has massive implications for the habitability of the biosphere.

Heat pump

A heat pump employs the same mechanical system as used by an air-conditioner or refrigerator, but provides heating as the desired quantity as opposed to cooling.

Kilowatt

A measurement of the rate of energy transfer equal to 1000 joules per second.

Ozone Depletion Potential

A relative measure of the ability of a substance to deplete the ozone layer.

III. DEFINITIONS

Refrigerant

The working fluid compressed and expanded continuously in a refrigeration cycle.

Transcritical CO2

Referring to the mode of operation of a CO2 cycle in which the CO2 properties enter the transcritical state. In this configuration CO2 can be used as the exclusive refrigerant removing the need for cascade with a synthetic refrigerant.

1. ACKNOWLEDGEMENTS

The Fellow sincerely thanks the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide him throughout the Fellowship program.

Awarding Body – International Specialised Skills Institute (ISS Institute)

The International Specialised Skills Institute Inc is an independent, national organisation that for over two decades has worked with Australian governments, industry and education institutions to enable individuals to gain enhanced skills and experience in traditional trades, professions and leading-edge technologies.

At the heart of the ISS Institute are our Fellows. Under the **Overseas Applied Research Fellowship Program** the Fellows travel overseas. Upon their return, they are required to pass on what they have learnt by:

1. Preparing a detailed report for distribution to government departments, industry and educational institutions.
2. Recommending improvements to accredited educational courses.
3. Delivering training activities including workshops, conferences and forums.

Over 200 Australians have received Fellowships, across many industry sectors. In addition, recognised experts from overseas conduct training activities and events. To date, 22 leaders in their field have shared their expertise in Australia.

According to Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010':

> Australia requires a highly skilled population to maintain and improve our economic position in the face of increasing global competition, and to have the skills to adapt to the introduction of new technology and rapid change.
>
> International and Australian research indicates we need a deeper level of skills than currently exists in the Australian labour market to lift productivity. We need a workforce in which more people have skills, but also multiple and higher level skills and qualifications. Deepening skills across all occupations is crucial to achieving long-term productivity growth. It also reflects the recent trend for jobs to become more complex and the consequent increased demand for higher level skills. This trend is projected to continue regardless of whether we experience strong or weak economic growth in the future. Future environmental challenges will also create demand for more sustainability related skills across a range of industries and occupations.

In this context, the ISS Institute works with Fellows, industry and government to identify specific skills in Australia that require enhancing, where accredited courses are not available through Australian higher education institutions or other Registered Training Organisations. The Fellows' overseas experience sees them broadening and deepening their own professional practice, which they then share with their peers, industry and government upon their return. This is the focus of the ISS Institute's work.

For further information on our Fellows and our work see http://www.issinstitute.org.au.

1. ACKNOWLEDGEMENTS

Kaldor-Bull also thanks the CEO (Bella Irlicht AO) and staff of ISS Institute, Ken Greenhill and Paul Sumner for their assistance in planning and development of this Fellowship.

Fellowship Sponsor - The George Alexander Foundation

The Fellow sincerely thanks the George Alexander Foundation for providing funding support to the ISS Institute for this Fellowship.

In 1972, George Alexander AM (1910 - 2008) set up an independent philanthropic foundation as a way of sharing his wealth and giving back to the community. Today, the main focus of The George Alexander Foundation is access to education for promising young people, particularly students with financial need and those from rural and remote areas.

The George Alexander Foundation (GAF) Scholarship Programs form the core of the foundation's work, operating in partnership with major tertiary institutions, while our Fellowships and other Education grants provide a variety of other unique and challenging educational experiences.

George Alexander believed in the notion of 'planting seeds and hoping they grow into pretty big trees'. The programs supported by the Foundation endeavour to support this ideal and as GAF students graduate and go on to contribute to the community, George's legacy and spirit lives on through their achievements.

George Alexander came to Australia as a child migrant, and went on to become a mechanic, an entrepreneur and a businessman and later, a generous philanthropist, who held that you do not own the possessions you have, 'you're just minding them'. This philosophy guided him to give during his lifetime and to hope that through his example, he might inspire others to do the same.

Other Organisations and individuals who contributed to the planning, preparation and approach to this Fellowship research for their considerable assistance.

Government

- Arron Wood - Councillor, Melbourne City Council

Industry

- Alessandro Greggio - Group Head of Marketing Retail and Refrigeration, Carel, Italy
- Alexander Cohr Pachai -Technology Manager, Johnson Controls, Denmark
- Anders Juul - Segment Strategy Manager CO2, Danfoss, Denmark
- Dr. Andrew Pearson - Group Engineering Director, Star Refrigeration, United Kingdom
- Davide Refosco - Export Area Manager, SCM Frigo, Italy
- Elga De Zanet - Marketing Refrigeration Systems, EPTA, Italy
- Erik Wiedenmann - Research and Development, Frigo Consulting, Switzerland
- Jana Topley Lira - Partnerships & Community Manager, Shecco, Belgium
- Jonas Schoenenberger - Head of Research & Development, Frigo Consulting, Switzerland
- Kim Christensen - Managing Director/ Director of Engineering, Advansor, Denmark
- Klass Visser - Principal Consultant, KAV consultants, Australia

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- Paul Alway - Manager of Refrigeration Specification R&D. Marks and Spencer, United Kingdom
- Peter Hommerin - Operations Project Manager Industrial Refrigeration, Johnson Controls, Holland
- Sergio Girotto - Chief Executive, Enex, Italy
- Shaun Kennedy - Building Services Manager, Harrods, United Kingdom
- Steven Lawlor - Data Centre Operations Manager, Imperial College, United Kingdom

Professional Associations

- Joan Whelan, Project Manager, CPSISC, Melbourne
- Robin Mellon, Chief Operating Officer, Green Building Council Australia, Melbourne
- Tim Edwards, President, Australian Refrigeration Association, Melbourne

2. ABOUT THE FELLOW

Name:

Kirkland Kaldor-Bull

Employment:

Self employed energy systems consultant

Qualifications:

- Bachelor of Science, Monash University, 2001
- Double Physics Major and a Mathematics Minor.

Biography:

The Fellow has been actively working in research and development of energy saving technologies for more than five years. Upon graduating, he worked as a seismologist in remote parts of the Australian countryside where he developed an affinity for the natural environment. In 2008, whilst working as a geophysicist on several major infrastructure projects in Victoria, he decided to move into renewable energy. Returning to Monash University, he successfully designed and built a low temperature heat to power generator. This led to a technical research and development role to improve machine efficiency for air compressor manufacturer Atelier Francois. His passion for energy efficiency extends from buildings technology to industrial processes and he established a consultancy for advising on improvement and development of energy systems.

3. AIMS OF THE FELLOWSHIP PROGRAM

The Fellowship allowed a direct interface with leading professionals and manufacturers in the rapidly developing European CO_2 industry. This allowed the Fellow to achieve the following aims:

- To learn about the thermodynamic differences between synthetic refrigerants and CO_2
- To discover the range of applications where CO_2 may be employed
- Establish relationships with a network of experts that can provide support for the development of CO_2 technology in Australia
- Develop recommendations to accelerate the adoption of CO_2 technology in Australia.

It is intended that subsequent dissemination of the Fellowship findings will stimulate the Australian industry to invest in expanding its capabilities in this field.

4. THE AUSTRALIAN CONTEXT

According to CHF2, in 2013, 11.7 per cent of Australia's entire greenhouse gas (GHG) emissions were due to the HVAC&R industry. Direct emissions of refrigerant gas through leakage contributes 1.7 per cent of GHG emissions.[1] The Australian Refrigeration Association believes that the impact of synthetic gas leakage into the environment has been underestimated and considers the impact is closer to four per cent of emissions.

Up until the 1930s, the only refrigerants used were those that were available from nature. Carbon Dioxide (CO_2) was first proposed as a refrigerant in 1850 and its use steadily grew until it peaked in the late 1920s. The decline in use that followed was due to the introduction of synthetic gases that were intended to have more favourable safety and performance properties.

Unfortunately these synthetic gases caused environmental issues that were not discovered until much later. In 1974, synthetic CFC's that were commonly used as refrigerants and propellants were found to be responsible for a hole in the ozone layer, part of which is positioned above the southeast of Australia. The subsequent increase in ultraviolet radiation reaching the Earth's surface has resulted in increased instances of skin cancer. The depletion on the ozone layer is an environmental disaster that occurred silently over a period of 60 years. In 1987 the Montreal Protocol was brought into effect to phase down and stop the production of CFC's. This phase out and eventual ban is still taking place and CFC's in the atmosphere are still causing ozone thinning in other parts of the world.

The industry response to the impact of CFCs was to develop HFCs. These gases have no Ozone Depletion Potential (ODP) but do have a very high Global Warming Potential (GWP). The GWP of HFC's are commonly hundreds to thousands of times more potent than carbon dioxide.

New synthetic gases have been developed, known as HFO's, which have zero ODP and low GWP. Aside from being very expensive, this new breed of synthetic gas is generally flammable and is known to form neurotoxins during combustion. They may have other environmental and health effects that are not yet known.

The atmosphere is an integral part of the biosphere that sustains life on earth. Refrigerant gases will always find their way into the atmosphere and the subsequent chemical process that may occur from synthetic gases within the environment are not always entirely understood. As we have already seen, the full impact of using synthetic gases may not be realised until many years into the future.

As a response to the environmental issues of HFC's, heavy taxation and phase-out legislation has been introduced in many parts of Europe. This pressure placed on the use of HFCs has prompted a renewed interest in natural refrigerants.

In the pursuit of solving the environmental issues associated with synthetic refrigerants it seems obvious that naturally occurring substances will provide a more benign alternative. There are five main naturally occurring refrigerants that are currently being used for refrigeration. They are air, water, ammonia, hydrocarbons and CO_2. There is no refrigeration task that naturally occurring gases cannot handle. Different refrigerant gases suit different applications. The final selection is generally decided on a balance of safety, performance and associated hardware cost.

Just like synthetic gases, natural alternatives can also be dangerous to humans. Our kidneys produce ammonia, however exposure to large quantities is toxic. Likewise we respire CO_2 and yet too much CO_2 is toxic. Synthetic refrigerants are also toxic and must be handled with care. Through proper handling and system design, the risk of an accident with any refrigerant gas can be minimised to an acceptable level. The important difference with natural refrigerants is that they do not harm the environment in the same way synthetic gases clearly do.

1 Expert Group 2013, Cold Hard Facts 2.

4. THE AUSTRALIAN CONTEXT

Hydrocarbons perform exactly like synthetic gases. In Europe there are currently over 480,000 hydrocarbon plug in refrigeration units that are operating safely.[2] Hydrocarbons are flammable and this has created a perception that they are unsafe limiting their use to mainly small volumes. Indeed, as with ammonia, precautions need to be taken especially when large volumes are concerned.

CO_2 dropped out of favour until 1993 when Gustav Lorentzen initiated its revival. In recent years the main thrust of market development came as a response to legislation. Whilst CO_2 gas operates at much higher pressure than other refrigerants, it is non-flammable, widely available and cheap. The use of CO_2 as a refrigerant has been steadily increasing in recent years in Europe. The purpose of this Fellowship was to investigate exactly why this is, where the application areas are and to discover insights that can help advance the adoption of the technology in Australia.

Initially one of the main barriers to the uptake of CO_2 systems was cost. In 2006 when use of CO_2 in the supermarket sector was still relatively recent, a CO_2 system cost 15 to 40 per cent more than a standard HFC solution. The variation here is due to the difference in installation type. If a system were simply upgraded by replacement of the main compressor rack than the relative cost was higher. When a new system was to be installed there were actually significant savings due to reduced pipe diameters that balanced the increased main rack cost. Today the story is different. In 2014 a replacement compressor rack is in the order of 10 per cent more expensive than a traditional HFC rack. In the case of an entirely new system, today a CO_2 system cost has reached parity with the HFC alternative.

The running costs for a CO_2 system involves cost of refrigerant as well as cost of energy. CO_2 refrigerant is in the order of ten times less expensive than synthetic HFC's. Supermarket systems generally have many valves and connections that make them more susceptible to leaks. It is estimated that a supermarket will leak in the order of 10 to 20 per cent of its entire charge annually. The average charge size of a large supermarket is 900kg in Australia so the cost of refrigerants is a significant ongoing expense. [3]

Refrigeration systems are designed to allow for appropriate capacity to be supplied during hot weather events. During these operating conditions, Synthetic gases generally perform better than CO_2. However, when comparing the performance of a refrigeration system it is important to consider the operating conditions over the entire year. The performance of CO_2 is actually higher than that of commonly used synthetic refrigerant R134a at ambient temperatures below a crossover temperature between 25C to 30C. This efficiency crossover temperature will vary depending on the specific system design and requirements. Perth, Brisbane, Sydney and Melbourne all have annual average maximum temperatures below 25C allowing existing CO_2 technology to perform equal to or better than existing HFC systems.

Melbourne City Council has estimated that the energy demand of commercial buildings needs to be reduced by 40 per cent to meet their ambitious global warming gas reduction targets. Modelling of office buildings fitted with CO_2 air-conditioning systems in Melbourne climatic conditions, have shown a potential reduction of global warming gas emissions of 58 per cent and reductions in primary electrical consumption in the order of 43 per cent. [4]

2 Shecco Publications 2014, Guide 2014: Natural Refrigerants Continued Growth & Innovation In Europe.

3 Expert Group 2013, Cold Hard Facts 2.

4 Visser 2008, A Case Study Into The Application Of CO_2 Cooling And Heating In American Office Buildings, 8th IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen.

4. THE AUSTRALIAN CONTEXT

There is significant scope for the Australian market to embrace the innovation and application of CO_2 technologies that are currently being employed to strong effect in Europe. As the environmental and efficiency benefits of these systems begin to be recognised locally, a new Australian industry can be expected to take off. With the recent loss of hundreds of manufacturing jobs in the automotive industry, there is a workforce of capable technicians that could deliver this hugely beneficial technology to our building services and commercial refrigeration industries.

5. IDENTIFYING THE SKILLS AND KNOWLEDGE ENHANCEMENTS REQUIRED

Knowledge of the application areas where natural refrigerants, including CO2, can be of benefit.

If you were to ask the leading air-conditioning suppliers and building service consultants in Australia about the application of CO2, they would likely speak about supermarket refrigeration and domestic hot water. In fact the application landscape is much larger than this. Consultants, architects, developers and consumers all need to be made aware of the huge environmental and cost benefits that are possible with CO2 are applicable in much greater range of applications than is generally understood.

This Fellowship addresses this knowledge gap by reporting on a variety of CO2 installations that are successfully operating in Europe.

Specific knowledge of the specific techniques that can be applied to reduce energy consumption and cost with CO2 systems.

Awareness of the application areas that can benefit needs to be complimented by knowledge on how to achieve the benefits. Currently the courses taught in CO2 are primarily about cascade CO2 refrigeration and/or about safe handling of CO2. The potential to gain the large energy savings offered by CO2 in other building systems is not widely understood. For example, CO2 has tremendous heat transfer properties, which means that pipe sizes can be dramatically reduced. This in turn leads to a reduction of pumping costs and, depending on system design, can eliminate the need for auxiliary pumping altogether. CO2 heat capacity and transfer properties also allows for reduced heat exchanger size, which helps to reduce system capital cost. When used in a transcritical cycle, CO2 has the ability to simultaneously produce potable hot water at temperatures as high as 95C whilst also producing cooling. This double use of the thermodynamic cycle leads to Coefficient of Performance (COP) figures in the order of seven to 10 or higher. In addition, the evaporator of a CO2 system can be placed in the stream of a buildings air discharge to recover heat that would otherwise be sent to the atmosphere. Knowledge of these and other techniques needs to be gathered, documented and disseminated.

This Fellowship report documents examples of proven techniques that are being successfully implemented and is intended to bring awareness to application engineers of the possibilities.

6. THE INTERNATIONAL EXPERIENCE

Destination - Frigo Consulting, Zurich, Switzerland

Contacts: Jonas Schoenenberger, Head of Research and Development

Erik Wiedenmann, Research and Development

Objective: To gain insights into the latest technical approaches and to learn about Frigo's impressions of the industry.

Outcomes:

Frigo Consulting is known in the industry for developing leading edge Heating, Ventilation, Air-Conditioning and Refrigeration (HVAC&R) innovations. They implement sustainable design concepts and gain direct experience of the performance and viability of such innovations.

The government in Switzerland has imposed regulations that have driven exponential growth in the number of CO_2 installations that Frigo has completed. In Switzerland any installation with a capacity above 40 kW must use natural refrigerants. Furthermore, all installations must have heat recovery.

Frigo designed a hydrocarbon mechanical sub-cooler system for a CO_2 installation in Valencia. This design was required to deal with the high ambient temperatures. The client was primarily trying to future proof the system from any European regulations and taxes. As a side benefit, in the client's eye, the system was showing 50 per cent reduction in energy costs during the first three months of operation in winter.

Frigo see that many new installations will provide the entire building air-conditioning and refrigeration from the same main CO_2 system. This has already been achieved at an installation in Bulle, Switzerland.

Frigo completed an 800 kW CO_2 direct expansion system for a data center in Berne, Switzerland. The installation is considered a huge success in terms of performance.

Working in collaboration with Sergio Girotto of Enex, they have tested ejectors systems in several locations. The configuration is designed so that ejectors suck liquid from a receiver that is fed to the medium temperature flooded evaporators. The evaporators can be run at a saturation temperature six degrees higher than when in superheat mode without ejectors, therefore reducing the pressure differential of the main compressors. The ejector discharge raises the pressure of the suction of two parallel compressors. Both of these effects result in efficiency improvements in the order of 16 to 20 per cent.

Expanders of the free piston type have been tested at a supermarket in Switzerland and yielded performance improvements in the order of 10 to 15 per cent. Theoretical improvements of 23 per cent were not achieved and this is suspected to be due to leakage. Liquid is being valved into the expander at a frequency from zero to five Hz. This caused a pipe hammering effect that was felt through the whole skid. Mechanical expanders are still very much at the prototype stage at this point.

Destination - GEA Bock, Frickenhausen, Germany

Contact: Manuel Froeschle, Product Manager CO_2 and Natural Refrigerants

Objective: To receive general training in CO_2 systems and gain an industry perspective from a major compressor supplier.

Outcomes:

Bock is one of a small group of compressor manufactures in the world that make high quality CO_2 compressors. Bock was recently acquired by GEA. In 2013 GEA generated revenue of €4.3 billion, 70 per cent of this came from the food industry which is considered a long-term growth market. Bock's strongest area of growth is in sales of CO_2 compressors that, at this stage, are primarily used in the food retail industry.

The increase in CO_2 compressor sales growth is believed to be due to the European F-gas regulations. The regulations will limit the total amount of high GWP HFC gases used in Europe; both produced and imported. Another factor influencing the change has been recognition that running costs are significantly lower with CO_2 systems.

Compressor production is done using lean manufacturing principles. Strict quality control is used at every stage; in this way, they are able to achieve compressor lifetimes in excess of 40,000 hours. Every compressor in the range has an inbuilt oil pump and specialised oil passages that allow for speed modulation down to 20Hz. This is seen as advantageous for efficient operation of systems at part load.

Bock has a transcritical CO_2 system at the headquarters in Frickenhausen. The installation is complete with refrigerated cabinets and is used to teach technicians about the specifics of CO_2. Although Bock is a component supplier they recognise that there is a need to train people about the specifics of CO_2 technology. In this way they help support and develop the market that will purchase their compressors.

The Fellow undertook a technical training in CO_2 refrigeration. The training looked at CO_2 properties, common system designs, system control, material compatibility, safety and handling and EU legislation. The outcomes are summarised in Section 7 of this report.

Destination - Shecco, Brussels, Belgium

Contact: Marc Chasserot, Managing Director

Objective: To gain larger perspective of the CO_2 industry globally and develop industry contacts.

Outcomes:

Shecco is a market development company that exists to support the introduction of climate friendly technologies. They achieve this through market research, event management, public affairs, consulting and online marketing.

Shecco started with a primary focus to facilitate the uptake of CO_2 as a natural refrigerant. They have relationships with practically every CO_2 related component supplier, major consultancy and systems supplier. They organise events under the brand, ATMOsphere, that bring all these people together to discuss technology advances, market trends and future opportunities. This gives the organisation a unique and powerful perspective on the market.

Shecco has conducted extensive industry surveys throughout Europe and the world. Their recent publication on European innovations comprehensively covers the industry activities in Europe and provides a series of case studies on recent innovations. This document can be downloaded for free at: http://publication.shecco.com/publications/view/2014-guide-natural-refrigerants-europe

The Fellow's visit to Shecco took place after the third ATMOsphere America event held in San Francisco. Shecco reported a record number of attendees and clear indication that CO_2 is gathering momentum in America. Many large companies attended and presented their current activities in natural refrigerants such as Target, McDonalds, Coca Cola, Walgreens and Wholefoods to name a few.

Advancor is currently the largest CO_2 rack manufacturer in Europe and was recently purchased by American company Hill Phoenix. Likewise, American owned company, Carrier, recently purchased Swedish rack manufacture Green and Cool. This demonstrates clear indications that the big HVAC&R players see the future of this technology for America.

Shecco have expressed the desire to develop the Australian natural refrigerant market. They have observed a highly conservative approach to the adoption of CO_2 in Australia. The rapid growth in Europe has led to significant reductions in hardware cost. This, coupled with the performance improvements, led Shecco to believe the market is ready for the change.

Destination - Johnson Controls, Dordrecht, Netherlands

Contact: Peter Hommerin, Operations Project Manager Industrial Refrigeratio

Objective: To learn about the use of CO_2 for industrial refrigeration aboard ships and in cold stores.

Outcomes:

The Fellow was invited to take a tour of a large fishing vessel and land based cold store.

Shipping vessels in Holland are often required to be at sea for four to six weeks before returning to harbour with their catch. These vessels will therefore have freeze processing plants and cold storage on board. Cornelis Vrolijk has begun converting their fleet to natural refrigerants CO_2 and ammonia and for good reasons.

According to European f-gas regulations, as of January 2015, there is now a complete ban on the use of CFC R22. This includes a ban on the servicing of existing systems. When a refrigeration plant is faced with this type of regulation they have a couple options to choose from. They can replace the gas charge with another synthetic gas that is currently legally acceptable, or they can replace the entire system with a natural refrigerant solution that will essentially be future proof from any further regulations.

When looking for replacement, synthetic gases R507 and R404a are commonly chosen. These gases can be dropped directly into an R22 system obviating the need for any hardware change. This might seem like a sensible option, however in this case we have simply exchanged ozone depletion for global warming and failed to address the environmental hazards.

The new regulations state that HFCs with GWP greater than 2,500 will not be permitted for the servicing of large refrigeration systems as of 2020 for virgin HFCs and as of 2030 for reclaimed or recycled HFCs. R404a has zero ODP and a GWP of 3,922. Therefore, using R404a or R507 as a drop in replacement is only a short-term solution.

Being aware of the environmental impacts of synthetic refrigerants and of the new f-gas regulations, Cornelis Vrolijk engaged Johnson Controls to propose a solution for their fleet of fishing vessels. The logical choice, based on performance, availability, longevity and ultimately cost, was to employ a new CO_2 cascade with ammonia system.

Johnson Controls had already gathered technical expertise in 2002 when they implemented Cornelis Vrolijk's first land based CO_2 ammonia cascade cold store. This system replaced 30 tons of harmful R22. The success of this system encouraged the commissioning of several CO_2 based systems for both land-based projects and on vessels.

In total, five of the Cornelis Vrolijk vessels have been converted to use CO_2 as a secondary refrigerant for fish processing and cold storage. At the end of 2013 the vessel known as Frank Bonefaas SCH 72 was converted to a state-of-the-art CO_2 cascade ammonia system. The ship is powered by 10,000HP of engines, measures in at 126 meters in length and has capacity for 300 tons of frozen fish.

The system uses pumped CO_2 for rapid freezing of fish into blocks. The blocks are packaged and moved to large cold storage holds.

With the experienced gained from the land based cold store, it was expected that a CO_2 processing plant would have increased performance. In practise, the designers were surprised to see just how great the performance increase was. The extremely high heat transfer properties of CO_2 resulted in freezing times of fish blocks three to four times faster than experienced with R22. The cascade system operating at its design conditions of -50C to 40C has a Coefficient Of Performance (COP) of 1.5 that is almost double the COP of 0.8 for R22 operating under the same conditions. As power for the system is provided by on-board generators, the reduction in fuel costs are significant.

The high density of CO_2 allows for reduced compressor sizes giving the benefit of space and weight reduction that are important considerations for ships. The CO_2 is transferred around the ship within stainless steel pipework. A three-fold reduction in the required pipe diameters and valve sizes meant that much of the installation cost was actually lower when compared with the conventional larger diameter carbon steel components.

The entire plant is made to operate very simply with the aid of a sophisticated supervisory system. Touch screens located in the plant room allow operators to access any system information they need.

Safety is paramount aboard vessels. Gas detectors positioned throughout the vessel continuously monitor the atmosphere in each zone to ensure worker safety and to help identify any leaks that may arise. The ammonia compressor is contained in a room that is held at a partial vacuum. This ensures that fresh air will always fill the space as personnel enter the room.

Had the owner opted for a drop in replacement gas, approximately 40 tons of a HFC like R404a would be required. When purchased in large quantities the gas will cost in the order of 13 to 17 €/kg. Therefore, for Frank Bonefaas SCH 72, a drop in would have cost in the order of €500,000. The new system requires 14 tons of CO_2, of which five tons is backup and the ammonia charge is limited to 3000 kg. At the bulk price for CO_2 at 0.36 €/kg and for ammonia at 1.40 €/kg, the entire system charge costs under €9,000.

The refrigeration plant equipment costs were €2.8M. The total system cost, including the processing facility and cold store, was €7.2M. It is expected that the end user will be able to write off the plant cost through tax deductions within 20 years. The hardware itself is expected to last 30 to 40 years.

The ongoing replacement gas costs have been reduced by a factor of 50 and the system is immune to future f-gas regulations. When considering the environmental benefits along with the massive increase in system performance, it is little wonder this technology is now being embraced by commercial fishing fleets in the Netherlands.

Destination - Marks and Spencer, London

Contact: Paul Alway, Manager of Refrigeration Specification R&D

Objective: To hear technology perspectives from an experienced technical engineer from a major food retailer.

Outcomes:

Marks and Spencer has made a commitment to improve community, sustainability and energy efficiency in all aspects of their business operations. A key aspect of this, is the evaluation of current energy systems in order to set benchmarks for ongoing assessment of targets. This evaluation has informed the ambitious target of 80 per cent reduction in emissions due to direct refrigeration emissions from 2006/2007 levels by 2020. They also plan to remove all HFC refrigeration and air conditioning systems by 2030.

CO_2 supermarkets got off to a flying start in the UK. Between 2011 and 2013, the number of stores with transcritical CO_2 systems rose by 65 per cent. Now there are over 440 stores with transcritical CO_2. The rapid uptake was great for helping to drive system costs down. On the other hand, the rapid rollout meant that some retailers used system designs that required specialised operation and they did not live up to performance expectations. Fortunately, the lessons were learned and the advance of CO_2 continues in the United Kingdom.

Marks and Spencer currently have 78 stores that use CO_2, five of which are transcritical. They have chosen a more measured approach to implementing future systems by investing in a research facility in Birmingham that is dedicated to transcritical development and learning. They have chosen to develop capability in-house so that they can make informed decisions about the best ways to move forward with CO_2.

There are so many possible arrangements that finding the right balance between cost and efficiency requires a high level of understanding and know how. Beyond the design of the transcritical circuit, they have looked at the viability of having a centralised plant using a water loop or ducted air as the heat transfer medium. They have considered using ice for a thermal storage and utilising the waste heat in power cycles where it is not required as heat.

Their environmental policies and ambitions are high reaching. Beyond the positive impact on the environment, ultimately this leads to a huge reduction in operating costs as well as impacting positive consumer sentiment about their activities.

Destination - Harrods, London, UK

Contact: Shaun Kennedy, Building Services Manager

Objective: To learn about practical realities from a modern multi purpose CO_2 installation.

Outcomes:

In 2011, Harrods, the well-known luxury retail store, decided to invest in a state-of-the-art CO_2 system. The iconic food hall and associated cold room have a huge demand for refrigeration and potable hot water. The previous systems that were in operation used R22, an ozone depleting gas. They were aware that in 2015 it would be illegal to maintain an R22 system due to the f-gas regulations. After much consultation, Harrods decided that CO_2 was the logical next step.

Harrods installed three 160kW transcritical racks with parallel compression that were built by Enex of Italy. The racks are situated in a purpose built room that allows for noise containment and easy monitoring of CO_2 levels in the atmosphere. Air-conditioning for the room is integrated into the system. CO_2 provides the cooling requirements of all of the cold rooms and the majority of the food and beverage cooling display cabinets. These cooling cabinets are built from several different manufacturers but all with electronic expansion valves to allow highly efficient direct expansion of CO_2.

The CO_2 system operating parameters are integrated into the main building management system and can be accessed from numerous terminals. The services manager reports that the system is easily comprehended and has been running with very few issues since being commissioned.

As well as very high cooling performance, the system utilises all the waste heat for the large potable hot water demand. The water comes via a reverse osmosis purifier from a deep well underneath the building. The cold water allows the full use of the waste heat and boosts the cooling performance of the system. Practically all of the waste heat is used and placed in a large buffer tank at 60C. This removes the need to use the boiler. In the early morning hours when there is not enough usage of the hot water, the heat is rejected to a water chiller circuit or to a cooling tower on the roof.

Due to the utilisation of the waste heat and direct expansion of CO_2 for cooling, the system at Harrods has an extremely high performance that will reduce the investment payback period. The system is also immune to future f-gas regulations.

Destination - Imperial College, London

Contacts: Dr Andrew Pearson, Group Engineering Director, Star Refrigeration

Steven Lawlor, Data Centre Operations Manager, Imperial College

Objective: To gain application and technology insights from an expert with a PhD in CO_2 refrigeration and to visit a CO_2 cooling system for a data center.

Outcomes:

Dr Pearson joined Star Refrigeration in 1986 and has been working on CO_2 systems since 1999. He completed a PhD on the optimisation of CO_2 refrigeration systems in 2005. Over the years he has become highly regarded for his comprehensive technical knowledge of CO_2 systems. Through contribution to journals, magazines, conference presentations and interviews Dr Pearson has been a strong proponent for the use of CO_2.

The first major project that Dr Pearson undertook with Star was a retrofit of a coffee freeze drying refrigeration plant. Initially CO_2 was chosen as there was a limitation on pipe size that meant only CO_2 was able to handle the required capacity at -54C. They subsequently went on to build CO_2 systems into distribution warehouses, plate freezers and blast freezers.

Dr Pearson corroborates the findings of Johnson Controls on the fishing vessels. The performance of CO_2 for plate freezers is so good, that for this application, CO_2 is simply the best choice. Likewise with blast freezers, the ability of CO_2 to provide much faster pull down time, sets it far ahead of all the current alternatives.

An interesting area that has a growing market is the application for data centers. Steven Lawlor manages a huge data center at the Imperial College in London that is used for scientific research. The computer racks are packed with a high density of Central Processing Unit (CPU) cores. There are 1680 cores contained in each rack and a corresponding heat load of 20kW. In order to achieve enough cooling capacity in such a small space, CO_2 was chosen by Star Refrigeration as the best refrigerant for the job. The installation is approaching 10 years of age and has run trouble free in this time. Being an older system, it uses a cascade with HFC R134 as the primary refrigerant.

Interestingly, as Star Refrigeration is primarily a commercial and industrial refrigeration business, the choice of refrigerants is generally driven by performance and cost. The fact that Star has found so many applications where CO_2 is the best option shows that its use as a refrigerant is not solely due to the environmental benefits, but clearly also about performance and economics.

Expansion devices, such as ejectors and expanders, improve the cycle efficiency by making use of energy that is normally lost by use of an isenthalpic expansion valve. This area of development has shown the ability to improve performance in hot climates. Dr Pearson makes the point that if sub-cooling is available, then expansion devices are no longer effective or necessary. Removing the need for expansion devices helps to keep system complexity low. System complexity can be a real barrier for the widespread implementation of new technology.

Dr. Pearson has recently published a comprehensive guide about the use of CO_2 as a refrigerant. The guide is available from the International Institute of Refrigeration website at http://www.iifiir.org.

Destination - SCM Frigo, Piove di Sacco, Italy

Contact: Davide Refosco, Export Area Manager

Objective: To discuss the state of the CO_2 rack manufacturing business with a major rack supplier.

Outcomes:

SCM Frigo is the second biggest manufacturer of CO_2 rack systems in Europe. The company started in 1979 building traditional HFC refrigeration systems. They identified the trend in the market toward CO_2 systems, responding by offering customised CO_2 packages. Production of CO_2 packages began eight years ago and now accounts for 55 per cent of total production. They have seen sales of HFC systems slowly decline and a rapid increase in the number of CO_2 sales.

With the benefit of their significant CO_2 experience, SCM is geared to respond rapidly to technical trends and improvements as they become evident to the industry. An example of this is the recent development of an integrated refrigeration and air conditioning system that has been prototyped for Sainsburys in the UK. The technique, which is gaining traction, involves employing parallel compressors to handle air conditioning loads.

SCM offers pumped CO_2 solutions for light industrial and food distribution applications. They are also on-trend by offering single compressor CO_2 condensing units in capacities from three to 35kW. This is considered a developing market for smaller capacity systems such as convenience stores. The approach taken by SCM is to build customised systems based on individual customer requirement. SCM believes that in this way they can achieve high efficiency due to accurate sizing. They use a riveted framing system to allow for rapid construction for the customised rack structure. With the ability to choose from any component supplier that meets the specifications, they can produce a cost competitive rack. Currently they are producing approximately 200 CO_2 racks per year.

Destination - Carel, Piove di Sacco, Italy

Contact: Alessandro Greggio, Group Head of Marketing – Retail and Refrigeration

Objective: To gain industry perspectives from a major controls and expansion valve manufacturer.

Outcomes:

At their home base in Italy, Carel operate a state-of-the-art lean production facility that manufactures electronic expansion valves, programmable controllers, humidification and building monitoring products. The HVAC&R controllers they produce are highly flexible and customisable. They work with compressor manufacturers to develop compressor control libraries so that rack manufacturers have the flexibility to select the compressors that best suit their needs.

At the heart of CO_2 refrigeration are specialised control systems. The modern electronic expansion valves allow for refrigeration systems to be optimised. In traditional refrigeration systems this results in increased performance. In transcritical CO_2 systems they are actually critical to allow the system to operate. Carel produces rack controllers that are specifically designed to work with CO_2. Specialised algorithms allow for the compressor discharge pressure to be optimised based on the gas cooler exit temperature.

Carel also produces inverter controllers for BLDC motors that allow for the most efficient speed control available. This technology is currently being implemented by an increasing number of small compressor manufacturers to achieve highly efficient systems.

The controllers allow for system monitoring that provides important feedback for implementing system improvements. Carel invest in research and development to provide leading solutions for energy efficiency in the industry.

Carel has developed a range of controllers aimed at the small convenience store market. Like others in the industry, they have identified this as a large and underserved market. Key to providing viable solutions in this market is system integration. This means that the small systems will need to provide air-conditioning and heating as well as refrigeration. This sort of development is possible with Carel controllers that have design and configuration software that allows for customization.

Destination - Enex, Treviso, Italy

Contact: Sergio Girotto, Chief Executive

Objective: To learn from a leading technical CO_2 rack manufacture and discuss innovation areas.

Outcomes:

Sergio Girotto, founder of Enex, is widely respected, highly experienced and knowledgeable on CO_2 systems. Enex focuses exclusively on CO_2 systems, producing customised and standardised racks and packaged heat pump units. Included in their range are small CO_2 units for the convenience store market. After 10 years of operation and production of several hundred CO_2 systems, Enex are considered as pioneers in the industry.

The latest pioneering innovations for Enex included the introduction of ejectors to improve performance in warm climates. Energy normally lost through an expansion valve can be recovered with an expander. The higher the ambient temperature the more expansion energy available in a typical CO_2 gas cooler configuration. The ejector is attractive for recovering expansion energy as it has no moving parts. The trade-off to the simplicity of the device is that they have a very narrow operating range and require specialised knowledge to design. Enex have worked with the independent research organisation SCINTEF of Norway, to design ejectors that are optimised for transcritcal CO_2 expansion.

At a test installation in southern Spain the ejectors were used in combination with an auxiliary parallel compressor. The combined system improved the performance by 25 per cent compared to a simple cycle. This level of improvement makes the technology competitive with HFCs in warmer climates. In the colder climates of Northern Europe, CO_2 already beats HFCs on performance.

With 15 ejector installations currently in operation, Sergio believes that this is a robust and sound solution to the hot climate issue of CO_2.

Destination - Epta, Limana, Italy

Contact: Elga De Zanet, Marketing Refrigeration Systems

Objective: To discuss the state of the CO_2 rack manufacturing business with a major rack supplier that distributes to Australia.

Outcomes:

Epta manufactures an extensive range of commercial refrigeration products, employs 4,000 people and have an annual turnover of €650 million. They see the development of environmentally friendly CO_2 solutions as a major opportunity. Epta produce CO_2 racks from their manufacturing facility in Limana. The racks are sent all over the world including to Australia. The company promotes refresher courses to train in excess of 100 professionals per year at the EPTA CO_2 Training Centre in England.

In Australia, Epta works with AJ Baker who has installed over 150 cascade CO_2 plants with capacities varying from 6kW up to 50kW of low temperature CO_2 load. They have installed seven pumped liquid CO_2 racks and have just completed a CO_2 transcritical booster system in WA. The majority of installations are in supermarkets including ALDI, IGA, Woolworths, other independents and some food processing plants. In any given week, AJ Baker will have a CO_2 rack on the production line at Epta.

The relationship between Epta and AJ Baker is playing a critical role in facilitating this positive technological transformation in Australia.

Destination - Dorin, Florence, Italy

Contact: Mauro Arsenio, Technical Sales Officer

Objective: To learn about CO_2 compressor design and construction.

Outcomes:

Founded in 1918, Dorin is a family owned business that has been operating in refrigeration and air-conditioning since the early 1930s. They produce a large range of reciprocating piston compressors and condensing units for the HVAC&R industry. In 1996 they started producing CO_2 compressors. They now offer the widest range of CO_2 compressor capacity on the market.

The CO_2 compressors have been designed specifically for use with CO_2 rather than using a modified HFC design. Consideration has been given to robust design and quiet operation. They are designed with high-pressure ratings and offer transcritical compressors that can operate up to 140 bars. One unique feature is the thermal separation of hot discharge gas with the suction gas that minimises un-useful superheat and helps to maximise cycle performance. They also offer a two stage CO_2 compressor that allows for low temperature applications to be serviced by a single compressor.

Whilst CO_2 is clearly a rapidly growing market for Dorin, they also see hydrocarbons as an important growth market. They offer a range of ATEX compressors that allow operation in explosive environments.

Destination - Danfoss, Nordborg, Denmark

Contact: Anders Juul, Segment Strategy Manager CO_2

Objective: To learn about market trends and innovations from the leading CO_2 controls company.

Outcomes:

Danfoss was established in the early 1930s to service the market need for valves in refrigeration plants. The company now employs 22,500 people globally and services a wide range of industries.

Refrigeration valves are still core business and Danfoss has positioned itself, in the medium to large CO_2 rack business, as the leading supplier of electronic expansion valves and controllers.

By accurately controlling system pressures, electronic expansion valves allow optimisation of refrigeration systems. Due to the unique operating characteristics of CO_2, electronic control is almost indispensable.

At their research facility in Nordborg, Danfoss develops the controllers and software that manage the unique behaviour of CO_2. Danfoss controllers are designed to greatly simplify the manufacturing and commissioning of CO_2 racks. Users can set the value of operational parameters and Danfoss take responsibility for the control regimes.

The high pressure CO_2 valve market has seen huge growth in the last 10 years. During this time Danfoss has been improving and refining the valve design and control functionality. This investment has ensured that they have remained as the market leader and more importantly helped make CO_2 refrigeration accessible.

Destination - Advansor, Aarhus, Denmark

Contact: Kim Christensen, Managing Director/ Director of Engineering

Objective: To learn about the range of applications for CO_2 refrigeration and to hear about the practice of manufacturing CO_2 racks.

Outcomes:

Advansor was founded in 2006 by Kim Christensen and Torben Hansen. The founders had previously worked at the Danish Institute of Technology where they developed knowledge and experience of CO_2 systems. They saw CO_2 as the future of refrigeration and were aware of both the great benefits of CO_2 systems and that the market was not being adequately serviced.

Denmark had introduced tough legislation limiting HFC charge to a maximum of 10kg per refrigeration circuit. Advansor made the decision to only work with CO_2, allowing them to focus their efforts and rapidly develop very high quality and high performance CO_2 systems. To help offset the higher component costs, Advansor chose to streamline manufacturing and produce a standardised product range.

Today Advansor are the leading CO_2 rack manufacturer, selling approximately 400 racks annually. Their success attracted the American owned company Hillphoenix, who in 2011 purchased Advansor. The sale was a clear indication that CO_2 refrigeration is seen as an important growth area in the American market.

Currently the majority of CO_2 racks produced are for the food retail sector. For this market they have developed a wide range of standardised solutions from the very small low temperature condenser units, to the large low and medium temperature racks with heat recovery and integrated air-conditioning.

Advansor has seen costs of new full CO_2 supermarket systems fall rapidly. In 2006 CO_2 systems cost were approximately 15 to 40 per cent more expensive than HFC systems. In 2014 this number has fallen between zero to 10 per cent. Insightful retailers see that the extra capital cost is recovered rapidly by the reduction in running costs.

Advansor's CO_2 product offering extends into industrial refrigeration, building air-conditioning, ice rinks and heat pumps for district heating and industrial applications.

Destination - Johnson Controls, Aaurhus, Denmark

Contact: Alexander Cohr Pachai, Technology Manager

Objective: To hear perspectives on CO_2 technology from an experienced CO_2 refrigeration expert.

Outcomes:

Alexander Cohr Pachai started working in refrigeration in 1978. His experience and expertise are highly regarded throughout the industry. Pachai has worked in Research and Development, production, sales and in installations of natural refrigerant systems. His experience working with CO_2 began in 1997. The first cascade hydrocarbon CO_2 in Auckland was sold and commissioned by Pachai, as well as the largest hydrocarbon CO_2 cascade supermarket system in the UK

In Denmark, single HFC refrigerant circuits are permitted with charges under 10kg. Systems may not be multiplexed as a legal work-around if a natural refrigerant can be configured to do the job. Designing systems that are compatible with these constraints has given Johnson Controls the incentive to develop a suite of natural refrigerant solutions.

A recent project for a hospital in Aarhus uses hydrocarbons to produce 2MW of chilling and 500kW of 80C water. In Europe there are no charge limits of flammable hydrocarbons when used outside.

Refrigerant safety is always a prime consideration. Pachai emphasised the fact that the toxicity of HFCs is often overlooked. Reports of nausea and headaches are common after exposure to HFCs. When combusted, newly developed HFOs have been found to produce neurotoxins.

Concluding Remarks

The Fellow was able to visit many of the leading companies and key people in the established European CO_2 market. The trip revealed much about the benefits, limitations, innovations and application areas of CO_2 and other natural refrigerants.

The Fellow found an industry that is undergoing a period of rapid growth with an overwhelmingly positive and coherent narrative of CO_2 technology. The industry unanimously sites legislation as being critical in bringing about the shift toward natural refrigerants such as CO_2. The industry in Europe is dynamic, showing continued development to enhance performance, with steadily decreasing costs and rapidly increasing demand.

The largest challenges appear to be in the education of the customer and technician base. Much effort has been invested in making the technology as simple and understandable as possible. At the same time, extra complexity is required to improve the performance of transcritical CO_2 in warmer climates. The approach by the market leaders has been to introduce incremental and comprehendible changes to the systems.

Kaldor-Bull was able to engage in face-to-face technical discussions with leading academics, application engineers, innovators and manufacturers. This comprehensive immersion was highly effective in accelerating the learning process and bringing the Fellow up to speed with the leading edge of CO_2 technology.

7. KNOWLEDGE TRANSFER: APPLYING THE OUTCOMES

For the vast majority of climates on Earth, transcritical CO_2 performs better than traditional harmful HFCs from an annual seasonally weighted performance perspective.

Like all refrigeration systems, the greater the temperature difference the more energy required to achieve the cooling. The properties of CO_2 result in significant capacity reduction in high ambient temperatures when used in a basic vapour compression cycle. There are several techniques that are used to overcome this issue for CO_2 systems operating in warm climates. The most notable are parallel compression, mechanical or evaporative sub-cooling and ejector cycles.

Parallel compression is currently the most widely used technique for overcoming the high ambient temperature challenge. It involves re-compressing flash gas from the intermediate pressure vessel. Additional parallel compressors can be used to handle air-conditioning loads thereby increasing functionality and cost viability.

Mechanical sub-cooling involves a secondary refrigeration circuit that removes heat that cannot be removed by the primary gas cooler under high temperature ambient conditions. This technique has been done successfully using natural hydrocarbons where the additional circuit can be placed outdoors. Depending on the climate, the mechanical sub-cooler is required to handle in the order of 20 per cent of the heat rejection.

Evaporative sub-cooling is typically achieved by evaporative cooling of air before the air is used to remove heat from the gas cooler. Evaporative sub-cooling can be highly effective but has the drawback of consuming water. However, water consumption can be minimised by applying evaporative cooling only to the heat rejection required after the dry gas cooler. This technique allows CO_2 to equal or beat traditional HFC performance in extreme climates such as Darwin where the annual 3pm wet bulb temperature is 23.6 degrees Celsius.

Ejector cycles use ejectors in place of an expansion valve. The ejector is able to utilise the otherwise wasted expansion energy for liquid pumping or gas compression. Ejector cycles can improve performance in warm climates by up to 15 per cent.

CO_2 systems allow for integration with additional building heating and cooling loads. Waste heat provides for massive efficiency gains; so much so that using waste heat recovery has been made mandatory for systems over 40kW in Switzerland. Air-conditioning can be easily integrated into the common CO_2 refrigeration rack design.

System integration such as combining air-conditioning, refrigeration and hot water is considered critical for the viability of small CO_2 systems.

Some of the main advantages of using CO_2 are:

- Ozone Depletion Potential = 0
- Global Warming Potential = 1
- Non-flammable
- Only harmful to persons in high concentration levels
- High volumetric refrigeration capacity
- High heat exchange coefficient
- Low-pressure ratio
- Low influence of pressure drops
- Low price and high availability levels
- Compatible with many other materials

7. KNOWLEDGE TRANSFER: APPLYING THE OUTCOMES

The manageable disadvantages are:

- High pressure (up to 130 bar)
- High triple point -56.6 °C / 5.2 bar
- Capacity drop with increasing ambient temperatures
- Pressure control when system is at standstill
- Danger of suffocation in high concentration levels
- Permeability with some elastomers
- Lack of comprehensive training courses

Denmark was the first country to impose tough legislation on high GWP refrigerants. The CO2 technology that emerged as a response to this legislation has proven to be superior in performance to its harmful predecessor. The political decisions made by Denmark provided an environment that gave rise to the world leader in CO2 rack technology, Advansor. Advansor has refined system design and produce standardised CO2 products that successfully service refrigeration and heating requirements in a wide range of applications.

The technology has spread rapidly through northern Europe and now with further advances in high ambient performance is making its way into southern Europe. Whilst the prime motivator for this change has been European Union f-gas regulations, the performance improvements are being recognized as having significant fiscal benefit to the equipment owner.

Major supermarket retailers in the UK have been quick to adopt full transcritical CO2 systems. This is driven both by EU legislation and by a need to be in-line with adopting the same green technology as their competition. This rapid uptake has been a great boost to the industry and helped to lower system costs.

Australia's approach to CO2 has been measured and cautious with virtually all CO2 installations done in cascade with HFCs and CO2 running subcritically. This has given the industry experience of handling CO2 and will be beneficial in a transition to full transcritical CO2 systems. Some rack manufacturers in Europe have an eye on the Australian market but currently see it as small, underdeveloped and too costly and too slow to ship to. This perspective highlights an opportunity for local manufacturers to enter the market early and consolidate a leading position in the future of the industry.

There are others in Europe that believe the Australian market is poised to boom, as it currently is in Europe, and they are making moves to be ready. Epta, who currently exports racks to Australia and are working with Australian contractor AJ Baker, who has successfully installed their first transcritical system in Australia.

The technology has clear environmental benefits that could be exploited to help address the issue of climate change. In Australia the main barriers to its adoption come from lack of awareness, lack of government leadership and lack of adequate training for engineers and technicians.

In Europe, universities, private training companies and key component manufacturers offer the training of technicians. The f-gas regulations have created a market for these training facilities.

The German compressor manufacturer, Bitzer, has built a transcritical CO2 system that will be used for training purposes in Sydney. This indicates that there is a belief that transcritical CO2 will come to Australia. By offering training in CO2 systems, Bitzer is able to establish familiarity of their product range amongst system designers and technicians. The same approach is taken by Bock in Germany as ultimately this may lead to more purchases of their products.

Beyond manufacturers providing training, it is vital that government send an indication to the industry that this is the future of refrigeration in Australia. If Australia were to follow the lead of the European Union by imposing restrictions on the use of HFCs, a new manufacturing industry would be set into motion overnight. This in turn would stimulate government and private training institutions to expand and create new training courses.

The Fellow intends to disseminate the findings of this study through his consultancy. Where appropriate, clients with potential applications of the technology will be presented with the high performance and environmentally friendly alternative of CO2.

8. RECOMMENDATIONS

Government

As demonstrated in Europe, the impact of implementing regulations in Australia on the use of HFCs with high GWP would be incredibly productive for generating new jobs in the manufacturing and service industries. Furthermore it has the potential to significantly reduce greenhouse gas emissions in an industry that accounts for almost 12 per cent of total emissions.

By adopting the same regulations that have been rigorously debated and tested in Europe, Australia would be taking direct action on climate change whilst simultaneously stimulating an important industry.

Industry

As Bitzer has done in New South Wales, other component manufacturers could produce demonstration facilities that can be used for training of technicians and engineers in the other major cities.

The HVAC&R industry could offer support to educational institutions by providing CO2 system hardware to be used as training aids. This is a great opportunity of mutual benefit to both the manufacturer of the equipment and the trainees. Trainees gain familiarity with manufacturers components and selection software. This could be a collaborative contribution that would help lower the skills barrier and encourage retailers to invest in the technology.

Education and Training

Current refrigeration certificate courses could be amended to include a transcritical CO2 module. Emphasis should be placed on the importance of natural refrigerants for the environment and for future employment opportunities.

The training institutions could provide a facility for a transcritical rack for teaching purposes donated by industry.

International Specialised Skills Institute

As part of a transition to a fully functioning CO2 industry in Australia, ISS Institute could provide Fellowships specifically to personnel who hold an accredited refrigeration certificate. The Fellowships would allow refrigeration mechanics to expand their skill base by attending an international CO2 training facility.

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