Refrigeration from Catch to Market

A study of refrigeration technology options for the Northern Prawn Fishery fleet and the Sydney Fish Market

FRDC Project number: 2013/227

November 2013

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

NPF

EXPERTGROUP

Phone	Web
03 95929111	www.expertgroup.com.au

Table of Contents

Appendices

List of Tables

List of Figures

Glossary

Ammonia refrigerant	Anhydrous ammonia (R717) has excellent thermodynamic properties, making it effective as a refrigerant. It is widely used in industrial and process refrigeration applications because of its high energy efficiency and relatively low cost. Ammonia is used less frequently in commercial refrigeration applications, such as in supermarket and food retail, freezer cases and refrigerated displays due to its toxicity, and the proximity of the general public.
Azeotrope	See refrigerant glide.
Cascade refrigeration system	An advanced refrigeration system made up of two separate but connected vapor-compression refrigeration systems, each of which has a separate primary refrigerant. The systems are interconnected in such a way that the evaporator of one system is used to serve as condenser to a lower temperature system (i.e. the evaporator from the first unit cools the condenser of the second unit). Cascade systems in operation today in Australia are HFC-404A or HFC-407A/R744 (CO_2); HFC-134a/R744 and R717 (ammonia)/R744.
Chlorofluorocarbons (CFCs)	Molecules containing carbon, fluorine, and chlorine. CFCs are the major ozone depleting substance phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. Many CFCs are potent greenhouse gases.
Coefficient of performance (COP)	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 circuit which compresses refrigerant vapour, and circulates that refrigerant through to its phases of condensation and evaporation, in order to produce the refrigeration effect. The compressor is available in many forms such as piston (reciprocating), rotary, scroll, or screw.
Compressor rack	The machine assembly which accommodates the main high pressure components of a refrigeration circuit in a single structure, allowing off site connection to associated pipe work and vessels.
CO_2 refrigerant	A widely used industrial refrigerant with high thermodynamic properties is suitable for process refrigeration applications, and automotive air conditioning use. In the past its high operating pressures have limited its use in small to medium commercial refrigeration applications. Technical innovation such as micro cascade systems and commercial availability of components such as compressors and other in line accessories is assisting its transition into smaller scale applications.
CO_2-e	Carbon dioxide equivalent to the number of tonnes of CO_2 emitted.
Direct emissions	Global warming effect arising from emissions of refrigerant, or any other 'greenhouse gas', from the equipment over its lifetime.
Energy consumption per year	Energy consumption of the appliance, equipment or system per annum in kWh per year, or GWh per year for an application or equipment sector.
End-of-Life (EOL)	Domestic, commercial or industrial device reaching the end of its useful lifespan. End- of-life (EOL) emissions are direct emissions from ozone depleting substance (ODS) and synthetic greenhouse gases (SGG) refrigerants not recovered for destruction or reclamation.
Equivalent Carbon Price (ECP)	Under the Australian Government's Clean Energy Future Plan, synthetic greenhouse gases listed under the Kyoto Protocol have an equivalent carbon price applied through the Ozone Protection and Synthetic Greenhouse Gas Management legislation. Gases covered will include hydrofluorocarbons, perfluorocarbons (excluding gases produced from aluminium smelting) and sulfur hexafluoride, and any equipment or products which contain these gases.
Gas	A general term used throughout this report, referring to ozone depleting substances, synthetic greenhouse gases and natural refrigerants. The term can refer to refrigerants when the substance is used as a working fluid in equipment or used in other applications.
Global Warming Potential (GWP)	A relative index that enables comparison of the climate effect of various greenhouse gases (and other climate changing agents). Carbon dioxide, the greenhouse gas that causes the greatest radiative forcing because of its abundance is used as the reference gas. GWP is also defined as an index based on the radiative forcing of a pulsed injection of a unit mass of a given well mixed greenhouse gas in the present-day atmosphere, integrated over a chosen time horizon, relative to the radiative forcing of carbon dioxide over the same time horizon. The GWPs represent the combined effect of the differing atmospheric lifetimes (i.e. how long these gases remain in the atmosphere) and their relative effectiveness in absorbing outgoing thermal infrared radiation. The

	Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.
Greenhouse Gases (GHG)	The Kyoto Protocol covers emissions of the six main greenhouse gases, namely Carbon dioxide (CO_2); Methane (CH4); Nitrous oxide (N2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulfur hexafluoride (SF6). The scope of this study covers the equivalent in carbon dioxide due to indirect emissions from electricity generation, and direct emissions from HFCs.
Hydrocarbons (HCs)	The term hydrocarbon refers to the main types and blends of hydrocarbon gases in use as refrigerants in Australia including HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290). HC-600a is the preferred hydrocarbon refrigerant in domestic refrigeration applications as it is suited to both refrigerator and freezer applications. HC-290 is the preferred hydrocarbon option for non-domestic stationary applications as its performance characteristics are more suited to medium temperature applications (i.e. greater than zero degrees Celsius). HC-436 is a hydrocarbon blend that is commonly used in mobile air conditioning retrofit applications.
Hydrochlorofluorocarbons (HCFCs)	Chemicals that contains hydrogen, fluorine, chlorine, and carbon. They do deplete the ozone layer, and have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFC-22 is the most common refrigerant in the Australian refrigerant bank.
Hydrofluorocarbons (HFCs)	Chemicals that contain hydrogen, fluorine, and carbon. They do not deplete the ozone layer and have been used as substitutes for CFCs and HCFCs. Many HFCs are potent greenhouse gases.
Hydrofluoroolefins (HFOs), and HFO blends	HFOs sometimes referred to as low GWP HFCs contain hydrogen, fluorine and carbon like the HFCs, but they are distinctly different. They are olefins, which mean they have very short atmospheric lifetimes of a few days, leading to distinct environmental benefits such as low GWPs. Refer to section 3.6 for further details on the various classes and blends.
Indirect emissions	Global warming effect of the CO_2 emitted as the result of the generation of the electrical energy required to operate electrical equipment, sometimes also referred to as 'energy related emissions.'
Indirect emission factor	The indirect or CO_2 emission factor is the mass of CO_2 emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking in efficiency losses in generation and distribution.
kWr	Refers to kilowatts of refrigeration capacity whereas kW relates to kilowatts of electrical power.
KWh	Kilowatt hour (1 watt hour x 10^3).
Kyoto Protocol	The Kyoto Protocol sets binding emissions limits for the six greenhouse gases listed in the Protocol. The Australian Government is committed to reducing emissions of the six main greenhouse gases, which includes the synthetic greenhouse gases (SGGs) listed under the Kyoto Protocol, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6). PFCs and SF6 are excluded from the scope of this study, as they are not used in RAC applications.
Lifespan	Lifespan is the expected useful life of the equipment in years.
Low GWP substances or refrigerants	This term can and is used to refer to both the commonly referred 'natural' refrigerants, HFC substances with a GWP lower than those commonly used today and the near to commercial HFOs being scaled up by the major synthetic greenhouse gas manufacturers that are sometimes referred to as low GWP HFCs.
Low temperature refrigeration	Temperatures below 0^oC that the general public would often think of as the point of 'freezing'. On a NPF vessel this is typically around -35^oC.
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer sets binding progressive phase out obligations for developed and developing countries for all the major ozone depleting substances, including CFCs, halons and less damaging transitional chemicals such as HCFCs.
Natural refrigerants	Hydrocarbons (R600a, R290 and R436), ammonia (R717) and carbon dioxide (R744) are commonly referred to as natural refrigerants. The term 'natural' implies the origin of the fluids as they occur in nature as a result of geological and/or biological processes, unlike fluorinated substances that are synthesised chemicals. However it has to be noted that all 'natural' refrigerants are refined and compressed by bulk gas manufacturers via some process and transported like other commercial gases so also have an 'energy investment' in their creation, storage and transport.
Operating hours per year	The number of hours the appliance, equipment or system operates at full input load or maximum capacity.
Ozone depleting substances (ODS)	Chemicals that deplete the ozone layer (e.g. HCFCs).

Refrigerant	Working fluid in the vapour compression refrigeration cycle.
Refrigerant charge	The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a piece of equipment.
Refrigerant glide	The difference between the saturated vapour temperature (or dew point is the temperature at which all of the refrigerant has been condensed to liquid) and the saturated liquid temperature (temperature at which a liquid refrigerant first begins to boil in the evaporator) is referred to as the temperature glide of the refrigerant. At a given pressure, single component refrigerants such as HFC-134a have zero glide and are therefore azeotropes. Refrigerant mixtures (blends) behave somewhat differently and have measurable temperature glide when they evaporate (boil) and condense at a constant pressure. HFC-507A is an azeotropic blend whereas HFC-404A is a near azeotrope .
Refrigerant leak rate	The annual leak rate is defined as the sum of gradual leakage during normal operation, catastrophic losses amortised over the life of the equipment and losses during service and maintenance expressed as a percentage of the initial charge per annum.
Refrigerant recovery	Removal of refrigerant from a system and its storage in an external container.
Second Assessment Report (AR2)	Second Assessment Report of the United Nations Framework Convention on Climate Change, released in 1996. Australia's legally binding emission obligations under the Kyoto Protocol are calculated based on AR2 and therefore Australian legislation, including the Ozone Protection and Synthetic Greenhouse Gas Management Act, also cite GWPs from AR2.
Specific Energy Consumption (SEC)	Specific Energy Consumption is a measure of energy consumption intensity of a cold storage facility in kWh/m^3 per year.
Synthetic greenhouse gases (SGGs)	SGGs listed under the Kyoto Protocol, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6). PFCs and SF6 are excluded from the scope of this study, as they are not used in RAC applications.
Synthetic substances or synthetic refrigerants	HCFCs, HFCs and HFOs are commonly referred to as synthetic substances or synthetic refrigerants.
Walk-in coolroom	A walk-in coolroom is a structure formed by an insulated enclosure of walls and ceiling, having a door through which personnel can pass and close behind them. The floor space occupied by this structure may or may not be insulated, depending on the operating temperature level.

Acknowledgements

The project team would like to acknowledge the Fisheries Research and Development Corporation for their investment and support, the Sydney Fish Market for their financial contribution and in-kind support, and the in-kind support of NPF Industry Pty Ltd shareholders.

The authors would like to acknowledge the contribution from Jeremy Spence of Neptune Refrigeration and Air Conditioning and thank him for providing invaluable information, technical advice and insights into refrigeration systems on fishing and prawning vessels.

This paper has been prepared for NPF Industry Pty Ltd.

Prepared by Peter Brodribb and Michael McCann of the Expert Group (A.C.N. 122 581 159) and with technical input from Jonathan Fryer, ISECO Engineering Services.

Level 1, 181 Bay Street, Brighton, Victoria 3186

Ph: +61 3 9592 9111

Email: inquiries@expertgroup.com.au

Web address: www.expertgroup.com.au

Disclaimer

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

ISBN: TBA

FRDC Project number 2013/227: Addressing the urgent needs to identify viable refrigerant alternatives for the use in the Northern Prawn Fishery.

For bibliographic purposes this report may be cited as: Refrigeration from Catch to Market, A Study of Refrigeration Options for the Northern Prawn Fishery Fleet and the Sydney Fish Market, Expert Group 2013.

1 Executive summary

Modern fishing fleets and the fish product supply chains are entirely dependent on effective and reliable refrigeration systems, from the point of catch to consumption.

The fishing vessels of the NPF (Northern Prawn Fishery) have one of the most demanding tasks for refrigeration equipment, operating in constrained spaces, under heavy load, in high ambient temperatures, requiring snap freezing of tonnes of sensitive product using equipment operating in a moving vessel, with heavy vibration and exposed to corrosive salt spray and water. Aside from the severe mechanical constraints and conditions, this demanding refrigeration task is only easily achieved using HCFC-22 (R22), a refrigerant that is on the verge of being completely phased out within a matter of years. HCFC-22 is rapidly becoming unaffordable.

As a result of the age of the NPF fleet, the majority of refrigeration equipment employed is also at, or well past its original design life, making the potential for component failure increasingly likely, with the potential for total loss of the very expensive refrigerant.

This report examines a number of options for the NPF fleet to transition to technology that provides the best mix of performance, reliability and affordability, while proposing a process for minimising the design risk for individual vessel owners. The future technology options however are clouded by new rounds of international discussions and proposals to restrict the use of what might be the best refrigerant option for vessel owners to move to. The long life of refrigeration plant means that even proposals to restrict availability of a refrigerant in 10 or 12 years needs consideration in design decisions now.

In short, the frank assessment must be that there are, no easy, off-the-shelf, technology options available for the fleet to move to today that can be guaranteed to not be subject to restrictive regulation and supply constraints inside the life of the equipment.

Nonetheless the authors have recommended moving to a refrigeration system capable of operating on a 3rd generation refrigerant, HFC-507A. To do this most effectively it is recommended that a short, focussed research program is funded to demonstrate a reference design that focuses on refrigeration containment, reduction in refrigerant charge, improved build quality and energy efficiency. Details of this proposed approach is set out in *Section 6: Conclusions and Recommendations*.

Further down the supply chain, the very large refrigeration system around which the SFM (Sydney Fish Market) is built, is also at the end of its design life and reliant on more than half a million dollars of the same refrigerant, HCFC-22, that is becoming increasingly more expensive and harder to source.

The SFM have few of the mechanical constraints and conditions of the NPF fleet, however it has other significant issues that have to be managed in design and replacement of the existing system. Firstly the scale of the system, and the thousands of cubic metres of refrigeration it provides, to a market that retails thousands of tonnes of product a year, requiring a range of medium temperature and low temperature storage areas, means that replacement of the system has the potential for significant business disruption unless it is handled well.

Aside from the logistics of replacing a working system of this size, in a facility that requires 7 days per week operation to maintain the stock in trade, the locality of the SFM, on the edge of the largest CBD in Australia, in the middle of an active tourism, retail and hospitality precinct, means that the use of certain refrigerants that have potential safety issues is unlikely to be acceptable, even though they may be the best technical solution to the requirements. As such the analysis proposes the SFM conduct a detailed feasibility study of the use of an advanced HFC-134a/CO_2 cascade refrigeration system of a type that has in recent years been employed in many dozen very large supermarket installations in Australia. A system of this type should deliver all of the reliability and range of performance required at the SFM. Should the board choose to embark on additional engineering, the ammonia/CO_2 system would eliminate any future scrutiny from government regulators on HFC refrigerant usage.

Throughout the report the authors have identified and proposed a number of measures that both the NPF fleet and the SFM could employ to reduce refrigerant losses from their equipment and to improve the general energy efficiency of their operations.

2 Introduction

Changes to the regulation of refrigerant gases in Australia during 2012, coupled with changes in the production and availability of certain refrigerant gases on international markets, has made it more important than ever before for any business reliant on refrigeration to understand the technical options available to ensure the continuation of reliable, and affordable refrigeration services into the future.

Refrigeration is central to the successful operation of Australia's multi-billion dollar commercial fisheries. To put it simply, without reliable refrigeration, many fishing vessels are unable to fish.

The very hardworking, very confined and very low temperature refrigeration systems operating on fishing vessels are only the first vital step in a long refrigerated supply line that delivers fresh and frozen fish and crustaceans to markets around the world. Any failure of refrigeration at any point in the supply chain for fish products can very quickly result in 50% to 100% losses.

Halfway along the supply line, between catch and kitchen, are the wholesale fish markets that have huge areas of refrigerated space operating 24/7 all year round. The Sydney Fish Market for instance has around 10,200 m^3 (36 cold stores totalling 2,500 m^2) of refrigerated space through which thousands of tonnes of fresh and frozen product moves every year.

All of these systems rely on a constant supply of affordable refrigerant gases to operate.

The main refrigerant gas used in the Australian fishing fleet, and the predominant gas currently employed at the Sydney Fish Market, is HCFC-22, known by industry as R22, is being rapidly phased out under the terms of the international Montreal Protocol. Supplies of HCFC-22 will be extremely constrained by 2016.

For the majority of refrigeration applications a raft of new refrigerant gases and systems are available that can be employed to replace HCFC-22 systems. These include the so-called 'natural refrigerants' such as ammonia, CO_2 and hydrocarbons, and the synthetic HFCs.

Although at the present time there is no practical, or safe technical option for existing fishing vessel refrigeration systems to operate on natural refrigerants.

It is possible for HCFC-22 in fishing vessel refrigeration to be replaced with HFCs. However the cost of this change over is estimated at $250,000 to $300,000 per vessel. In some instances this could be significantly higher depending on the design of the vessel and its age.

At the same time the international community has started considering a phase out of HFCs, possibly by 2030, or even earlier, depending on the global warming potential (GWP) of the refrigerant. The proposed timeframe for a phase out of high GWP refrigerants is well within the life of a new refrigeration system.

While new low GWP refrigerants (HFOs) have been developed, and are now being tested in some applications, they are not yet commercially available. The price of HFOs, when they do become available, is unknown. The mechanical properties of HFOs that have been demonstrated thus far means that at present, they are unsuitable for the low temperature requirements of fishing vessels.

This leaves fishing fleet owners with one technically viable but possibly uncomfortable option. They must weigh the cost and risks of replacing their existing refrigeration systems with systems run on HFCs, knowing that regulatory restrictions may make the presently effective HFCs scarce and more expensive within the working life of that new equipment, against the certainty of increasingly tight and expensive supplies for HCFC-22.

This report, focussing on the vessels of the Northern Prawn Fishery, explores the available options fishing vessel owners have that can ensure they can continue to operate the reliable, affordable low temperature refrigeration systems that make their enterprise possible.

An examination of options for the main refrigeration plant at the Sydney Fish Market (SFM) is also included. While the central Sydney location of the SFM imposes some limitations on choice of refrigerant, the SFM has a much wider range of options available to it than the fishing fleets that supply it.

2.1 *Australian fisheries*

Australia is the world's sixth largest country and has the world's third largest fishing zone, extending up to 200 nautical miles out to sea around most of the more than 35,000 km long Australian coastline. Despite this huge area, Australian waters tend not to be as productive as those in many other regions. Australia ranks only 52nd in the world in terms of volume of fish landed.

While Australian fisheries cover large areas of ocean and coastal waters, much of the areas available for fishing are a marine desert relatively speaking. For instance a combination of factors means that most of the Australian fisheries do not enjoy the rich upwelling of nutrients that make parts of the Peruvian or Argentinian fisheries so incredibly rich. Of course some of the most productive areas of State and Commonwealth waters are also excluded from commercial fishing, providing both protection for fish breeding grounds and, in some cases, areas where only recreational fishing can take place.

Although the overall amount of fish products caught in Australian waters is relatively low, Australian fisheries production focuses on high value export species such as lobsters, prawn, tuna, salmon and abalone. Australia's commercial fishing and aquaculture industry is worth more than $2.2 billion annually and employs around 11,600 people (7,300 directly and 4,300 indirectly) (ABARES 2012).

All of this economic activity, and the roughly 234,000 (ABARES 2012) tonnes of wild caught and farmed fish products that are produced from Australian waters annually, are completely dependent on having reliable refrigeration, from the point of harvest to the point of preparation for eating. From first going into an on-board refrigerator or snap freezer, most prawn and some wild caught fish will never leave a low temperature refrigerator for more than a few minutes at any time.

Wild caught fish that end up, often within just a few days of being caught, in a domestic refrigerator are likely to have been passed through at least 7 low temperature or medium temperature refrigerated spaces. Immediately after being caught the fish or crustaceans are stored in the fishing vessels' refrigerators or on ice. For some species that means being snap frozen in 8 to 14 hours, then stored in very low temperature freezers. Soon after arriving in port the catch is sorted and transferred to a portside refrigeration facility where it is often sorted and partially processed, and then transported in refrigerated trucks to a large regional market, such as the Sydney Fish Market.

At the regional market fish products will come out of refrigerated transport and find their way to the wholesalers facility who will at some point display the product, or a sample of it, often packed in ice, on the sale room floor. Having been sold the product is then transported by refrigerated truck again to a retail outlet with refrigerated storage, before going on display in refrigerated cabinets in retail outlets for sale direct to consumers.

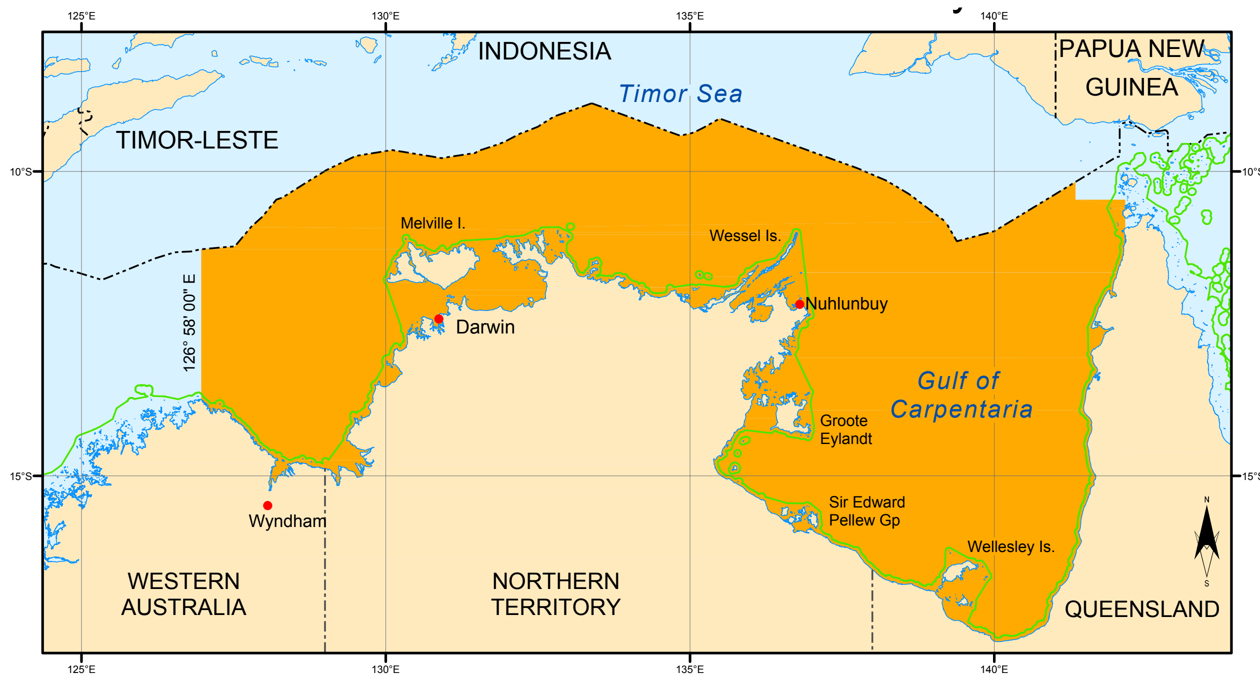
Failure of the refrigeration at any point in the supply line can lead very quickly to total loss of any product on hand, or deterioration of the product quality. On top of the product losses, on any one of Australia's estimated 400 active registered fishing vessels, failure of the refrigeration essentially puts the ship out of business while refrigeration is not available. Losses due to spoilage have to be replaced with fresh product, so in that sense, effective and highly reliable refrigeration has an important role in reducing pressure on fish stocks – by minimising post-harvest losses that may lead to shortages, higher prices, and thus more incentive to increase catches.

The ownership, operation and maintenance of refrigeration equipment is a significant part of the total capital equipment, and of the energy invested in delivering fresh fish product from point of harvest to the major wholesale fish markets, and beyond, to retailers and consumers.

2.2 *The Northern Prawn Fishery*

The Northern Prawn Fishery (NPF) is often referred to as Australia's last 'wild frontier' fishery. Covering approximately 880,000 square kilometres of Australia's northern waters (*see Figure 1: Map of the Northern Prawn Fisheries*) and including more than 6,000 kilometres of mostly mangrove covered coastlines that run from Cape York to the Kimberleys, the NPF is a remote and wild area seen by very few people.

Map of the Northern Prawn Fishery



LEGEND

- Northern Prawn Fishery
- Land and coastline
- Limit of Coastal Waters (3nm)
- Treaty / Median line

1. The area of the Fishery is sourced from the Northern Prawn Fishery Management Plan 1995 (17 October 2003 - amendments up to "Northern Prawn Fishery Management Amendment Plan 2003 (No NPF 04).").
2. Within this fishery, arrangements exist between the Commonwealth and WA, NT and QLD, whereby the Coastal Waters of these States are deemed part of he AFZ.
3. The maritime zone boundaries shown on this map are sourced from AMBIS 2001 (v1.1) (October2001).

Figure 1: Map of the Northern Prawn Fishery.

(Source: © Australian Fisheries Management Authority, Australian Government, 2005)

In 2010-11 the Northern Prawn Fishery was the most valuable Commonwealth managed fishery, with the gross value of production rising by 7 per cent to $94.8 million. The second most valuable fishery in that year, by way of comparison, was worth $48.6 million (ABARES 2012).

It is also considered to be one of the best managed fisheries in the world, and is certified as sustainable against the Marine Stewardship Council (www.msc.org) global environmental standard for sustainable and well managed fisheries. There are 9 main species harvested from the NPF, although they are broadly grouped into three 'product types' for market, the Banana, Tiger and Endeavour prawns. These prawns can be sold carrying the blue MSC marine eco-label, guaranteeing access for the products to premium markets around the world.

However achieving global recognition for being managed using world's best practice principles is also testament to how highly regulated the fishery is.

With 52 active fishing vessels licenced by the Australian Fisheries Management Authority (www.afma.gov.au) to operate in the NPF, less than 12% of the waters are actually fished. Among other controls on activity, it is compulsory for all fishing equipment to be fitted with Turtle Excluders and By-catch Reduction Devices. As a result, in the last decade the by-catch of turtles in the fishery has been reduced by 99%. This meant that in the 2012 season, while catching a total of more than 6,600 tonnes of prawns, the entire fleet, with nets in the water for more than 8,000 days in total, reported just 3 turtle deaths. This is an achievement that allows prawns from this region to be exported to the USA for instance. As part of the management of this extremely valuable fishery, government appointed scientific observers are often on board vessels in the fishery to verify the reporting of by-catch and interactions with other species such as sea snakes (the subject of a significant research effort to reduce crew/snake encounters), sawfish, and turtles.

Alongside the regulated fishing practices, restrictions on the actual area that can be fished and maintenance of detailed ship and fishing logbooks, the participants are required to provide detailed reporting and auditable documentation under several pieces of legislation on matters as diverse as chain of custody of product, monitoring of catch for heavy metals content, and training and OHS requirements for crew.

The fishery participants are also actively engaged in data collection for a range of research programs in association with AFMA, the CSIRO and others, often through their incorporated body the NPF Industry Pty Ltd (www.npfindustry.com.au).

Among the many dozens of points of legislative control and reporting the fishery participants must deal with, is a requirement to report on refrigeration of product and product storage temperature in accordance with HACCP food safety guidelines.

The NPFs remote location and the distances that some fishing vessels have to travel to their home ports in Cairns and Darwin, combined with the generally high ambient air, humidity and sea temperatures in the area, and the need for low temperature snap freezing and storage, means that this fishery requires extremely hardworking and effective refrigeration systems.

Unlike vessels set up to fish for fresh fish product, the NPF vessels must effectively snap freeze their catch. This can involve reducing the temperature of 6,000 kg of prawns a day from around 28°C to -18°C in a 6 to 16 hour period, and then store as much as 30 tonnes of frozen product at -35°C for up to a couple of weeks before unloading to mother ships. This would be a significant refrigeration task for a land based system, let alone one designed and installed in a confined space, on a constantly moving and vibrating fishing vessel, with high levels of exposure to the corrosion of salt spray and water.

The market for fish products is international, and indeed much of the catch from the NPF is exported. Primarily due to the effectiveness of the refrigeration technology that this report examines, fish products from around the world compete with each other in all the major markets.

Product harvested from a fishery like the NPF, with the world's highest standards of management, must compete with product harvested from fisheries that have little or no regulatory oversight, or by-catch reduction strategies. Input costs in many competing fisheries are also significantly lower.

In an already highly regulated fishery, and one that in global terms is expensive to operate in, any additional costs erode the competitiveness of the NPF against fish protein harvested elsewhere. Of direct relevance to this study for instance is the higher cost of HCFC-22 refrigerant borne by Australian fishing vessel owners, compared to costs for this critical input in other markets.

In many of the other prawn fisheries around the world, such as in Argentina and Asia, HCFC-22 required to service and operate low temperature refrigeration systems would cost 80% less than the cost paid by Australian fishing vessel owners. Even the largest prawn fleet in Europe, the Spanish fleet, pays a fraction of the cost for refrigerant versus Australian operators.

Given this economic reality, the NPF, and Australian fisheries in general, have to very carefully consider any decisions that might lock the participants into investments in technology that could later incur higher costs.

Alongside the obvious economic interests of their members in minimising the operating and capital costs of effective refrigeration in the future, the demonstrated commitment of the industry to sustainability in the broadest sense is one of the driving motivations behind NPF Industry Pty Ltd commissioning this study to examine options for economically sensible, and environmentally responsible refrigeration systems on their fishing vessels.

2.3 *The NPF catch fleet*

There are 52 vessels active in the Northern Prawn Fishery, 44 vessels sail out of Cairns, and 8 out of Darwin with the longest steaming time being the 850 nautical miles into the western extent of the fishery from Cairns. To minimise costs some vessels are now using alternative off shore ports, such as Port Moresby in PNG, for basic vessel maintenance, although they will also fly in technicians to undertake specialist work.

As with many fisheries, the total annual catch is quite variable. Total NPF prawn catch for 2012 was 6,601 tonnes compared with 8,335 tonnes in 2011. *Figure 2* illustrates the significant variability in the catch of two of the main species found in the fishery from year to year.

NPF catch statistics from 1970 to 2012

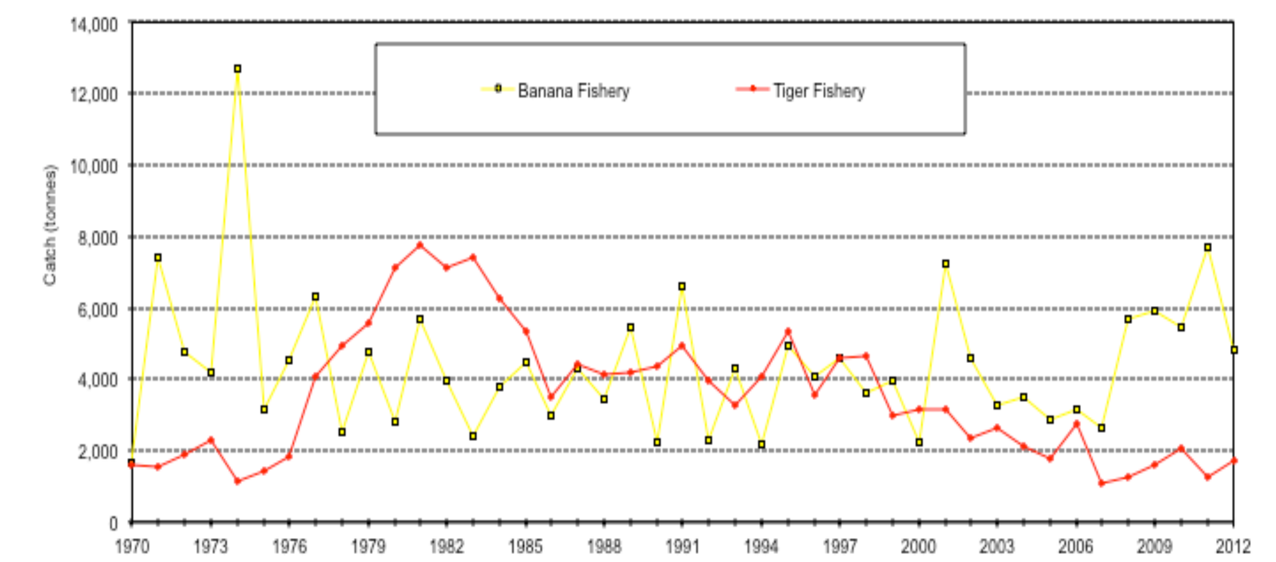


Figure 2: Catch in the banana and tiger prawn fisheries from 1970 to 2012.
(Source: NPF 2012)

The average catch per vessel in 2012 was around 127 tonnes with an average number of days fishing across the entire fleet of 154 days. However when fishing for banana prawns that aggregate, vessels can catch up to 6,000 kg per day.

Most of the vessels in the NPF are purpose built from steel and range in length from 17 to 28 meters.

A total of 53 different vessels fished in the NPF during 2012. The total number of vessels fishing at any one time was limited to 52, however leasing of SFR (Statutory Fishing Rights) during the year resulted in a total of 53 vessels operating within the fishery in total during the year. *Figure 3* shows the frequency of the vessel lengths in the current activate fleet.

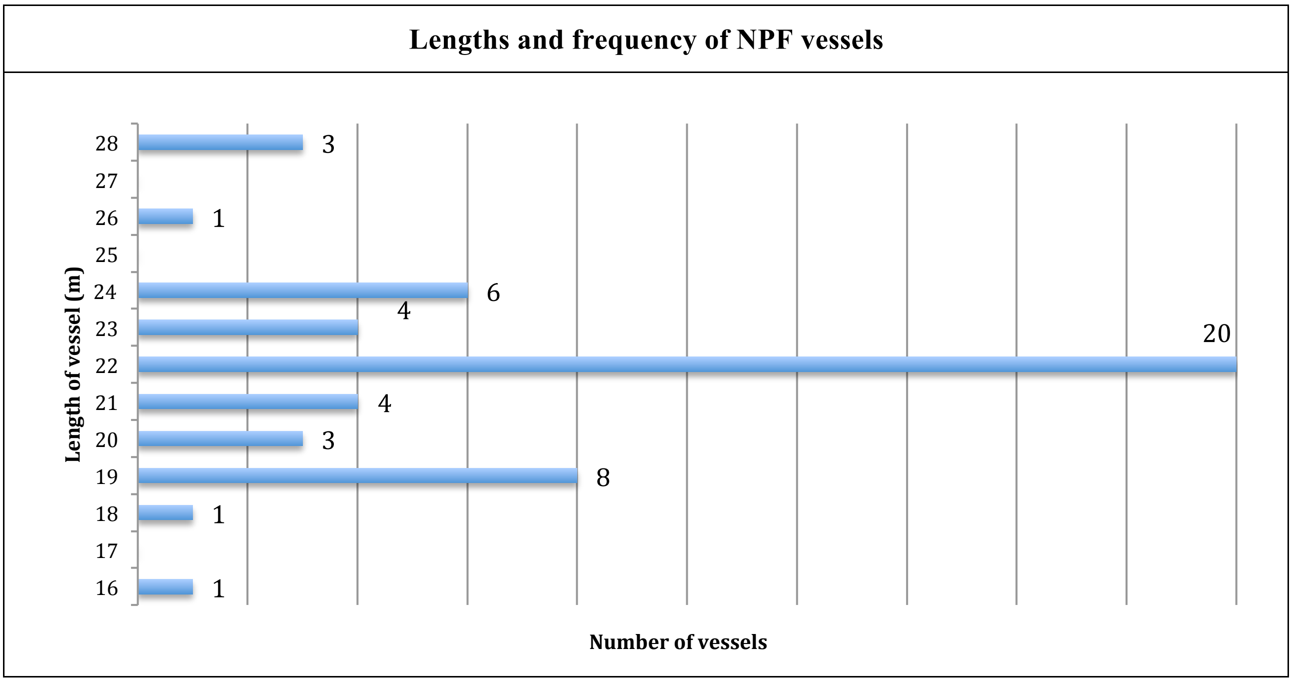


Figure 3: Lengths in meters and frequency of current NPF vessels.
(Source: AMSA 2013)

All NPF boats have relatively modern catch handling, packing and freezing capabilities as well as wet (brine) holding facilities. In the course of the past decade all vessels of the fleet have adopted the use of advanced electronic aids, such as colour echo sounders and Global Positioning Systems (GPS) and plotters. Satellite phones and fax equipment is used by most vessels and many have introduced on-board computing facilities, as well as electronic logbooks. All vessels are required to have a Vessel Monitoring System (VMS) installed.

The oldest vessel in the fleet is 42 years old with the most recent being just 6 years old. In total the fleet represents an investment of more than $200 million in seaborne assets and directly employs a workforce of around 300 to 400 comprising highly experienced ships captains, fishermen and fleet engineers as well as deck hands and a variety of contractors that specialise in marine refrigeration and other equipment exclusively used on vessels. The value of the portside supporting infrastructure down the value chain would be roughly 2 to 3 times the value of the vessels themselves. The Gross Value of Production of the fishery is assessed by ABAREs as being worth more than $94 million in 2011 (the most recent year for which economic data is available). In terms of refrigeration systems just three of these vessels are fitted with modern semi hermetic or screw compressors throughout. A dozen vessels have smaller 12 kWr semi hermetic auxiliary compressors recently fitted to service brine chillers.

However the large majority of vessels (>90%) still have original open drive screw compressors as the main plant, most of which ceased being manufactured almost two decades ago.

It is often quoted that 80% of leaks come from 20% of the systems (DSEWPaC 2010) and this appears to be true with NPF vessels, in terms of the volumes of refrigerant gas lost to air during the course of a year, due to the smaller number of ‘catastrophic’ losses from systems that experience a major failure. However the reality is that refrigerant losses occur from all refrigeration systems, and the large majority of direct emissions are from gradual leaks during normal operation. This is particularly the case with very old equipment operating in the harshest of conditions.

Sealed compressors, when properly maintained, in normal operation will lose much less refrigerant gas to air than the open drive designs, and they are much more energy efficient. As a rough comparison, the newer compressors are on average 25% more efficient than the old open drive compressors in terms of the amount of energy consumed to achieve a similar refrigeration capacity.

The average evaporator employed in the fleet refrigeration systems is 16 years old, with some vessels still employing the original 35 year old galvanised steel evaporator. Some of the vessels employ new plate evaporators with a unique bespoke design, constructed with aluminium due to its superior heat transfer properties. However, those newer components are the exception with more than 55% of the fleet still employing the original galvanised steel evaporators (some refurbished).

Finally a new system with a vertical liquid receiver, optimised pipe work and redesigned evaporator could achieve the same or better refrigerating capacity with a significantly smaller refrigerant gas charge (around 20% to 50% depending on the existing configuration and new evaporator design).

While these older systems and technologies have proved themselves in the test of time as being reliable and effective, they are essentially design limited to using HCFC-22.

Table 1: Vessel statistics and main refrigeration characteristics.

Vessel statistic			
Number of vessels	52 vessels in active fleet		
Age of vessels	Average	Oldest	Newest
	24 years	42 years	6 years
Length of vessels	Average	Longest	Smallest
	22.3 meters	28.3 meters	16.8 meters
Typical annual operational characteristics (1)	Banana prawns	Tiger prawns	Total 2011
	48 days	106 days	154 days
	94 tonnes	33 tonnes	127 tonnes
Main refrigeration system characteristic			
Refrigerant type	94% HCFC-22, and only three vessels operating on HFC-507A		
Refrigerant charge	Average	High	Low
	236 kg	390 kg	100 kg
Annual leak rate	Average	High	Low
Last year	22%	175%	Negligible
Historical	Previously around 35% per annum		
Refrigeration capacity (2)	Average	High	Low
	91 kWr	150 kWr	38 kWr
Specific refrigerant capacity (kg of refrigerant per kWr)	Average	High	Low
	2.7	5.8	1.3

1. Source: NPF Data Summary 2012 (NPF 2012). The value for tiger prawn includes 487 tonnes of endeavour prawns, 11 tonnes of king prawns and 1,203 tonnes of tiger prawns, averaged over 52 vessels that were active at any time in 2012.
2. Refrigeration capacity of main system which includes the snap freezer, freezer room and brine chilling systems. The vessel air conditioning systems and medium temperature cool room for the galley are additional.

Thus the efficiency and effectiveness of the closely temperature controlled refrigeration systems on most of the NPF fishing fleet depends on the continuing availability of HCFC-22.

In simple terms the refrigerant gas is the medium which is used to transfer heat around in a vapour compression refrigeration system, allowing heat to be rejected to the open air and create refrigerated spaces and snap freeze produce. *Appendix C* provides process diagrams of a typical commercial vapour-compression refrigeration system and the latest generation NPF refrigeration system.

Australia imports all of its supplies of refrigerant gases from international manufacturers. Over the past 30 years international efforts and treaties intended to limit the impact of refrigerant gases on the environment has seen three significant transitions of refrigerant gas types, each of which has had impacts on the hardware and systems used to provide refrigeration.

HCFC-22 is an incredibly effective working gas that has been the mainstay of commercial refrigeration and air conditioning equipment for most of the past 35 years. However when it is lost to the atmosphere it is very long lasting, and makes its way to the upper atmosphere where it causes damage to the ozone layer.

As a result of its ozone depleting potential, HCFC-22 has been progressively phased out of the Australian and international market under the terms of the very successful international treaty, the Montreal Protocol. Production and supplies of all HCFCs are now limited and destined to become ever more so. The Australian import quota is dropping to a relatively tiny ‘service tail’ in 2016 of around 45 tonnes per annum, down from more than 2,000 tonnes that were imported in 2006 (~98% reduction in quota and supply volumes in a decade).

Since a ban on the imports of equipment charged with HCFCs only came into force in Australia in 2010, there is a large stock of operating equipment that needs to be serviced. This will create strong ongoing demand for the remaining HCFC-22 stocks and imports for at least a decade, and possibly longer.

Because of the tremendous low temperature performance of the HCFC-22 charged systems employed, the NPF fleet has effectively maintained a generation of technology, in many cases well past the intended design life of the original equipment, and indeed almost to the limits of the international phase out of this gas.

While fishing vessel owners have been aware for many years that HCFCs would eventually be phased out all together, even the sudden price rises that occurred in mid-2012, post the July 2012 introduction of an import levy on alternative refrigerant gases, did not catalyse a sudden round of investment by fishing fleet owners in new or refurbished equipment.

The fact is that there are very limited technical options available for fishing vessel owners in Australia, or anywhere else, to easily replace HCFC-22 charged low temperature refrigeration systems.

Thus with a combination of regulatory and commercial pressures coming to bear on the work horse HCFC-22 charged systems, the options for a low risk migration to a new technology platform depends firstly on the selection of the most suitable new generation working gas for the fishing fleet.

The increasing scarcity and rising cost of HCFC-22 is part of a broader set of changes sweeping through the global markets for refrigerant gas. A raft of new gas options is becoming available to refrigeration system designers. The operating characteristics and requirements of the new gases are also ushering in a range of new component, design and system options.

However the reality of the constrained and harsh working environment on board fishing vessels and the demanding requirements for the NPF vessels refrigeration task, mean that any plan to migrate to a new technology mix or platform, must have extremely low technical risk, and very manageable costs.

2.4 *Energy audit of typical vessel*

One aspect of the analysis of refrigeration options for vessels in the NPF fleet is the conduct of a TEWI assessment. TEWI is the 'Total Environmental Warming Index' and the purpose, methodology and results are discussed further in *Section 4.3*.

However one of the critical steps in delivering a TEWI analysis is understanding total energy consumption in the system, and in this case, on the vessels of the NPF fleet.

A detailed desktop audit was undertaken of a typical NPF vessel to understand the primary sources of energy consumption, and to determine what portion of diesel fuel consumption was consumed to power the refrigeration system(s). In doing the audit, the Expert Group identified a number of areas where improvements in the energy use on vessels could possibly be made. These are listed on the following page.

In the NPF the daily energy consumption of a vessel varies depending on the type of catch, as the vessel operating behaviour is different when catching banana prawns versus tiger prawns. For instance banana prawns are aggregating prawns and processing them is more refrigeration intensive, consuming more auxiliary power, however they may require slightly less trawling when found. *Table 2* provides a summary of daily fuel consumption for the main engine and auxiliary power generator for a typical NPF vessel catching both banana and tiger prawns, and the entire catch for the season.

Table 2: Diesel consumption of typical NPF vessel.

Type of catch	Operating days (incl. steaming)	Average fuel consumption (L/day)	Main engine (L/day)	Auxiliary engine for power (L/day)
Banana	77	2,070	1,190	880
Tiger	127	1,970	1,450	520
Totals per annum				
All catch	204	409,000	283,000	126,000

More than 30% of total fuel consumption can be attributed to the auxiliary engine for generating power on board the vessel, and an estimated 75% of the fuel consumed by the auxiliary engine per season is for delivering refrigeration services. Many vessels have two auxiliary diesel engines to generate electricity. They are typically the same capacity, with one servicing the main daily loads and a back up generator for emergencies or to cover high peak loads that mostly arise when refrigerating large catches of banana prawns.

The details of the energy audit can be found in *Appendix D*. *Figure 4* provides a break down of the main uses of electricity.

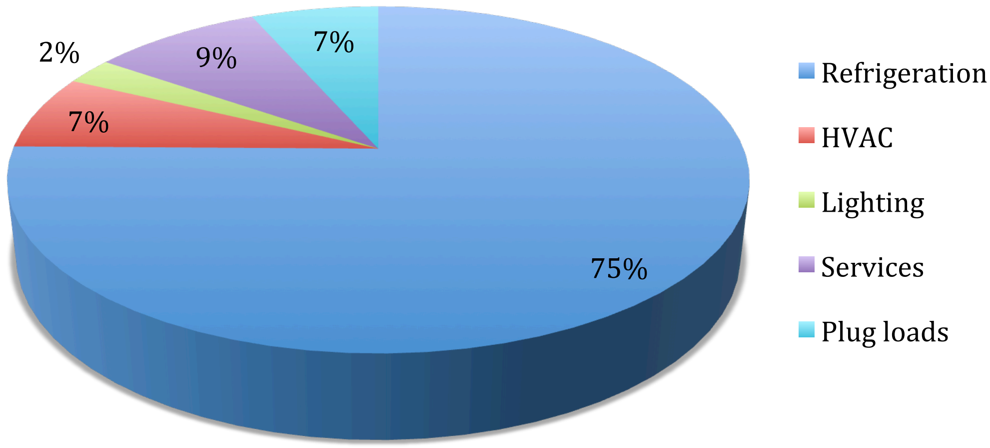
Dissection of energy consumption of typical vessel

Electrical energy source: Diesel generator
Refrigeration: Snap freezer, FDC in hull, and associated components; medium temp cool room and chest freezer for test samples.
HVAC: Air conditioning system for occupied spaces and ventillation fan(s) for engine room.
Lighting: General lighting, Freezer room, flood lights and navigation lighting.
Services: Pumps including deck wash/bilge/fuel transfer/water reticulation; domestic hot water system; conveyor motor and hydraulic powerpack.
Plug loads: Controls, instrumentation, domestic appliances cooking/washing/general.

Figure 4: Dissection of the daily energy consumption of a typical NPF vessel.

While noting that technology choices and systems on fishing vessels must always be proven in the field and reliability of operation is of fundamental importance, this analysis identified many areas of opportunity to potentially reduce energy consumption including:

- Lighting (majority of lights could be upgraded to highly energy efficient LED or CFL technology, delivering savings in the range of 50% to 90% depending on the application, and reductions in maintenance costs.
- Most air conditioning systems could be upgraded to new systems with efficiency improvements in the order of 25%.
- The majority of pumps could be replaced with more efficient pumps fitted with high efficiency motors. The pumps that should be investigated are the condenser pump (i.e. 6 kW nominal input power) that runs nearly 24/7, and the deck wash pump (i.e. 5 kW nominal input power) that can run up to 6 hours per day.
- There are a significant number of appliances on board including cooking appliances, clothes washing machines, and clothes dryers. Similar to household appliances, energy efficient options should always be chosen when they exist and minimise use where practical.
- The large majority of evaporator fan-motors on vessels are very old and inefficient. At present there are limitations with “off-the-shelf” evaporators and fan motors using the latest fan motor technology (i.e. Electric Commutated) in low temperature applications. However new specifications capable of operating down to -40^{o}C by sealing the electronics, and special bearing/lubricant selection, are expected to emerge in the next couple of years.

2.5 *Sydney Fish Market*

Further down the supply chain, and in a relatively enviable position when it comes to refrigeration technology options, the Sydney Fish Market (SFM) still has several important issues to assess about the future of its large investment in refrigeration technology.

The SFM is located close to the Sydney CBD on Blackwattle Bay, a vibrant and attractive retail, tourism and hospitality precinct that is patronised by millions of international and interstate visitors, as well as millions of Sydney residents every year. Famous for its fine fish restaurants and café style eating, as well as the numerous retail fish stores. Sydneysiders throng to the market, the rush for fresh lobster just prior to Christmas and New Year being probably the busiest time of the year.

Surrounded by commercial, retail, hospitality, hotel and residential sites, the SFM is the largest market of its kind in the Southern Hemisphere and the world's second largest seafood market in terms of variety outside of Japan.

More than 14,000 tonnes of seafood worth more than $100 million is traded at the SFM annually with as many as 100 species of Australian seafood traded every day. The SFM employs more than 50 staff to organize the daily wholesale auction.

This important part of Sydney's commercial and social landscape is built around a major refrigeration plant providing approximately 10,500 m^3 of low and medium temperature storage options. The large centralised plant is charged with around 6 tonnes of HCFC-22 and delivers medium and low temperature refrigeration to 36 separate rooms, requiring temperatures from 7^{o}C to -25^{o}C, for a wide range of products. In the event of catastrophic loss of the refrigerant (a relatively unlikely event given the management reporting and gas detection systems built into the SFM plant), it would cost a minimum of $700,000 to replace the gas charge in an emergency.

The entire refrigeration system has natural gas fuelled emergency back-up power and compressor systems to ensure that the refrigeration of product is maintained in the case of any disruption to the grid supplied electricity.

With full time, on-site professional engineering and facilities management staff available, the SFM can afford to closely manage and optimise its very significant refrigeration plant. However, even with the considerable financial and human resources available to them, the SFM has sought advice on future refrigeration options that will allow them to move away from reliance on HCFC-22.

3 Fresh Prawns and Refrigerant Gas

3.1 *Refrigerant selection*

Very few refrigeration installations on land or sea can deliver the performance required for the effective operation of a vessel in the Northern Prawn Fishery. Essentially this is among the most demanding refrigeration tasks required anywhere.

Refrigeration on NPF vessels must have the ability and capacity to:

1. Handle large daily snap freeze loads of up to 6 tonnes of high temperature product (25 to 28^{o}C) down to -18^{o}C within 8 and 14 hours with evaporators operating at -40^{o}C saturated suction temperature (SST);
2. Have a holding capacity of 30 to 40 tonne of produce at -35^{o}C;
3. Provide chilled water to assist in quality control;
4. Endure extremely harsh operating conditions where equipment is constantly exposed to salty intake, vibration and shock; and
5. Operated by low skill level personnel.

This section discusses the refrigerant gas options that are suitable for use in this application, and then explores what the available gas options mean for equipment and system specifications.

It is commonly said that there is no 'one-size-fits-all' refrigerant solution, and the most suitable working gas is highly dependent on the application. There are numerous factors to be taken into consideration when making refrigerant selections, such as the availability of suitable technology and components, whether it is being employed in new or existing equipment, investment and operating costs, technical barriers in the required equipment to later transition to new refrigerants, and the feasibility of design, fabrication and installation including most importantly the ready availability of the skills required.

The main technical considerations for selecting a refrigerant for a task are:

- **Thermodynamic properties** of the refrigerant (i.e. co-efficient of performance, capacity, glide, pressure and temperature operating envelopes, etc.);
- **Safety risks** and probabilities due to flammability and toxicity of substances (classifications defined by technical standards and regulations) and the circumstances of the refrigerating application; and,
- **Life cycle carbon emissions** (i.e. direct, indirect and end of life), which encompasses refrigerant GWP, equipment efficiencies or co-efficient of performance and total system energy consumption.

The commercial considerations of course are security of supply, stability or at least predictability of price, and a reasonable assessment of regulatory risks (i.e. is this controlled substance going to retain approvals required for sale and use beyond the expected life of the capital equipment).

To illustrate some of the issues relevant to this last point *Figure 5* Illustrates the evolution of refrigerant species and how they are managed under international environmental protocols.

Refrigerant types and progression of synthetic refrigerants

Natural refrigerants [(1)]

Ammonia	ODP = 0	GWP = 0
Carbon dioxide	ODP = 0	GWP = 1
Hydrocarbons	ODP = 0	GWP ≈ 4

Synthetic refrigerants [(2)]

Montreal Protocol (in response to ODP)		**Kyoto Protocol (in response to GWP)**	
CFC	HCFC	HFC	Low GWP
1st Generation	**2nd Generation**	**3rd Generation**	**4th Generation**
CFC-12	HCFC-22	HFC-507A	HFO-1234yf
GWP = 8,000	GWP = 1,500	GWP = 3,300	HFO blends
ODP = 1	ODP = 0.055	ODP = 0	ODP = 0
		GWP ≥ 1,300	GWP ≤ 150
		3.5 Generation	
		HFC-428A (GWP of 2,930)	

Figure 5: Refrigerant types and international industrial gas management regimes.

1. The term 'natural' implies the origin of the fluids, i.e., they occur in nature as a result of geological and/or biological processes, unlike fluorinated refrigerants that are synthesized chemicals.
2. The GWP values for the refrigerants listed above are based on the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 (IPCC 1996). While these values have since been superseded by the Fourth Assessment Report (AR4) in 2007, all of the Australian legislation that refers to the GWP of HFCs use the values listed originally in AR2, based on Australia's obligation under the Kyoto Protocol.

Some supermarket chains and large corporate users of commercial refrigeration systems around the globe are demanding systems with working gases that have lower global warming potential. This is fostering the development of pure CO_2 charged systems, cascade refrigeration systems with a reduced HFC charge, hydrocarbon charged self-contained systems, and a resurgence in the use of ammonia for large commercial systems.

The so-called 'natural refrigerants' have been employed at various times as refrigerants in a range of applications since the earliest days of refrigeration in the 1880s. However, they have their own constraints and issues, including potential safety issues, particularly in the working environment of a relatively small fishing vessel. The properties and constraints of natural refrigerants are discussed in more detail in *Section 3.4*.

At present the most commonly used refrigerant in new commercial refrigeration applications is HFC-404A. HCFC-22 is still employed in a great many older systems, and HFC-134a is now gaining market share in newer medium temperature applications.

HFC-404A, a blend containing 44 per cent HFC-125, 4 per cent HFC-134a and 52 per cent HFC-143a with a GWP of 3,260, is a near azeotrope (ie a refrigerant gas for which the composition of the liquid and the vapour phase are the same).

HFC-507A is a refrigerant with a very similar blend to 404A containing 50% HFC-125 and 50% HFC-143a with a GWP of 3,300. HFC 507A is an azeotrope with similar characteristics to 404A and is the synthetic refrigerant of choice for low temperature applications that employ flooded evaporators, as the gas has zero temperature glide. The systems employed on NPF vessels are best described as over charged direct expansion systems or semi-flooded systems. The over charging of the direct expansion systems employed in vessels results in flooding of the evaporator, delivering additional snap refrigeration capacity, a very desirable characteristic in the NPF refrigeration system. The few NPF vessels that have migrated away from HCFC-22, and that are operating on HFCs, have migrated to HFC-507A for this reason.

3.2 *Regulatory risk for HFCs*

Following ratification of the Montreal Protocol in 1989 and the commencement of the HCFC phase out, several different types of HFCs were developed, and blends were created to supply gases with different properties, ensuring that there was a HFC suitable for the majority of refrigeration and air conditioning applications.

Since the early 1990s HFCs have taken over many, but not all, of the largest air conditioning and refrigeration applications and major technology segments of the market.

HFCs have no effect on the ozone layer, however like the HCFCs, they are still potent greenhouse gases with HCFC-22 having a global warming potential of 1,500. As a result, with the increased international focus on achieving greenhouse gas reduction targets, the international community is now discussing phasing HFCs out as well.

There are already requirements in place for European auto manufacturers to move to very low GWP gases in mobile systems (discussed further in *Section 3.6: Fourth generation synthetic refrigerants*), however a new recommendation on refrigerant gas regulations in circulation in the European Commission proposes reducing HFC use by more than 80% in Europe by 2030.

Notably the European Commission made a recommendation to prohibit new stationary refrigerating equipment containing refrigerant with a GWP of more than 2,150 from 2015 (depending on class and charge). They further recommended reducing the 'GWP cap' on gases employed in stationary refrigeration equipment to 150 by 2020 with a similar cap imposed on the gases used in mobile refrigeration by 2025. However fishing vessels were specifically excluded in the draft of the recommendation presently in circulation.

A completely separate, but recent agreement between China and the USA to work towards a phase out of HFC production in roughly the same time frame, and discussions at the meeting of the parties to the Montreal Protocol in a similar vein, all point to a growing international movement to phase out at least the high GWP HFCs (gases with GWPs > 600) in the next two decades.

While that is a relatively long time in terms of most business machinery and equipment, this is not necessarily the case with refrigeration equipment. Many of the NPF fishing vessels are getting good refrigeration services from equipment that is now more than 30 years old, even though it may not be operating at optimal efficiency or with the highest degrees of refrigerant gas containment. New equipment, that in most vessels would cost a minimum of a quarter of a million dollars, could certainly be expected to be operational in 20 years.

The fact that even the European Parliament, which has traditionally taken the lead in regulating industrial gases, has excluded fishing vessels from their latest proposal for increased regulation, points to the fact that the Australian fishing industry is not alone in struggling with a plan for technology transition.

Even so, it is apparent that within the lifetime of the vessels of the NPF fleet, that high GWP HFCs, including those that might present an immediate path for transition away from HCFCs, are going to be subject to increasingly stringent regulatory controls, and thus supply restrictions.

3.3 *Refrigerant prices*

In July 2012, the Australian government imposed a 'carbon equivalent levy' on the import of all HFCs. As these gases have high to very high global warming potentials, the new levy resulted in retail prices increasing by more than 300% in some cases. The quite dramatic price rises of HFCs had the effect of accelerating price increases for HCFCs, which in some cases could be used as an alternative to some of the more expensive HFCs.

Table 3 provides a summary of list prices of common refrigerants, and typical wholesale prices based on a 40% discount for small purchases, and 60% discount for larger users. The actual price paid by end users largely depends on the volume involved and where they purchase the refrigerants in the value chain (i.e. from the importer, wholesaler or contractor, each or whom adds margins).

Table 3: Summary of refrigerant prices from 2012 to 2013.

Refrigerant type	List price ($ per kg) 13/06/12	List price ($ per kg) 01/09/13	Sell price (small volume) ($ per kg)	Sell price (large volume) ($ per kg)
HCFC-22 (R22)	108.36	$377.71	$227	$132
HFC-404A	92.88	$377.71	$227	$132
HFC-507A	111.38	-	$231	$135
HFC-407C	97.87	$234.40	$141	$82
HFC-407F	-	$239.60	$144	$84
HFC-434A	153.40	$370.00	$222	$130
HFC-438A	153.40	$370.00	$222	$130
Hydrocarbon	-	-	$40.00	
Ammonia	-	-	$9.00	
Carbon dioxide	-	-	$7.00	

(Source: Heatcraft Australia list prices for synthetic refrigerants and other suppliers for natural refrigerant prices)

The list prices shown in the left hand column, just prior to the introduction of the carbon equivalent levy had already had increases of up to 20% in the previous 12 months. The most commonly used refrigerants HFC-404A and HCFC-22 typically sold at $25 to $40 per kg to contractors throughout 2011 so that even at the large volume trade prices charged in 2012, these essential inputs to refrigeration increased in price by more than 300% to end users post July 2012.

With the expected removal of the carbon equivalent levy, as promised by the recently elected Abbot Federal government, access to new imports no longer subject to the levy is expected to quickly drive these prices down. Even the promise of its removal has already put downward pressure on prices, as wholesales move to sell as much stock as they can in the existing high price environment. In October 2013 the market saw the first signs of discounting with one wholesaler offering a special for HFC-404A at $80 per kg versus $130 per kg the month before. Within a month or two of a total removal of the levy, trade prices for HFC-404A and other HFCs should fall back to within 10% to 15% of 2011 prices, in line with the normal price inflation witnessed on global markets since the beginning of 2012. If the levy is phased out slowly it may take longer for prices to revert to the normal range.

Irrespective of the repeal of the carbon equivalent levy on HFCs, prices for virgin HCFC-22 are likely to remain high as the next import cap reduction on this refrigerant is scheduled for the end of 2013, and will maintain supply pressure on this refrigerant.

3.4 *Natural refrigerants*

3.4.1 Ammonia

Ammonia (R717, GWP of 0) is a naturally occurring substance that has successfully been used as a refrigerant for over a century and is commonly employed in very large capacity refrigeration applications in the refrigerated cold food chain (e.g. meat and dairy processes, cold storage facilities). This is primarily due to its excellent thermodynamic characteristics and zero GWP. However ammonia carries a B2 safety classification, meaning that it is mildly flammable and has high toxicity risk.

Ammonia applications are generally more complex than conventional commercial refrigeration systems using synthetic refrigerants. Ammonia systems cannot be purchased 'off-the-shelf' and each solution needs to be fully engineered for the individual application. The hazardous characteristics of ammonia require strict standards and regulations for the construction and operation of ammonia refrigerating systems. Great care needs to be taken when used in applications in close proximity to the general public. There are examples where this has been achieved successfully (e.g. Heathrow Airport, Logan City Council Administration Building, etc.).

The potential safety risks and the relatively thin supply of skilled technicians and engineers available to work on ammonia systems outside metropolitan areas make it a highly unlikely choice for smaller marine applications.

3.4.2 Carbon dioxide

CO_2 (R744, GWP of 1) charged systems are emerging in a number of commercial refrigeration applications with the technology, components and industry capability evolving rapidly.

CO_2 refrigerant is ideally suited to large process applications that involve both chilling and heating stages (e.g. brewing) as the *heat recovery* from carbon dioxide chilling systems can deliver significant energy savings for heating and hot water.

Some hard lessons were learnt on early pure CO_2 refrigerant systems installed in hot climates resulting in poor operating efficiencies. CO_2 refrigerant has a very low critical temperature (31^{o}C – the point at which it returns to a liquid phase) with a very high pressure required (around 7,400 kPa). In northern Australia high seawater temperatures prohibit CO_2 refrigerant condensing. Therefore a cascade system with a secondary refrigerant (i.e. HFC-134a or ammonia) to cool and condense the CO_2 refrigerant would be required in an NPF application.

Recent innovations from equipment suppliers to the supermarket industry include micro cascade air cooled condensing units available in capacities from 2.5 kWr upwards. These units offer hybrid refrigeration (HFC-134a/CO_2) systems for use in smaller sites and have potential for application across a broad range of commercial refrigeration applications.

CO_2 systems have been commercialised aboard large marine vessels internationally, and to a very limited extent in larger fishing vessels. An example is large European fishing vessels greater then 80 meters in length using highly efficient ammonia/CO_2 cascade systems (UNEP 2013b). These large vessels have dedicated plant rooms and technology to isolate and monitor the refrigerants and mitigate the risks. There have been some discussions about advanced refrigeration systems being dropped into the stern of vessels smaller than 80 meters in sealed units however this is not applicable to NPF vessels as they are far too small (average length of 22 meters) and would require a total redesign to incorporate such systems.

Although CO_2 is an excellent refrigerant it is colourless, odourless and tasteless, which can present significant hazards when found in high concentrations in enclosed spaces such as vessels. CO_2 is fatal before 20% atmospheric concentration is reached. At 8% to 10% concentration problems develop, headaches, sweating, dimness of vision, and dizziness are experienced, and consciousness is lost after 5 to 10 minutes. Death follows. It should be noted that death through asphyxiation is a risk with HCFC and HFC refrigerants in confined spaces due to oxygen depletion.

3.4.3 Hydrocarbons

Hydrocarbon refrigerants (GWP of around 3 depending on type) are gaining acceptance in a variety of applications that have very small refrigerant charges of less than 1 kg (thus reducing the potential for damaging accidents, fires or explosions) such as in domestic fridges. Hydrocarbons have particularly efficient thermodynamic properties, primarily due to their lower molecular mass which results in a reduction in refrigerant charge required of around 50% relative to commonly used synthetic refrigerants.

Although using hydrocarbons in applications requiring larger refrigerant charges are technically feasible, strict safety concerns currently do not favour the application of flammable refrigerants aboard fishing vessels, or in large capacity applications such as the Sydney Fish Market, which for instance would require several tonnes of hydrocarbon refrigerant.

3.5 *Drop-in refrigerant replacements*

There are a variety of products being promoted as drop-in replacements for HCFC-22 including HFC-438A, HFC-434A, HFC-428A and HFC-407F. These are interim solutions (still third generation HFCs but in novel blends) with different characteristics and GWP values. There are many technical factors to consider when selecting a suitable drop-in replacement including seals, lubricating oil, capacity, mass-flow, glide and operating pressures. Whilst HFC-438A is a better pressure and capacity match to HCFC-22, the only technically viable drop-in replacement for NPF vessels, and for the Sydney Fish Market, is HFC-428A (GWP of 2,930) as none of the other drop-in replacements is suitable for flooded evaporators.

Finally, before considering a drop-in refrigerant replacement, the equipment owner should consider if the system is relatively leak proof (i.e. low leak rates) and well maintained. If this is not the case, then retrofitting with a drop-in replacement is not advisable as leakage can result in the blend changing composition, leading to many other issues including increased energy consumption, reduction in refrigeration capacity and shortening the life of equipment.

3.6 *Fourth generation synthetic refrigerants*

There are three classes of new low GWP HFCs, known as hydrofluoroolefins (HFOs) that are relatively close to full commercial release. The HFOs have very low or substantially reduced GWP values. The first is HFO-1234yf, with a GWP of around 4, that has been proposed as a replacement for HFC-134a in mobile air conditioners (e.g. car air conditioners) and potentially many other refrigeration and air conditioning applications. Another low GWP molecule is HFO-1234ze, with a GWP of around 6 that is currently being commercialised for foam, aerosol and refrigeration applications.

The second class of HFO based refrigerants comprises azeotropes, which are blends of refrigerant gases for which the composition of the liquid and the vapour phase are the same, such as Opteon XP10 with a GWP value of about 600 which has attracted great interest from the supermarket industry interested in its potential for medium temperature refrigeration applications.

The third class of reduced GWP refrigerants includes, among others, DR-33 and DR-7. These developmental refrigerants are made up of blends of HFO-1234yf, HFO-1234ze and other stable refrigerants, including HFCs and CO_2. Preliminary information on DR-33 and DR-7 suggest they are replacements for HFC-404A with GWPs of around 1,400 and 250 respectively. DR-7 is expected to have an ASHRAE 2L refrigerant classification, which is mildly flammable and will only be suitable for replacing smaller charge HFC-404A systems due to charge size restrictions in codes and standards. Whereas DR-33 is a non-flammable refrigerant with potential for retrofit into existing low temperature systems operating on HFC-404A (DuPont 2013).

There is uncertainty if a low GWP blend suitable for flooded evaporators will emerge. Preliminary information suggests these blends will contain four or more ingredients that may be susceptible to fractionation (i.e. refrigerant blend changing composition on leakage) with a wide range of boiling points which generally translates to high glide.

The main source of information on performance characteristics of these developmental refrigerants is available via the AHRI (Air Conditioning, Heating, and Refrigeration Institute) Low-GWP Alternative Refrigerants Evaluation Program. There are three rounds of field tests planned for these developmental refrigerants. The first round of tests is largely focused on air conditioning applications, which is where the main economies of scale and opportunities exist for chemical suppliers. Some testing has also been undertaken in medium temperature refrigeration applications (i.e. -5°C to -18°C evaporating temperatures).

The timing of the release of these emerging refrigerants in Australia is dependent on several factors including:

- Testing of refrigerant by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and allocation of ‘R’ numbers and refrigerant classifications in accordance with *ANSI/ASHRAE 34, Designation and Safety Classification of Refrigerants*.
- NICNAS (National Industrial Chemicals Notification and Assessment Scheme) registration and accreditation to allow the importation of HFO-1234yf and HFO-1234ze in commercial volumes.
- Sufficient scaling of production of HFO’s to make them available for blending into emerging refrigerants.[1]

The latest market intelligence suggests the first blends will be available for sale in 2014 although there is no indication of price. At this stage there is insufficient detailed information (i.e. performance characteristics such as operating pressures and temperature glide) to guarantee a low GWP solution will emerge that would be suitable to be used on NPF vessels (i.e. -40°C evaporating temperature and semi-flooded systems).

[1] *Du Pont and Honeywell have manufacturing plants and Arkema announced the construction of production capacities for new refrigerant fluorinated gas HFO-1234yf in a press release in September 2013.*

3.7 *Equipment selection*

A complex range of criteria and issues needs to be considered when selecting refrigeration equipment for fishing vessels. *Figure 6* illustrates the main considerations, which also need to be evaluated in context with the main technical considerations for selecting a refrigerant.

Considerations and constraints for equipment selection

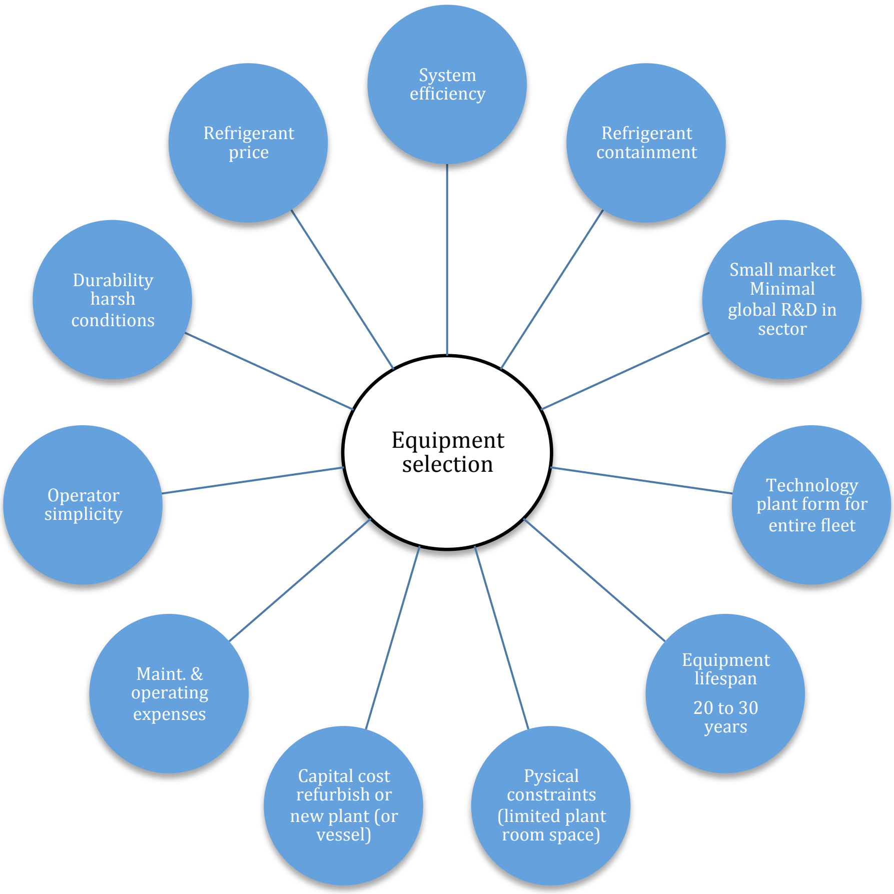


Figure 6: Illustrates complex range of issues to consider when selecting a the refrigeration equipment for a fishing vessel.

These considerations have been consolidated into four categories to provide a framework for comparing technically feasible options including:

- Safety (technically feasible solutions but with high OH&S risk with limited potential to mitigate the risk will be eliminated);
- Financial considerations (capital investment and ongoing expenses);
- Technical (refrigerant characteristics, equipment types, application constraints, performance and associated technical risk); and,
- Regulatory and environmental (direct, indirect and life cycle carbon emissions, and associated regulatory risk).

4 NPF vessels options analysis

4.1 *High level analysis*

Natural refrigerants are not considered a technically feasible option for existing NPF vessels, the chief reason being safety issues in the confined environment of a fishing vessel.

The main reasons why natural refrigerants have been eliminated are as follows:

Ammonia: The use of ammonia on NPF vessels would require significant structural changes to the vessel in order to create a sealed plant room that could only be accessed from deck level. The average vessel is only 22 meters in length and creating a suitable plant room would only be possible when designing brand new vessels. An ammonia system on a small vessel would introduce considerable safety requirements, not the least being sensors and alarms, ammonia concentration meters, extensive signage, training, breathing apparatus, etc. The additional risks, costs and stringent legal obligations make it unviable and impractical.

A report from May 2013 providing information on ODP alternatives for the United Nations Development Programme, stated that highly efficient ammonia CO_2 cascade systems are the systems of choice on European fishing vessels (UNEP 2013b). Research of the international fishing registers and investigation by European prawn fleet operators confirmed these complex systems only exist on very large vessels greater than 80 meters in length. The practical limitations to the use of ammonia on small vessels is clearly recognised in the EU where the recent draft for revised EU F-Gas regulations provide an exemption for fishing vessels to allow them to use existing HFC refrigerants until 2025.

Hydrocarbons: Hydrocarbons on vessels are technically feasible, but the strict safety concerns and large refrigerant charges required make the practical application of flammable refrigerants aboard vessels unlikely (UNEP 2013a).

CO_2 (R744): The use of CO_2 refrigerant on fishing vessels would require significant structural changes to the vessel in order to create a sealed plant room that could only be accessed from deck level. CO_2 refrigerant has a very low critical temperature (31^{o}C) with a very high pressure (around 7400 kPa) which prohibit CO_2 condensing with high sea water temperatures found in Northern Australia.

This means an indirect or cascade system is required with a second refrigerant (i.e. HCF-134a or ammonia) to cool and condense the CO_2 refrigerant. This option is technically feasible however would only be viable in new vessels, requiring an investment of an estimated $2.5 million in the vessel, plus a further $450,000 to $500,000 to develop, construct and fully commission a prototype and first generation demonstration system. This investment would come at considerable technical risk to the operator (i.e. complexity, industry first, specialised training for a mechanic required on board, reliability, etc.) with little or lower return on investment versus a conventional refrigeration system.

Another possibility that this review has effectively eliminated is the option of retrofitting existing refrigeration systems to work with the HFC-22 drop-in refrigerant replacement, HFC-428A. This drop-in replacement gas, with a GWP of 2,930, satisfies the technical requirements of a refrigerant gas for the NPF task. However, as the refrigeration equipment in the fleet is generally very old, much of it already operating beyond its original design life, it is highly susceptible to refrigerant leaks. Thus the extent of equipment replacement and reconditioning required on the majority of the vessels in the fleet to make this option practical, combined with the fact that HFC-428A is a still a high GWP gas, means that on balance we would not recommend this path. Further, given the higher risk of a catastrophic loss of refrigerant and thus the risk of product loss, it would be more commercially sensible to entirely replace the capital equipment and move to a new refrigerant.

The high level options analysis concluded that the technically feasible scenarios for any of the NPF fleet are as follows:

- Option 1: Install a new conventional refrigeration system operating on HFC-507A.

- Option 2: When constructing a new vessel, design it with a sealed plant room and advanced cascade refrigeration system, with ammonia or HFC-134a as the primary refrigerant, and CO_2 as the secondary refrigerant.
- Option 3: Extend the life of the existing HCFC-22 system until further information emerges on fourth generation refrigerants including characteristics, toxicity, affordability and expected timelines for commercial availability. This would involve replacing some older pieces of equipment and components that have a high risk of leakage, implementing a rigorous maintenance regime, leak testing and upgrading components at every opportunity to improve containment.

This last option leaves vessel owners open to a potential risk of interruptions to supplies of HCFC-22, particularly post 2015 when the import cap is reduced to its lowest level, and the potential of significant further price rises. Any vessel owner who elected to go down this path would be advised to secure a small strategic stockpile of HCFC-22 equivalent to roughly 1.5 times the total gas charge of their equipment. In a worst case scenario, that means that they could recharge the system if a catastrophic leak were suffered. In a best case scenario, coupled with increased focus on containment, the reserve would ensure 3 to 5 further years of operation on HCFC-22 while the assessment of new refrigerants was underway.

Each of these options will be explored in further detail in the sections that follow particularly focussing on use of legacy equipment and improvements to the existing technology platforms.

4.2 *Opportunities to improve existing equipment design and practices*

There are a variety of opportunities to immediately improve the energy efficiency and containment of existing refrigeration systems employed on the majority of the NPF vessels. They include:

Energy Efficiency

- Replace all lights in refrigeration spaces with LED lights if suitable light fitting that comply with working conditions can be found.
- Where practical, all thermal insulation should be upgraded or maximised with best in class insulation (particularly around the snap evaporator), and ensure that hatches have effective insulation, seal properly and are always closed when not in use.
- The large majority of evaporator fan-motors on vessels are very old and inefficient. At present there are limitations with "off-the-shelf" evaporators and fan motors using the latest fan motor technology (i.e. Electric Commutated) in low temperature applications. However, new specifications capable of operating down to -40^{o}C by sealing the electronics, and special bearing/lubricant selection, are expected to emerge in the next couple of years.
- Improving the fan motor efficiency not only saves direct energy consumptions it also removes parasitic heat loads that need to be removed by refrigeration effect.
- Add thermostatic controls on FDCs so they only need to operate when required, and maintain desired temperature in freezer.
- Use variable speed drives where possible (e.g. on compressors and condenser pumps) to optimise use of key components and reduce energy consumption.
- Replace existing condenser pumps with high efficiency pumps and controls (i.e. fit efficient pump, high efficiency motor and VSD to match heat rejection with demand).

Maintenance

- Only allow skilled tradesmen to undertake brazing of joints with quality materials (high silver content of solder) and installation of pipework must be properly crafted to ensure effective vibration elimination and correct sizing.

- Pump refrigeration system down at end of season and undertake thorough leak test. This can be undertaken by a qualified refrigeration mechanic and involves pumping the refrigerant charge into the liquid receiver and pressure testing the rest of system with nitrogen/hydrogen test gas mix (as used by major retailers such as Aldi Australia, as it will detect smaller leaks than nitrogen alone), or alternatively removing all refrigerant and testing the entire system.
- Check for corrosion of evaporator and condenser at end of each season (failure to detect corrosion before it penetrates the full width of any of the containment of refrigerants could result in a total refrigerant loss – this is referred to as a 'catastrophic' loss, and if it were to occur at the wrong time could result in the total loss of catch).

Containment

- Replacement of old open drive compressors with high efficiency semi-hermetic or screw compressors (eliminates shaft seals and associated components).
- Improved containment by eliminating all non-essential mechanical joints or connections. The objective should be to achieve a hermetically sealed system except for essential service points. Examples include:
  - Flared connections should be replaced with soldered connections on all valves, TX valves, sight glasses;
  - Old gauge panels can be replaced with transducers and an electronic control panel (existing gauge panels can have more than 20 or 30 flared connections);
  - Replace old style valves prone to leaking where plastic caps have been used, from wear of spindles and failing packing glands;
  - Eliminate Schrader valves; and,
  - Replace flexible PVC hose connections with the highest quality purpose designed flexible hoses.
- Install leak detection devises and undertake regular inspections.

Reduce refrigerant charge

Opportunities to reduce the refrigerant charge include:

- Replace horizontal liquid receivers with vertical receivers so the large majority of charge can be utilised;
- Revise piping configurations with reduced piping sizes; and,
- Engage a mechanical designer to redesign the existing snap evaporator to maximise heat transfer and reduce the refrigerant charge.

On this last point, the Expert Group has identified a number of vessels that are already employing custom made aluminium evaporators that have been fabricated by a local refrigeration engineering firm that services many vessels of the fleet. The design of the evaporator demonstrates some worthwhile performance characteristics that could be improved on. These evaporators come in several types:

- **Fixed shelf snap freezer** that is a hybrid between a plate and blast freezer. This configuration has contact between the snap plate and the bottom of the packaged product (i.e. conductive heat transfer) and the shelves are spaced so there is a 50 mm gap between the top of the product and the next plate, allowing convection heat transfer similar to a blast freezer. The original generation evaporators used galvanised steel serpentine coil pipes whereas the latest generation uses extruded aluminium that has reduced the snap times by around 4 to 6 hours. The aluminium plates have a nominal cross-section of 300 mm wide by 25 mm high with 9 refrigerant channels (approximately 23 mm by 15 mm). The plates are connected in a unique tongue and groove arrangement. The fixed position plate snaps have been chosen for durability and their maintenance free nature.

- **Hydraulic plate snap** uses double contact horizontal plate freezers where one plate is a fixed shelf and the second plate is hydraulically pressed onto the product to provide double sided contact with the product and conductive heat transfer. The connections from the headers to the plates are flexible PTFE hoses of the highest quality with stainless steel braiding. All the joints are metallic with conical "hydraulic type" fittings rated for extreme pressures. The snap times for this type of evaporator is typically reduced by a further 4 to 6 hours versus the fixed shelf style described above. Moving components inevitably have leaks created eventually, and the mechanisms for movement also inevitably have problems. Granted however that doubling the surface contact increases direct contact efficiency, although the air flow then reduces resulting in a pro's and con's technology decision.
- **Automatic plate snap** supplied by Danish company DSI plate freezing is similar in principal to the hydraulic plate snap described above, however the DSI technology is automated and used on larger vessels with a wide range of refrigerants including HFCs and ammonia.

Expert Group feels that the design of the extruded aluminium evaporator should be investigated and technically evaluated, in partnership with the a good equipment designer, to determine if it can be optimised for the attributes of HFC-507A and blends that exhibit glide and thus form part of a custom refit for transition away from HCFC-22. The investigation could assess the potential to reduce the refrigerant volume (i.e. reduce refrigerant channel cross section without compromising structural integrity or overusing material that increases cost); consider coil circuit design and refrigerant pressure drops; compare mechanical, maintenance and performance characteristics of the two styles of evaporator that have been developed (i.e. fixed shelf or hydraulic plates) and possibly review the existing seafood product packaging to enhance heat transfer.

The specialised and demanding conditions in which this technical solution has been developed, is exactly the sort of environment in which industrial innovation and inventiveness is often to be found, solving a very specific customer problem. This innovation could be the key to the lowest cost transition path for the NPF fleet. In the opinion of the authors this technology deserves a modest research and development program that we believe would be required to validate and refine the designs into a standardised product format with documented performance, so that it can be supplied to the NPF fleet, and other vessels, as an off-the-shelf solution.

4.3 *TEWI analysis of main options*

A Total Equivalent Warming Impact (TEWI) analysis was undertaken as part of the detailed analysis of the main technically feasible options.

TEWI is a simplified version of Life Cycle Climate Performance (LCCP) calculation and therefore is a measure of the global warming impact of equipment at design stage based on the total emissions of greenhouse gases during the operation of the equipment, and the disposal of the operating fluids at the end of life. It specifically excludes direct fugitive emissions during manufacture of equipment and fluids, and the greenhouse gas emissions associated with embodied energy in materials. The justification for excluding these items is that they typically equate to around 1% of total life cycle emissions in refrigerating applications, and are complex and difficult to accurately estimate.

The aim of undertaking a TEWI analysis is to assist fleet operators and industry practitioners to compare the environmental implications of the different technical options available that meet their refrigerating requirements. For further details on the definitions, methodology of calculation and parameters refer to *AIRAH Best Practice Guideline: Methods of Calculating Total Equivalent Warming Impact* (AIRAH 2012).

The main options reviewed are as follows:

NPF Option 1: Conventional refrigeration system operating on HFC-507A

This scenario was calculated on a system that carries a 240 kg charge of HFC-507A, without any energy efficiency or major equipment upgrades, but including improved containment practices. A leak rate of 15%

per annum is modelled, as compared to the present leak rates reported, of as much as 35% of the total charge per annum.

The result of this scenario is not that far different from the TEWI result produced when running the analysis on an existing HCFC-22 charged system. The main reason the two models produce such similar outputs is because, despite the lower leak rates modelled in the HFC-507A charged system, HCFC-22 has a lower GWP of 1,500, compared to HFC-507A which has a GWP of 3,300.

Thus modelling of worst case leaks on NPF vessels of 35% per of HCFC-22 per annum produce direct emissions equivalent to 126 t CO_2-e per annum. Due to its higher GWP, a vessel modelled using HFC-507A and a leak rate of 15% produces direct emissions equivalent to 119 t CO_2-e per annum.

Obviously on this analysis a move to HFC-507A *may not* produce any improvement in the TEWI result for a vessel – but it does migrate the equipment away from using the ozone depleting HCFC's, which on any measure is a better environmental result.

At the same time the authors are confident that in combination with efficiency measures identified, and with adoption of the maintenance and leak reduction processes and techniques recommended, the TEWI of a vessel that invested in a HFC-507A charged system could be significantly improved.

In the few instances in the fleet where the drop-in replacement of HFC-428A (GWP of 2,930) could be used in an existing system, with improved containment and leak rates of 15%, the direct emissions would be around 14% lower at approximately 106 t CO_2-e per annum. This may be considered an option for a very limited proportion of the fleet, but only where an equipment inspection verified that the gear had recently undertaken upgrades and had the potential for improved containment.

A process diagram of latest generation NPF vessel refrigeration system is provided in *Appendix C2*.

NPF Option 2: Advanced cascade refrigeration system on newly built vessels

A cascade refrigeration system could be developed with CO_2 refrigerant (GWP of 1) for the snap freezers, freezer room and brine cooling, connected to the medium temperature circuit, which could use HFC-134a refrigerant (GWP of 1,300) or ammonia (GWP of zero).

The best case low emission senario would be the ammonia/CO_2 cascade refrigeration system that has potential to achieve a 10% to 20% efficiency improvement (depending on design) from the baseline energy consumption scenario with no direct emissions. This option would have nil regulatory risk, however would have very high technical and commercial risk, as this technology is still evolving and has never been used on a vessel under 80 meters.

The indirect emissions from the HFC-134a/CO_2 cascade refrigeration system are likely to be similar to the ammonia system however will have direct emissions equivalent less than 4% of the indirect emissions.[2]

Both of these cascade refrigeration technology concepts will require considerable product development effort, costing an estimated $100k, plus the higher cost of equipment ($350k to $400k) and carry a risk of loss of earnings due to breakdowns during the development phase.

An ammonia/CO_2 cascade system could be constructed in a new vessel with a dedicated plant room, with safety equipment designed for toxic and mildly flammable substances, and a new equipment layout with CO_2 sensors, monitoring and alarms throughout.

It may be possible to install one of the modern and very compact HFC-134a/CO_2 cascade systems on some existing vessels, however at considerable additional expense to reconfigure the entire engine room therefore making it improbable.

[2] *Assuming a 50 kg charge of HFC-134a leaking at 10% per annum equates to 133,250 kg CO_2-e over 20 years including end of life emissions or 3.5% of indirect emissions.*

NPF Option 3: Conventional refrigeration system operating on fourth generation HFO refrigerant blend

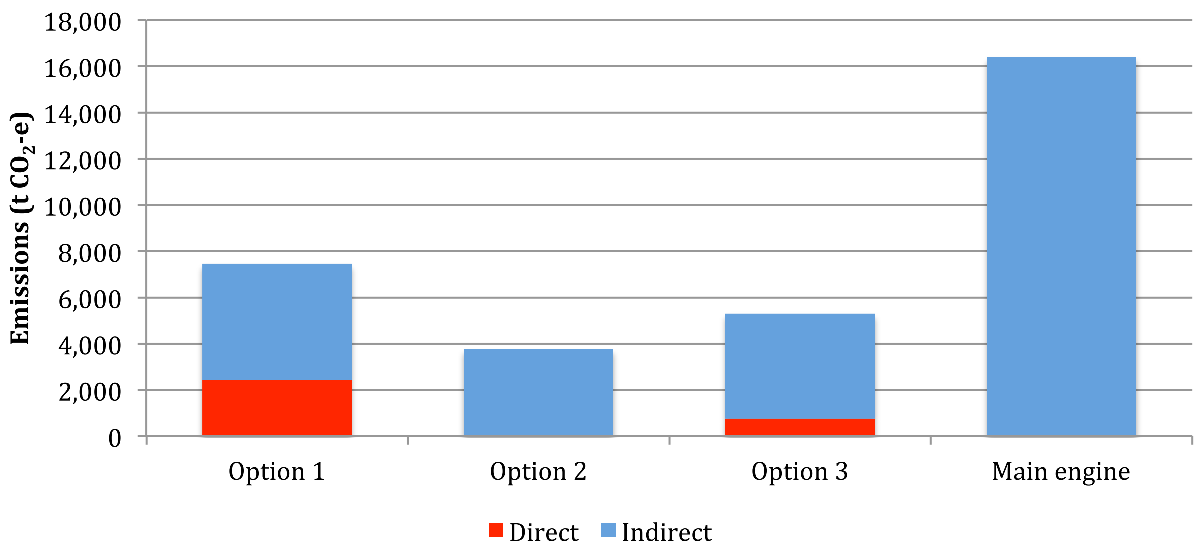
A TEWI calculation was undertaken for this option for comparative purposes only to understand the carbon emissions of the most plausible fourth generation refrigerant blend.

The significant benefit with this option is that it may employ a conventional refrigeration system, technology that the industry is familiar with, and potentially the same equipment designed to operating on HFCs. This would require a complete refrigeration system re-build resulting in a 10% efficiency improvement from baseline energy consumption scenario (mostly due to equipment efficiency improvements).

However this is only a cursory assessment for comparative purposes only as it is not possible to evaluate this option in detail, there is insufficient technical and commercial information on the HFOs, and no certainty of the timing of the release of these refrigerants.

The TEWI analysis of the carbon emissions of these options are summarised in *Figure 7*. They compare carbon emissions over a typical lifespan of 20 years, and with the emissions from diesel consumption from trawling from the main engine to provide additional context.

TEWI comparison of main options for NPF vessels



Option 1: Base case scenario: Conventional refrigeration system operating on HFC-507A: Baseline efficiency scenario with a refrigerant annual leak rate of 15% p.a.[3]

Option 2: Best case scenario: Advanced cascade refrigeration system with ammonia as the secondary refrigerant and CO_2 as the secondary refrigerant: 20% efficiency improvement from baseline energy consumption scenario and no direct emissions.

Option 3: Future prospect: Conventional refrigeration system operating on fourth generation refrigerant blend: 10% improvement from baseline energy consumption scenario (mostly due to equipment efficiency improvements) with an refrigerant annual leak rate of 15% p.a.[4]

Main engine: Emissions from diesel consumed from trawling.

	Emissions over 20 year lifespan (t CO_2-e)		
	Direct	Indirect	Total
Option 1	2,416	5,037	7,453
Option 2	0	3,778	3,778
Option 3	769	4,533	5,302
Main engine	-	-	16,386

Figure 7: TEWI comparison of main refrigeration technology options over a 20 year lifespan.

[3] *Option 1: Other assessment parameters include refrigerant charge of 240 kg, refrigerant recovery rate of 95% at end of life and diesel energy content and emission factors found in Appendix A.*

[4] *Option 3: Other assessment parameters include a refrigerant charge of 180 kg for a refrigerant with a GWP of 1,400. All other parameters were consistent with other scenarios.*

4.4 *Summary of main options*

A simplified framework of the issues and considerations outlined in *Section 3.7* is used to compare technically feasible options including:

- Financial considerations (capital investment and ongoing expenses);
- Technical (refrigerant characteristics, equipment types, application constraints, performance and associated technology risk);
- Regulatory and environmental (direct, indirect and life cycle carbon emissions, and associated regulatory risk);
- Safety risks (high OHS risk options with limited risk mitigation treatments are excluded as they are not considered technically feasible).

Table 4: Review of the technically feasible options for NPF vessels.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 year horizon)
	Capital investment	Operating expenses		
1. Conventional refrigeration system				
DX system with semi-flooded evaporator system (over charged) operating on HFC-507A Develop next generation of evaporator plus proto-type ≈ \$120k	Medium Suitable for existing vessels. Equipment replacement ≈ \$250 to 280k. See *Appendix B1* for details.	Low HFC-507A ≤ \$40 per kg without ECP levy.	Low No significant change in type of technology and components.	Medium to high Refrigerants with GWP > 2,150 under scrutiny for phase out within 10 year horizon. Uncertainty if alternative azetrope blend with lower GWP suitable for flooded evaporators will emerge. Blend with GWP ≤ 1,400 expected to emerge (e.g. DR-33) to replace HFC-404A. High glide and effects of refrigerant fractionation may limit its use in this application.
2. Advanced cascade refrigeration system				
a) HFC-134a/CO_2 cascade system New vessel ≥ \$2.5M (required in most instances) Develop new concept ≈ \$100k excluding proto-type Equipment ≈ \$350k	High Requires new vessel layout with CO_2 sensors, monitoring and alarms for safety reasons.	Medium Potential improvement in efficiency. High maintenance cost due to complexity.	Very high Harsh conditions and complexity likely to result in breakdowns and loss of income. Limited technical capability on board vessels.	Low to nil Blend with GWP ≤ 600 expected to emerge (e.g. XP-10). Carbon emissions 47% lower than base case scenario.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 year horizon)
	Capital investment	Operating expenses		
2. Advanced cascade refrigeration system				
b) Ammonia/CO_2 cascade system New vessel ≥ \$2.5M Develop new concept ≈ \$100k excluding proto-type Equipment ≈ \$400k incl. safety measures	Very high	Medium	Very high	Nil
	Requires new vessel with separate plant room.	Potential improvement in efficiency. High maintenance cost due to complexity.	Highly complex relative to on board capabilities. Additional safety risk of ammonia (mildly flammable and highly toxic).	No environmental policy risk throughout expected life of equipment. Carbon emissions 49% lower than base case scenario.
3. Conventional refrigeration system operating on fourth generation refrigerant blend.				
TEWI calculation was undertaken for this option for comparative purposes only. Unable to evaluate this option as there is insufficient technical and commercial information, and no certainty of the timing of the release of these developmental refrigerant blends.				
4. Extend the life of the equipment				
a) Existing plant with improved containment operating on HCFC-22 Short term solution and may not be practical for all vessels (maximum of 4/5 years)	Low	High	Low	Very high
	Improve gas containment of system ≈ \$30k to 50k.	High cost of HCFC-22 Currently ≥ \$30k to recharge vessel. Price expected to increase.	No change in technology Limited supply of HCFC-22 in emergency.	HCFC-22 phase out in advanced stages. Further tightening in imports by 75% at end of 2013 and a further 75% in 2015 inevitably requiring capital investment in new system.
b) Existing plant with improved containment operating on HFC-428A	Low	Medium	Medium to high	High
	Improve containment of system ≈ \$30k to 50k.	HFC-428A less expensive without ECP levy. Leakage issues could require system recharge.	High risk of failure with old equipment (i.e. open drive compressors and containment issues). Risk of leaks causing performance issues with refrigerant blend.	Refrigerants with GWP > 2,150 under scrutiny for phase out within 10 year horizon.

In summary Expert Group believes that the most practical commercial options available to NPF fleet owners, depending on the condition of each vessel, availability of capital and other business considerations, are:

A. Maintain HCFC-22 charged plant for a maximum of four to five years, requiring;

   a. Comprehensive upgrade for improved refrigerant containment.

   b. Increased focus on preventative maintenance regimes.

   c. Securing sufficient stock of gas to be held in reserve.

   d. Planning for an inevitable capital equipment replacement program at the end of the period to either HFC-507A or to a newly released low GWP HFC/HFO blend to be assessed closer to the equipment replacement date.

e. Estimated costs (depending on vessel condition and age) $30,000 to $50,000 plus cost of gas reserves.

B. Commence design and planning for replacement of equipment with HFC-507A system;

   a. Including best practice containment, leak monitoring and preventative maintenance regimes.

   b. Capture and store HCFC-22 charge on decommissioning of old system, for later reconditioning and reuse in other fleet systems, or trade with wholesaler for reduced price on other gas stocks.

   c. Maintain watching brief on refrigerant gas markets and regulations to ensure adequate reserves of this high GWP HFC for life of equipment.

   d. Maintain watching brief on opportunities for later shift to low GWP drop-in replacements.

   e. Estimated cost $250k to $280k.

C. On a limited number of existing vessels that have recently upgraded equipment evaluate practicalities of refitting with HFC-428A drop-in replacement.

   a. Comprehensive upgrade for improved refrigerant containment.

   b. Increased focus on preventative maintenance regimes.

   c. Capture and store HCFC-22 charge on decommissioning of old system for later reconditioning and reuse in other fleet systems, or trade with wholesaler for reduced price on other gas stocks.

   d. Maintain watching brief on refrigerant gas markets and regulations to ensure adequate reserves of this high GWP HFC for life of equipment.

   e. Maintain watching brief on opportunities for later shift to low GWP drop-in replacements.

   f. Planning for an inevitable capital equipment replacement program at the end of the period to either HFC-507A or to a newly released low GWP HFC/HFO blend to be assessed closer to the equipment replacement date.

   g. Estimated costs (depending on vessel condition and age, and ECP levy) $30,000 to $50,000.

Any plan to design and build any new vessel for the NPF should invest in detailed engineering assessment of cascade refrigeration systems seeking to employ either a HFC-134a/CO_2 cascade system or an ammonia/CO_2 cascade system.

5 Sydney Fish Market options analysis

5.1 *High level analysis*

The full range of refrigeration systems, refrigerant types and energy efficiency initiatives were considered for the future of the Sydney Fish Market (SFM) refrigeration plant including:

- Extending the life of existing plant by 10 years;
- Employing currently available natural and synthetic refrigerant types as well as taking into consideration likely developments with fourth generation refrigerant blends;
- Employing a large capacity ammonia direct expansion (DX) system;
- Assessing the full range of CO_2 systems possible including trans-critical and sub-critical systems;
- Staying with conventional refrigeration systems operating on HFC-404A, HFC-507A or HFC-407A;
- Employing advanced cascade refrigeration system(s) in a variety of refrigerant configurations including HFC-407A/CO_2, HFC-134a/CO_2 and ammonia/CO_2.
- Assessing the potential for emerging refrigeration technologies (i.e. ice slurry systems);
- Assessing the potential for hybrid renewable innovations that utilize natural resources (i.e. seawater or ground to reject condenser heat); and,
- Assessing the potential for heat recovery systems.

The large majority (>90%) of major cold storage warehouses in Australia (typically 75,000 m^3 up to 300,000 m^3) are serviced with large industrial refrigeration systems that use ammonia as a refrigerant. These systems can contain refrigerant charges up to 6 tonnes and significantly larger charges up to 150 tonnes can be found in energy intensive processes such as in abattoirs. Large ammonia charges have not been used in retail precincts in industrialised countries due to the potential safety risks to the public and the associated liability. There are increasing numbers of new generation small charge ammonia systems being used in these non-traditional applications. One example, using a smaller ammonia charge as the primary refrigerant, and CO_2 as the secondary refrigerant, was installed at a Woolworths supermarket in Rouse Hill, NSW in 2008 with the charge located in a rooftop plant room. Another system was installed at the Logan City Council Administration Building in Queensland.

CO_2 only (i.e. trans-critical) systems are ideally suited to low ambient temperature applications, and in large process applications that involve both chilling and heating stages (e.g. brewing), as the heat recovery from the CO_2 chilling systems can deliver significant energy savings for heating and hot water. Neither of these circumstances is applicable to the SFM.

A new conventional refrigeration system operating on HFC-404A or HFC-407A was not considered a good option as high GWP refrigerants have considerable regulatory risk, raising the potential for stranded assets over the expected lifespan of the equipment. Extending the life of the existing plant for a shorter period by refurbishing the existing plant and transitioning to a drop-in replacement was considered a more practical high GWP refrigerant alternative.

The existing structure (36 freezer/cool rooms), locality (highly populated retail precinct frequented by general public), flexible refrigeration requirements (freezers and cool room capability from 7 to -30^oC), building structure (age of building and predominantly non-structural roof) and site constraints (planning restrictions and limited real estate) eliminated many options available to other sites, such as distribution centres, with similar refrigeration requirements.

In summary, a pure ammonia or pure hydrocarbon system, with a large refrigerant charge, was considered too great a safety risk for a densely populated retail precinct; the limited heat recovery prospects restricted the potential for CO_2 only chilling systems and utilising the harbour as a heat rejection sink was considered an unlikely prospect due to environmental constraints.

The high level options analysis concluded the most viable technically feasible options are as follows:

- Option 1: Extend life of plant by 10 years by refurbishing the existing plant and transitioning to a drop-in refrigerant replacement.
- Option 2: Advanced cascade refrigeration system with HFC-134a as the primary refrigerant and CO_2 as the secondary refrigerant.
- Option 3: Advanced cascade refrigeration system with ammonia as the primary refrigerant and CO_2 as the secondary refrigerant.

Each of these options will be explored in further detail in the sections that follow particularly focussing on use of legacy equipment and improvements to the existing technology platforms.

5.2 *Technical description of existing system*

The existing refrigeration system is a large liquid recirculation system operating on HCFC-22 comprised of the following main components:

- 4 x Mycom Screw compressors (1 x 1612 and 3 x 200LG) with a nominal capacity of 150 and 287 kWr each respectively.
- 2 x Caterpillar 3408 gas engines fitted to two of the Mycom screw compressors.
- Vertical liquid receiver with a capacity of 5,030 litres.
- A large suction accumulator with an oil recovery system and two HCFC-22 pumps located beneath.
- 2 x Muller KC 19713 water cooled evaporative condensers with a base heat rejection capacity of 560 kWr each.
- 53 x Evaporators (approx. 5 fins per inch) with electric defrost heaters servicing 36 cold stores with freezer and chiller capability.
- Copper reticulation piping with modulating pressure regulator valves to control refrigerant flow and a variety of accessories including solenoid valves to control the room temperature, check valve, isolating valves and hand expansion valve to balance the refrigerant flow liquid supply lines.
- PLC to control the system and a supervisory system providing monitoring, trends and alarms for all key measures.
- Leak detection system comprising interconnecting conduit in freezer/cool rooms to sense refrigerant leaks in critical areas as well as liquid level monitoring in the receiver.

Other system characteristics include:

- The ability to service a wide range of fresh and frozen product temperature requirements ranging from fruit (7^{o}C), Oysters (4 to 5^{o}C), fresh fish (0 to 2^{o}C) and frozen fish products (-20 to -30^{o}C). The existing system also provides air conditioning to the sales room however the cooling effect is rarely used and is not considered part of the future design criteria.
- Defrost is largely done by electric defrost heaters equating to a total connected load of 464 kW of electrical power (only 4 to 5 rooms are defrosted at once so not all of this connected load is drawn at any one time). To minimise some consumption from this large electric load, door switches are used to detect when the cold store doors are open to switch off evaporators so they can defrost naturally during these periods.
- Power redundancy; the gas powered units primarily act as a redundancy system in the event of a mains power failure. One gas driven compressor services the refrigeration system whilst the auxiliary of the second unit provides sufficient power to operate all pumps, fans, heaters and controls.
- In normal operation the entire system is generally serviced by just two electric driven compressor, with the second mains powered compressor running at part load during low loading conditions and full load at peak.

Operating characteristics

The main refrigerant plant consumed an average of 3,332 MWh per annum over the last two years, which is illustrated in *Figure 8* showing expected seasonal peaks leading up to Christmas.

The specific energy consumption for the site is around 327 kWh/m^3/year. This may seem high when compared to the 60 kWh/m^3/year typically found in large cold storage facilities refrigerated by large capacity ammonia direct expansion systems. However the SFM plant is still quite efficient when compared to individual condensing units and evaporators employed in facilities where every cold store is serviced by its own small system that may consume 300 kWh/m^3/year in a medium temperature cool room, and up to 500 kWh/m^3/year for a freezer room.

Main refrigeration system electricity consumption

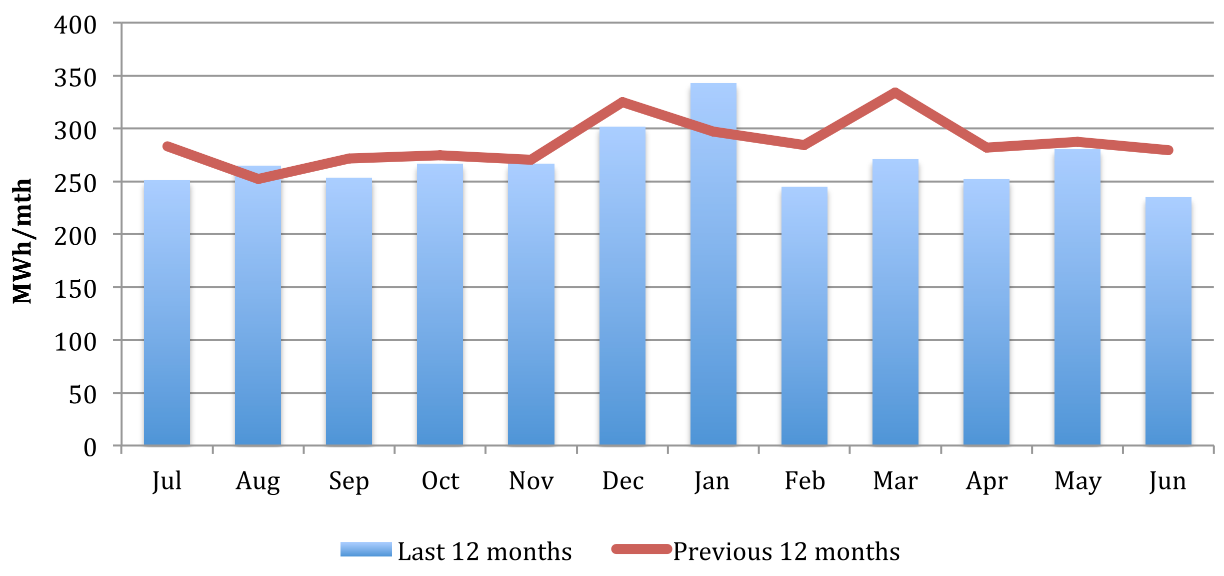


Figure 8: Main refrigeration system electricity consumption over the past two years in MWhr per month.

The table below provides further detail on the main energy consuming sources.

Table 5: Dissection of refrigeration energy consumption.

	Proportion of total (%)
Compressor 1: Mycom 200LG	42%
Compressor 1: Mycom 1612LC	19%
Ancillary components	39%
Condenser fans	4%
Condenser pumps	1%
Oil cooling water pump	2%
Liquid re-circulator pump (low/high temp)	3%
Evaporator fans	18%
Compressor oil pump	1%
Defrost heater	3%
Door and drain heater	8%

The refrigerant consumption for the past two years was 510 kg in 2012, and 715 kg the previous year, equating to an average annual leak rate of around 10% per annum.

The system is almost 25 years old, and despite being innovative for its time and well maintained throughout its life, the plant has reached a critical point in its effective lifespan. The SFM plant requires between four to six tonnes of HCFC-22 to ensure continued operation.

5.3 *TEWI analysis of main options*

A TEWI (Total Equivalent Warming Impact) analysis was undertaken as part of the detailed analysis of the main technically feasible options.

The main options reviewed are as follows:

SFM Option 1: Extend life of existing plant by 10 years

There are a variety of drop-in replacements being promoted for HCFC-22 including HFC-438A, HFC-434A, HFC-428A and HFC-407F. These are interim HFC solutions each with different characteristics and GWP values. There are many technical factors to consider when selecting a suitable drop-in replacement including seals, oil, capacity, mass-flow, glide and operating pressures. Whilst HFC-438A is a better pressure and capacity match to HCFC-22 the only technically viable drop-in replacement for this application is HFC-428A (GWP of 2,930) as none of the other options are suitable for flooded evaporators.

Retrofitting the system with HFC-428A will mean the system will need to be able to cope with elevated pressures required for this refrigerant. As a result many aging components with a high risk of leaking over the next ten years will need to be replaced to improve the containment and robustness of the system.

A preliminary list of items that would need to be undertaken is as follows:

- Replace all evaporators. They are old and potentially the weakest point in the system, and present the greatest risk of causing a refrigerant leak.
- Replace all pressure regulating valves.
- Replace all mains reticulation piping.
- Replacement of all elastomeric seals. HCFC-22 is forced into them over time, causing swelling. When the HCFC-22 is removed from the system, it leaches out of the seals, causing the seals to shrink, dehydrate and crack resulting in a refrigerant leaks.
- Install new pressure relief valves suitable for higher pressures and assess the pressure ratings on all components and accessories.
- Following charging with HFC-428A several frequent filter changes will be required to clean out the system as the new refrigerant can act as a solvent and dislodge particles built up over time.
- Oil change from the existing mineral oils to POE oil is recommended for systems with long pipework runs and flooded systems.
- Eliminate any non-essential requirements such as air conditioning the sales room and long pipe runs (including retail outlets as per discussions with site engineering personnel).

If this option is to be considered a complete refurbish program should be undertaken on the assumption that all equipment and components with an expected residual lifespan of less than 10 years should be replaced. In addition a thorough investigation of this option should be explored with the drop-in refrigerant supplier to fully understand the technical and commercial risks. This would involve providing testimony of similar sites so SFM personnel can visit to learn from others experiences.

The TEWI calculation for this option is based on its existing design load of 532 kWr at -33^{o}C SST (saturated suction temperature) whereas the cascade refrigeration system options are based on a lower temperature design criteria of -38^{o}C SST requiring higher capacity. Two calculations were undertaken; Option 1a operating the existing plant on HCFC-22 that uses actual energy consumption; and, Option 1b operating on

HFC-428A which has an increased capacity of around 16% with the existing compressors resulting in slightly less power consumption. Option 1a uses the existing leak rate of 10% per annum, whereas option 1b uses a lower leak rate of 5% per annum based on the improved containment following the refurbishment. Option 1b is modelled based on electric defrost, door and drain heater, and slightly more efficient fan motors (10% improvement) on the new evaporators.

SFM Option 2: HFC-134a/CO_2 cascade refrigeration system

The cascade refrigeration system would use CO_2 refrigerant (GWP of 1) to deliver cooling down to -30^{o}C in the cold stores, The CO_2 is cooled after compression by heat exchangers located in the plant room. The plant room heat exchangers would be connected to the medium temperature circuit, which would use an estimated charge of 500 kg of HFC-134a refrigerant (GWP of 1,300).

There are an estimated 160 supermarket refrigeration systems in Australia containing CO_2 refrigerant the majority of these (>90 per cent) are cascade systems with charges of around 200 to 500 kilograms of CO_2. Other CO_2 systems can be found in industrial food processes and other retail applications such as large licensed clubs.

To provide a high level of system and capacity redundancy, the low temperature refrigeration duty would be spread over multiple compressors configured in duty and standby mode. Similarly for the medium temperature circuit, multiple HFC-134a compressors and evaporative condensers would be provided. The TEWI analysis calculated the indirect emission based on using three Grasso medium temperature compressors operating on HFC-134a with a combined design load of 940 kWr at -8^{o}C SST, in cascade with three Grasso low temperature compressors operating on CO_2 with a design criteria of -38^{o}C SST, allowing cold stores to operate down to -30^{o}C.

Although the cooling capacity hours (kWh) of each cascade system was matched to the capacity of the existing system in order to meet the operational loads, the existing system has a cold store capability of -25^{o}C versus the cascade system options that are based on -30^{o}C.

Refer to *Appendix C3* for a conceptual process diagram of the cascade refrigeration system.

SFM Option 3 Ammonia/CO_2 cascade refrigeration system

As an alternative to using HFC-134a refrigerant on the medium temperature circuit, this option would use ammonia refrigerant (GWP of zero) working with a flooded plate heat exchanger to generate cold glycol. The glycol would then be circulated through the CO_2 heat exchangers to condense the CO_2 refrigerant. The system would be very similar to the conceptual process diagram illustrated in *Appendix C3* except the HFC-134a plant is replaced with an ammonia/glycol plant.

The ammonia charge would be reduced to a minimum, estimated at 200 to 300 kg and would be limited to within the plant room only. Ammonia carries a B2 safety classification, meaning that it is mildly flammable and has high toxicity risk. Although no ammonia is reticulated to the cold store rooms, it is classed as a dangerous good and will require safety measures, handling, training and processes in accordance with requirements prescribed by a variety of authorities (i.e. Environmental Protection Agency, WorkSafe and relevant fire services).

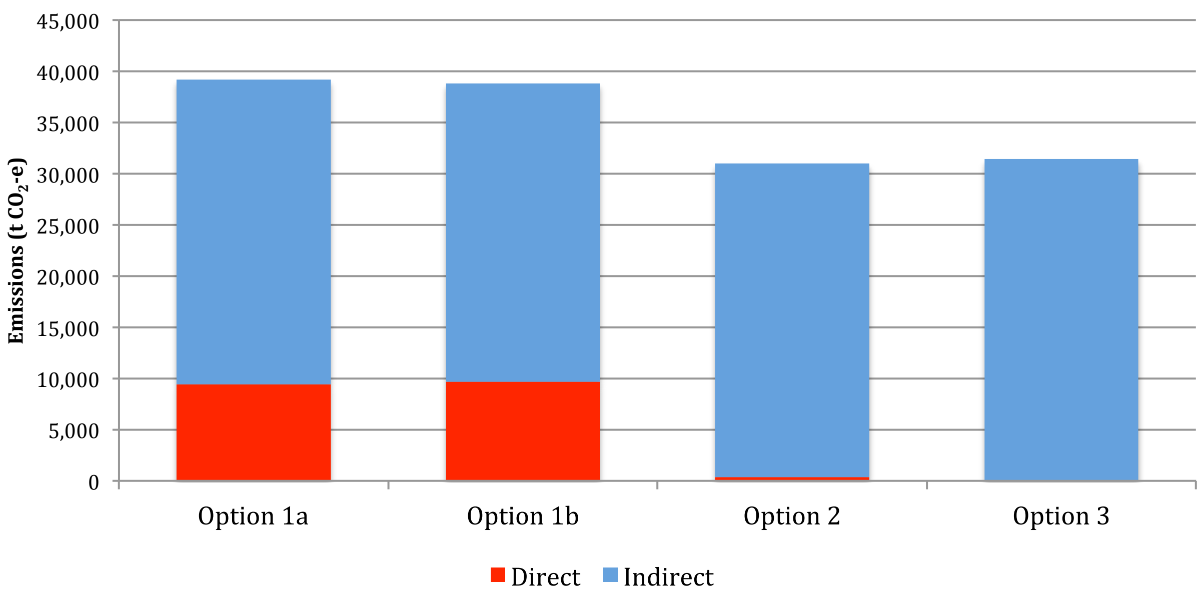
The TEWI analysis calculated the indirect emission based on three Grasso medium temperature compressors, operating on ammonia, with a combined design load of 940 kWr at -10^{o}C SST. This is slightly lower temperature than the other cascade system so as to accommodate the glycol to ammonia heat exchanger. A further three Grasso low temperature compressors operating on CO_2 with a design criteria of -38^{o}C SST allow the low temperature cold stores to operate down to -30^{o}C.

A summary of the advantages and disadvantages of the two cascade systems is as follows:

Advantages:	Disadvantages
▪ New system capable of operating freezers below -30°C and in accordance with HACCP food safety guidelines ▪ Eliminates large charge of high GWP refrigerant and mitigates future regulatory risk and financial penalties from reliance on high GWP or ODS refrigerants. ▪ Savings in overall carbon emissions equivalent resulting from reduced refrigerant leakage and power usage. ▪ Lower cost refrigerant to replace in the event of a leak (approximately $10 per kg for ammonia). ▪ Technology concepts are well proven and tested over the last 5 years including multiple Coles and Woolworths sites (in larger format), cold storage facilities and industrial applications. ▪ Still significantly lower cost and complexity than full CO_2 trans critical system, and does not have any periods where efficiency is reduced due to high ambient temperatures. ▪ Potentially lower maintenance costs due to age of new plant.	▪ Increased capital cost on initial installation arising from some increased complexity and reconfiguring plant room. ▪ Installing a new system will pose logistical challenges (i.e. maintaining existing tenants operational) and construction OHS risks that need to be effectively managed (i.e. overhead pipework, etc.). ▪ CO_2 operates at higher pressures. There is no potential for reuse of existing components on CO_2 circuit side and all existing reticulation piping will need to be replaced. ▪ Ammonia charge of 200 to 300 kg poses some safety risk that requires sound engineering, safety devices, monitoring and emergency procedures to mitigate the risk. ▪ Need to have a CO_2 detector and warning lights in each freezer and chiller room to manage safety issues. CO_2 detectors will require routine checking and calibration. ▪ Whilst this may be considered a significant disadvantage in a remote location or on a fishing vessel due to shortages of skills, the required technical skills are available in all major metropolitan regions in Australia. ▪ Will need a small back-up system on generator power to prevent CO_2 charge being released (outside) in the event of extended power outage.

Figure 9 summarises the results of the TEWI analysis of the main options over a 10 year period. The TEWI assessment is a comparative assessment tool. As the expected lifespan of Option 1 is limited to 10 years the TEWI assessment was done on this comparative basis for all options, despite the much longer life expectancy of the new cascade systems.

TEWI comparison of main options for SFM



Option 1a: Existing plant operating on HCFC-22: Baseline refrigeration load scenario based on actual energy consumption and an refrigerant annual leak rate of 10% p.a.[5]

Option 1b: Existing plant operating on HFC-428A: Baseline refrigeration load scenario with improved capacity and an refrigerant annual leak rate of 5% p.a.

Option 2: HFC-134a/CO_2 cascade refrigeration system with enhanced cold store specfication resulting in slightly higher energy consumption and an refrigerant annual leak rate of 5% p.a.

Option 3: Ammonia/CO_2 cascade refrigeration system with enhanced cold store specification resulting in slightly higher energy consumption.

	Emissions over 10 year lifespan (t CO_2-e) [(1)]		
	Direct	Indirect	Total
Option 1a	9,450	29,757	39,207
Option 1b	9,669	29,182	38,851
Option 2	359	30,627	30,987
Option 3	0.3	31,438	31,438

Figure 9: TEWI comparison of main refrigeration technology options over a 10 year lifespan.

The key energy saving measures factored into the TEWI analysis are:

- High efficiency compressor technology;
- Warm glycol defrost as opposed to the existing 464 kW electric defrost; and,
- Warm glycol circulation to replace the existing door heaters.

---

[5] Other assessment parameters include refrigerant recovery rate of 95% at end of life and Indirect (scope 2) emission factors from consumption of purchased electricity from a grid found in Appendix A.

Although the TEWI analysis shows there is a slight increase in electricity consumption with either of the new cascade refrigeration systems, they are expected to be around 10% more efficient than the existing system.

If the low side suction temperature were reset to -33°C SST (cold store rooms operating down to -25°C) the COPs of the CO_2 compressors would improve by 20% from 4.1 to 4.96. This would result in energy saving with the CO_2 compressors as well as the high stage compressors on either the HFC-134a or ammonia cascade systems.

Other energy saving opportunities to consider for all future options are as follows:

- Upgrade existing evaporator fan motors to latest fan motor technology (i.e. Electric Commutated) where practical. Standard "off the shelf" evaporators for low temperature applications do not have EC fan motors as they can have starting and operation issues. A special order for a batch quantity should be considered where special attention is taken with sealing the electronic and bearing/lubricant selection so the motors can operate down to -40°C. Improving the fan motor efficiency not only saves direct energy consumptions it also removes parasitic heat loads that need to be removed by refrigeration effect.
- The existing freezer/cool rooms are made of sandwich panel constructed from colorbond panels with EPS (Expanded polystyrene) insulation. Many of the panels have been pierced from fork truck traffic resulting in waterlogged sandwich panels that loose most of their insulating properties. Consider upgrading to thicker sandwich panels with better insulating properties such as PIR (polyisocyanurate). Future forklift or other accidental penetrations of the panel cladding material must require an immediate report and water tight patch applied within hours of report.
- Avoid and minimise heat infiltration and loss of refrigerated air with well-designed doors and airlocks and incentives for tenants to keep doors closed. Fit door alarms (visual and/or audible) with short time triggers.

5.4 *Summary of main options*

A simplified framework of the issues and considerations is used to compare technically feasible options including:

- Financial considerations (capital investment and ongoing expenses);
- Technical (refrigerant characteristics, equipment types, application constraints, performance and associated technology risk);
- Regulatory and environmental (direct, indirect and life cycle carbon emissions, and associated regulatory risk); and,
- Safety risks (high OHS risk options with limited risk mitigation options are excluded as they are not considered technically feasible).

Table 6: Review of the technically feasible options for SFM.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory risk (10 year horizon)
	Capital investment	Operating expenses		
1. Extend life of existing plant by 10 years				
Stage 1: Operate existing plant on HCFC-22 for 2 to 3 years	Low	Low	Low	Very high
	Improve refrigerant containment of system, replace evaporators, piping replacements, etc.	High cost of HCFC-22. Worst case refrigerant loss ≈ 3t equivalent to around $400k Maintenance ≈ $150k	No change in technology. Limited supply of HCFC-22 in emergency.	HCFC-22 phase out in advanced stages. Further tightening in imports by 75% at end of 2013 and a further 75% in 2015 inevitably requiring capital investment in new system. Very high risk for large charge plant.
Stage 2: Retrofit existing plant with HFC-428A in 2 to 3 year	Low	Low	Low to medium	High
	As above plus major upgrade and retro fit ≈ $1.65M See *Appendix B2* for details	HFC-428A ≤ $60 per kg without ECP levy.	Main components are already 25 years old. Potential performance issues and operating cost penalties if retrofit not successfully implemented.	Refrigerants with GWP > 2,500 under scrutiny for phase out expected to commence within 10 year horizon.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory risk (10 year horizon)
	Capital investment	Operating expenses		
2. Advanced cascade refrigeration system (HFC-134a/CO_2)				
a) HFC-134a/CO_2 cascade system	Medium	Low	Low to medium	Low to nil
	New plant ≈ $3.4M Estimate based on clear site Detailed investigation required to budget based on site constraints.	Slightly higher efficiency and lower energy running costs. Warranty period 12 months. Maintenance ≈ $75k	More complex than existing system. These systems have been used (in larger format) at many new Coles and Woolworths sites in Australia so industry experience has increased.	Blend with GWP ≤ 600 expected to emerge (e.g. XP-10).
3. Advanced cascade refrigeration system (ammonia/CO_2)				
b) Ammonia/CO_2 cascade system	Medium	Low	Medium	Nil
	New plant ≈ $3.55M As above on budgeting.	As above. Maintenance ≈ $100k	As above Additional safety risk of ammonia (mildly flammable and highly toxic).	No environmental policy risk throughout expected life of equipment.

All three options examined are technically sound and feasible for the Sydney Fish Market.

The next step is for the Board to review these options and decide which of them merit the undertaking of a detailed feasibility study.

Option 1: Extending the life of the existing plant for 10 years through a two stage process of upgrades and migration to a high GWP HFC drop-in replacement gas. This is the least expensive option in the short term, although the existing system falls short of HACCAP requirements.

If the Board chose to conduct a detailed feasibility study into this option to thoroughly examine the extent of works required, the cost and the time involved, that investigation should involve extensive enquiries with suppliers of drop-in refrigerants to fully understand the technical and commercial risks. The investigation should include gathering testimony from operators of similar sites so SFM personnel can visit and learn from other's experiences, to avoid mistakes or problems that have been encountered in similar situations, and to mitigate operational risks. It has to be noted that this option leaves the SFM open to risks of higher gas prices if international action on high GWP HFCs proceed as expected, and it will only delay the inevitable requirement to completely replace the existing system with new plant. On the other hand, as an interim measure, it will buy several years during which all of the other technology options, and new low GWP gases, will evolve rapidly and be more widely implemented, improving market expertise in these technologies.

It should further be noted that even if one of the following two options are taken instead of Option 1, the existing system will still have to remain fully operational and gas tight for possibly another 2 years anyway. So some of the costs associated with improving containment are likely to be incurred in any scenario to ensure continued reliability and eliminate as far as possible the loss of refrigerant as the cost of HCFC-22 can only go up.

Option 2; Design and build a new CO_2/HFC-134a cascade system; With an early estimate of cost of at least $3.4 million, which could be 50% more expensive than a competing conventional system installed to run on existing high GWP HFCs, but able to deliver very good performance, major efficiency improvements and with very limited regulatory risk, this is the authors preferred option. This technology is consistent with technology platforms deployed by major food retailers in Australia and globally in the last ten year, and particularly in the last five.

If, in a worst case scenario, the HFC-134a used to condense the CO_2, becomes expensive or supplies are seriously curtailed by the late 2020's, given that HFC-134a is so widely employed, the authors are confident that lower GWP replacements will have been developed and proven by that time that can substitute in the condensing part of the cascading refrigeration plant.

Option 3: Design and build a new Ammonia/CO_2 cascade system: With an early estimate of cost of around $3.55 million, but with real potential for even higher efficiency and better performance than Option 2, and thus operating cost savings, and with lower cost refrigerant throughout its operational life, for which no regulatory risk is expected, this is a sound technical option for SFM to consider. There is however the trade off with increased risk and increased technical and management complexity of having any ammonia on site. This can be mitigated by using current low charge design practices and has the major advantage that it will not be impacted by future supply or regulatory issues associated with synthetic refrigerants.

A new plant must eventually be constructed on the SFM site, whether that is within a year or two, or in ten or twelve years time, any new plant construction on this site is a major piece of work, with considerable logistical challenges. Undertaking these major works while maintaining the full capability of refrigerated operations on site, plus maintaining access for the public and buyers, will be a challenge. However supermarket operators do this all the time, and while a resource intensive and complex project, it is essential for the continued operation of the SFM.

For either of the new plant options a preliminary design would be highly advisable, outlining where plant and pipe work would be located. This would involve a preliminary design, and a detailed budget and logistics schedule that takes into account the costs and complexities of undertaking construction and maintaining operations. The review would have to take into account of how overhead works could be undertaken in areas such as the auction room or if they would need to be temporarily relocated or simply use half of the auction room while work was completed in the other half.

6 Conclusions and recommendations

The Northern Prawn Fishery fleet

The NPF vessel refrigeration application is considered among the most difficult and demanding RAC applications in the Australian economy.

Much of the fleet's plant is at or beyond its design life and it must move away from the reliance on HCFC-22. Even with enhanced maintenance regimes and increased scrutiny of sealing and leak detection, the risk of catastrophic failure of older components, and the total loss of an increasingly expensive HCFC-22 charge, rises dramatically in these aging systems every year they are not replaced.

The modern fishing fleet is entirely dependent on effective and reliable refrigeration systems and there is no easy 'off-the-shelf' solution for the NPF fleet. Refrigeration engineers and practitioners with specialist knowledge and experience in dealing with this tough and complex application must devise the next generation refrigeration system.

The only refrigerant that is entirely suitable for delivering the workload required for the existing NPF vessels is HFC-507A, a refrigerant that will come under regulatory scrutiny within the next decade (or sooner), and face a similar fate as HCFC-22. This leaves fishing fleet owners with one technically viable but possibly uncomfortable option.

Given the promised removal of the carbon equivalent import levy the authors could not recommend that any vessel owner proceed with paying to replace their system until the timing of that change is confirmed. In the meantime, development work on a new system reference design can be undertaken that focuses on refrigeration containment, reduction in refrigerant charge, improved build quality and energy efficiency. This task is too complex for one operator to take on board alone and industry needs to act collectively as the majority of the operators are facing this decision at the same time.

The authors are of the opinion that the most efficient way to manage the transition for the fleet is for the industry body to invest in a vessel technical standard and demonstration system. New refrigeration systems can then be ordered with delivery and installation dates scheduled for post the removal of the levy, ensuring reasonable prices are paid for gas.

This approach has two major benefits. Firstly it will greatly reduce the cost and time for vessel owners who contract refrigeration services companies to provide new systems to NPF vessels, if they have a reference design with all the important technical decisions made.

Secondly this process will prove up the capacity and design constraints so that sizing of the critical components for individual vessels will not entail any guess work, but will be able to be confirmed by the results of the reference design and its demonstrated performance.

The project would involve engaging a project manager, experienced in developing refrigeration systems to undertake a critical review of all the main equipment, components and accessories. This process would require extensive consultation with specialist refrigeration practitioners and may involve engaging and co-ordinating design work of a contract refrigeration engineer and mechanical designer.

The demonstration system for the fleet should be based on the following criteria:

- Primarily designed as a conventional system operating on HFC-507A;
  - With a key design objective to achieve a practical hermetically sealed system (i.e. eliminate all mechanical connections and joints except for essential service points) and minimise the refrigerant charge;
  - Noting that areas of opportunity to reduce refrigerant charge are in the use of a vertical liquid receiver, revised piping configurations with reduced piping sizes, and employing the next generation evaporator requiring less refrigerant volume to achieve the same or better snap times;
- The overall system design would also optimise the type and thickness of insulation, the sealing of the snap evaporator and/or partitioning systems for the freezer room, the use and load requirements of key components by employing variable speed drives and controls where possible (e.g. on compressors and

condenser pumps), refrigerant leak detection (equipment and inspection routine), vibration elimination and reduce energy consumption;

- The demonstration system would employ the most efficient components throughout including multiple high efficiency compressors (either reciprocating or screw). The emphasis should always be on selecting the most energy efficient, correctly sized components configured in an optimal layout.

Other considerations include:

- The project could be expanded to engage a mechanical designer to assist in developing the next generation snap evaporator for the industry (possibly with both shelf and hydraulic plate configuration options) with enhanced heat transfer characteristics, reduced refrigerant charge and improved snap times.
- Design features that may enhance the prospects for retrofit with a fourth generation refrigerant blend within the expected lifespan of the equipment.
- Final documentation could be expanded to include operator guidelines that can be used as a training aid and a preventative maintenance manual.

Overall this should represent a considerable cost saving to the fleet as a whole, and it should eliminate much of the design risk for individual vessels.

In the meantime many in the industry may need to buy time, to ensure continued operation while preparing to install new equipment. Existing HCFC-22 systems will have to be tightened up and inspected for leaks and likely points of leaks eliminated.

Whenever a vessel is refitted, any HCFC-22 refrigeration that can be reclaimed for reuse should be recovered and stored for sale to others in the fleet that may be retaining HCFC-22 systems for longer.

All NPF vessels should engage in active preventative maintenance of their refrigeration systems to give them the best chance of operating without major breakdowns, and avoid the potential for loss of charge until they can be replaced.

The Sydney Fish Market

The SFM have a number of constraints in its location that prohibit possibly the most technically attractive option of using an advanced ammonia/CO_2 cascade system. The additional risk and complexity, and the potential for local planning opposition to an ammonia charged system in such a busy public site, means that whilst this option is manageable it is probably less appealing than a HFC-134a/CO_2 cascade system.

As such the authors are recommending that the Board consider conducting a detailed feasibility study into the design and development of an advanced HFC-134a/CO_2 cascade system. Should the board choose to embark on additional engineering, the ammonia/CO_2 system would eliminate any future scrutiny from government regulators on HFC refrigerant usage.

Given the size of the HCFC-22 charge required to operate the existing SFM plant, and the age of the equipment, the option of simply extending the life of the existing plant for long enough that an effective and affordable low GWP fourth generation refrigerant becomes available, comes with ever increasing risk of both component failure, and rapidly escalating HCFC-22 gas prices.

References

ABARES 2012 — Australian Fisheries Statistics 2011 by the Australian Bureau of Agricultural and Resource Economics and Sciences, Dec 2012.

AMSA 2013 — Registrar of Ships, Ship Inspection and Registration Division, Ship Safety Division, Australian Maritime Safety Authority, 2013.

ANSI/ASHRAE 34 2010 — ANSI/ASHRAE 34-2010, Designation and Safety Classification of Refrigerant, which is published on the ASHRAE website.

AHRI 2013 — AHRI Low-GWP Alternative Refrigerants Evaluation Program, 2013

AIRAH 2013 — AIRAH Safety Guide for Flammable Refrigerants, 2013

AIRAH 2012 — AIRAH Best Practice Guideline: Methods of Calculating Total Equivalent Warming Impact (TEWI), 2012.

AIRAH 2011 — Code of Practice, Victoria – Ammonia prepared by an Ammonia Taskforce lead by AIRAH 2011.

Arkema 2013 — Arkema is announcing the construction of production capacity for new refrigerant fluorinated gas 1234yf, Arkema France press release, September 2013.

DCCEE 2012a — Quarterly Update of Australia's National Greenhouse Gas Inventory (NGGI), Figures for the June Quarter 2012, Department of Climate Change and Energy Efficiency.

DCCEE 2012b — Baseline Energy Consumption and Greenhouse Gas Emissions, In Commercial Buildings in Australia, Department of Climate Change and Energy Efficiency, November 2012. Available for public download in open word document formats from http://goo.gl/wr1qd.

DIT 2012 — Department of Infrastructure and Transport, Canberra, Bureau of Infrastructure, Transport and Regional Economics, Australian infrastructure statistics, Yearbook 2012.

DAFF 2012 — Department of Agriculture, Fisheries and Forestry, Australia's agriculture, fisheries and forestry at a glance', 'National Food Plan Green Paper, 2012.

DAFF 2007 — Department of Agriculture, Fisheries and Forestry, Foodmap: A comparative analysis of Australian food distribution channels, 2007.

DRET 2011 — Strengthening the foundations for Australia's energy future, Draft White Paper, Department of Resources, Energy and Tourism, 2011.

DSEWPaC 2013a — Cold Hard Facts 2, A study of the refrigeration and air conditioning industry in Australia, prepared by Expert Group for the Department of Sustainability, Environment, Water, Population and Communities, Ozone and Synthetic Gas Team, July 2013.

DSEWPaC 2013b — Clearing the Air, The options for a Rebate for Destruction of ODS and SGGs in Australia, by Thinkwell Australia in association with Expert Group for the Department of Sustainability, Environment, Water, Population and Communities, Jan 2013.

DSEWPaC 2012 — A review of existing uses of SGGs prepared by Expert Group for the Department of Sustainability, Environment, Water, Population and Communities, Ozone and Synthetic Gas Team, April 2012.

DSEWPaC 2011 — A study into HFC consumption in Australia, prepared by Expert Group for the Department of Sustainability, Environment, Water, Population and Communities, Ozone and Synthetic Gas Team, October 2011.

DSEWPaC 2010 — Refrigerant emissions in Australia: Sources, causes and remedies by Expert Group for the Department of Sustainability, Environment, Water, Population and Communities, Ozone and Synthetic Gas Team, 2010.

DuPont 2004 — Temperature Glide in DuPont Suva MP, DuPont Suva HP, and DuPont Suva 407C Series Refrigerant Blends, DuPont Fluoro chemicals 2004.

E3 2009a — Draft Non-Domestic Energy Efficiency Strategy: In from the Cold, prepared by Mark Ellis,

	Peter Brodribb, Tony Fairclough, Rod King and Kevin Finn for DEWHA, October 2009.
EG 2012	Independent review of transport refrigeration sector by Expert Group for Navman Wireless, 2012.
ES, 2007a	Assessment of the HCFC Bank and Forecasts of Future Demand for DEWHA Ozone & Synthetic Gas Team, prepared by Michael McCann and Peter Brodribb for Energy Strategies, September 2007.
ES, 2007b	Cold Hard Facts, prepared by Energy Strategies in association with Expert Group for DEWHA and Refrigerants Australia, 2007.
ES, 2008	ODS and SGGs in Australia; A study of End Uses, Emissions and Opportunities for Reclamation, prepared by Energy Strategies in association with Expert Group for the Department of Environment, Heritage, Water & the Arts, June 2008.
ICF 2010	Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-Gases) Banked In Products and Equipment, ICF International, May 2010.
NPF 2012	NPF Data Summary 2012, prepared by NPF Industry Pty Ltd on behalf of Australian Fisheries Management Authority, April 2013.
NGERS 2012	NGERS technical guidelines for the estimation of GG emissions by facilities in Australia, July 2012.
OPSGGMA	Ozone Protection and Synthetic Greenhouse Gas Management Act 1959, including amendments.
QGDME 2012	Hydrocarbon Appliance Register, Queensland Government, Department of Mines and Energy, 2012.
UNEP 2013a	May 2013 progress report of the Technology and Economic, Assessment Panel, Volume 2, Decision XXIV/7 Task Force Report, Additional Information on Alternatives to ODS Draft Report for the Thirty-third Meeting of the Open-ended Working Group).
UNEP 2013b	Issues for discussion by and information for the attention of the Open-ended Working Group of the Parties to the Montreal Protocol at its thirty-third meeting, United Nations Environment Programme, 17 May 2013.
UNEP 2010	Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2010 Assessment, United Nations Environment Programme, Technology and Economic Assessment Panel, 2010.
	May 2013 progress report of the Technology and Economic, Assessment Panel, Volume 2, Decision XXIV/7 Task Force Report, Additional Information on Alternatives to ODS Draft Report for the Thirty-third Meeting of the Open-ended Working Group).

Appendix A: Technical resources

This appendix summarises the main assumptions used in the study, and provides other technical resources used in calculations.

Table 7: GWP factors of main refrigerant gas species used in commercial refrigeration applications.

Common substances	AR2 GWP-100 Year	AR4 GWP-100 Year
Substances controlled by the Montreal Protocol		
CFC-12 (1)	8,100	10,900
HCFC-22	1,500	1,810
HCFC-406A	-	1,943
HCFC-408A	-	3,152
HCFC-409A	-	1,585
Hydrofluorocarbons (HFCs)		
HFC-134a	1,300	1,430
HFC-404A	3,260	3,922
HFC-407C	1,526	1,774
HFC-407F	1,824	2,107
HFC-428A	2,930	2,265
HFC-438A	1,890	3,667
HFC-507A	3,300	3,985
Low GWP alternatives (2)		
HC-600a	-	3
HC-290	-	3
CO_2 (R744)	-	1
Ammonia (R717)	-	0
HFO-1234yf	-	4
HFO-1234ze	-	6
HFO-HFC blend (XP10)	-	600
DR-7	-	≈ 250
DR-33	-	≈ 1,400

1. No longer in common use, banned in 1996. GWP values of blends such as HFC-507A and others are calculated based on the mass composition of substances listed in the IPCC assessment reports.
2. The GWP values of HFO substances are those cited by DuPont and Honeywell as based on AR4. These are new and were not reviewed, included or published in the IPCC, Fourth Assessment Report published in 2007. HC-600a and HC-290 are not published in the AR2 or AR4.

The ASHRAE refrigerant mass chemical compositions are used to calculate the GWP values of these blends from the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 (IPCC 1996). While these values have since been superseded by the Fourth Assessment Report (AR4) in 2007, all of the Australian legislation that refers to the GWP of HFCs use the values listed originally in AR2, based on Australia's obligation under the Kyoto Protocol.

Table 8: Fuel combustion - liquid fuels for transport energy purposes for post-2004 vehicles

Fuel type	Energy content factor (GJ/kL)	Emission factors (kg CO_2-e/GJ)
Diesel oil	38.6	69.2

(Source: NGERS 2012)

Table 9: Indirect (scope 2) emission factors from consumption of purchased electricity from a grid

Category code	Population by State	% by State	Emission factors (kg CO_2-e/kWh)
New South Wales	7,290.3	32%	0.88
Victoria	5,623.5	25%	1.19
Queensland	4,560.1	20%	0.86
South Australia	1,654.8	7%	0.65
Western Australia	2,430.3	11%	0.82
Tasmania	512.0	2%	0.26
Northern Territory	234.8	1%	0.71
Australian Capital Territory	374.7	2%	0.88
National	22,680.5	100%	0.914

1. The indirect emission factors are from NGERS technical guidelines for the estimation of Greenhouse Gas emissions by facilities in Australia, July 2012. The factors used in this report are the indirect (scope 2) emission factors from consumption of purchased electricity from a grid.
2. The State and Territory emission factors were used to calculate a national indirect emission factor weighted based on Australian population, excluding other territories not listed above (ABS 3101.0, 2012).

Appendix B: Budget cost estimates of main options

B1. NPF vessel

Table 10: NPF Option 1: New conventional refrigeration system operating on HFC-507A

Item	Option 1
Compressors (1)	$60,000
Condenser	$25,000
Brine/water chilling system	$15,000
Receiver	$15,000
Accumulator	$7,000
Accessories	$5,000
Pipework	$8,000
Controls	$6,000
Tx valves	$5,000
Snap evaporator (2)	$45,000
FDC	$9,000
10% contingency	$20,000
Labour ($)	$28,000
Refrigerant (no ECP levy R507A @ $40 per kg) (3)	$8,000
Total with no ECP levy	**$256,000**
Refrigerant (no ECP levy additional $90 per kg)	$18,000
Total with ECP levy	**$274,000**

1. Compressor rack constructed in China potentially 50% less expensive.
2. Price depends on the type of snap freezer, more expensive for double plate snap.
3. Refrigerant cost based on an average reduced charge of 200 kg.

B2. Sydney fish market

Table 11: SFM budget cost estimates of main options

Item	Option 1
Replace 53 evaporators incl. labour	$600,000
Mains piping replacements, expansion valves, oil change, seal changes, etc.	$600,000
Refrigerant charge (excl. on HCFC-22)	$450,000
Total	**$1,650,000**

Item	Option 2	Option 3
Plant	$715,000	$865,000
Evaporators	$380,000	$380,000
Pipework & warm Glycol defrost	$185,000	$185,000
Warm glycol circulation to replace door heater	$180,000	$180,000
Labour	$600,000	$600,000
Electrical and controls	$720,000	$740,000
Ammonia safety systems	$ -	$30,000
Refrigerant	$170,000	$130,000
Contractors costs, contingency and warranty, etc.	$434,500	$434,500
Total	**$3,384,500**	**$3,544,500**

Note: Cost estimates are based on clear site and are accurate to plus 15%. A detailed estimation is required to cost preferred options taking site constraints and managing tenants into consideration.

Appendix C: Process diagrams of refrigeration systems

C1: Typical vapour compression refrigeration system

Figure 10 depicts a typical, single-stage vapour-compression commercial refrigeration system. All such systems have four main components:

1. Compressor;
2. Condenser, typically air cooled with fan(s) and motor(s) or can be water cooled. The NPF vessels and the SFM have water cooled condensers;
3. Thermostatic expansion valve abbreviated by industry to TX valve (also called a throttle valve), and an
4. Evaporator with fan(s) and motor(s). The evaporators found on NPF vessels are snap plates with evaporator fan(s) and FDCs (Forced Draught Coolers) in the freezer rooms.

Other common components found on typical commercial refrigeration systems include:

5. Dual (high and low) pressure controls (screw, flare or solder connections) with copper capillary, nylon flexible, steel breaded or ¼" copper lines;
6. Service valves typically brass 'packed capped' valves with packing glands and brass or plastic valve caps and service access ports available in flare or solder connections;
7. Service access points typically Schrader valve connections;
8. Liquid receiver typically with screwed and solder connections;
9. Filter drier;
10. Solenoid valve, and
11. Sight glass.

Each of these components and their connections has potential to cause refrigerant leaks. The level of risk of them causing leaks depends on the size and complexity of the refrigeration system, types of connections used and service points, operating conditions (i.e. pressures, ambient temperatures, vibration), equipment design and vintage, quality of maintenance, and many other factors. TX valves, filter driers, solenoid valves and sight glasses are installed with either flare or solder connections.

Typical vapour compression refrigeration system

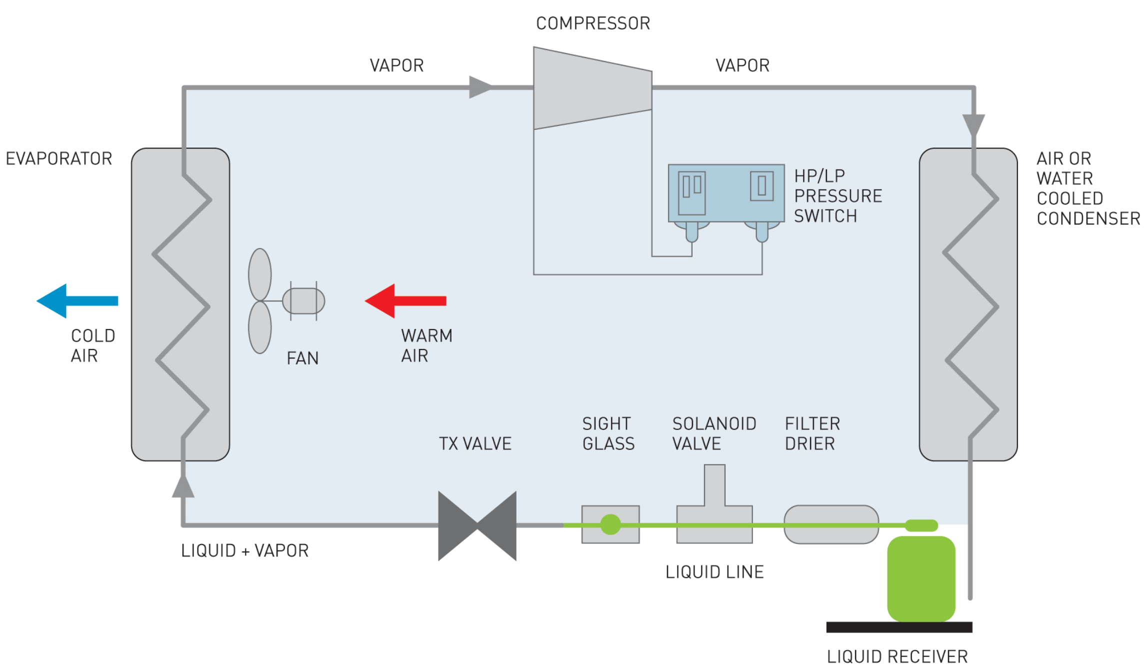
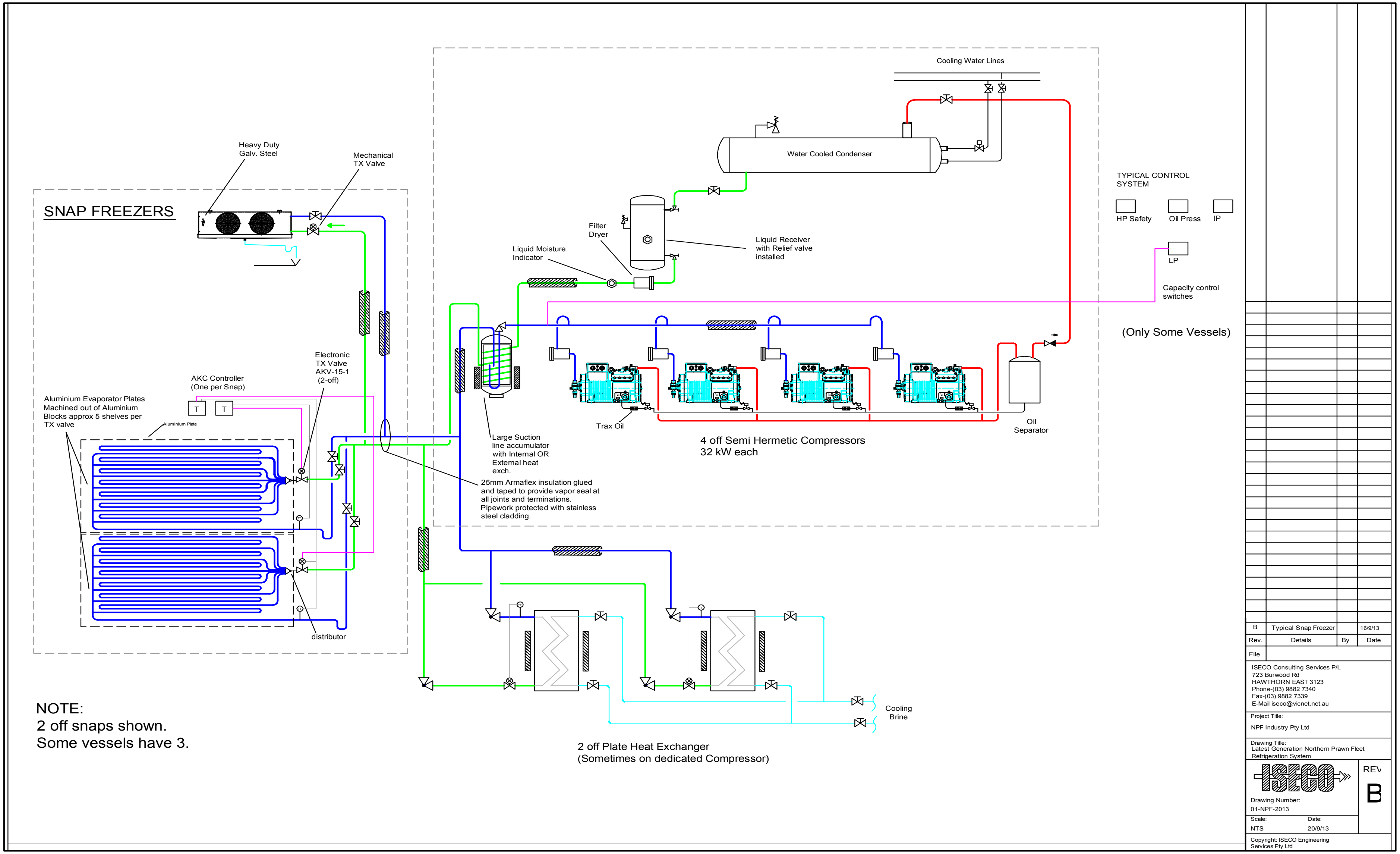
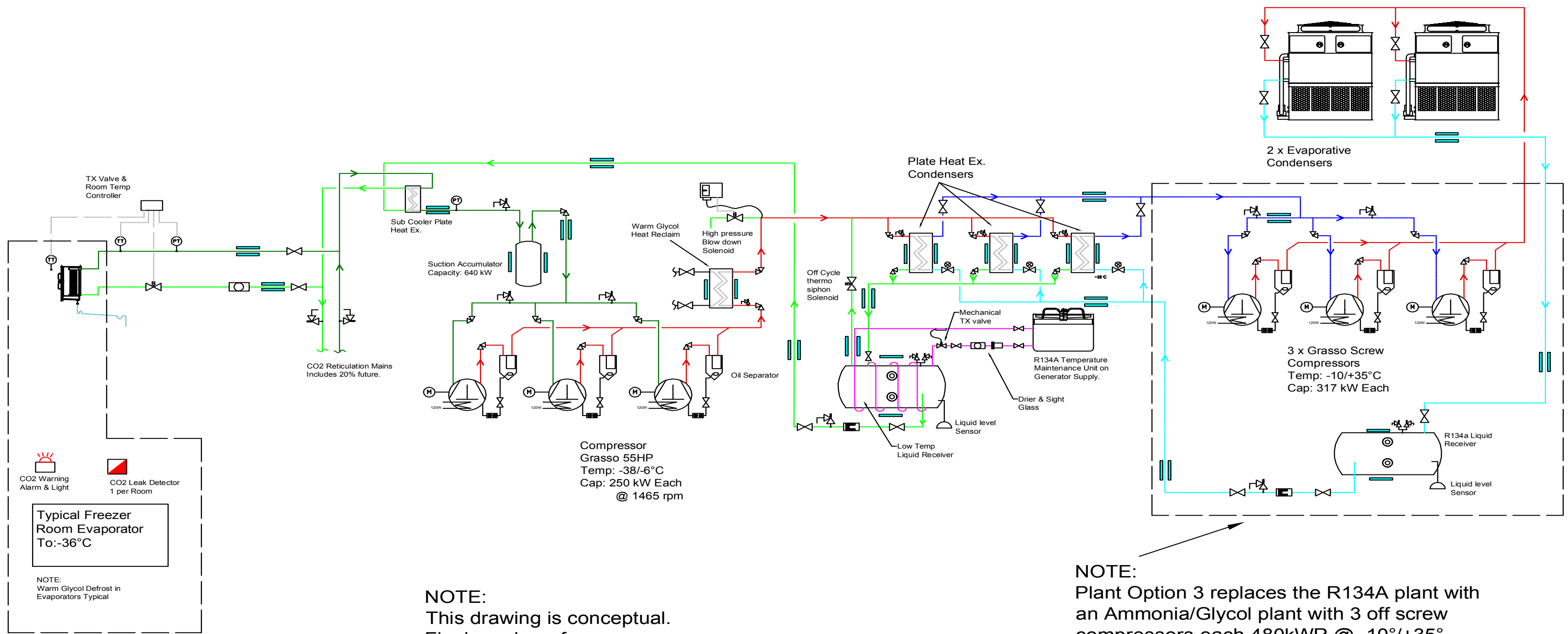


Figure 10: Typical, single-stage vapor-compression commercial refrigeration system.

C2: Latest Generation Northern Prawn Fleet refrigeration system



C3: Sydney Fish Market Cascade refrigeration system



NOTE:
This drawing is conceptual.
Final number of compressors to be confirmed.

NOTE:
Plant Option 3 replaces the R134A plant with an Ammonia/Glycol plant with 3 off screw compressors each 480kWR @ -10°/+35°.
Estimated Ammonia Charge 250-300 kg.

Piping Insulation Schedule

Nom. Dia.	Layers	−46°C	−16°C
15mm	Single	19mm	9mm
20mm	Single	19mm	9mm
25mm	Single	19mm	13mm
32mm	Single	19mm	13mm
40mm	Single	19mm	13mm
50mm	Single	19mm	13mm
65mm	Single	19mm	13mm
80mm	Single	25mm	13mm
100mm	Single	25mm	13mm
125mm	Single	25mm	13mm
150mm	Single	25mm	13mm
200mm	Single	25mm	13mm
250mm	Single	25mm	13mm
300mm	Double		
P/Vees	Double		

LEGEND: Refrigeration Valves & Controls.
ISECO Consulting Services Pty Ltd

- Straight Stop Valve
- Solenoid Valve
- Single releif valve
- Dual relief Valve
- Electronic TX Valve
- Insulation
- Sight Glass
- Liquid Line Filter
- Pressure Transmitter
- Temperature Transmitter
- Angle Valve Suction Line
- Sight Glass
- Trax Oil
- Drier

Equipment
Discharge Hot Gas
Return R134A (Suction)
Supply R134A (Liquid)
Supply CO2 (Liquid)
Return CO2 (Suction)
Text & Dimensions

Rev.	Details	By	Date
A	For Information		17/9/13

File M

ISECO Engineering Services P/L
723 Burwood Rd
HAWTHORN EAST 3123
Phone–(03) 9882 7340
Fax–(03) 9882 7339
E–Mail iseco@vicnet.net.au

Project Title:
Sydney Fish Market

Drawing Title: Sydney Fish Market CO2 Cascade plant–Option 2

REV. A

Drawing Number:
SydF–R–1122–01

Scale: NTS
Date: 17/9/13

CO2 SYSTEM PIPING
Installation to comply to EN 378.
A piping design must be carried out in accordance with EN 378 Pressure Piping

Appendix D: Energy audit of typical vessel

Location	Type of device	Description (i.e. type/model)	Qty	Power input (Watts)	Usage	Stand-by (Watts)	Duty/ Run time (%)	Hours	Consumption (kWh/day)		Peak (kW)
									Each	Sub-total	
Refrigeration											
Plant room	Main refrigeration plant	Bitzer: S6F-30.2: R22	4	16,000	22 hrs per day	100	95%	22	336.8	1,347.2	64.0
Plant room	Main refrigeration plant	Condenser pump	1	6,000	22 hrs per day	-	95%	22	125.4	125.4	6.0
Hull	Snap room	Evaporator fans	4	155	22 hrs per day	-	100%	22	3.4	13.6	0.6
Hull	Freezer room	Forced Draught Cooler (FDC) fans	2	250	14 hrs per day	-	100%	14	3.5	7.0	0.5
Hull	Main refrigeration plant	Solenoid and electronic TX values	8	10	22 hrs per day	-	50%	22	0.1	0.9	0.1
Galley	Medium temp cool room	Condensing unit	1	1,100	24 hrs per day	-	50%	24	13.2	13.2	1.1
Galley	Chest Freezer	Fisher & Paykel Freezer H220X	1	-	24 hrs per day	-	-	24	1.0	1.0	-
Sub-total: refrigeration										**1,508.3**	**72.3**
HVAC											
Living/helm	Heating and air conditioning	-	1	6,400	22 hrs per day	20	60%	22	85.0	85.0	6.4
Plant room	Ventilation fan: Engine room	-	2	1,125	24 hrs per day	-	100%	24	27.0	54.0	2.3
Sub-total: HVAC										**139.0**	**8.7**
Lighting											
-	General lighting	Tube: Fluorescent T8 600: 24W	24	28	18 hrs per day	-	-	18	0.5	12.1	0.7
Hull	Freezer	LED: 10W	4	10	4 hrs per day	-	-	4	0.0	0.2	0.0
Deck	Flood lights	Metal Halide: 500W	4	500	18 hrs per day	-	-	18	9.0	36.0	2.0
External	Navigation lighting	Bayonet: Incandescent: 25W	5	25	12 hrs per day	-	-	12	0.3	1.5	0.1
Sub-total: lighting										**49.8**	**2.8**

Location	Type of device	Description (i.e. type/model)	Qty	Power input (Watts)	Usage	Stand-by (Watts)	Duty/ Run time (%)	Hours	Consumption (kWh/day)		Peak (kW)
									Each	Sub-total	
Services											
-	Deck wash pump	-	1	5,000	6 hrs per day	-	-	6	30.0	30.0	5.0
-	Bilge pump	-	1	3,000	15 mins per day	-	-	0.25	0.8	0.8	3.0
-	Fuel transfer pump	-	1	3,000	15 mins per day	-	-	0.25	0.8	0.8	3.0
-	Conveyor	-	1	750	16 hrs per day	-	-	16	12.0	12.0	0.8
-	Water reticulation pump	-	1	750	3 hrs per day	-	-	3	2.3	2.3	0.8
-	Hydraulic power pack	-	1	15,000	1 hrs per day	-	-	1	15.0	15.0	15.0
-	Electric hot water system	-	1	-	24 hrs per day	-	-	24	115.3	115.3	-
Sub-total: services										**176.0**	**27.5**
Plug loads, cooking and miscellaneous											
-	Instruments/screens/controls	-	1	1,000	24 hrs per day	-	20%	24	4.8	4.8	1.0
Galley	Electric cook top	-	1	3,600	3 hrs per day	-	-	3	0.0	0.0	3.6
Galley	Electric oven	-	1	4,500	1 hrs per day	-	-	1	0.0	0.0	4.5
Galley	Range hood	-	1	75	2 hrs per day	-	-	2	0.0	0.0	0.1
Galley	Microwave	-	1	1,200	2 hrs per day	5	100%	2	2.5	2.5	1.2
Galley	Cooking appliances	Toaster/Kettle/Sandwich maker/Knife	1	2,500	2 hrs per day	-	-	2	0.0	0.0	2.5
-	Washing machine	-	1	-	3 hrs per day	-	-	3	25.0	25.0	-
-	Cloths dryer	-	2	750	4 hrs per day	-	-	4	0.0	0.0	1.5
-	Plug loads and miscellaneous	-	1	-	-	-	-	0	-	100.0	-
Sub-total: plug loads and misc.										**132.3**	**14.4**
Grand totals								**Daily**		**2,005.3**	
								Hourly (kW)		**83.6**	**138.2**
								Hourly (HP)		**111.9**	**185.0**