Transcritical CO_2 (R744) Supermarket Refrigeration in Australia
By the Australian Green Cooling Council

Abstract

Conventional supermarket refrigeration systems commonly use HCFC 22, an ozone depleting and very high Global Warming Potential (GWP) refrigerant gas. Replacement of these systems with cascade or transcritical CO_2 systems will assist both phase out requirements of the Montreal Protocol, and also compliance with Kyoto Protocol obligations to control emissions of high GWP HFC alternatives. Based on the Australian experience, CO_2 systems will have higher initial installation costs of around 20%, although it is expected that capital equipment costs will decrease once the volume of installed systems grows. Reductions in annual electricity costs of up to 23% are expected to be achievable with transcritical CO_2 systems, depending on the climatic zone in which facilities are located. Due to the energy savings, CO2 systems will deliver further greenhouse gas emission reductions and provide a short-term payback period on higher installation costs.

Background

In the commercial refrigeration sector the most common installations are Direct Expansion (DX) Systems, also known as centralised or multiplex systems, typically used in supermarkets, cold storage warehouses, built-up refrigeration/freezing systems for food processing and small and medium food retail outlets. These conventional systems result in high direct emissions arising from both leaks due to vibration and thermal expansion of numerous pipes, threaded joints, fittings, and valves, and from catastrophic losses from ruptures or compressor failure. They also result in high indirect emissions due to energy inefficient system components, and system design issues, such as lack of heat recovery in some systems, open cases, poor air curtains, inefficient lighting, use of anti-sweat heaters, and inadequate maintenance.

Historically, CFCs were the standard refrigerants in use in these systems. However, since the CFC phaseout in the 1990s, HCFCs (e.g., R22) and HFCs (e.g., R404a, R507 and R134a) have been used as replacement refrigerants. Leakage rates of fluorocarbon refrigerants from conventional DX supermarket systems in Australia are known to be around 23% on average,[1] which typically account for 40% to 50% of total greenhouse gas emissions from a supermarket.

In Australia, major supermarket chains have become increasingly concerned about high replacement costs of conventional fluorocarbon refrigerants, and the environmental impacts of leaked ODS and high GWP refrigerants. The introduction of global warming emissions reporting requirements for large companies beginning mid-2008 by the *National Greenhouse and Energy Reporting Act 2007* has stimulated further interest from the commercial refrigeration industry in reducing direct and indirect emissions.

Since 2005, around 30 commercial refrigeration and food processing facilities have installed cascade CO_2 systems, and the first Australian transcritical supermarket refrigeration system was commissioned in December 2007. With zero ozone depletion potential (ODP) and a global warming potential (GWP) of only 1, the use of CO_2 in refrigeration systems can lead to decreased direct emissions of ozone depleting substances (ODS) and greenhouse gases (GHGs), and also reduced indirect GHG emissions through improved energy efficiency compared to DX systems.

[1] This is reflected in the commercial refrigeration default annual loss rate provided for in the proposed National Greenhouse and Energy Reporting regulations emissions factor.

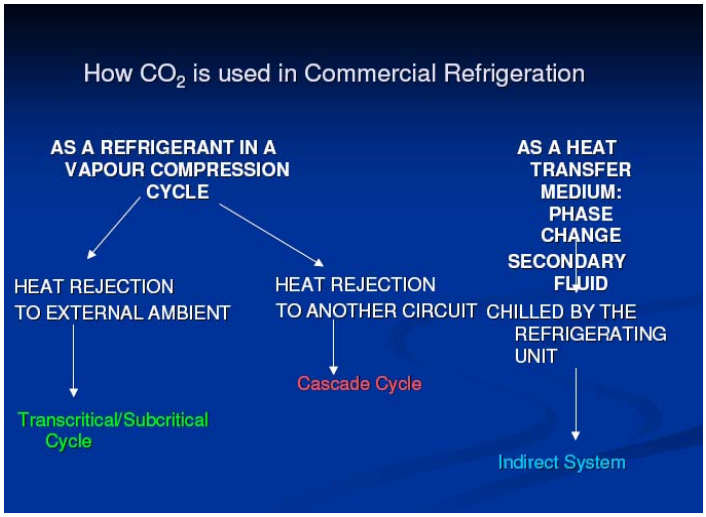
Development of Alternative

Companies in Australia now recognise the economic, environmental, regulatory and corporate image benefits of reducing their ecological footprint, and all levels of the commercial refrigeration industry in Australia are showing strong interest in the development of CO_2 equipment and systems.

The Green Cooling Council (formerly the Natural Refrigeration Transition Board) is a not-for-profit, membership based association. Our role is to encourage the use of environmentally preferable refrigeration and air conditioning systems in Australia. We work in the national interest to effect change in the refrigeration and air condition industry.

The organization was formed in 2004 and received funding from the Commonwealth Government Greenhouse Gas Abatement Program in 2006 for the purpose of evaluating environmentally preferable supermarket refrigeration systems and working with training institutions to increase the availability of refrigeration technicians able to install and service environmentally preferable refrigeration and air conditioning technologies. Industry sponsors include Bitzer, Austral, Danfoss, Carel, Heatcraft, GEA (Grasso), Alfa Laval, Guntner, Scantec and Minus40.

As a refrigerant, CO_2 (R744) has the significant advantages of having the lowest GWP, a very low refrigerant cost and excellent heat transfer. Transcritical CO2 only systems reject heat via a gas cooler, whereas cascade systems reject heat to another refrigeration circuit. Challenges that need to be overcome in applying CO_2 systems include designing for the high operating pressures, absorbing increased system costs and implementing systems controls that can accommodate the low efficiency of the basic cycle.



Bringing the Alternative to Market

Since 2005, around 30 cascade CO_2 systems have been installed in commercial refrigeration and food processing facilities in Australia. The first transcritical CO_2 supermarket refrigeration system was commissioned in Australia in December 2007 at the Drakes Foodmarkets store at Angle Vale, North Adelaide.

The Drakes Foodmarkets store at Angle Vale, North Adelaide in South Australia is the first transcritical supermarket to be built in the Southern Hemisphere. A number of CO_2 cascade facilities have been built in Australia, but the Angle Vale project is unique. It requires no temperature cascading or secondary fluid recirculation pumps, and is fully charged with low-cost CO_2. As CO_2 is neither toxic nor flammable, it presents no significant safety barriers.

Current technical options for commercial refrigeration

- **Transcritical CO_2 systems,** for both medium temperature (MT) and low temperature (LT).
- **Subcritical Cascade CO_2** for both medium temperature (MT) and low temperature LT), in combination with a high stage system.
- **Secondary systems** for MT and LT, generally in combination with heat-recovery for defrost and a range of fluid chiller system options
- **Hybrid systems**, with various combinations of the above concepts
- The high stage refrigerant options include:
  - **Low GWP synthetics** (under development)
  - **HC - Hydrocarbon refrigerant**, such as R290 (Propane) or R1270 (Propylene)
  - **NH_3 - Ammonia**
  - **R723**, a modern blend of ammonia and di-methyl ether (DME).

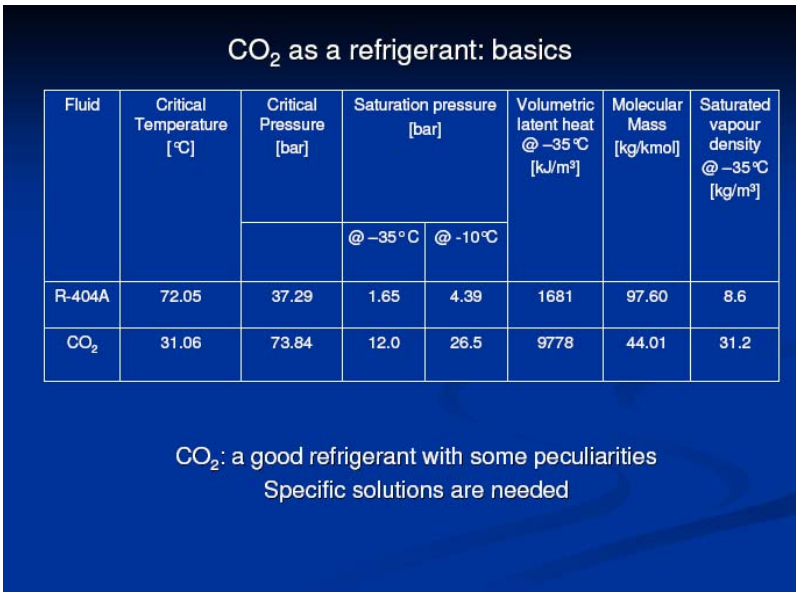
The higher design and installation costs associated with the CO_2 systems (compared to conventional DX systems) were met by an Australian Commonwealth Government subsidy under the Greenhouse Gas Abatement Program, administered by the Green Cooling Council. With the objective of reducing both direct and indirect greenhouse emissions, Angle Vale is one five demonstration and evaluation projects that have been enabled by this program grant. In addition the development of training courses in CO_2 refrigeration is taking place through the TAFE technical training institutes, and training is now available to the industry.

Overcoming Barriers

The lack of skilled people in the design, installation and maintenance of CO_2 systems remains a barrier to the wider uptake of CO_2 refrigeration, and further efforts to address this issue are required. In particular, the lack of availability of training courses in regional areas remains a barrier to the adoption of CO_2 outside the main metropolitan areas, and this problem is being addressed by other initiatives currently under development. Negative perceptions about the feasibility of CO_2 systems among sections of the industry is another barrier that requires attention, but the success of the Angle Vale project is proving effective in assuaging these.

Identification of project costs and opportunities for cost savings are among the outcomes of the project, and are expected to provide many useful lessons to the industry in the development of further transcritical systems. These costs are still in the process of being analysed, and production of an interim report is planned for later in 2008, with the final report due for completion in 2009.

Perhaps the most significant barrier that had to be overcome for this project to succeed was to find a client prepared to take on the risks associated with doing something new for the first time in Australia. With much at stake, innovation in the commercial refrigeration industry is a challenging process, and Drakes Foodmarkets displayed commendable leadership in pursuing their green values and answering their search for a better environmental solution to their refrigeration needs with a transcritical system.



As a small independent chain, Drakes Foodmarkets has a short chain of command and was able to act decisively in ways that are more difficult for larger companies. Their willingness to take a risk and provide innovative leadership to the industry is highly commendable. The assistance of Enex Consulting, the installer Hill Equipment, their subcontractor Marks Electrics, Carel Australia and the refrigeration industry component suppliers is also acknowledged.

Adoption of the CO_2 solution in commercial refrigeration world wide is at an early stage, yet sufficient experience has been gained to firmly establish its use as the most environmentally preferable way forward. Development of CO_2 refrigeration is being pioneered in Europe, particularly in the Nordic countries and Italy, where around 100 facilities are using CO_2. Significant interest in CO_2 has also been demonstrated in Australia and New Zealand, where these systems are beginning to penetrate the market.

Major supermarket operators in other countries are also showing interest in pursuing the solutions provided by CO_2. As attention to the need to reduce greenhouse gas emissions increases and global emissions trading regimes are developed, the future for both cascade and transcritical commercial

refrigeration looks very promising, in spite of attempts to promote HFCs as the only acceptable alternative by certain sectors of the global refrigeration industry.

Impacts of Switch to Alternative

What has been established at Angle Vale is that transcritical CO_2 refrigeration systems will operate in +40°C climates. All reports on performance of the system to date clearly demonstrate that it is performing extremely well, and coping admirably with the high ambient temperatures experienced during a very hot summer and a record-setting heat wave in Adelaide.

Commissioning of the Angle Vale transcritical system took place in early December 2007, and monitoring of power consumption and system efficiency has not been in place for a sufficient period of time for results to have been gathered and analysed. Full energy monitoring is being undertaken and will be openly reported by the Green Cooling Council as this data is obtained.

Maintenance costs will only become apparent in the medium to longer term, but overseas experience suggests that transcritical CO_2 systems are very reliable and result in significant cost savings over time, compared to conventional DX systems.

In spite of the inability to provide measured results, the predicted benefits of replacing conventional DX systems with CO_2 systems are very significant. As conventional supermarkets are known to leak refrigerant at 20%-40% per annum, it is easily demonstrated that the direct global warming effect of refrigerant leakage is 40%-70% of a conventional supermarket's carbon footprint.

The reduction in power consumption and associated indirect emissions of CO_2-only systems will vary according to the climatic area of the facility, and range between only a 1% improvement in hot humid climates, roughly 15% in hot dry climates, and up to a 23% improvement in cool temperate areas. As CO_2 only systems have a negligible direct global warming impact, it is expected that the carbon footprint of CO_2 systems will only be between 30% to 60% of conventional fluorocarbon systems. Further development and monitoring of these systems will shed more light on the scale of these improvements, but it is clear that significant emissions abatement is achievable by the worldwide adoption of CO_2 systems.

As the most environmentally benign refrigerant known, the use of CO_2 by definition eliminates any ozone depletion impacts, and even in the event of catastrophic leakage of refrigerant results in negligible global warming impacts.

Both non flammable and non toxic, the only risk presented by CO_2 is of asphyxiation at high concentrations. Although not required by safety codes, at Angle Vale refrigerant leak detectors have been installed in the plant room, cool rooms and trading area, which trigger both visual and audible alarms well in advance of dangerous concentrations being reached. In addition, staff members working in enclosed spaces for any length of time have personal alarms available to detect and record CO_2 levels.

In order to supply anticipated demand generated by the success of CO_2 supermarket refrigeration systems, Australian companies are developing an expanded range of products including transcritical and cascaded hybrid solutions, as well as CO_2 only packages for both new and retrofit applications. Leading refrigeration industry component providers are making this product range available through their established distribution networks.

By adopting CO_2 commercial refrigeration systems supermarket owners can demonstrate leadership in responding to climate change, reduce regulatory burdens and take advantage of genuine third party eco-labelling opportunities for eliminating ozone impacts and minimizing global warming emissions.

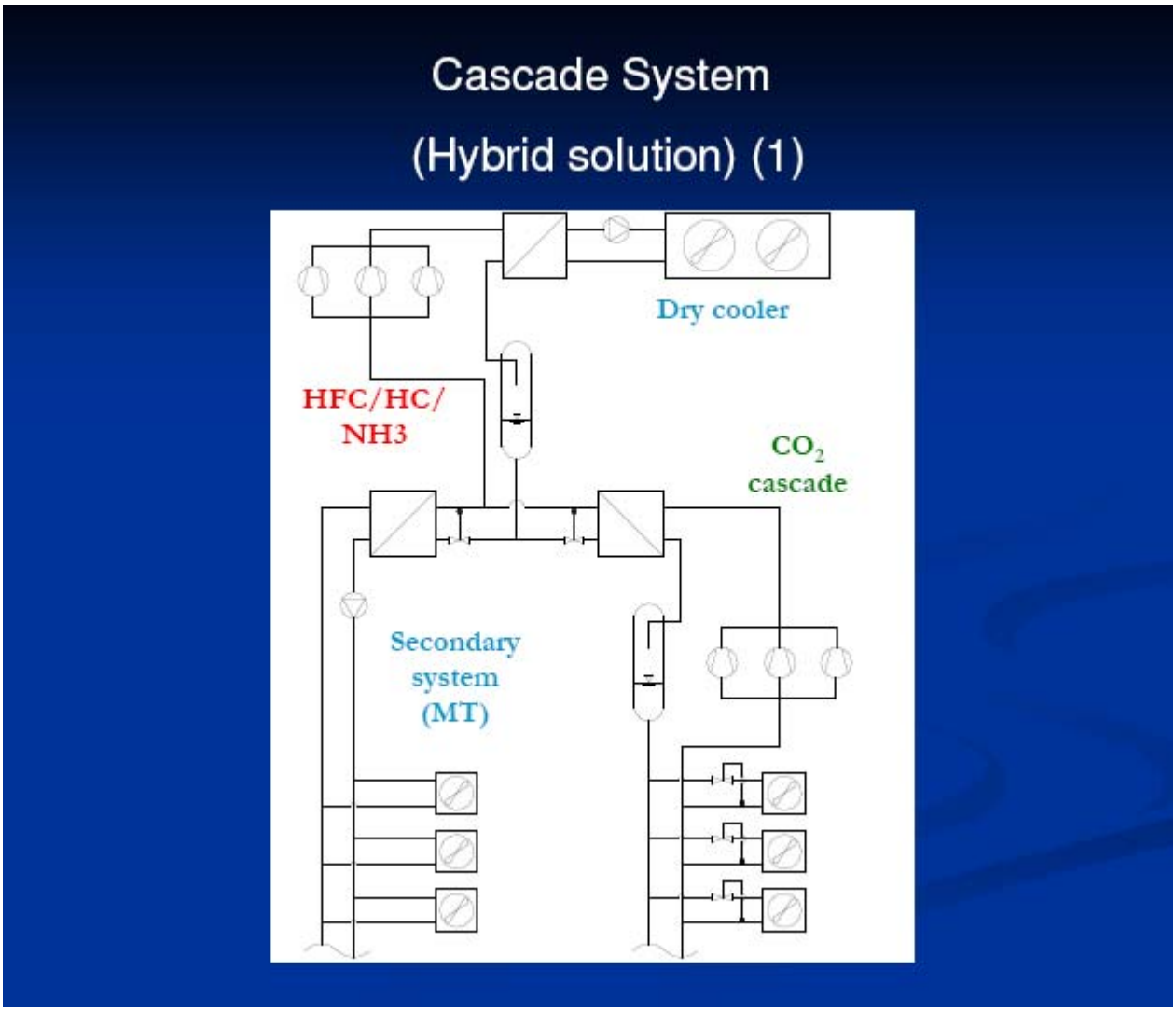
Comparison of Transcritical and Cascade CO_2 supermarket refrigeration systems

Concept	Advantage	Disadvantage
Transcritical CO_2	• **Simple concept** • **One gas, one oil** • **Possibly cheapest option** • **Low power consumption in cool climtes?**	• **Lack of knowledge and familiarity** • **Remote location servicing** • **High power consumption in hot climates?**
Cascade CO_2	• **Low power consumption?** • **Increasing use by industry**	• **Two gases, two oils** • **Lack of knowledge and familiarity** • **Remote location servicing**
Secondary	• **Simple** • **Easy to service** • **Product quality**	• **High power consumption?** • **Expensive**

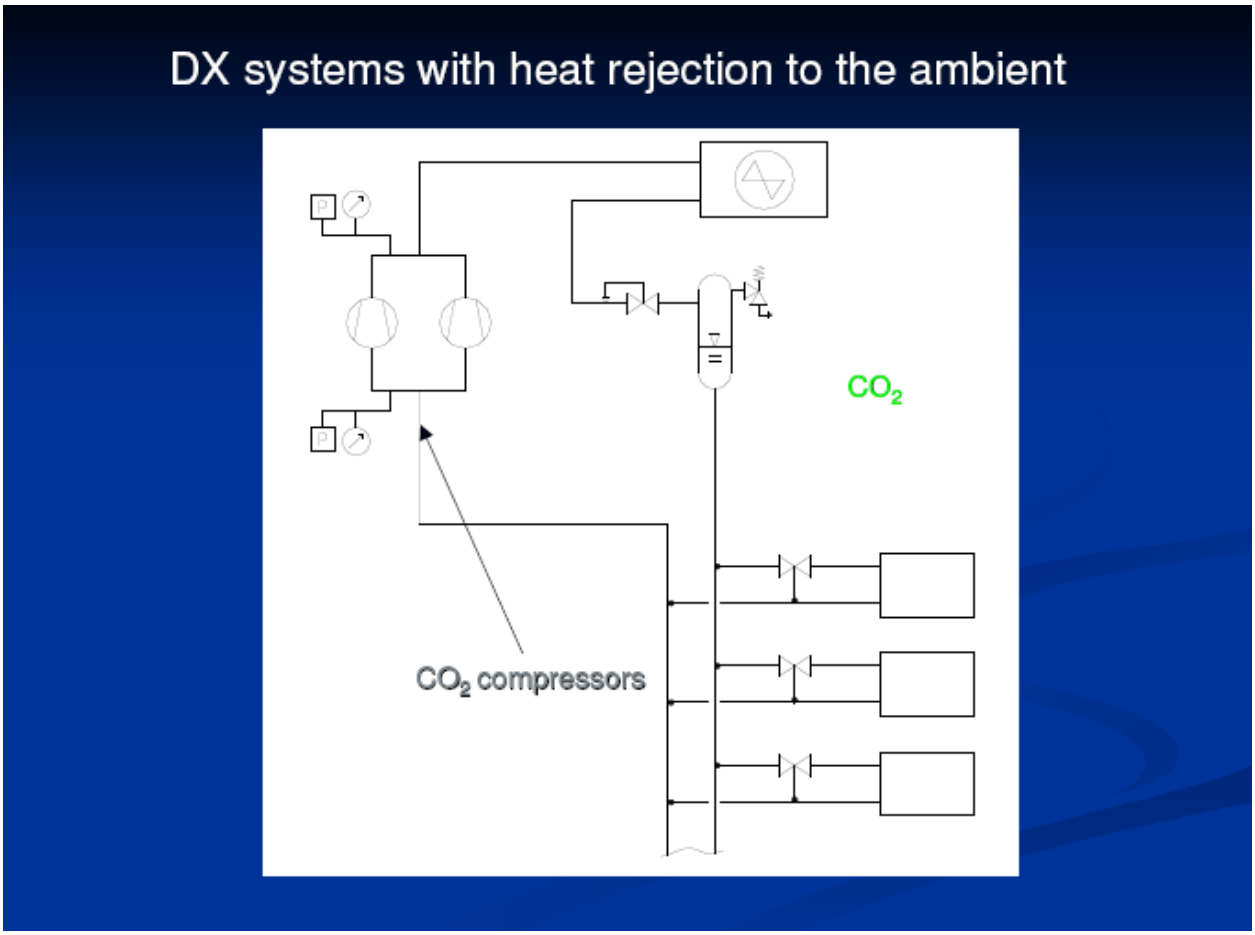
Annex – CO_2 Design Features

Specific Design Hints for CO_2

Active high pressure control
Minimization of liquid line pipe size (charge minimization)
Limitation of liquid line working pressure
Oil cooling/compressor cooling
Limitation off compressor discharge temperature
Oil recovery on the low pressure side
Pressure limitation in stand-still conditions
Sub-cooling of the high pressure refrigerant at high ambient temperature
Proper design of gas cooler/condenser
Proper design of piping: copper tubes, small diameter (low cost)
Proper design of piping with respect to oil return
Capacity control to meet seasonal load variations



Cascade system. All supermarkets have two temperature levels (chilled food at 0°C and frozen food at -30°C) a first possibility is to use a conventional systems, charged with common refrigerants HFC (in some cases NH3 – Ammonia) for the cabinets / cold rooms at 0°C, cooled with a secondary fluid, and at the same time using part of refrigeration at 0°C to remove heat from condenser of a LT system using CO2 as a working fluid in direct expansion



Direct heat rejection. It is possible to use 2 separate plants both working with CO2 as a refrigerant, in this case the two systems are completely independent and heat can be rejected directly to outside air, exactly like with conventional Direct Expansion (DX) plants working with HFC. In this case there isn't the complexity and the cost of a secondary system.

Inspecting Angle Vale Transcritical CO2 System at Drakes Foodmarket in South Australia

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