FOOD COLD CHAIN OPTIMISATION:

Improving energy productivity using real time food condition monitoring through the chain

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AUTHORSHIP OF THIS REPORT

This report is published by the Australian Alliance for Energy Productivity (A2EP). A2EP is an independent, not-for profit coalition of business, government and environmental leaders promoting a more energy productive and less carbon intensive economy.

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Note: Acknowledgement of this support does not indicate stakeholders' endorsement of the views expressed in this report.

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Executive Summary

The Australian Alliance for Energy Productivity (A2EP) has prepared this report for the NSW Office of Environment and Heritage. This is an initial feasibility study into improving temperature monitoring in the food cold chain to improve energy productivity (EP) by enhancing value adding through improved food quality and reduced waste and reducing energy use.

The project team consulted extensively with cold chain stakeholders and conducted research to:

- Understand global/Australian research and best practices in cold chain optimisation.
- Ascertain food cold chain temperature monitoring practices and issues in Australia.
- Identify and evaluate opportunities to improve cold chain temperature monitoring and control to improve EP.
- Identify barriers associated with the deployment of these solutions.

The key findings of this project are:

1. The Nature of the Problem/Opportunity

- There is limited food condition monitoring in the Australian food cold chain, and what is in place is largely limited to stationary locations, particularly cold stores.
- Temperature is the most significant factor affecting the shelf life of perishable foods, though for some foods humidity is also important. Storing perishable foods consistently within recommended temperature ranges is critical for food safety.
- Increased deployment of real time temperature monitoring at the most granular level that is economical - pallet, crate, carton, or product - presents a significant opportunity to improve food shelf life, quality and revenue, and reduce food waste, waste disposal costs and associated emissions.
- Real time condition monitoring of food from farm through to retailers is expected to become an industry standard within five years, facilitated by technology development and competitive pressure around consumer quality expectations.
- The technology already exists to monitor the temperature of food products throughout the value chain. The falling cost of internet of things (IOT) technology is now on the cusp of justifying real time tracking down to pallet level for all perishable food products, and is already used for high value, highly temperature sensitive products. The main constraint on ubiquitous low cost monitoring in Australia is the extent of low power wide area networks (LPWAN), but this should be resolved within 1-2 years.

- At this stage the cost of monitoring equipment currently is still sufficiently significant (e.g. $20-$30+/unit) to require recovery of the sensor/transmitters.
- The cost of real time condition monitoring and reporting is falling rapidly. Ultimately the size and cost of monitoring hardware will fall sufficiently to allow tracking of temperature and other variables of all perishable products using disposable sensors, which would allow real time monitoring from paddock to use. Disposable food provenance tags are already commercially available.
- Greater deployment of sensors, complemented by other analysis, for example, thermal imaging and refrigeration leak detection, would enhance understanding of deficiencies in present practices and systems.

2. Managing Temperature Variability

- Perishable products are generally at greatest risk of experiencing temperature variability on the farm, when they are in transit, and during transfers. The long distances perishable goods travel in Australia and the number of times perishable goods are handled from the producer to the consumer creates unique challenges.
- Poor temperature control in trucks provides an opportunity for savings. Truck thermal performance is not routinely tested, and pilot trials by the CSIRO and equipment supply companies indicated that large (of the order of 6°C) temperature variations are common within trailers due to poor air circulation and/or radiant heat via the floor or poorly insulated areas. Also, when the temperature of goods loaded is too high, truck refrigeration systems may take hours to pull the temperature down to the target range. Refrigerant leakage can also lead to deterioration in temperature control.
- There is poor visibility of product temperatures along the cold chain, which presents difficulties in ensuring food safety compliance and assigning responsibility between the large number of players along the chain for loss/degradation of product quality. This lack of transparency also inhibits effective targeting of improvements to equipment and practices. There is a challenge to educate all parties handling perishable goods on decreased shelf life resulting from temperature abuse.
- The large number of participants involved in the cold chain creates split incentives, where the party that is best able to act may not capture the financial benefits, or face the cost impact of their actions. Improved tracking and a better understanding of the downstream implications of actions will provide greater opportunity to address cold chain problems.

3. Opportunities for improving energy productivity

The types of energy productivity benefits from better condition monitoring expected by stakeholders are listed below.

Value gains associated with:

- **Increased value of product**, increased shelf life, reduced product loss/reduced discounting due to improved quality. This is a large dollar benefit and is the major justification for the food suppliers and retailers engaging in this activity.

  Note: While it is recognised that the greatest source of waste in the food chain is food wasted in the home and food service, it is currently only economical to implement real time monitoring from farm to retailer. Greater temperature control throughout the cold chain, enabled by temperature monitoring, will reduce the build-up of spoilage organisms and reactions occurring throughout the chain, likely extending shelf life and reducing waste at the consumer end, but is only a partial solution to the issue of consumer food waste.

- **Indirect cost and logistics benefits** from avoiding transporting, processing and handling product that cannot be sold, and improved scheduling of maintenance activity.
- **Reputational benefits** from more consistent, good quality food with longer shelf life at home and improved environmental outcomes.
- **Reduced carbon emissions** from reduced energy use, reduced refrigerant leakage and also reduced emissions relating to food waste.

Energy savings associated with:

- **Reduced food waste:** There is a significant opportunity to reduce food waste through optimising conditions in the cold chain, and there are substantial energy losses and greenhouse gas emissions associated with food waste. Energy saving benefits of reducing food waste include avoiding cooling food which is ultimately wasted, and the energy involved in manufacturing the fertiliser and direct energy consumed in growing the food, transporting, processing, storage, and disposal.
- **Reduced operational energy waste**: This includes cooling energy wasted from truck doors left open, excessive transfer times, and delays in unloading. There is ample evidence from confidential pilot testing that these are common occurrences, though it is difficult to estimate the extent of energy loss.
- **Justify action to rectify poorly operating equipment**: Identifying (and then correcting/replacing) poorly designed equipment and poor maintenance and work practices causing high temperature variability within spaces/trucks and heat gain due to poor insulation and seals, particularly in trucks.
- **Justify investments to control temperatures more precisely** using inverter-driven refrigeration equipment, variable speed fans and controls.
- **Justify improvements in energy performance of cold stores** by reducing heat infiltration into refrigerated storage areas. Examples of cold store energy performance improvements include: more effective thermal insulation on walls, ceilings and floors; better airflow; providing airlocks to personal and forklift access

doors; loading docks with tight seals around truck doors; installing refrigerated loading docks as a break between ambient and chamber temperatures; high speed chamber doors; and, pallet conveyors to reduce use of forklift access doors.

- **Potentially reducing overcooling** of frozen products.

Quantification of the overall energy productivity benefits

We have only been able to provide order of magnitude estimates of benefits due to: the limited data available on refrigeration energy use in stationary uses (electricity) and trucks (diesel); the complexity of the cold chain; the difficulty of attributing value benefits to condition monitoring without good pilot field data; and, the fact that existing pilot data is kept closely confidential by the participants.

Attribution of savings to the condition monitoring system is difficult as there are many factors influencing food quality. While the general opinion of stakeholders in this project was that real-time condition monitoring would have a very significant impact on food quality, we also received feedback on the range of other factors influencing food quality, particularly at the farm. However, we consider these factors do not negate the benefits of temperature monitoring identified in this report, and temperature monitoring may help to quantify the significance of on-farm and home food handling and help justify remedial action.

The following indicative cost savings reflect the impact of relatively small percentage savings as a result of improving food condition monitoring in the cold chain:

- A 5% reduction in food waste would result in a $1 billion annual saving.
- A 5% reduction in energy use of stationary elements of the cold chain would result in energy cost savings of approximately $120 million per year.
- A 10% reduction in energy use of trucking refrigeration would result in energy cost savings of approximately $15 million per year.

Potential energy productivity improvements far larger than these indicative levels of savings have been identified in this project.

4. Implementation issues/Barriers

There are very significant challenges involved in gaining the full benefits from implementing these monitoring and reporting systems. While the technology barriers of real time condition monitoring are seen as being economically surmountable, a much bigger challenge is implementing changes to resolve the causes of temperature variability uncovered by this monitoring. This ranges from deciding how to use the information, for example, defining what is an acceptable deviation of time and temperature, through to how to resolve poor operating procedures and equipment deficiencies uncovered, as well as addressing the split incentives between participants in the cold chain. The fact that much of the plant and equipment involved has an economic life of 15 years+ may limit the rate of implementation of identified necessary capital investments in replacement equipment. On the other hand, large increases in energy costs, combined with the continued decline in the cost of energy efficiency and renewable energy increases the incentive for action.

Some of the specific barriers include:

- The poor level of information and knowledge in the industry about opportunities from better condition control, and technology available to make this possible.
- Fragmentation of the industry and the large number of players in the food cold chain makes it difficult to allocate costs and responsibilities for action, and to target and fund improvements optimally. Note that it is this very problem that makes these IOT solutions so powerful, as all players will have visibility of condition information near to real time on cloud computing applications.
- Cost may be a barrier to the uptake of advanced temperature monitoring systems, particularly for small and medium players. Many participants in the food industry are SMEs, often operating on lean margins, and with limited analytical and R&D capabilities. However, trials would identify downstream benefits, so the incentive for sharing of implementation costs would become clearer.
- To realise the benefits of real time temperature monitoring, it will be critical to establish automated response systems and standard operating procedures throughout the industry, with trained and motivated staff to respond in a timely manner to significant temperature excursions. This will require training and culture change. The large number of small family businesses working long hours and on very small budgets makes this an even greater challenge.
- Implementing these systems will identify the need for repairs, maintenance and upgrading to refrigerated transport and warehousing and the challenge arises of getting this work done effectively, and ensuring the key investments are made to replace equipment where required. In an industry with a multiplicity of small independent operators, encouraging/enforcing these changes will be very challenging. But at least it will be possible to identify who benefits and who pays.
- The Government's regulated phase-out of HFCs and HCFCs provides a once-off opportunity to integrate costs of refrigerant changeover with upgrading efficiency of refrigeration equipment and adjusting capacity sizing to reflect lower cooling loads. It is estimated that 90,000 commercial refrigeration units reach the end of their useful life each year[1] and this may increase significantly with the phase out. Governments should implement information and investment incentive programs to encourage selection of energy efficient/productive plant.

[1] Brodribb, P & McCann, M. (2013) *Cold hard facts 2: a study of the refrigeration and air conditioning industry in Australia*. Canberra: Australian Government

5. Recommended Actions

- Conduct pilot trials and economic feasibility analysis to prove up the claims made by technology providers around the cost, effectiveness, and likely impact of implementing condition monitoring systems, and further define the full implementation costs (including problem rectification systems) and benefits, and to whom they accrue.
- Firm up data on energy use in refrigeration, the causes of food waste, and potential savings that can be attributed to condition monitoring to overcome some of the serious data shortfalls that make it difficult to provide a more accurate industry wide business case.
- Support the Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH) to establish a Cooling Knowledge Hub, providing there is demonstrated support from academic institutions, support from commercial stakeholders, and ongoing funding based on results.
- Support governments implement information and investment incentive programs to encourage selection of energy efficient/productive refrigeration plant, particularly compressors due for replacement.
- Examine how the refrigerated trucking industry can be provided with compelling incentives to lift the thermal performance of their vehicles.
- Further examine the potential for smart packaging to reduce the requirement for refrigeration of perishable food.

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1 Purpose and context of this report

This report was prepared by the Australian Alliance for Energy Productivity (A2EP). A2EP is an independent, not-for profit coalition promoting a more energy productive economy.

This report examines the feasibility of real time food condition monitoring in the Australian food cold chain to improve energy productivity (EP) by reducing energy use (for refrigeration) and enhancing food quality. The cold chain "refers to the management of the temperature of perishable products in order to maintain quality and safety from the point of slaughter or harvest through the distribution chain to the final consumer"[2]. This report investigates the use of food condition monitoring in the cold chain up to the point of sale to the consumer: residential refrigeration is outside the scope of this report.

What is energy productivity?

Energy productivity (EP) refers to the value created from using a unit of energy. National energy productivity is calculated by dividing gross domestic product by primary energy deployed. To improve EP, we can increase economic value added by using energy more effectively, or use less energy – in short, do more with less energy.

In many cases, much of the economic benefit comes from indirect effects of using energy more effectively, such as improved product quality, OH&S or reduced equipment maintenance. In the past, these 'multiple benefits' have not been factored into evaluation of the business case for energy productivity improvement.

Refrigeration is essential to maintaining food quality, maximising shelf life and minimising health risks and spoilage within the food cold chain. The report *Cold Hard Facts 2* estimates there are more than one million refrigeration installations and pieces of equipment in the Australian food cold chain[3]. Refrigeration is an energy intensive activity and so is consequently a major contributor to energy consumption in the food value chain. It is estimated approximately 178 PJ of energy are used for refrigeration in the Australian cold chain, costing around $2.6 billion each year[4]. So, even small efficiency gains would mean substantial energy and cost savings through measuring and controlling temperature better.

Retail sales of food in Australia exceed $140 billion per year[5]. *Cold Hard Facts 2* (CHF2) estimates that this includes 20 million tonnes per year of perishable agricultural food product. A 2002 ABS survey[6] found that 27.2 million tonnes of refrigerated food were transported in Australia, involving 10.7 billion kilometres of travel. For analysis in this report, the ABS values have been updated by

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[2] Global Cold Chain Alliance. (2017). *The Cold Chain*. Retrieved February 23, 2017, from http://www.gcca.org/about-us/the-cold-chain/

[3] Brodribb, P & McCann, M. (2013) *Cold hard facts 2: a study of the refrigeration and air conditioning industry in Australia*. Canberra: Australian Government

[4] Energy use calculations for stationary elements of the cold chain based on 2012 data from *Cold hard facts 2*, uplifted by 10% to reflect notional estimated 2% pa growth over 5 years from CHF2 2012 data. Note stationary cold chain refrigeration does not include residential refrigeration. The transport estimates were made by the authors, based on ABS data (updated by 35% from 2001) and industry data (testing conducted at SuperTest in Brisbane). Energy cost estimates based on diesel price of $1.30/litre and electricity price of $150/MWh.

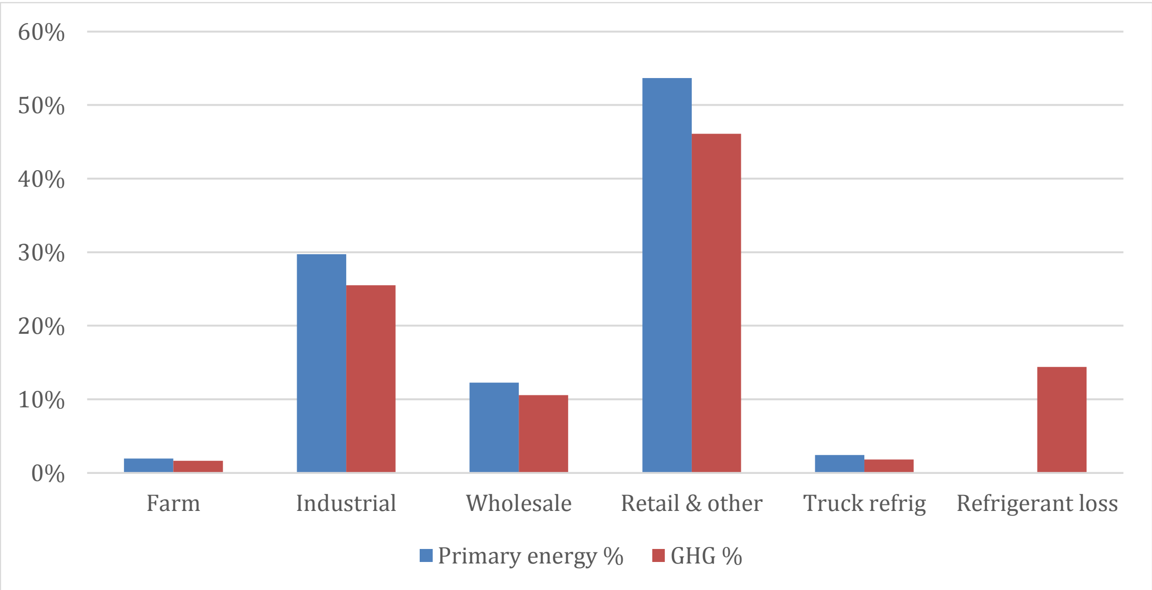
[5] Department of Agriculture. (2014) *Australian Food Statistics 2012-13*. Canberra: Australian Government.

[6] Australian Bureau of Statistics (2002) *Freight Movements: Australian summary – Re-issue Cat no 9920.0* Table 14 p.29

35% based on an assumed 2% per annum increase in transport of refrigerated food. This gives a significantly higher estimate than the CHF2 report, calculated to be 36.6 million tonnes of refrigerated food transported in the current year. Given that the ABS report specifically refers to 'refrigerated food', while CHF2 refers to 'perishable food' and does not seem to include processed products, we have used the ABS value, adjusted as noted.

Figure 1 below, shows the percentage breakdown of approximately 178 petajoules of total annual primary energy use related to refrigeration (excluding exports) between sectors in the Australian cold chain. Figure 1 also shows the sector breakdown of the climate impact of approximately 18 MT of carbon dioxide equivalent related to refrigeration in the cold chain. Around 14% of total cold chain greenhouse gas emissions, or 2.5 Mt CO2e [7], relate to emissions from refrigerant loss. This value is significantly lower than that published in the National Greenhouse Gas Inventory, but is based on a bottom-up industry analysis. Clearly, as in many areas in the energy and environmental sector, data collection and analysis is in serious need of better resourcing and improvement. It is very difficult to develop good policy without high quality, detailed end-use data.

Figure 1 – Cold chain refrigeration: breakdown of 178 PJ primary energy use and 18 Mt CO2e greenhouse gas emissions



Approximately 29,000 refrigerated vehicles transport perishable food in Australia[8]. While it can be seen from the figure above energy used for truck refrigeration accounts for a relatively small share of total refrigeration energy use, refrigerated transport is a critical element in the cold chain. This is because perishable goods are at significantly higher risk of exposure to unfavourable temperature variances when in transit and during transfers.

[7] Emissions from refrigerant loss in 2012 were estimated in *Cold Hard Facts 2* to be 1.7 Mt. This figure has been increased by 4%p.a., in line with economic growth, plus 0.5 Mt of end of life emissions, resulting in an updated figure of 2.5 Mt.
[8] Brodribb, P & McCann, M. (2013) *Cold hard facts 2: a study of the refrigeration and air conditioning industry in Australia*. Canberra: Australian Government

Given the significant energy usage related to and value of food in the cold chain, any measure that can enhance the value of perishable food, and reduce food waste can have a very substantial impact on energy productivity. An estimated 9 million tonnes of food is wasted each year in Australia, costing the economy $20 billion annually[9].

It is becoming feasible to improve the energy productivity of the food cold chain through internet of things (IOT) technologies of lower cost sensors, transmitters and communications, together with cloud computing to provide visibility of the data along the whole chain.

Solutions to optimize cold chain temperature monitoring have been evaluated by the project team while being fully cognizant of stakeholders' sensitivity to increased exposure to risk, particularly in relation to food safety. The solutions documented in this report should allow participants in the cold chain to better track and respond to potential risks. For example, sensor technologies that provide continuous temperature monitoring of products and diagnostic capabilities may provide real time alerts when deviation of temperature is experienced. To realize the full benefit of this tracking technology, the challenge will be to develop and build the systems and capacity to correct problems (both immediate responses and repairs/replacement of equipment identified as being necessary from the monitoring) in a timely manner.

The emergence of these technologies coincides with a window of opportunity to replace inefficient refrigeration plant, driven by the agreement to phase out HFC refrigerants in Australia[10]. It is critical that government and industry use this window to drive replacement of poorly performing and end of economic life refrigeration plant with more efficient modern units.

[9] Department of Environment and Energy. (2017, 11 April) Media release: *Roundtable on food waste marks the beginning of halving Australia's food waste by 2030*. Retrieved from http://www.environment.gov.au/minister/frydenberg/media-releases/mr20170411.html

[10] http://www.environment.gov.au/protection/ozone/legislation/opsggm-review/hfc-phase-down-faqs

2 Process for developing the report and scope of work

This report was prepared using the following approach. The project team:

1. Identified cold chain stakeholders and consulted with them to:
   - Review international research and best practices in cold chain optimisation.
   - Ascertain food cold chain temperature monitoring practices and issues in Australia.
   - Identify and evaluate opportunities to improve cold chain temperature monitoring and control, particularly by deploying ICT technologies, to improve EP.
   - Identify barriers associated with the deployment of these solutions.
   - Raised awareness of the project, for example, by presenting at the AIRAH refrigeration conference in March 2017 and the 2xEP Summit in April 2017.

2. Identified temperature sensitive perishable products that would benefit significantly from improved temperature monitoring and control in the cold chain, and we documented the optimal storage temperature ranges and the impact of temperature variation on the shelf life of a variety of these products.

3. Defined key elements required to monitor, report and optimize food temperatures through the cold chain. Reviewed the technical feasibility of real time monitoring, and did a first cut estimate of the economic feasibility of implementing the most promising measures.

4. Conducted review of barriers.

5. Prepared a draft report and distributed it to stakeholders for their input. The project team received over 20 well-considered sets of comments prior to a workshop.

6. Conducted a stakeholder workshop to review project outcomes, which was attended by over 20 people with others sending apologies that they could not attend (and many of these sent written comments in advance).

7. Designed a feasibility study and pilot to test the conclusions reached, and approached a retailer to partner in an application to Food Innovation Australian Limited (FIAL) for funding for a detailed feasibility project and pilot trials. This project was approved and will start in June.

8. Finalised this report for OEH, to be made available on-line on the 2xEP website.

Scope of work

- This project focuses on food condition monitoring in the cold chain from farm through to retail shelves. While we do not underestimate the crucial importance to energy productivity in the food chain of on-farm and consumer transport of food and storage, or meal preparation, they are not part of this scope.
- The focus of this project is on the domestic supply chain. While the export chain has similar challenges, the technical communications solutions examined in this report are limited in applicability for exports and there is currently greater deployment of condition monitoring in export shipping than in the domestic food cold chain.
- Cold chains for non-food products such as flowers and vaccines are outside the scope of this project. However, some observations regarding practices in the pharmaceutical cold chain that could be replicated in the food cold chain have been made in this report.

3 Importance of temperature control of perishable food

Temperature is one of the most significant variables affecting the shelf life and quality of perishable foods. Other factors can have an impact on shelf life of some fruits and vegetables, for example, humidity and carbon dioxide levels. Shelf life and quality decline if food is stored and transported at temperatures higher than the recommended temperature range for that product, or varies significantly for some of the time. Some perishable products, such as some fruit and vegetables, are susceptible to chilling injury if kept at temperatures lower than the recommended range for the product.

Standards and guidelines

Storing perishable foods within their recommended temperature ranges is also extremely important for ensuring food safety. Clause 1 (a) of Standard 3.2.2 of the Australian New Zealand Food Standards Code applies to perishable food in the cold chain, stating that food must be kept at a temperature of 5°C or below "if this is necessary to minimise the growth of infectious or toxigenic microorganisms in the food so that the microbiological safety of the food will not be adversely affected for the time the food is at that temperature". The standard does not specify a temperature range for frozen goods but does require frozen goods to remain hard frozen throughout the cold chain [11].

The Australian Food and Grocery Council publishes the Australian Cold Chain Guidelines [12], which provide guidance to cold chain participants on the safe storage and handling of food in the cold chain. The "never warmer than" rule in the Guidelines stipulates that:

> "While the manufacturer can set any NEVER WARMER THAN and KEEP ABOVE temperatures that they consider necessary for the safety and quality of their product, these Guidelines strongly recommend that two temperature be used as far as is possible:
>
> - CHILLED FOODS must be transported, stored and handled at temperatures **NEVER WARMER THAN +5°C**; and
> - FROZEN FOODS (including ice creams) must be transported, stored and handled at temperatures **NEVER WARMER THAN -18°C**."

The Australian Cold Chain Guidelines also contain a "maximum out of refrigeration time limit" rule relevant for periods when chilled and frozen goods are being transferred between controlled temperature environments, for example while being loaded or unloaded onto docks. The "maximum out of refrigeration time limit" rule in the Guidelines stipulates:

> "While the actual time limit is set by manufacturers or producers, these Guidelines recommend some time periods as being appropriate
>
> For Chilled Foods

[11] Australian Government. (2014). *Australia New Zealand Food Standards Code*. Retrieved from https://www.legislation.gov.au/Details/F2014C01204/Download.

[12] Australian Food and Grocery Council. (2017) *Australian cold chain guidelines for food 2017*. Canberra, Australia: Author

- Where CHILLED FOODS are being un-loaded or dispatched in either **ambient** (room temperature) or in **+5°C to +15°C air conditioned ante-room** conditions, the **MAXIMUM "OUT OF REFRIGERATION" TIME LIMIT** is **20 minutes**.
- Chilled foods unloaded or dispatched in **+0°C to +5°C refrigerated ante-rooms** are usually still meeting their **NEVER WARMER THAN** Cold Chain condition and so no time limit is necessary.

For Frozen Foods

- Where FROZEN FOODS are being un-loaded or dispatched in **ambient** (room temperature) conditions, the **MAXIMUM "OUT OF REFRIGERATION" TIME LIMIT** is **20 minutes**.
- Where FROZEN FOODS other than ice cream are being un-loaded or dispatched in **+5°C to +15°C air conditioned ante-room** (air conditioned temperature zone) conditions, **MAXIMUM "OUT OF REFRIGERATION" TIME LIMIT** is **60 minutes**.
- Where FROZEN FOODS other than ice cream are being un-loaded or dispatched in **+0°C to +5°C refrigerated ante-room** (chilled temperature zone) conditions, the **MAXIMUM "OUT OF REFRIGERATION" TIME LIMIT** is **90 minutes**.
- ICE CREAM and ICE CONFECTION and similar products respond more rapidly than other frozen food to temperatures above -18°C, and should be **loaded last and unloaded first direct from/to storage freezers** whenever possible. The **MAXIMUM "OUT OF REFRIGERATION" TIME LIMIT** for ice cream is **20 minutes,** irrespective of the unloading or dispatch environment."

It should be noted, in the absence of continuous temperature monitoring it is not possible to be certain Standard 3.2.2 and the Australian Cold Chain Guidelines have been consistently complied with throughout the cold chain. Unidentified breakdowns in the cold chain could potentially lead to contaminated foods being consumed.

Supermarket quality assurance scheme for growing, packing and supply of whole produce for retail sale

Australia's major grocery retailers, ALDI, Coles, Costco, Metcash (IGA) and Woolworths are in the process of introducing HARPS, the Harmonised Australian Retailer Produce Scheme. This will result in the major grocery retailers accepting a single suite of food safety standards[13]. The introduction of a consistent set of quality assurance requirements provides an opportunity to increase adoption of better quality control systems, such as food condition monitoring systems.

Examples of temperature sensitive food products

In the course of the stakeholder consultation process and other research conducted for this project, a variety of temperature sensitive products were identified. The more temperature sensitive the product, the more benefit to be gained from improved visibility of temperature conditions the

[13] http://harpsonline.com.au/about/

product experiences. The higher the value of the product, the more economically viable investing in advanced temperature monitoring becomes.

Examples of highly temperature sensitive perishable foods include:

- Fruit and vegetables, for example, strawberries, bananas and salad greens;
- Dairy products such as milk and cheese;
- Meat;
- Seafood, for example, prawns;
- Ice cream; and,
- Cooked, chilled foods, for example, pre-prepared meals.

Appropriate temperature ranges for temperature sensitive products

As mentioned above, perishable products have optimal temperatures for storage and handling. Perishable products are considered to have suffered temperature abuse if they are stored or handled for an extended period of time above the recommended temperature limit. In the case of, for example, fresh produce, there may be both a recommended upper and lower temperature limit - as the temperature move away from the optimum, product quality deteriorates as a result of either increased respiration at higher temperatures, or due to chilling or freezing injury at lower temperatures[14].

The Global Cold Chain Alliance (GCCA) produces a food storage manual[15], accessible to members of the GCCA, which is a source of information on the storage and handling, including optimal storage temperatures, of almost 300 perishable products.

Storage conditions recommended by the GCCA food storage manual for a selection of temperature sensitive products are discussed below:

- Strawberries – it is recommended rapid removal of field heat occurs immediately after harvest for maintenance of fruit quality. Every hour in delay in cooling can reduce the percentage of marketable fruits by about 5%. Storage and transport temperatures should be maintained at 0°C. Strawberries held at 10°C have a life expectancy of only one third of that of strawberries held at 0°C. Ideal relative humidity is 90-95%. In addition, modifying the storage atmosphere by increasing carbon dioxide (15-20%) and reducing oxygen extends shelf life and controls decay.
- Ice cream – the GCCA recommends storing ice cream at -27°C or lower. Textural defects arise when storage freezer temperatures fluctuate or product is allowed to warm in movement between freezers. Ice crystals grow with each temperature fluctuation until noticeable textual changes cause consumer complaint. Prolonged warming will cause loss of

[14] Tanner, D. J., & Amos, N. D. (2002, June). Temperature variability during shipment of fresh produce. In *International Conference: Postharvest Unlimited 599* (pp. 193-203).

[15] Global Cold Chain Alliance. (2017). *Commodity Storage Manual*. Accessible to GCCA members at http://www.gcca.org/resources/publications/technical-guides-manuals/

air and settling of sugar syrup. Product in this state is totally unacceptable before or after refreezing. The product develops a soggy, heavy characteristic that is offensive to consumers. Thus, the critical importance of temperature maintenance for ensuring the quality of ice cream can be seen.

- Frozen fish – in order to maintain quality, fish should be held for as short a time as possible, and at temperatures near 0°C prior to freezing. Headed and eviscerated Whiting held for two days on ice at 0°C had good quality frozen storage life of 12 months at -18°C. In contrast, Whiting held in ice for 4 days prior to freezing had a frozen storage life of only 6 months. Other factors that affect the quality of frozen fish include: the condition of the fish at the time of freezing as it relates to the nutritional status or stage of spawning; the pH of the flesh post-mortem, which can be influenced by the fishing method and degree of struggling; and, the stage of rigor mortis at the time of freezing.

The table following, reproduced from a report prepared by Food Chain Intelligence for the CSIRO[16], shows the optimum storage temperature, relative humidity and storage time for a selection of perishable food products.

[16] Estrada-Flores, S. (2010). *Quality characteristics, factors of spoilage and shelf-life models for selected foods*.

Figure 2 – Optimum storage conditions for a range of perishable products

Category	Product	Optimum relative humidity (%)	Optimum storage temperature (°C)	Recommended storage time
Fruits and Vegetables	Carrot	98 to 100	0 to 1	7 to 9 months
	Cauliflower	95 to 98	0	7 to 10 days
	Tomato	85 to 95	Unripe tomatoes: 7 to 13 During ripening: 19 to 21 After ripening: 7 to 10	Before ripening: 1 to 2 weeks After ripening: 1 week
	Potato	Curing: 80 to 100	15 to 20	1 to 2 weeks
		Storage: 95 to 98	7 to 10 (for fresh consumption) 15 to 20 (Chipping cultivars) 4 to 5 (for seeds)	2 to 12 months
	Okra	90 to 100	7 to 10	7 to 14 days
	Brinjal (eggplant)	90 to 95	10 to 12	2 weeks
	Mangoes	85 to 90	10 to 13	2 to 3 weeks
	Guava	90 to 95	Mature green:8 to 10	2 to 3 weeks
			Ripe, soft fruit:5 to 8	1 week
	Apples, hardy varieties	90 to 95	-1 to 4	2 to 4 months (air) 3 to 11 months (CA)
	Banana (green)	90 to 95	13.3 to 14.4	7-28 days
Seafood	Perch	95 to 100	-1 to 1	12 days
	Salmon	95 to 100	-1 to 1	18 days
	Tuna	95 to 100	0 to 2	14 days
Meat & poultry	Beef, fresh, average	88 to 92	0 to 1	1 to 9 weeks
	Prime, 54% lean	85	0 to 1	1 to 3 weeks
	Pork, fresh, average	85 to 90	0 to 1	3 to 7 days
	Ham, cured	--	-3	3 months
	Bacon, medium fat class	80 to 85	3 to 5	2 to 3 weeks
	Lamb, fresh, average	85 to 90	0 to 1	5 to 12 days
	Poultry, fresh, average	95 to 100	-2 to 0	1 to 4 weeks
Dairy	Fluid, pasteurized	--	4 to 6	7 days
	Raw	--	0 to 4	2 days
	Cream, sour	--	-2 to 0	3 months
	Butter	70 to 75	0	1 month
	Cheddar cheese	65	0 to 1	12 months
	Brie	65	0 to 1	2 months
	Mozzarella	65	0 to 1	6 to 8 weeks
	Roquefort	65	0 to 1	2 months

Impacts on shelf life and food safety of temperature level and variability

As can be seen from the examples and table above, storage and handling temperatures are a critical aspect of ensuring the quality and safety of perishable foods. For example, traditional kinetics models used to predict product shelf-life indicate that a storage temperature of -15°C can lead to a decrease in shelf-life of up to 36 per cent in frozen hamburger patties, and up to 45 per cent in frozen prawns, in comparison to products held at -18°C[17]. Appendix C: Relationship between shelf life and temperature, reproduces five tables from the report *Quality characteristics, factors of spoilage and shelf-life models for selected foods*[18] showing the relationship between the shelf-life and temperature.

The *consistent maintenance* of optimal temperatures for perishable foods is a critical element of maintaining perishable food safety and quality. Temperature variations can lead to conditions that irreparably deteriorate the quality of products, as discussed above with regard to the impact of temperature variations on ice cream quality.

Temperature variations in the cold chain may also expose food to the risk of contamination. Estrada-Flores and Tanner[19] conducted a study on urban delivery of food products, characterised by the use of small vans with frequent, though short-lived, temperature variations. Integration of the measured temperature histories with mathematical models to predict growth of pseudomonads and *Escherichia coli*, showed that all products presented adequate growth temperatures for pseudomonads, and less than half the temperatures measured were suitable for *E. coli* growth. The factors commonly leading to loss of temperature control, particularly in summer, were door opening to load the van, with the loading period strongly influencing the thermal behaviour of food products inside the van, and door openings to deliver parcels.

International experience in implementing best practice cold chain temperature monitoring and optimization

See Appendix D: International work on cold chain temperature monitoring and optimisation for a summary of examples of work conducted internationally on cold chain temperature optimization, with particular emphasis on examples that use ICT to improve monitoring of temperatures.

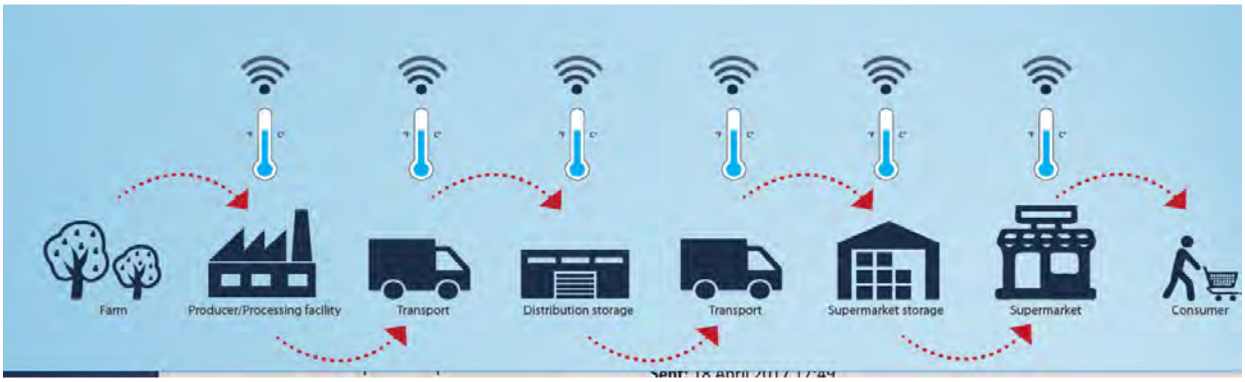
[17] Estrada-Flores, S. (2012). Achieving control and efficiency in the cold chain. *Climate Control News*. January 2012. 18-21.
[18] Estrada-Flores, S. (2010). *Quality characteristics, factors of spoilage and shelf-life models for selected foods*.
[19] Estrada-Flores, S., & Tanner, D. (2005, May). Temperature variability and prediction of food spoilage during urban delivery of food products. In *III International Symposium on Applications of Modelling as an Innovative Technology in the Agri-Food Chain; MODEL-IT 674* (pp. 63-69).

4 Technical analysis

4.1 Key elements required to monitor and control food temperature in the cold chain

The ultimate vision for optimising food temperatures through the cold chain is to track the real-time temperature of all refrigerated foodstuffs from harvest (or slaughter) through to consumption. This information would then be used to optimise the input of energy to deliver the environmental conditions required to maintain food freshness (within an acceptably low level of deterioration before eating) and minimise food waste associated with the cold chain. As explained in the 'scope' section, this project focuses on the steps through to the retail shelves.

Figure 3 – Steps in the cold chain

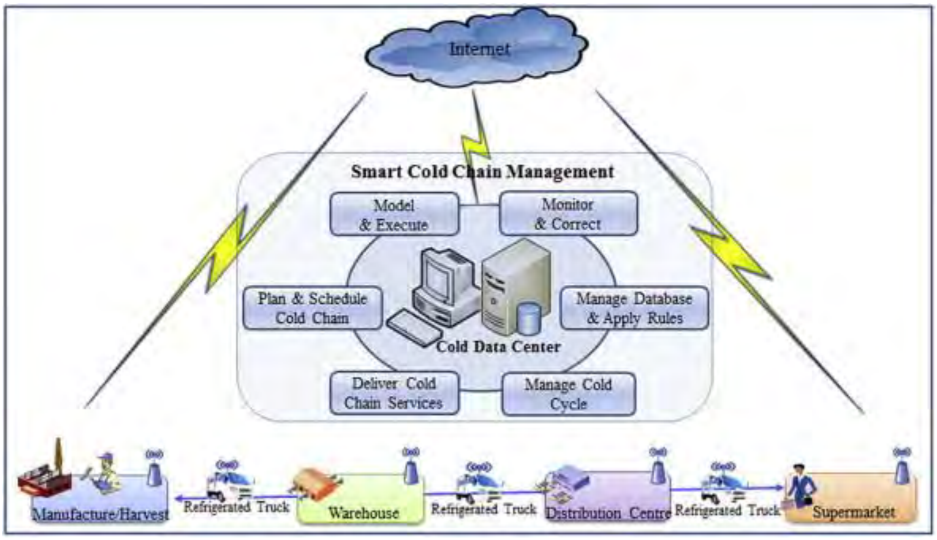


Source: http://cool.it/

For a system to be able to real time monitor food temperature from farm to retail shelves, we need processes to measure, transmit, and collect the data; to analyse it and determine any deviations from target conditions, and to send corrective information to a responsible person or device to resolve any problems. The figure below, reproduced from the paper *Temperature management for the quality assurance of a perishable food supply chain*[20], depicts a real time temperature monitoring system in place from manufacture/harvest through to the food retailer.

[20]. Myo Min Aung, Yoon Seok Chang. (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control*, Volume 40, 2014, 198–207.

Figure 4 – Smart cold chain management system



The elements of a system to monitor food conditions in the cold chain in real time include:

Sensors

For monitoring perishable food, the key is to measure temperature. In some cases, it is worthwhile also to monitor humidity, as this has an impact on the water content of the food, and freshness of some items is sensitive to humidity. There are other variables that can be beneficial to track, including light (which indicates when doors are open or potential radiant heat), and impact/bumps, and GPS positioning. Data collected would ideally be linked with the product bar code information.

There is no shortage of low cost sensors measuring these variables and the price is coming down further over time. Typically, the packages available monitor temperature, humidity and light.

How many sensors is enough?

The next question is how many sensors are required to provide assurance on the temperature of a product in a truck or storage facility? CSIRO pilot work would indicate that there can typically be up to 6°C variation within a truck load. The implications of this are that more than one sensor is essential in each truck. The study also indicates that work is needed to rectify air distribution problems, or establish zoning, in many trucks before the benefits of monitoring can be fully delivered. At a minimum it would seem that 12 sensors per truck would be needed, but ideally there should be to be at least one sensor per pallet of product. It may also be useful to install permanent sensors at key positions within the truck.

In the New Zealand kiwi fruit industry, they have been putting in one sensor per 10 pallets for the last five years. This has brought about great benefits in terms of kiwi fruit quality, but would not seem adequate for the purposes of bringing optimal refrigeration control, as it will not pick up temperature variations between unmonitored pallets in a truck, for example.

In the case that pallet loads are split before they go to their final destination, it will be preferable to monitor to crate level. Initially this could be done on a sample basis - perhaps one on the outer layer on the pallet and one on the opposite side - it would be worthwhile if feasible to put one on the inside of the pack. It is not cost justifiable at this time to put a sensor on each crate/box, but this will change as the size and cost of these sensors continues to plummet.

There also may be value in using much larger numbers of sensors for research/pilot purposes, so that optimum numbers of sensors can be defined. Also, by monitoring trends of problems along a cold chain, locations may be identified where short term use of additional sensors could help diagnose problems (such as handling, equipment faults, local environmental conditions, etc.) so weak points in the chain can be identified and addressed. This approach could also be used to help build a business case for ongoing application of the approach. The relevant equipment could be rented or loaned to firms that wished to use it.

Transmitters

The type and cost of the transmitter is a function of the communications network. The transmitter is typically packaged with a battery and sensors. Emerging communications network providers are increasingly aiming to have open source to allow multiple technology manufacturers produce transmitters/sensors for their systems. Typical battery lives are 5-10 years and as power requirements are falling over time and batteries are improving, potential portable battery life is extending.

The cost of sensors/transmitters is falling rapidly, and high volume costs as low as around the $10-15 mark are being quoted for matchbox sized units with sensor/electronics chip, battery and aerial. While this is expected to continue to fall much further with production volume and technology improvements, we are not yet in the era of disposable sensor/transmitters unless very high value products are being transported. This raises the issue of the logistics of recovering the devices – and for the purposes of this analysis it is assumed that this would occur at the supermarket. Monitoring through to the home would rely on the price of sensors coming down to cents rather than dollars each, unless customers can be convinced to use reusable insulated bags with built-in sensors. Once sensors are so small and cheap they can be can be incorporated into the label on a package, a phone app could alert the consumer to both the food provenance and any handling problems encountered.

Communications network

McKinsey Global Institute sees the Internet of Things (IoT) as a top disruptive technology trend that will have an impact of as much as US$6 trillion on the world economy by 2025 with 50 billion connected devices. There are a range of technologies which are in some ways complementary but overlap with considerable competition to these devices while fulfilling the ultra-low cost, ultra-low energy and deep coverage requirements necessary for IoT applications.

Key connectivity requirements for IoT solution include:

- Optimized for small payloads (with low signalling and control overhead), support for large numbers of terminals per cell (tens of thousands).
- Extended coverage compared with existing mobile system.
- Optimized for ultra-low terminal cost.

- Allowing very long terminal battery life (10 years feasible in many scenarios).

The key options for networks to meet these needs are currently:

- **Evolution of GSM (Global System for Mobile Communications)/LTE (Long Term Evolution – the mobile communication standard)** to support IoT applications: longer battery life, longer range, lower cost in exchange for lower throughput. The big telcos like Vodafone and companies like Huawei are planning deployment of narrow band networks using existing mobile phone infrastructure to give them a competitive role in this market. However recurring delays and a lack of agreement between Huawei & Ericsson on the standard is delaying implementation. Further, higher costs, higher power consumption than unlicensed LPWAN is likely to limit the usage to high value items.
- **LP WAN (low power wide area network) technologies** developed especially for IoT connectivity. Since today's mobile networks cannot cover the IoT requirements, there are a few other solutions being developed, trying to fill the gap.

  In the LP WAN space, there are 2 major competitors in Australia:

  Sigfox, a French business with its local operator Thinxstra, is using ultra narrow-band modulation supporting data rates of 100/600 bps, using frequencies of 868 MHz in Europe and 915 MHz in the US.

  LoRaWan, developed by Semtech, is using spread spectrum modulation on sub-GHz bands, offering data rates from 0.3 kbps to 50 kbps. The LoRa Alliance aims to drive the LoRa protocol's global success.

Note: Mesh technologies (typically based on Zigbee) and Wi-Fi extensions have been used in private networks but are not easily scalable for wide-area coverage.

A summary of the main network options follows:

- Sigfox offers the most limited data transfer capabilities and limited two-way communications capability but also looks like being the cheapest (in terms of connection and operating costs) network in the market. It appears to have suitable capacity to do the job required with a strong network operation centre to monitor the nationwide network. The key issue could be the coverage which is rapidly being increased - by the end of 2017 it claims it will cover 95% of the population. Even though the back-end is proprietary for security and compatibility reasons, it is open to any IoT platform. If Sigfox operator in Australia New Zealand (Thinxtra) went out of business, Sigfox would take over the network. If Sigfox was to be going out of business, the network would remain live for another 5 years.
- LoRaWan offers more extensive data transfer capabilities and two-way communication (and consequently higher power use), and aims to be an open source standard, encouraging many providers to participate in rolling out the network. Networks are low cost to roll out and operate. Customers can keep low cost base stations in warehouses plus a small very inexpensive base station can move with the truck, sending regular information 'back to base'. Users gain integrity of data, an audit trail and information is double encrypted. This enables clear identification of timing and nature of failure. It has been tested with a gateway and GPS tracker between Frankston and Melbourne CBD. It appears more expensive that

Sigfox in capital, operating costs, and device costs. It was originally designed more for local /private networks than as a nationwide network.

- The GSM options are capable of the greatest data transfers, two-way communications and flexibility, but will be significantly more expensive in operating costs than the other two alternatives, and 100 times more power consuming. The existing 2G network is being closed down at present by Telstra, which is causing angst for several businesses in this space, and the 3G/4G networks are expensive to use, while the new narrow band entrants using existing infrastructure (such as NB-IoT and forms of CAT 1M/LTE) are probably two years away from fruition.

The bottom line is that no one has a perfect solution at the moment, but there are likely to be several viable options by the end of 2018, and even now it would be possible to deliver real time tracking for many purposes using these networks. Additionally, particularly where open standards exist for sensors and/or base stations, these are likely to reduce in price over time, potentially significantly.

4.2 Issues for consideration in evaluating solutions

Networks

Some of the issues that might be considered in evaluating a network should include:

- Signal interference – While all technology providers claim that this is not a major issue and thus not a differentiator, this has to be confirmed. However, users see this as a real issue depending on the operating condition of the goods and the nature of the walls in the cold space. Many of the technologies are improving but may occasionally result in data not being transmitted. If this occurs, you need to ensure that the data is stored and retransmitted when the signal can connect.
- Reliability/backup – again we need to confirm claims to define how significant the risk of losing data is between providers. Generally, the approach is to store data on the device or truck until it gets back into a covered area to send the data.
- Security of the data – all systems have strong encryption so this is unlikely to be a material issue. Data ownership should also be included here, and the expectation is that no vendor should have any data ownership rights.
- Financial/business security – to the extent that systems are closed and require decisions that preclude a user from switching if the network owner was to either go bankrupt or be compromised to the extent that they could not meet commitments to expand coverage, then this would constitute a risk. Sigfox has strong financial backing and Thinxstra apparently has back-up solutions in partnership with Sigfox in case of failure to deliver the committed coverage or the company went bankrupt. Furthermore, new modules which are embedding LoRa & Sigfox protocols, even though more expensive, could be a solution to this possible problem. Some of the integrated solutions mentioned are effectively delivered by start-ups and they would also have significant risks to the extent that their hardware, systems are not transferrable to another vendor if they failed.

- Technology upgrade path – this is an extension of the issue above, particularly for the start-up ventures which are not well capitalised, as they may be constrained in their investments to upgrade over time by cashflow.

Real time or stored data

One of the options in designing a system for this purpose is deciding whether data needs to be transmitted in real time, intermittently, or downloaded when the truck reaches its destination. This has an important relationship to the need for communications coverage and the cost of transmitting data. Several companies offer systems where data is data logged in the truck and downloaded automatically when the truck docks – this is the approach used by Emerson and the Kiwi fruit industry in NZ.

The ideal for real time quality/refrigeration control is near real time data transmission. The optimal approach will link the frequency of data communication to the potential actions that can be taken. It is important to look at both how frequently we collect the data and how frequently we transmit the data. This could be 2 different answers depending on the use cases. Frequent transmission requires comprehensive route coverage, low power consumption, low cost data transmission, and low cost devices (i.e. LPWAN rather than 3G/4G).

Data logging approaches, which are common, have very much simpler communication needs, but clearly only provide a retrospective view of the temperature profile of products and lose (at least theoretical) ability for real time rectification of problems. However, it is still a far better solution that having no monitoring, and is useful for piloting and for justifying the business case for investing in more comprehensive, real time systems.

A middle ground solution would be to have real time monitoring with the signal sent to the driver or staff operating the relevant facility, to warn them of a problem so they can address it.

Ultimately, real time systems are likely to win the day as the cost of communications continues to plummet.

Cloud application for processing the data stream

Once the data stream has been captured (either real time or downloaded from a data storage device, it then requires software applications running on remote servers to process the data, convert it to useful information – particularly temperature trend versus time for the product (e.g. from farm to supermarket shelf), compared to the ideal temperature range for that product. Cloud computing is a critical element to make this solution practical as it allows access for all the value chain participants to the same set of condition data.

There are already off the shelf monitoring and reporting systems which use an API (Application Programming Interface) to accept data from multiple monitoring systems and provide end to end tracking against the bar code of the product.

Once that is achieved, the next challenge is to determine what is the significance of a deviation from the target temperature. This is not a trivial question because for each product type, a deviation from target temperature range versus the time it occurs has a different level of significance in terms of shelf-life, likely customer acceptability and safety.

The application needs effective algorithms to differentiate between acceptable and unacceptable deviations from target, and ideally automatically decide the next actions. These actions could include sending an alert to result in action to rectify the problem, and ultimately defining whether the product is acceptable or not. If action is needed, the application needs to trigger a message to be issued to the appropriate place to ensure corrective action.

Output communication requesting action

In some systems, this could be done through two-way communications to immediately respond to some deviations: the application would send a response to a call centre, which would trigger a mobile call or message to the logistics company, and ultimately to the operator/driver to take measures to rectify the problem if this is feasible.

Action implementation

The people element of this system could be the most problematic. Once deviations from target performance are identified that are determined to warrant immediate corrective action, there has to be the ability to implement the changes. This may involve an array of contractual/commercial, training, change management, work practices and possibly capital investment requirements.

It should also be noted that the act of collecting this data could also raise issues about liabilities relating to products that might now be finding their way to the shelf, but may need to be disposed once detection systems are in place. There could be legal liabilities associated with not disposing products that are indicated by the system to have significantly reduced shelf life – but are they unfit for consumption? It is possible that if this is not managed well it could result in increased food waste in the short term, but ultimately should drive change in the industry that would dramatically cut waste. Effectively these systems link together the disparate parts of the supply chain, and draw attention to the elements of the chain which are not functioning as they should – IF effective action is taken to correct these issues, then the result will be improved outcomes for all.

Existing packaged technical solutions

A number of packaged supply chain refrigeration tracking systems have been identified in the course of this work. They provide (or have the aspiration to provide – as it is hard on the surface to separate aspiration from reality) some or all the elements of a tracking and control system, apart from the communications system itself (and typically are set up to use GSM, or to use an API interface to access data from someone else's communications platform):

SmartTrace: https://smarttrace.com.au/
Emerson: http://www.emerson.com/en-u

Xsense: http://www.bt9-tech.com/xsense-system-layout/

SensaData: http://www.sensadata.net/

Danfoss http://cool.it/

Perhaps: BXB Digital http://www.brambles.com/bxb-digital

Euroscan http://www.euroscangroup.com/B.php?id=11&lang=eng&ready=go3

Bosch http://www.bosch-presse.de/pressportal/de/en/sustainably-from-field-to-plate-bosch-provides-innovative-solutions-72000.html

Hanwell iSense http://www.the-imcgroup.com/images/Datasheets/iSense-Datasheet.pdf

Silvertree Icespy https://www.the-imcgroup.com/brand/icespy-wireless-temperature-monitoring-systems/

SenseAware www.mnx.com/gps_tracking_service.aspx

SmartSensor http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/smartsensor.html

Summary of current technical feasibility of cold chain temperature optimisation

The technology already exists to be able to monitor the temperature of food products throughout the cold chain, and for high value non-food products like expensive pharmaceuticals, it is becoming standard practice. The falling cost of technology will change the economics sufficiently to justify real time tracking at least down to pallet load level for all perishable food products within the next 12-24 months, if not already. Solutions are already available. The main constraint so far on low cost monitoring in Australia is the extent of the LPWAN networks. Sigfox has plans to cover 95% of the population by the end of 2017, but this will still leave gaps in coverage for some rural areas.

Ultimately it will become economical to track all food with disposable sensors. In the meantime, it is likely that as prices drop, economics will favour using a greater number of reusable sensors to provide more data granularity as this will then provide sufficient marginal benefits relative to the lower implementation costs.

5 Economic analysis

A variety of direct and indirect costs and benefits are associated with improving temperature monitoring in the cold chain. This section provides a high level overview of the costs and benefits of moving towards real time temperature monitoring systems that provide visibility of perishable product temperature as they move through the domestic cold chain.

The higher the value and the more temperature sensitive the product, the more robust the business case for investing in real time monitoring becomes. It is expected uptake of more advanced temperature monitoring systems will occur in line with the temperature sensitivity and value of products, driven by falling costs, and consumer demand and competitive pressure for assurance of safe, quality foods. Other factors such as reduced insurance costs and theft could add to the business case. Eventually, it is envisaged, real time temperature monitoring will become continuous throughout the cold chain and industry standard across all perishable product lines.

Note that detailed data on some of the aspects discussed below are not freely available, and in some instances are subject to confidentiality constraints, restricting our ability to provide very specific information in this report.

5.1 Costs of temperature monitoring, reporting and control

The direct costs of real time temperature monitoring systems include the cost of sensor devices (which include the sensor, transmitter and battery) and communications costs (connection, service, and data transfer charges). Real time temperature monitoring systems typically include a real time alert capability and so organisations may need to also consider the costs of instituting systems to respond to alerts in a timely manner if the benefits of deploying real time temperature monitoring are to be realised. Response system costs should consider items such as additional staff training.

Sensor devices and communications services are typically offered in a package including chip/sensors, battery and antenna. The stakeholder consultation process revealed a broad range of prices and pricing structures are in operation. For example, prices for sensor packages were quoted as costing from around $20 (large volume of Sigfox-ready devices) to $50+ each, depending on the functionality of the device, the type of network it communicates to, and how it is packaged with charges for communications. Contracts may be structured so the customer purchases the sensor devices, and pays a fee for communication services and access to a cloud-based database. In some cases, a higher charge for devices was paired with a relatively lower fee for communications services.

Real time temperature monitoring is not widely adopted in the Australian food cold chain outside stationary facilities such as cold stores, even though the in-transit phases of the cold chain are among the most difficult to control temperatures. Adding wireless data transmission capability to temperature monitoring devices adds an incremental cost. There is a perception in many businesses operating in the cold chain that this additional cost is not outweighed by the benefits of accessing temperature data in real time. This is despite the significant benefits attributable to monitoring temperatures in real time, as discussed below in section 5.2 Deriving and quantifying the energy productivity benefits.

Split incentives appear to be a contributing factor in the commonly held perception that real time monitoring is not economically viable: the party that bears the cost of implementing a more sophisticated monitoring system does not accrue all the benefits. In addition, there are many smaller players in the cold chain, many of which are operating on tight margins with limited ability to bear additional costs. Smaller players may also have less time or information available to analyse the business case. Some may even see improved information as a problem, as it may pressure them to change practices or make investments to adapt.

Some indirect benefits of real time monitoring may not be recognised by businesses and factored into the business case. Examples include reduced insurance costs, reduced product weight loss (for products sold by weight), saved staff time (doing manual checks, dealing with damaged product), and capacity to pinpoint areas causing problems. Some of these benefits may also accrue to players in the cold chain that do not pay for the cost of the system, creating split incentives.

As discussed in the technical analysis in section 4 of this report, the cost of real time sensor devices is on a rapid downward trajectory, which is expected to continue. As sensor costs come down in price, it becomes more economically viable to increase the number of sensors deployed throughout each load, providing greater data granularity. This additional temperature data is particularly valuable when perishables are in transit, and significant temperature variations may occur in different parts of the cargo space. Ultimately temperature sensors may reduce in cost and size to the point where they will be disposable, and possibly printed on 3D printers and/or incorporated into product packaging. Further, intermittent and targeted use of sensors offers a transition path that can capture some of the benefits at lower cost. The experience gained will support informed investment decision-making as costs fall further.

New narrow band communications technologies with lower data transfer capabilities and much lower costs (e.g. transmission 'towers' costing less than $1,000) have resulted in order of magnitude falls in communications charges. This downward trend in costs is expected to continue, driven by technology improvement and rapidly increasing deployment of IoT devices.

5.2 Deriving and quantifying the energy productivity benefits

It is one thing to determine that it is technically feasible to economically monitor the temperature of food from farm to supermarket shelf (or export market) and begin to optimise this, but our ultimate objective is to demonstrate energy productivity benefits from the undertaking.

The sources of energy productivity benefits of improved food condition monitoring include the following:

1. **Energy savings** associated with:
   - **Reducing food waste:** There is a significant opportunity to reduce food waste through optimising conditions in the cold chain. This is critical as there are substantial energy losses and greenhouse gas emissions associated with food waste. Benefits of reducing food waste include energy savings from avoiding cooling required for food which is ultimately wasted, and also all the energy involved in manufacturing the fertiliser and direct energy consumed in growing the food, transporting it, processing it and storing it, and its disposal.

- **Reducing operational energy waste**: This includes cooling energy wasted from truck doors left open, excessive transfer times, and delays in unloading. There is ample empirical evidence from confidential pilot testing that these are common occurrences, though it is difficult to estimate the extent of energy loss.
- **Monitoring and driving action to rectify poorly operating equipment**: Identifying (and then correcting/replacing) poorly designed equipment and poor maintenance and work practices causing high temperature variability within spaces/trucks and heat gain due to poor insulation and seals, particularly in trucks.
- **Monitoring and driving investments to improve energy efficiency by maintaining temperatures more precisely** using inverter-driven refrigeration equipment, variable speed fans and controls.
- **Food condition monitoring** confirming need to improve energy performance in cold stores and reduce heat infiltration into refrigerated storage areas through measures such as: the construction of energy efficient cold storage rooms using thicker and/or more efficient thermal insulation on walls, ceilings and floors; ensuring good airflow and ventilation; providing airlocks to all personal and forklift access doors; properly designed loading docks with tight seals around truck doors; installing refrigerated loading docks as a break between the ambient and chamber temperatures; high speed chamber doors; and, use of pallet conveyors to reduce frequency of operation of forklift access doors.
- **Potentially reducing overcooling** of frozen products.

2. **Value gains** associated with:

- Increased value of product, increased shelf life, reduced product loss, and reduced discounting due to improved quality. This is a large dollar benefit and is the major justification for the food suppliers and supermarket chains to get engaged in this activity.

  Note: While it is recognised that the greatest source of waste in the food chain is food wasted in the home and food service, it is currently only economical to implement real time monitoring from farm to retailer. Greater temperature control in the cold chain reduces the build-up of spoilage organisms and reactions occurring throughout the chain, so improved temperature control is likely to extend the shelf life and reduce waste at the consumer stage, but it is only a partial solution at the consumer stage of the chain.
- Indirect cost and logistics benefits from avoiding transporting, processing and handling product that cannot be sold, and improved scheduling of maintenance activity.
- Reputational benefits from more consistent, good quality food with longer shelf life at home and improved environmental outcomes.
- Upskilling and empowerment of staff.
- Reduced losses from theft in the cold chain.
- Reduced carbon emissions from reduced energy use, reduced refrigerant leakage and also reduced emissions relating to food waste.

- Reduction in costs of conversion to low climate impact refrigerants by combining equipment upgrades with conversion, reducing the need to replace existing equipment if the low global warming potential refrigerant has lower cooling capacity by reducing cooling loads of facilities, introducing energy storage, and other strategies to reduce peak cooling demand.

Quantifying the energy productivity benefits of improved food condition monitoring

Attribution of savings to condition monitoring systems is difficult as there are many factors influencing food quality. While the general opinion of stakeholders in this project was that real-time condition monitoring would have a very significant impact on food quality, we also received feedback on the range of other factors influencing food quality, particularly at the farm. However, we consider these factors do not undermine the benefits identified in this report: they offer opportunities to improve management of food on the farm and in unrefrigerated transport from the farm, and from shop to home. Indeed, temperature monitoring in these stages of the Value Chain may help to quantify their significance and justify remedial action.

The following indicative cost savings reflect the impact of relatively small percentage reductions in food waste and energy use as a result of improving food condition monitoring in the cold chain:

- A 5% reduction in food waste would result in a $1 billion annual saving to the Australian economy.
- A 5% reduction in energy use of stationary elements of the cold chain would result in energy cost savings of approximately $120 million per year.
- A 10% reduction in energy use of trucking refrigeration would result in energy cost savings of approximately $15 million per year.

These are very conservative estimates of the potential cost savings that could be realised by deploying real time condition monitoring and rectifying issues revealed by these monitoring systems. For example, reductions in energy use for trucking refrigeration could be at least 70% if best practice was followed[21], for example, regular maintenance, unclogging heat exchangers and improved staff work practices. Trucking refrigeration energy costs have been estimated at $150 million per annum: a 70% savings would result in energy cost savings of over $100 million per year, significantly higher than the $15 million estimate in the third dot point above.

The following sections set out in more detail potential for cost and greenhouse gas savings by a) reducing food waste and b) reducing energy use related to refrigeration in the cold chain.

A. Reducing food waste

The table below sets out the costs and emissions related to food waste, and the benefits associated with every 1% reduction in food waste. Deployment of real time food condition monitoring systems can be used as a tool to significantly reduce food waste related to loss of product quality and shelf

[21] The government regulatory impact statement for commercial refrigeration equipment (2016) shows the best products on the market use half of what worst do, and significant additional improvements could be made.

life by identifying parts of the cold chain where sub-optimal food storage conditions exists, so that these problems can be rectified.

Impact of food waste	Cost/emissions of food waste	Benefit of each 1% reduction in food waste
Waste of resources to produce food that is never eaten	• Each year an estimated 9 million tonnes food waste is costing the Australian economy $20 billion[22].	• $200 million annual saving to the Australian economy.
Food disposal costs	• Waste disposal charges and lost product is estimated to cost the commercial and industrial sector $10.5 billion each year.[23]	• $105 million reduction in commercial and industrial waste disposal and product loss costs.
Greenhouse gas emissions related to producing food that is wasted	• Agriculture produced 72.3 Mt of C02e in 2014, accounting for approximately 14% of Australia's greenhouse gas emissions[24]. It is estimated a third of food produced is wasted.[25] Therefore it can be surmised around 24 Mt of Australia's greenhouse gas emissions relate to food produced that is wasted.	• Approx. 240,000 tonne reduction in greenhouse gas emissions as a result of reduced production of food that is wasted. At the price paid by the Emission Reduction Fund (latest round average $11.82/tonne of avoided emissions) this reduction would be worth over $2.8 million.
Greenhouse gas emissions from food waste in landfill	• An estimated 6.8 Mt of carbon dioxide equivalent was released as a result of sending organic waste to landfill in 2011[26].	• Approx. 70,000 tonnes annual reduction in emissions from food waste in landfill.

[22] Department of Environment and Energy. (2017, 11 April) Media release: *Roundtable on food waste marks the beginning of halving Australia's food waste by 2030*. Retrieved from http://www.environment.gov.au/minister/frydenberg/media-releases/mr20170411.html

[23] Ibid.

[24] 2014 National greenhouse gas inventory total equals 523,309.82 Gg C02e of which Agriculture accounted for 72,383.41 Gg CO2e. Data from Department of Environment and Energy. *National Greenhouse Gas Inventory* Retrieved 23 April 2017 from http://ageis.climatechange.gov.au/NGGI.aspx

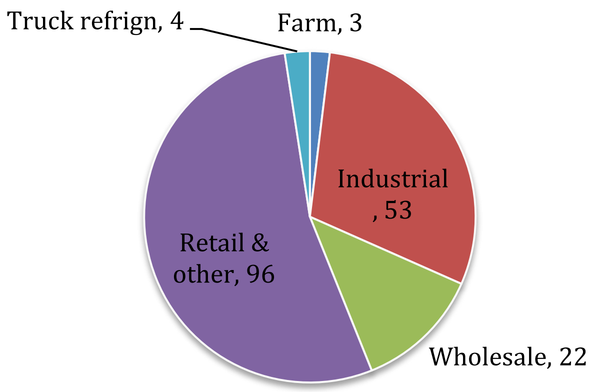
[25] Sheridan, J., Carey, R. and Candy, S. (2016) *Melbourne's Foodprint: What does it take to feed a city?* Victorian Eco-Innovation Lab, The University of Melbourne.

[26] Department of Environment and Energy. (2017).*Working together to reduce food waste in Australia*. Retrieved April 23 2017, from http://www.environment.gov.au/protection/national-waste-policy/food-waste

B. Reducing refrigeration energy use in the cold chain

The figure below shows the breakdown of the approximately 178 PJ[27] of primary energy used each year for refrigeration in the Australian cold chain. This energy is estimated to cost in the vicinity of $2.6 billion per annum, split $2.4 billion related to electricity use by stationary elements of the cold chain, and $150 million for diesel powered truck refrigeration[28].

Figure 5 – Breakdown of 178 PJ of primary energy used for refrigeration in the cold chain



The table below sets out the costs and emissions related to primary energy use for refrigeration used in the cold chain, and the benefits associated with every 1% reduction in that energy use.

[27] Energy use calculations for stationary elements of the cold chain based on 2012 data from *Cold hard facts 2*, uplifted by 10% to reflect notional estimated 2% pa growth over 5 years from CHF2 2012 data. The transport estimates were made by the authors, based on ABS (updated by 35% from 2001) and industry data (testing conducted at SuperTest in Brisbane).
[28] $2.6 billion energy cost estimates based on diesel price of $1.30 and electricity price of $150/MWh.

Element of cold chain	Cost/emissions of energy used for refrigeration	Benefit of each 1% reduction in refrigeration energy use
Stationary refrigeration	• Annual primary energy use (electricity) for stationary refrigeration is estimated to be 174 PJ, costing approximately $2.4 billion.	• $24 million reduction in annual energy costs for stationary refrigeration[29] in the cold chain.
Truck refrigeration	• Annual primary energy use (diesel) for trucking refrigeration is estimated to be 4 PJ, costing approximately $150 million.	• $1.5 million reduction in annual energy costs for truck refrigeration.
All cold chain refrigeration	• Annual greenhouse emissions related to refrigeration in the cold chain is estimated to be 18 Mt CO2e. Emissions are split approximately the following proportions: 84% for stationary refrigeration; 2% for truck refrigeration; and, 14% for refrigerant loss.	• Approx. 180,000 tonne reduction in greenhouse gas emissions related to cold chain refrigeration. At the price paid by the Emission Reduction Fund (latest round average $11.82/tonne of avoided emissions) this reduction would be worth more than $2.1 million.

Further discussion of energy productivity benefits associated with improved food condition monitoring

The potential to add value by improving food condition monitoring in the food cold chain is discussed in more detail below.

Increased shelf life and enhanced product quality and food safety

Temperature is the most significant variable affecting the shelf life of perishable foods in the cold chain. Storing perishable foods at appropriate temperatures is also extremely important for ensuring food safety: Clause 1 (a) of Standard 3.2.2 of the Australian New Zealand Food Standards Code applies to perishable food in the cold chain, stating that food must be kept at a temperature of 5°C or below "if this is necessary to minimise the growth of infectious or toxigenic microorganisms in the food so that the microbiological safety of the food will not be adversely affected for the time the food is at that temperature" [30].

Real time monitoring of product temperatures presents a significant opportunity to improve temperature control in the cold chain by early identification of instances or risks of temperature abuse occurring. Taking swift action to rectify the situation may result in longer shelf life and better

[29] Cold chain stationary refrigeration excludes residential refrigeration in this report.
[30] Australian Government. (2014). *Australia New Zealand Food Standards Code*. Retrieved from www.foodstandards.gov.au

food quality and safety outcomes than if no or delayed action is taken to return product to its recommended temperature range.

Greater transparency in the cold chain

Improved temperature monitoring across the cold chain would offer better visibility around if and when temperature abuse has occurred. In the longer term, continuous real time monitoring from paddock to plate is envisaged. This would enhance the ability of companies in the cold chain to demonstrate food safety compliance and would also assist in assigning responsibility for loss if degradation of product quality occurs as a result of temperature abuse. It also helps to identify where split incentives (i.e. agent who acts does not capture the returns from savings) exist, and their level of significance, so that win-win solutions can be developed and implemented.

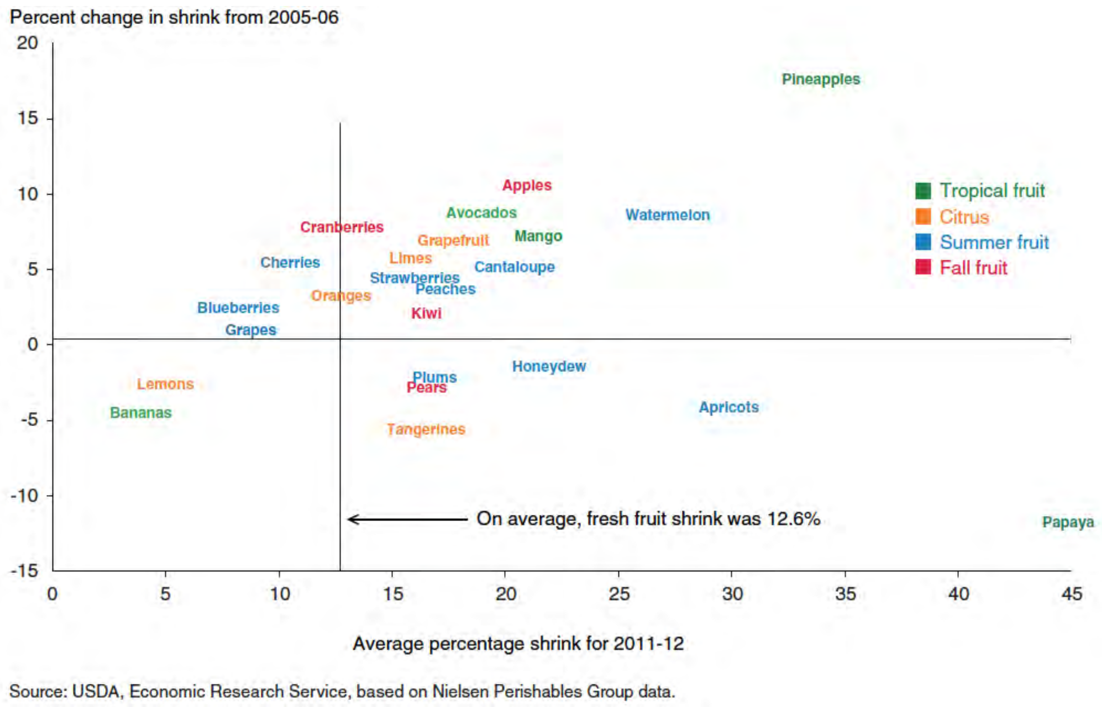
Reduced food waste

Food waste in Australia, as in many parts of the world, is a serious issue. An estimated nine millions tonnes of food is wasted each year in Australia. This food waste is costing the economy $20 billion annually, according to Environment and Energy Minister, Josh Frydenberg at the 5th annual Global Food Forum held in Melbourne in March 2017. At the same event businessman Anthony Pratt said “stopping food waste would effectively double your product sales to end-customers from the same farm footprint” [31]. A National Food Waste Strategy to halve Australia’s food waste by 2030 is currently being developed by the Australian Government, with a National Food Waste Summit to be held in November 2017[32].

Detailed Australian statistics on food waste are not available, but it is interesting to look at the statistics of another developed country, the United States. For example, the figure below, reproduced from a US Department of Agriculture report[33], depicts the supermarket shrink for fresh fruit in the US. Supermarket shrink captures wholesale and retail food losses and waste in handling and display, and also losses due to theft. The report calculated supermarket shrink by comparing supplier shipment data with supermarket point of sale data. The X axis shows the fresh fruit supermarket shrink figures for the 2011-12 year, and the Y axis shows the change in supermarket shrink from 2005-06 data. Looking along the X axis it can be seen average fresh fruit ‘shrink’ was 12.6%, with papayas having the highest shrink rate of approximately 45% and bananas the lowest at about 4%.

[31] Kitney, D. (2017, March 28). Global Food Forum. *The Australian*.
[32] Department of Environment and Energy. (2017, 11 April) Media release: *Roundtable on food waste marks the beginning of halving Australia’s food waste by 2030*. Retrieved from http://www.environment.gov.au/minister/frydenberg/media-releases/mr20170411.html
[33] Buzby, J.C., Bentley, J.T., Padera, B., Campuzano, J. & Ammon,C. (2016). *Updated Supermarket Shrink Estimates for Fresh Foods and Their Implications for ERS Loss-Adjusted Food Availability Data*. EIB-155, U.S. Department of Agriculture, Economic Research Service, June 2016.

Figure 6 – Average supermarket shrink for fresh fruit in the US



According to the International Institute of Refrigeration, food losses relating to refrigeration, including residential refrigeration, account for nearly 9% of total food produced in developed countries[34].

Reducing food waste is not just environmentally responsible, it also makes economic sense in most cases. The Champions 12.3 organisation found that more than 99% of 1,200 business sites surveyed in 17 countries that undertook food loss and waste reduction initiatives had a net positive financial return. Some of the food loss and waste reduction initiatives involved improvements in the cold chain. The Champions 12.3 analysis found that for every $1 (or relevant currency) invested in food loss and waste reduction, the median company site realised a return of $14. The table below, reproduced from the Champions 12.3 report, shows the spread of returns across industry sectors.[35].

[34] Walsh, A. (2017). Food Waste and the cold chain. *Cold Facts, January-February 2017,* 10-15.
[35] Hanson, C. and Mitchell, P. (2017). *The business case for reducing food loss and waste*. Retrieved from the Champions 12.3 website: https://champions123.org/the-business-case-for-reducing-food-loss-and-waste/

Figure 7 – Food loss and waste reduction: benefit-cost ratios of company sites by sector

Sector	Example entities	BENEFIT-COST RATIO Low	Median	High	Number of sites
Food service (for public sector clients)	Education institutions, hospitals, government restaurants	1.2	1.2	169.0	166
Food production/manufacturing	Crop-producing companies, food and beverage processors	1.1	1.3	318.0	5
Food retail (and manufacturing)*	Grocery stores	5.1	5.1	5.1	10
Hotel	Hotels	6.3	7.6	38.2	74
Restaurant	Restaurants, cafés	0.2	8.3	617.7	88
Food service (for private sector clients)		7.3	9.6	17.4	137
Hospitality	Nonhotel leisure, casinos	10.7	22.7	327.1	15
Workplace canteen	Canteens and restaurants located on company premises	1.7	24.7	618.1	673

*Involves four food retailers working in collaboration with six of their food manufacturers. The benefit-cost ratio is the average across all. The source data did not enable separation of benefit-cost ratios between them.

Source: WRI and WRAP analysis based on data provided by companies for 1,168 business sites

If perishable foods in the cold chain have a longer shelf life and are of higher quality as a consequence of better temperature monitoring and control, it can be expected that there will be a reduction in food waste related to temperature abuse. Greater visibility of what is happening to food as it moves through the cold chain due to improved monitoring can be used to prevent food losses from occurring. Greater temperature control in the cold chain reduces the build up of spoilage organisms and reactions occurring throughout the chain, extending shelf life at the consumer stage, potentially reducing food waste in this stage, which is the stage with the highest rate of food waste.

The more granular the level of temperature monitoring, the more targeted disposal of food can be in the event unfavourable temperature variations occur, providing that systems are put in place to act on the findings of the monitoring. For example, an air circulation issue might cause the temperature to increase in a particular section of a refrigerated trailer. The more temperature sensors present in the trailer, the more data is available to identify which stock has actually suffered temperature abuse and should be disposed of, reducing the amount of stock unnecessarily disposed of as a precaution due to lack of information. The additional data may also be used to more accurately establish the cause of the issue so it can be rectified, and future loads not be adversely affected.

The value to be gained from reducing food waste includes:

- Reduced wastage of resource inputs, such as energy, water, pesticides and fertiliser, throughout the value chain to produce food that is never consumed. As noted above, food waste is estimated to cost the Australian economy $20 billion per year.
- Reduced greenhouse gas emissions related to producing food that is wasted. Agriculture accounts for approximately 14% of Australia's greenhouse gas emissions[36] and it is

[36] 2014 National greenhouse gas inventory total equals 523,309.82 Gg C02e of which Agriculture accounted for 72,383.41 Gg CO2e. Data from Department of Environment and Energy. *National Greenhouse Gas Inventory* Retrieved 23 April 2017 from http://ageis.climatechange.gov.au/NGGI.aspx

estimated a third of food produced is wasted.[37] Therefore it can be surmised around 5% of Australia's greenhouse gas emissions relate to food produced that is wasted.

- Reduced food disposal costs. It is estimated waste disposal charges and lost product cost to the commercial and industrial sector is $10.5 billion each year.[38]
- Reduced greenhouse gas emissions from food waste in landfill. An estimated 6.8 million tonnes of carbon dioxide equivalent was released as a result of sending organic waste to landfill in 2011[39].
- Promotion of a more efficient food production system, potentially reducing the cost of producing food. This has both economic consequences for the industry and social consequences, particularly for lower income people who may find it difficult to afford safe, quality foods.

Reduced product weight loss

Improved temperature control reduces temperature variations that impact the weight and quality of some perishable products such as fruit and vegetables. For example, as apples ripen they need to lose some moisture or their skin will split. However if there is too much moisture loss due to temperature variations the skin shrivels. Most consumers will not notice a small amount of moisture loss, however this is an important issue for supermarkets for products sold by weight.

Improved viability and competitiveness in export markets

While this report is focused on optimising the domestic cold chain, improved temperature monitoring and control that results in longer shelf life may have implications for the food export industry, making some export markets (and also more remote local markets) more viable by increasing the range of markets into which products can be transported and sold. Voyage times to key markets range from seven days from Western Australia to Singapore, to 40 days from Melbourne to the United Kingdom[40]. In addition, improved temperature control may assist Australian exporters to enhance their reputation for food quality and safety, giving them a competitive edge. Furthermore, enhanced temperature control of exports assists with complying with the requirements of importing countries, such as the new US Food and Drug Administration sanitary transport rule which aims to prevent practices during transportation that create food safety risks, such as failure to properly refrigerate food[41].

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[37] Sheridan, J., Carey, R. and Candy, S. (2016) *Melbourne's Foodprint: What does it take to feed a city?* Victorian Eco-Innovation Lab, The University of Melbourne.

[38] Department of Environment and Energy. (2017, 11 April) Media release: *Roundtable on food waste marks the beginning of halving Australia's food waste by 2030*. Retrieved from http://www.environment.gov.au/minister/frydenberg/media-releases/mr20170411.html

[39] Department of Environment and Energy.(2017).*Working together to reduce food waste in Australia*. Retrieved April 23 2017, from http://www.environment.gov.au/protection/national-waste-policy/food-waste

[40] Tanner, D. J., & Amos, N. D. (2002, June). Temperature variability during shipment of fresh produce. In *International Conference: Postharvest Unlimited 599* (pp. 193-203

[41] US Food & Drug Administration. (2016*). Final rule on sanitary transportation of human and animal food*. Retrieved from https://www.fda.gov/downloads/food/guidanceregulation/fsma/ucm494118.pdf

Potential to add functionality to monitoring devices

Collecting additional data in addition to temperature data, like humidity, has the potential to be used to improve cold chain conditions. Note there may be incremental costs associated with: expanding the functionality of sensors; transmitting, processing and analyzing the additional data; and, responding to the additional data in a way that adds value.

It is also possible that in the future devices used to measure and transmit temperature data could be used to store data of value to consumers, such as provenance information. This data may be accessible to consumers, for example, by scanning the device with their smart phone.

6 Barrier analysis

A range of barriers to the uptake of real time food condition monitoring technologies were identified in the course of conducting interviews with stakeholders, reviewing the international experience and other research. An overview of these barriers is provided below, categorised under the following headings: technical/implementation, economic, organisational/industry structure and regulatory barriers.

Technical/implementation barriers

- Technical issues are discussed in section 4 Technical analysis. There are no significant technical barriers to tracking and reporting on product temperatures from farm to shelf. The key remaining technical barrier at this point to ubiquitous, low cost cold chain temperature monitoring is the coverage of low cost communications networks, but that will probably be resolved within two years. There are now low cost sensors, typically monitoring temperature, humidity and light, packaged with transmitter and aerial into a unit the size of a match-box.
- Implementing changes to resolve temperature variability uncovered by food condition monitoring will pose a greater challenge than technical issues with the monitoring systems. The long life of refrigeration equipment in the cold chain may constitute an obstacle to improving equipment issues identified by monitoring systems in the short term: land-based facilities can last for 20-30 years or longer and transport equipment is likely to last at least 5 to 15 years.

Economic barriers

- Cost is the most commonly cited barrier to uptake of real time temperature monitoring, particularly for small and medium players. Many participants in the food industry are SMEs, often operating on lean margins, and with limited analytical and R&D capabilities. Costs for monitoring devices and communications are on a downward trajectory, which should assist with uptake. We have reached the point where it is cost justifiable for every pallet of food to be monitored real time from farm to shelf, and now the key limitation to making this system ubiquitous for perishable food is the extent and reach of low cost communications networks like Sigfox.

  Present perceptions of cost among some industry participants may be based on limited information about the value of the benefits that can be captured. Business decisions should be based on informed estimates of net costs/benefits. Further, looking at broad averages can mask opportunities to apply a technology in niches, such as for high cost or delicate products, or as a diagnostic and quality control tool.

- There is a lack of agreement about who should bear the cost of deploying temperature monitoring systems in the food cold chain. The party that bears the capital and operating costs of the monitoring system may not enjoy all the benefits. These split incentives can be a disincentive to investing in advanced monitoring systems. In addition, many players in the industry are small operators, with limited ability to bear the costs associated with establishing better systems, and/or have limited time/resources to evaluate potential systems and capture the full potential gains.

- A combination of high and increasing electricity prices and strong competition is squeezing profitability in the cold storage part of the chain, restricting some participants', particularly smaller firms', ability to upgrade refrigeration systems and controls. On the other hand, higher energy prices should make it more cost justifiable to invest.

Organisational/industry structure barriers

- The poor level of information and knowledge in the industry about the opportunities from better condition control.
- The industry is complex and fragmented. The preface to the *Australian Cold Chain Guidelines* [42] notes the large number of operators and steps involved in moving food through the cold chain, and estimates the average food moves in and out of refrigeration control 14 times across the cold chain before consumption. If continuous monitoring does not take place in the cold chain, then it may be unclear when and where the temperature abuse has occurred. Note that it is this very problem that makes these IOT solutions so powerful as players will have visibility of condition information near to real time on cloud computing applications.

  A complicating factor is the party in possession of the food at the time temperature abuse occurs may not be involved in setting the temperature controls. For example, often the company transporting food does not own the food and has little responsibility for maintaining correct temperatures while the food is being transported.

- The greatest economic challenges for implementing these systems relate to the costs associated with managing and responding to data captured by the temperature monitoring system. This will require investment in response systems, and in some cases radical changes in work practices and culture: companies will need to invest in staff training to ensure staff understand guidelines for handling of perishable foods and respond appropriately to actual and potential instances of temperature abuse. The large number of small family businesses working long hours and on very small budgets makes this an even greater challenge. High turnover in some parts of the industry is an impediment to building these skills and incentivising businesses to invest in staff training. Research into driving behaviour change to promote better work practices in the cold chain may be required.

- Implementing these systems will identify the need for repairs and maintenance to refrigerated transport and warehousing and the challenge arises of getting this maintenance done effectively and ensuring the key investments are made to replace equipment where required. In an industry with a multiplicity of small independent operators, encouraging/enforcing these changes will be very challenging.

[42] Australian Food and Grocery Council. (2017) *Australian cold chain guidelines 2017*. Canberra, Australia: Author

Regulatory and guideline barriers

- Standard 3.2.2 from the Australia New Zealand Food Standards Code specifies the temperatures for storing and handling food[43]. Refrigerated foods must kept at or below 5°C unless the relevant party can demonstrate that the use of another temperature is safe to avoid food safety risks. The standard does not specify a temperature for frozen food but requires that frozen food remains hard frozen. However the *Australian Cold Chain Guidelines* do specify that frozen foods must never be transported, stored or handled at a temperature warmer than -18°C, unless advised by the manufacturer that an alternative temperature limit is applicable. It may possible to keep some frozen foods hard frozen at warmer temperatures than -18°C, but an assessment of food quality and safety risk would need to be performed.
- While not a direct barrier to uptake of temperature monitoring system, a strong theme to emerge from the stakeholder consultation process was there is a lack of compliance with Australian standards for refrigerated vehicles, with refrigerated trailers often being poorly maintained and having inadequate K factors (insulation value of the box). This is a significant barrier to improving temperature control in the cold chain.

[43] Australian Government. (2014). *Australia New Zealand Food Standards Code*. Retrieved from https://www.legislation.gov.au/Details/F2014C01204/Download.

7 Other opportunities to improve temperature control in the cold chain

A strong message emerged from the stakeholder consultation process that a variety of opportunities, in addition to deploying advanced temperature monitoring systems, exist to improve cold chain temperature control. Implementation of some of these measures may be required to fix an underlying problem that is identified by temperature monitoring. A brief summary of a selection of opportunities follows:

- Effective implementation of cold chain solutions requires more than technological change: changes to organizational culture and systems may be required. For example, staff training to improve the execution of basic procedures such as closing refrigerated trailers doors; transferring perishable products from supermarket receiving docks to chillers and freezers in a timely manner; and good loading practices. Good loading practices result in an even distribution of air within the cargo and leave sufficient air space between the top of the load and the ceiling if respiring cargo is included in the load.[44] These changes are likely to be driven by an economic imperative and competitive pressure to improve food quality and reduce waste, without government intervention.
- Develop a responsive product marketing and logistics system such that produce is sorted according to remaining shelf life, and products with the shortest remaining shelf life is sent to market first. The recently released version of the *Australian Cold Chain Guidelines* includes the "first to expire is first out" (FEFO) rule which states "products with the soonest expiry date should be selected first for dispatch or use"[45]. Correct stock rotation according to this rule requires an effective inventory management system.
- Create a "cooling knowledge" hub with access to case studies, guides and reports to be used to support improvement in the cold chain. The Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) is a potential host of such a knowledge hub. To be effective, the hub requires academic interest, commercial interest and an organised structure for working groups. It is recommended that research, such as the *Cold Hard Facts 3* project, which can contribute to understanding the value to be gained from improving the cold chain, be supported.
- Improve the design of refrigerated transport: increase compliance with voluntary Australian standards and explore how the refrigeration trucking industry can be provided with incentives to lift the thermal performance of their vehicles. Examples of measures to improve the thermal performance vehicles include: improving the insulation of truck trailers using novel insulation products such as lower K value aerogels and evacuated panel insulation; minimising thermal bridging and weight using carbon fibre framing; painting trailers and trucks white or with coatings that prevent heat transfer such as Thermoshield[46]; using flexible curtains inside trailers; using thermal imaging; using electric trucks and

[44] Estrada-Flores, S. (2008) *Top 10 reasons why a cold chain fails*. Chain of Thought *1(*1), 3-5
[45] Australian Food and Grocery Council. (2017) *Australian cold chain guidelines 2017*. Canberra, Australia: Author
[46] http://www.thermoshield.com.au/

refrigeration systems to reduce heat and noise. In the longer term, automation of refrigerated transport could present opportunities to improve temperature control, for example by reducing exposure to poor work practices.

- Improve the building fabric and design of cold store facilities – minimise heat gain by installing, for example, LED lighting, super-insulation in walls, floor (and some cold stores have traditionally not had insulated floors) and roof, rapid roll doors, and air seals on docks. Consider automated dark stores where appropriate. The introduction of a NABERS type rating or benchmarking tool is recommended. The AIRAH refrigeration special technical group are currently looking to progress this idea.
- Improve the design of refrigeration equipment used in the cold chain, for example, using enclosed rather than open refrigerated cabinets in supermarkets; installing refrigeration equipment with variable speed compressors and smart controls; conversion to low greenhouse warming refrigerants. See the report, *In From The Cold*[47] , for a detailed discussion of strategies to improve energy efficiency in non-domestic refrigeration.

Learn from the pharmaceuticals industry, which generally has more control systems in place, often combining insulated packaging with when transporting and storing temperature sensitive products. See Appendix

[47] Ellis, M. (2009). *In from the cold*. Retrieved from https://www.airah.org.au/Content_Files/UsefulDocuments/InfromtheCold.pdf

- D.2 Implementation of cold chain optimisation measures – pharmaceutical for examples.
- Use advanced product packaging, with shelf life extending attributes such as: reduced vulnerability to heat impacts, for example, reflective foil lined cardboard and low emissivity coatings in plastic film; microbial growth inhibitors; and, colour change sensors that indicate remaining shelf life more accurately than use by dates. Phase change materials may stabilise temperatures for longer. Advanced packaging may also be used to regulate other factors, such as humidity, that impact the shelf life of some perishable foods.
- Biochemical sensing technology to detect and transmit information about contaminants present in food well before the food deteriorates is currently under development, and is expected to be ready to deploy in around five years. This technology is likely to be embedded in food packaging. Greater understanding of the state of perishable products will allow better management of energy use in the cold chain by optimising conditions for those products.
- Prevent pathogens from contaminating food, for example, by processing food in sterile facilities, to reduce refrigeration requirements to ensure food safety.
- Precool/overcool product to store cooling in the products to minimise the cooling to be provided in the truck, particularly if food is very well insulated and stored. Warm product entering a truck, container or cold store can lead to a significant impairment in the performance of refrigerating equipment[48]. Truck refrigeration systems may many take hours to lower the temperature back to an acceptable level.
- A discussion regarding demand management could be explored with the energy supply market.
- Vision for super insulated pallets/shipping containers requiring minimal refrigeration in transit. There are potentially huge capital and logistics benefits in having non-refrigerated trucks being able to carry all food and other groceries. Example: http://coolpac.com/transport-chilled-frozen-product-in-non-refrigerated-truck/

[48] Estrada-Flores, S. (2008) *Top 10 reasons why a cold chain fails*. Chain of Thought *1(*1), 3-5

8 Next Steps

The Australian Alliance for Energy Productivity recommends the following actions be undertaken to utilise the information and findings in this report:

- Conduct pilot trials and detailed economic feasibility analysis to prove up the claims made by technology providers around the cost, effectiveness, and likely impact of implementing condition monitoring systems, and further define the full implementation costs (including problem rectification systems) and benefits, and to whom they accrue.
- Firm up some of the data around energy use in refrigeration, the causes of food waste, and potential savings that can be attributed to condition monitoring to overcome some of the serious data shortfalls that make it difficult to provide a more accurate industry wide business case.
- Support governments implement information and investment incentive programs to encourage selection of energy efficient/productive plant.
- Support AIRAH to establish a Cooling Knowledge Hub, providing there is demonstrated support from academic institutions, support from commercial stakeholders, and ongoing funding based on results.
- Examine how the refrigerated trucking industry can be provided with compelling incentives to lift the thermal performance of their vehicles.
- Further examine the potential for smart packaging to reduce the requirement for refrigeration of perishable food.

Appendix A: Cold chain stakeholder contributors

The list below contains the names of organisations and individuals that provided input to this report. We thank them for their contribution.

Australian Food and Grocery Council - Chris Preston
Australian Institute of Refrigeration, Air Conditioning and Heating – Phil Wilkinson
Air conditioning & Refrigeration Equip Manufacturers Association of Australia – Greg Picker
Americold - Melissa Hunt and Scott Eastwood
Bo Christensen Consulting – Bo Christensen
Carrier – Kelly Geddes
Chep – Justin Frank
CSIRO – Stephen White and Josh Wall
Data 61 - Peter Carter
Danfoss – Ian Jones
Emerson Climate Technologies – John Thorne
Food Agility Cooperative Research Centre - David Tomlins
Food Innovation Australia Limited - Mirjana Prica
Internet of Things Alliance Australia – Frank Zeichner
London South Bank University – Judith Evans
Massey University New Zealand – Don Cleland
NNN Co – Rob Zagarella, Margaret Wright, Eric Hamilton
NSW Environment Protection Authority - Amanda Kane
NSW Food Authority - Bruce Nelan and Alison Imlay
NSW Office of Environment and Heritage – David Malicki, Dan Granger and Jakki Trenbath
Orora – Wes Bray
Oxford Cold Stores – Gabor Hilton
Plant and Food Research Australia - Silvia Estrada-Flores
Queensland Thermoking refrigerated transport – Colin Apps
Refrigerated Warehouse and Transport Association - David O'Brien
RMIT Food Research and Innovation Centre – Harsharn Gill
SensaData – Scott McKenzie
Sensitech – David Bastock
SmartTrace - Don Richardson
Start Afresh – David Tanner
SuperTest/Euroscan Asia Pacific – Mark Mitchell
Thinkwell Australia – Michael McCann
Thinxtra – Loic Barancourt and Renald Gallis

Appendix B: Summary of stakeholder comments

A broad cross-section of participants in the cold chain were contacted in the course of conducting this project. A summary of comments made by stakeholders is tabulated below. Please note these comments are paraphrased, and are not verbatim quotes.

What are the most temperature sensitive goods in the cold chain with the most to gain from improved temperature control?
• Some fruit and veg are susceptible to chilling injury, as well as sensitivity to higher temperatures. CO2 levels, humidity, packaging also have an impact on quality. It is important to note that the temperature/time relationship is not the only factor impacting quality, and the impacts are very product specific. • Temperature variations impact quality for some products e.g. weight loss/shrivel for fruit and veg - as apples ripen they need to lose some moisture or their skin will split. However if there is too much moisture loss the skin shrivels. Most consumers will not notice a small amount of moisture loss, however this is an important issue for supermarkets as they sell by weight. • The most significant way to reduce energy use in the cold chain is by reducing food waste. Food waste is most often related to consumer behaviour. • Two types of items in the cold chain 1. Pharmaceuticals 2. Food. Most highly temperature sensitive foods include dairy, fruit and veg, meat and seafood. Seafood is both highly temperature sensitive and high value. Fruit and veg quality also dependent on respiration rates – C02 and humidity; evaporation from surface of product, affecting heat balance. Note that food safety issues are not always the same as spoilage issues. • Ice-cream - very temperature sensitive. Food quality a big issue – refreezing causes crystallisation. • Prawns – can be kept at any given temperature (within a range), but adversely affected by temp variation. • Meat, fruit and veg, cheese and nuts, are temperature sensitive, each with own peculiarities. • GCCA produce a product manual that can be accessed online by members. Contains optimal temperatures for products and advice e.g. do not store seafood in freezer with high fat content products such as ice-cream or nuts, as seafood smell may be absorbed by high fat products. • Seafood, fresh salads, live foods such as lobsters (high $ value), chilled meats - beef and lamb - local and export, fresh fruit& veg, dairy, etc. • Cooked, chilled foods (technical term is “refrigerated processed foods of extended durability”) are foods most prone to food safety issues such as botulism and listeria infection, spoilage and reduced shelf life due to temperature variation.

Could improved temperature control reduce the level of chilling/freezing required for perishable foods without compromising food safety and quality?
• Chilled products must be kept at 0-5 degrees for food safety reasons. Frozen products are kept at -18 degrees or below, as advised by manufacturer e.g. an ice cream manufacturer may advise storage of ice cream at -25 degrees. Ice cream may maintain quality at higher temperature, say -20 degrees, but manufacturer wants to allow a margin in event temperatures are not maintained throughout the entire cold chain. Significant energy cost reductions from freezing at -20 rather than -25 degrees. • Cannot run keep chilled foods at warmer temperatures without food safety risks, but may potentially be able to keep frozen foods at warmer temperatures – need to assess against food quality and safety risk. Frozen food regulations stipulate frozen foods must be "hard frozen" (Link for Standard 3.2.2 from the Food Standards code which specifies the temperatures for food https://www.legislation.gov.au/Details/F2014C01204/Download. A temperature is not specified for frozen food. The code requires that frozen food remains frozen during transport, receipt etc. Refrigerated foods must be at or below 5°C unless the relevant party can demonstrate that the use of another temperature is safe. High risk food covered by Safe Food Australia) • Frozen temperature defined as -18C, but the freezing point of different products varies, so one product may freeze at say -12C. Regulation change is required to allow freezing at warmer than -18C, but there is a fear of exposing the population to greater food safety risk. Need for risk management. • Chilled products – should be kept at no warmer than 4°C. Supermarkets generally keep chilled products at 1-2°C. This range is optimal for chilled products so do not advise keeping chilled foods at warmer temperatures. • Frozen products – industry standard is -18°C. However, many ice-cream manufacturers prefer ice-cream to be kept at -25°C. There are significant inefficiencies if temperatures are kept below -18°C as cold store systems are set up for -18°C. Ice-cream manufacturers may over-freeze ice-cream to allow a margin of error, assuming their product is likely to encounter higher temperatures than -25°C in the cold chain. • No - many countries have looked at this - but Australia is particularly a hazardous microbiological climate for chilled food/pharma - so, keeping at 0-5 C or 2-8 C critical. • America is well ahead of Australia with the introduction of their sanitary transportation act last year- FDA-FSMA-STF. You need some biological-science on your panel - and, it needs to be assessed with triple bottom line criteria - not only 'economic' - social & environmental impacts too. • Better to control temperatures more tightly than change the regulated temperature range.
How are temperatures typically currently controlled in the cold chain?
• AFGC cold chain guidelines provide default "never warmer than" and maximum periods out of refrigeration rules. Manufacturers can provide alternative guidelines if product requires it. Draft 2016 guidelines recommend speaking to food manufacturer before assuming all product is waste if there has been an issue with the cold chain. • Continuous temperature monitoring occurs within the cold chain facility using an in-house

temperature monitoring system (very accurate, to within 0.1 degree). Temperature variation outside the acceptable range results in a notification system being activated so swift ameliorative action can be taken rectify the situation.

- Freezers use less energy than chillers due to the effect of cold stored within the frozen goods.
- The temperature of product arriving at the cold store is checked before being accepted (a selection of pallets are temperature checked throughout the unloading process). If not within the acceptable temperature range, the food supplier is contacted. The product may not be accepted by the cold store or a note made on file of the temperature issue if a decision to accept the product is taken.
- Before product is transported from the cold store the temperature of the trailer is checked before being loaded. The product temperature is checked on arrival before being accepted by the customer.
- Data loggers may be inserted into food.
- Typically stationary refrigeration units have a thermostat setting the room temperature, say -18°C with 2°C fluctuation permissible.
- Common devices to retain temperatures in cold stores: floor sensors to register movement of forklifts in and out of cold stores; rapid roll doors; some, but not all, sites will have alarms that are triggered when cold store temperature moves out of range; most cold stores will have an ante room set to 2-5°C. Very capital intensive industry.
- High level of control exists in cold storage industry e.g. warehouse management systems in place for stock rotation, energy management systems.
- Department of Agriculture and Fisheries responsible for exports. Cold store industry closely intertwined with export businesses and needing to conform to export rules.
- Meat and Livestock Australia (MLA) developed set of Australian codes to aid export market. 15 years ago standardised bar coding system developed to identify cuts by sets of muscles, identify animal and animal's history. Cost of providing more data than this would be astronomical as bar codes can only hold a certain amount of information.
- Prawn industry trying to introduce RFID tags into cartons. Prawns frozen at sea. RFID tag will have day/time and GPS identification of where prawns were caught. Colour change temperature abuse sensors (pallet level, not carton due to cost) used by prawn industry. Might also be used by ice-cream manufacturers.
- Two types of colour change temperature sensors (passive i.e. no real time feedback):
    a. Data logger – different sizes, between the size of a mobile phone and a 20 cent piece. Decoded at the end of transportation. Not disposable.
    b. Adhesive stickers with impregnated with crystals that change colour if temperature varies. Disposable.
- Truck temperature controls are not always reliable so temperature loggers may be used. Number of loggers used on any given load depends on the level of perceived risk.
- Refrigerated trucks may contain a communications box for capturing air temperature data; a third party provides the communications services.
- There may only be a single monitor to take air temperature readings or more comprehensive monitoring using product probes may be used – it depends on the customer. Larger customers may require real time temperature and location monitoring relayed by satellite or GSM or GPS.

- In-transit is the most risky part of the cold chain most prone to temperature variations.
- For in-transit/mobile part of the cold chain temperature usually controlled only at the asset level, monitoring air temperature - and poorly. CSIRO trials showed product temperature was varying within the asset by 6°C.
- Product level temperature monitoring doesn't usually happen.

Where in the cold chain is there the greatest risk of experiencing issues with temperature control?

- Increased monitoring has reduced issues such as transport contractors turning off refrigeration to save fuel. A bigger issue is small delivery vans making many small deliveries, necessitating frequent door openings. Need to ensure van is loaded so last items loaded will be first items off.
- Issues with supermarket home delivery vans. Mix of ambient, chilled and frozen goods all transported at 4 degrees. Frequent opening of doors.
- Greatest risks occur when trucking perishables and points of transfer e.g. on loading and receiving docks. E.g. on Darwin to Perth route some truckies were turning off trucks, and therefore refrigeration, to reduce noise so they could sleep better.
- All cold chains have different issues depending on goods and transport type- air, sea or road. For example, air freight containers may contain high value products such as seafood. Period where containers are sitting on tarmac is most risky time as the containers are not designed to maintain constant temperatures for an extended period of time.
- A meat exporter had six containers of lamb exported to the US last year go bad. The exporter had not been using data loggers so it was difficult to identify the cause of the problem. Investigations revealed various issues such as the containers had sat at the port for an extended period of time in high temperatures and the vacuum packaging had not been properly sealed. The exporter has subsequently introduced a real time temperature monitoring system to identify and prevent reoccurrence of issue.
- Links/transfers in the logistics pipeline where temperature differentials exist e.g. produce waiting on loading dock – refrigerate dock to reduce temperature differential and risk.
- Human error e.g. truck turned off to save fuel
- Any situation where there isn't a tight air lock
- Mechanical failure – a low risk in cold stores as usually procedures in place to prevent refrigeration failing.
- Supermarket receiving docks a common place of problems with temperature control in the cold chain e.g. stock left for too long on dock
- In-transit is the weak link in the cold chain with temperature variability throughout refrigerated trailers/containers (old trailers, poor insulation, poor airflow control, human/equipment failure).
- Due to variability and cross docks/hand overs and Australian climate temperature abuse occurs which is often not recognised until consumer has product at home and wastes same or supermarket send to landfill.
- Truck doors being left open is a major cause of temperature variation and excess energy

use.

What is the impact of temperatures in the cold chain varying from the acceptable range?
• Some supermarkets have good data on in-store wastage but it is confidential, and some have programs to reduce food waste. (About 10% of supermarket waste is donated.) About 25% of waste is organic, so looking at what can be done with it. • Food processors tend to be able to utilise food waste to make other products such as pet food, fertiliser and not put it into landfill. • Reverse logistics – utilising empty delivery trucks to take food waste to distribution centres. • Sydney Waster Cronulla co-digester – working well, but regulatory issues with meat. • Circulate program – commercial and industrial food business waste program. • Love food hate waste – waste avoidance program. • Increased incidence of botulism in Europe may be linked with increased use of cooked, chilled foods. • Increase in listeria infection outbreaks in US for processed meats related to unhygienic factories and issues with refrigeration storage temperatures. Industry fixed these issues, at great cost, once they became aware of issues. • Data on decrease in food losses achieved by deploying real time temperature monitoring tags is not widely available as there is a competitive advantage associated with reducing food losses. However, it can be assumed there is a benefit in using tags for some foods, or otherwise they wouldn't be used. • Because of human frailty need automatic visibility - hidden upstream cold chain abuse results in massive downstream losses in 'Supermarkets' and 'Homes' - collectively >30% in USA. Share price sensitive -loss of product vitality, nutrition - resulting in product waste.
How could control of cold chain temperatures be improved?
• Increase awareness of the rules and processes to activate when there has been a problem with temperature control in the cold chain – a matter of education and training. • Change behaviour e.g. AIRAH "Cool room hero" fact sheets that encourage more energy efficient behaviour such as reducing door leakage and stacking cool rooms at cool time of the day. • Reduce refrigerant leakage on trucks, which leads to temperature variations. • Top 2 cold store costs are labour and electricity - therefore the cold store industry is very motivated to promote labour and energy efficient practices. Refrigeration is by far the biggest user of energy in cold stores. Lighting is also a significant user of energy. Increasing electricity prices have a big impact on cold store profitability. • Staff training and company culture are fundamental to ensuring labour and energy efficient practices are followed. • Major opportunities for improving the energy performance of cold store facilities lie in improving the fabric of the buildings and installing equipment such as automatic rapid roll doors and air seals. • Many Australian cold stores are 30+ years old and in need of refurbishment, presenting an opportunity to upgrade facilities to be more energy efficient. • There is potential to improve the insulation of truck trailers using light weight and

laminated materials

- Information sharing in trucking food should be increased. At present, the trucking company is not informed what food is being carried and what the temperature is set at – the food wholesaler sets the temperature. There is a lack of transparency about who is at fault/liable if food is spoiled. Temperature control needs to be demonstrated from farm to retailer.
- There are many very simple, but very impactful, actions that can be done to improve temperature control e.g. trucks should be "cold soaked" i.e. pre-cooled before produce is loaded, but this is not always done; doors are often left open too long on loading docks.
- Most temperature monitoring equipment just measures air temperature but need product level temperature monitoring.
- Get companies to commit to cold chain guidelines and have a certification process.
- Truck testing facilities e g. Supercool facility in Brisbane.
- Focus on reduction in food waste (which also has carbon reduction benefits). Federal Department of Energy and Environment is conducting a round table on food waste w/c 10/4/17, followed by a Summit and release of a national strategy to reduce food waste in late November.
- Improve the insulation of truck trailers.
- Use of monitoring technology (use both) e.g.:
    - Euroscan (Dutch cold chain monitoring specialist company): attached to truck or trailer to monitor performance of trucks' refrigeration system. Real time alerts.
    - Sensitech: tags placed inside the product box to monitor temperature of produce throughout the cold chain. Data is either downloaded at end of chain, but an option for real time transmission of data exists.
- Improved engagement with transport logistics companies: performance metrics – reward positive behaviour, star rating for product quality; better controls including better air circulation.
- Phase change materials – Frank Baruno, University of SA – unrefrigerated truck.
- Refrigerant leakage is a big issue (containers brought into Australia)– use sensors?
- A lot of gains to be made around improving segregation of fruit such that fruit that is most suitable for storage is stored, while fruit that isn't suitable for storage is taken straight to market. Not so much about temperature control as understanding what needs to go to market first.
- Supermarkets put a lot of effort into controlling the environment up to the point of sale, but do not educate consumers how to look after produce when they get it home.
- Track and trace/IoT creates opportunity to make a correction at time things go wrong. However, does not necessarily tell you how to fix system if there is a chronic issue.
- A lot of existing cold stores do not have insulated floors, however not cost effective to retrofit, but worthwhile to include insulated floors in new builds.
- Provide actionable real time monitoring of product temperatures - in transit by connectedness - IoT - to maximum extent affordable and determined by supplier's perception of risk to load rejection - more measurement devices for older trailers, etc.
- Provision of real time data required to improve temperature control in the cold chain. Use miniaturised reporting e.g. feedback to driver to take action if issue identified.

- Ideally real time temperature monitoring should occur from paddock to plate and would have significant benefits for improving food quality, safety, shelf life. Expect that paddock to plate real time temperature monitoring will eventually become industry standard, driven by consumer pressure and competitive pressure (i.e. to protect reputation for quality product)
- Other improvements in cold chain need to occur to maximise benefits of real time temperature monitoring, for example: improved control of other environmental factors such as humidity; improve compliance with standards for trucks and facilities; set up systems to respond if temperature goes out of range – ideally automated decision making as this makes it easier for smaller businesses to respond; use of advanced packaging that can extend shelf life, say by inhibiting microbial growth or has colour change sensors that indicate remaining shelf life (more accurate than use by dates, and avoids good food being thrown out as it is past an overly conservative use by date.)
- Some current RMIT Food Research and Innovation Centre projects relevant to cold chain optimisation project:
    - Adding value to waste streams
    - Developing packaging that will prevent microbial growth. Technology currently exists to include sensors on packaging that change colour as shelf life declines, but resistance from industry to adopt
    - Monitoring animals at processing plant prior to slaughter to detect dirt or injuries that would lead to contamination of plant. If, say dirt is detected, animal is diverted to washing bay to be cleaned before entering processing plant.
    - Developing sensors that predict quality of meat before animal is slaughtered, based on 4 or 5 indicators that are tracked while animal is alive
    - Developing sensors to detect gastro intestinal tract responses to different foods and food quality e.g. detect fungus growth resulting from treatment in supply chain

What are the barriers (technological, economic, organisational, regulatory etc) to improving control of cold chain temperatures?

- Cost – though this is becoming less relevant as technology costs decrease in price
- Personnel – investment required in cold chain handlers to ensure they understand guidelines. High turnover can be an issue is some parts of the industry. All food businesses must have a food safety supervisor.
- Standards for refrigerated vehicles exist, but they are not always followed – some truck trailer manufacturers don't even know the standards exist. Trailers often poorly maintained and with inadequate K factors (insulation value of the box). There is only one testing facility in Australia - Supercool in Brisbane. European ATP standards are the most developed standards.
- Trials have been run in banana supply chain using smart assets with real time data transmission capabilities, however probably won't progress at this time due to high costs. Need to be fitted with technology that can withstand water and heat as they get washed in hot water for hygiene reasons. Readers need to be installed at all receiving sites, therefore resulting in high infrastructure costs.
- Probably the main issue is that each sector of the cold chain tends to be organised and operated by different actors. It is therefore difficult to get an integrated system operating

unless you have the reach of a company such as Danfoss. Potentially it is possible to track food throughout the actively managed sectors of the cold chain and make decisions on whether food should be sold quickly to prevent waste or can be kept for longer. Also, adjust temperatures according to the shelf-life of the product. Making decisions about large batches of food is problematical as it is unlikely that temperatures are consistent through a load/batch of food. It therefore requires some quite complex predictions to make sure that the best decisions are made for quality/safety/reduced waste.

- There are plenty or TTI, RFID tags available that could help provide information on food temperatures throughout the cold chain. However, cost is an issue. Also I feel that sometimes there is no real perceived value from such information as it may potentially add complexity to how food is handled.
- Cost – but costs of systems coming down.
- IoT can help identify a problem, but it won't fix the problem.
- Issues with truck fleets being old, and expensive to retrofit.
- Energy efficiency/environmental issues associated with refrigerant choice.
- Cost of equipment
- Subcontracting arrangements/split incentives/large number of people involved in the cold chain – if continuous monitoring does not take place, then it may be unclear who is at fault when goods are in poor condition. Generally monitoring is only instituted as a reaction after a problem is identified, not routinely carried out.
- A combination of high electricity prices and high tech new entrants to the cold store industry are squeezing existing participants. Existing participants can't afford to invest in new technologies due to increasing operating costs, driven by increasing energy prices. Some new entrants engaging in pricing practices that have the potential to drive existing operators out of the industry, and reduce competition in the long term.
- Technology is not an issue – the issue related to technology is cost – who pays? For example, retailers do not want to pay for suppliers' technologies costs.
- Food safety risk exposure
- A standard to test refrigeration trucks exists, but is not used as it is too expensive. Truck insulation could be improved but then there is an issue with making the trucks wider.
- Cost is a significant barrier to introducing real time temperature monitoring systems, particularly for small and medium players, and many participants in the food industry are SMEs, often operating on lean margins. Larger operators like the big supermarkets generally have much better systems in place.
- The feasibility of paddock to plate real time monitoring will depend on product value and there is currently a lack of agreement as to who is responsible for bearing the cost of introducing food monitoring systems.
- Barriers to monitoring temperatures – cost and practicality. Trade-off between cost and benefit. Lots of devices are available but they are not always worthwhile. It is a waste of time and money to have pallet level sensors communicating back to base in cold stores as rooms are already being monitored. Shipping is the part of cold chain where real time sensors can provide the most benefit. Apply sensors to a sample of pallets.
- A major concern of the cold store industry is the reliability and affordability of the energy

supply. Growing demand for chilled and frozen goods will lead to increased energy demands from the industry.

- Cost is still a barrier for many; there is the cost of the data capture components of the system, but also the cost of managing and responding to the data captured.
- There are technical barriers with some wireless technologies. RF cannot transmit great distances through water (and most food products are largely water). Parts of the chain are difficult to get real-time information from; the sea-freight sector of the chain is cost-prohibitive to get information transferred (as it is by satellite connection) and so users often have their technology hold the information and transmit upon arrival in a destination.
- A further barrier is that the communication units from start-up companies are not everywhere. This technology would be incredibly powerful if every distribution centre and port in the world had full coverage and transmission power.
- Not many barriers - has been technology in the past - but doable these days and more cheaply. Australia has been very slow in regulatory/guideline sense - still not issued latest copy of Australian Cold Chain Guidelines due to disputation between the key parties.
- Many small freight operators – greatest opportunities to improve control and increase compliance. Supermarkets motivated to comply as customers unhappy when product is spoiled/reduced shelf life/increased waste.

What emerging/innovative ICT solutions are being researched or beginning to be implemented in Australia or overseas that could improve control of cold chain temperatures?

Examples of world's best practice?

- McDonald's sets the gold standard in transporting perishables with real time monitoring. Very efficient and process oriented.
- EU food waste reduction program, FUSIONS: Food Use for Social Innovation by Optimising Waste Prevention Strategies. http://www.eu-fusions.org/
- Martin Brower/McDonald's logistics is the gold standard
- Precooling control strategies for cold stores; thermal mass; demand management in cold stores – Batlow apples
- Meat industry – AMPC, MLA – grant funding
- Active RFID tags for cold chains
- I'm not aware of any fully integrated systems for the whole cold chain. Most systems seem to be dedicated to a sector of the cold chain. There is very little control once consumers take control, although there are beginning to be some 'smart' fridges come onto the market.
- Danfoss have been developing the Cool.it cold chain monitoring system which aggregates information from different IoT temperature monitoring systems throughout the cold chain.
- In Europe the Frisbee project looked at developing the cold chain through a number of initiatives http://frisbeetool.eu/FrisbeeTool/about.html . The project was coordinated by Irstea in France (Dr Graciela Alvarez).
- IoT of food – Wageningen University, The Netherlands
- Fridoc – IIR website

http://www.iifiir.org/ClientBookline/toolkit/p_requests/formulaire.asp?GRILLE=IIFRRECHFRIDOC&PORTAL_ID=portal_model_instance__fridoc_search_en.xml&INSTANCE=exploitation&SETLANGUAGE=EN • FRISBEE – EU project, cold chain database - http://frisbee-wp2.chemeng.ntua.gr/coldchaindb/ • Innovative insulation materials: http://www.worldtravelcateringexpo.com/__novadocuments/45300?v=635271250245930000. http://www.brainandwork-catertech.de/?page=prod&sub=scen&opt=coldstorage&optsub=sandwiches&lang=en • Pharma – food has a lot to learn from pharma. There are many transferable concepts and practices. Key organisations include the WHO, the PDA (cold chain interest group), the CDA. • European standards ATP agreement on transport of perishables (performance standards in force for approximately 30 years). Europe sets the gold standard and has the critical mass (that Australia lacks) to have testing stations. • The GCCA holds an annual trade expo showcasing innovations in the cold chain http://www.globalcoldchainexpo.org/ • World's best practice - for approx. 6 years now, Zespri have been engaged with an Israeli company, BT9, that produces a wireless RFID technology (Xsense) that measures temperature and relative humidity in packaged goods. Zespri have their pack houses place an Xsense tag in every 10th pallet of kiwifruit and this then transmits the temperature of that pallet from time of creation until sale to a customer in market. The system is made up of the Xsense tags and communication units that transmit information to the cloud either via 3G cellular network or via LAN connection. Smartphone Apps alert the user to temperatures out of range, and to the tag reaching different parts of the supply chain through shipment arrival notifications. This technology is used with a number of businesses in New Zealand, including pharmacies to monitor drug fridges to ensure vaccines are not subjected to temperatures outside of their recommended range. • More stringent temperature monitoring in pharma driven by government regulation and liability. Compliance often enforced by drug manufacturers as efficacy of drugs is affected by temperature.
Other stakeholder comments
• Labour and energy are the biggest costs for cold storage businesses. Most businesses lock in long term energy contracts, with many contracts coming to end in near future. Expecting very large increase in energy prices for new contracts (i.e. rates could double). Industry already very energy efficient (LED lighting, compressors controllers etc.). • The maximum width trucks are allowed to be is 2.5 metres, without being designated extra wide. If the trucks could be 2.6 metres wide, which would require regulatory change at state and federal level, trucks could be much better insulated. Better insulation would greatly reduce fuel consumption and increase efficiency by about 30%. • AFGC cold chain guidelines priorities: 1. Food safety 2. Food quality 3. Improved efficiency/reduction in food waste • 2013 is current published version of cold chain guidelines. 2016 draft yet to be released as

agreement with stakeholders yet to be reached. 2016 version contains a new appendix on monitoring and new stock rotation rules and introduces guidelines for consumers and retailers.

- There is a big export market in manufacturing refrigeration equipment.
- Cold storage is a heavily regulated industry.
- Food for export typically more stringently monitored for temperature control. Domestic suppliers less likely to monitor unless they are having problems that are costing them money.
- There has been increased interest in temperature monitoring over the last six months. It's all about maximising shelf life (to maximise profits). Usually difficult to tell a product has suffered temperature abuse until after it has arrived at the supermarket and it has shorter than expected shelf life.
- Liability if goods do not arrive in good condition –supplier/transport company/insurance usually have to sort it out.
- See great value in being able to improve fresh food freshness, food waste, loss of shelf life, reputation. Transport and logistics is not done very well in terms of keeping food at its optimal temperature range.
- Blockchain could be an enabler of more efficient and lower cost services in the cold chain for services that are data intensive and highly controlled. For a blockchain to work, you need to understand how the whole chain works to ensure at no stage the good is outside the cold environment to create blockchain code.
- Growth of fully automated dark stores – need long term contracts to justify investment in the technology. If a distribution centre is very tall, it indicates it is an automated centre, with high bay facilities (too high for forklifts). Dark stores are more efficient to keep cool.
- Advancements in monitoring device technology may mean devices are eventually 3D printed.
- Thermoshield – applied painted finish, built up coat by coat to stop heat transfer. If a truck or shipping container is sprayed with Thermoshield, a lot less diesel is required to keep product cold. No more expensive than ordinary paint.
- Vehicle standards: Australian is not a laggard, but definitely not a leader.
- Real time monitoring: very complex problem to be resolved e.g.:
    - Communications coverage and other technical issues
    - Economic feasibility – getting close but not quite there.
    - How to make the data into valuable info and deliver timely feedback to rapidly rectify problems

Appendix C: Relationship between shelf life and temperature

The following table, reproduced from the report *Quality characteristics, factors of spoilage and shelf-life models for selected foods*[49] shows the shelf-life in days of a variety of fruits and vegetables at a range of temperatures, from 0°C to 38°C. Note that for some products, such as tomatoes, mangos, guavas and bananas, shelf life increases as temperature increases above 0°C until the optimal storage temperature is reached, after which shelf life begins to decline at higher temperatures.

Figure 8 – Shelf life of selected fruits and vegetables stored at 0°C to 38°C

T (C)	T (K)	Keeping quality (or shelf-life)									
		Carrot, unwashed	Cauliflower	Tomato	Potato	Okra	Brinjal	Mango	Guava	Apple – Red Delicious	Banana
0	273.15	188.91	41.94	0.01	474.47	1.07	2.07	4.56	3.57	90.29	0.03
2	275.15	99.54	28.18	0.05	342.04	1.91	3.71	7.97	5.17	76.36	0.14
4	277.15	52.94	19.04	0.17	247.75	3.37	6.37	13.36	7.33	64.74	0.54
6	279.15	28.41	12.94	0.64	180.28	5.79	9.96	20.54	10.03	55.01	1.99
8	281.15	15.38	8.84	2.20	131.77	9.47	13.20	26.86	12.88	46.86	6.32
10	283.15	8.40	6.07	6.39	96.75	14.00	14.00	28.00	15.00	40.00	14.00
12	285.15	4.63	4.19	12.28	71.34	17.37	12.15	23.60	15.36	34.22	19.29
14	287.15	2.57	2.91	14.37	52.83	17.28	9.31	17.40	13.78	29.34	19.84
16	289.15	1.44	2.03	12.85	39.29	14.24	6.73	12.05	11.10	25.21	18.41
18	291.15	0.81	1.42	10.58	29.33	10.49	4.76	8.15	8.35	21.71	16.63
20	293.15	0.46	1.00	8.56	21.99	7.35	3.34	5.48	6.05	18.73	14.94
22	295.15	0.26	0.71	6.90	16.55	5.05	2.35	3.68	4.31	16.19	13.41
24	297.15	0.15	0.51	5.58	12.50	3.45	1.66	2.49	3.05	14.03	12.06
26	299.15	0.09	0.36	4.52	9.48	2.36	1.17	1.69	2.15	12.18	10.85
28	301.15	0.05	0.26	3.67	7.21	1.62	0.83	1.15	1.52	10.59	9.78
30	303.15	0.03	0.19	2.99	5.51	1.12	0.59	0.79	1.08	9.22	8.82
32	305.15	0.02	0.14	2.44	4.22	0.78	0.43	0.54	0.77	8.05	7.97
34	307.15	0.01	0.10	2.00	3.25	0.54	0.31	0.37	0.55	7.04	7.21
36	309.15	0.01	0.07	1.64	2.51	0.38	0.22	0.26	0.40	6.16	6.53
38	311.15	0.00	0.05	1.35	1.94	0.27	0.16	0.18	0.29	5.41	5.93

The *Quality characteristics, factors of spoilage and shelf-life models for selected foods* report also contains tables demonstrating the relationship between temperature, starting at 0°C, and shelf life for raw beef, poultry, raw carp fillets and liquid milk. For all these products, the lower the storage temperature, the longer the shelf life. These tables are reproduced below.

[49] Estrada-Flores, S. (2010). *Quality characteristics, factors of spoilage and shelf-life models for selected foods*.

Figure 9 – Shelf life of raw beef stored at 0°C to 38°C

T (C)	T(K)	Shelf-life (hrs)
0	273.15	349
2	275.15	280
4	277.15	225
6	279.15	181
8	281.15	147
10	283.15	119
12	285.15	97
14	287.15	79
16	289.15	65
18	291.15	53
20	293.15	44
22	295.15	36
24	297.15	30
26	299.15	25
28	301.15	21
30	303.15	18
32	305.15	15
34	307.15	12
36	309.15	10
38	311.15	9

Figure 10 – Shelf life of poultry stored at 0°C to 26°C

T (C)	T(K)	Shelf-life (hrs)
0	273.15	299
2	275.15	173
4	277.15	114
6	279.15	82
8	281.15	62
10	283.15	50
12	285.15	41
14	287.15	35
16	289.15	30
18	291.15	27
20	293.15	24
22	295.15	22
24	297.15	21
26	299.15	20

Figure 11 – Shelf life of raw carp fillets stored at 0°C to 30°C

T (C)	T(K)	Shelf-life (hrs)
0	273.15	288
2	275.15	226.6
4	277.15	178.3
6	279.15	140.16
8	281.15	110.2
10	283.15	86.6
12	285.15	68.2
14	287.15	53.8
16	289.15	42.2
18	291.15	33.1
20	293.15	26.2
22	295.15	20.6
24	297.15	16.1
26	299.15	12.7
28	301.15	10.1
30	303.15	7.9

Figure 12 – Shelf life of milk stored at 0°C to 30°C

T (C)	T(K)	Shelf-life (hrs)	
		Raw milk	Pasteurised milk
0	273.15	36	485
2	275.15	24	255
4	277.15	17	157
6	279.15	13	106
8	281.15	10	77
10	283.15	8	58
12	285.15	7	45
14	287.15	6	37
16	289.15	5	30
18	291.15	4	25
20	293.15	4	21
22	295.15	3	18
24	297.15	3	16
26	299.15	3	14
28	301.15	2	13
30	303.15	2	11

Appendix D: International work on cold chain temperature monitoring and optimisation

This appendix covers our review of international experience in implementing best practice cold chain optimisation.

The tables below summarise examples of work conducted internationally on cold chain temperature optimization, excluding the consumer stage, with particular emphasis on examples that use ICT to improve monitoring of temperatures. The first two tables provide commercial examples of the implementation of measures to optimize cold chains. The focus of the first table is the food cold chain.

In the second table, we include examples from the pharmaceutical cold chain because they supply very high value products, and some pharmaceutical products such as vaccines are highly temperature sensitive. This has driven the pharmaceutical industry to implement practices and technologies that are not yet cost effective in the food sector, including advanced methods for storing and transporting these items, often combining insulated packaging with monitoring to ensure maintenance of appropriate temperatures.

The final table provides examples of research into temperature optimisation, including research conducted by a number of the stakeholders consulted in the preparation of this report. It is recommended that further research into the value of improved temperature control in the cold chain be supported.

D.1 Implementation of cold chain optimization measures - food

Bosch, Germany: smart sea containers

The German federal government has funded a research project investigating smart monitoring of cargo containers. Under conventional conditions, approximately one-third of bananas shipped to Europe from South America do not withstand the two week sea voyage. The project equips containers on a cargo ship with wireless sensors that continuously monitor the fruit, acting as a digital bridge between the container's interior and external recipients at the food producer. If the temperature inside the container falls below 11 degrees Celsius, an alarm is triggered at the food producer, who can take steps to remediate the situation.

Bosch is considering a follow up project that covers all steps of the logistics chain, from loading the container to delivery of goods at supermarkets, utilising the internet of things to optimise temperature control.

Benefits:

- Nearly 10 per cent more fruit per load survives the sea journey.

Barriers:

- Value of reduced spoilage must outweigh cost of utilising sensor technology to be economically viable.
- Recipient of data must be in a position to initiate timely remediation action if alarm is triggered.

http://www.bosch-presse.de/pressportal/de/en/sustainably-from-field-to-plate-bosch-provides-innovative-solutions-72000.html

McDonald's, Asia: temperature control of perishable products in refrigerated transport

As an internationally recognised brand, McDonald's regard food safety and quality as a serious reputational issue. Every perishable product used in McDonald's stores is delivered on a refrigerated truck. HAVI Logistics Asia ships approximately one million tonnes of McDonald's product throughout Asia each year. Of the total, about 450,000 tonnes of product is temperature sensitive. HAVI adopted Euroscan continuous temperature monitoring in 2011 as it is able to monitor product temperature as well as the ambient temperature inside the truck.

Benefits:

- Temperature information provided on a docket printed in the truck cabin has replaced the need for spot checks at receiving docks to ensure chilled and frozen foods are within the correct range.
- Can provide verification of cold chain control standards compliance and if required, use journey information to correct behaviours such as excessive door opening times or insufficient truck precooling times: saving time and money.
- Provides alerts that maintenance is required if a pattern of borderline temperatures is experienced.

https://www.supercool.com.au/assets/pdfs/products/euroscan/News_McDonald'sAug2014.pdf

Genting Garden, Malaysia: temperature monitoring for salad delivery trucks

Due to relatively warm temperatures and high humidity, salad production can only take place in Malaysia in the mountains. Salad producer, Genting Gardens, uses multi-purpose trucks to deliver a wide range of produce to shops and restaurants without returning to base. Trucks were installed with Hanwell iSense to monitor temperatures. The iSense GPRS transmitter is a self-contained unit enabling remote monitoring of a variety of parameters via wireless GPRS technology. Alarms were set up to wirelessly relay temperature fluctuations back to base and to the driver so action may be taken if required. RL1001 temperature transmitters were installed in cold rooms and production areas.

Benefits:

- Reduced stock losses.
- Cost savings.
- Improved product quality.

https://www.the-imcgroup.com/case-study/genting-garden/

Zespri, New Zealand: temperature monitoring of packaged kiwifruit

Zespri have been engaged for approximately six years with an Israeli company, BT9 (http://www.bt9-tech.com/), that produces a wireless RFID technology (Xsense) that measures temperature and relative humidity in packaged goods. Zespri have their pack houses place an Xsense tag in every 10th pallet of kiwifruit and this then transmits the temperature of that pallet from time of creation until sale to a customer in market. The system is made up of the Xsense tags and communication units that transmit information to the cloud either via 3G cellular network or via LAN connection. Smartphone apps alert the user to temperatures out of range, and to the tag reaching different parts of the supply chain through shipment arrival notifications.

Benefits: • Traceability and transparency in the cold chain. • Continuous monitoring of environmental conditions. • Automatic alerts to temperature breaches, allowing corrective action to be taken, and reduce waste. http://www.zespri.com/storyofzespri/sustainability http://www.bt9-tech.com/wp-content/uploads/2015/01/Xsense-Leaflet-English-2015.pdf
Cherry exporter, Turkey: reducing losses shipping to Europe Use of a RFID near real-time temperature monitoring and alert system allowed an exporter shipping cherries from Turkey to various destinations in Europe to identify a number of process failures and correct them. Prior to installing the system, some cherries had suffered freezing injuries from temperatures dipping too low, and others had suffered excessive warming while being shipped. Benefits: • In the course of one season the cherry export made 253 shipments and 93 alerts were received across those shipments. Savings made in both product downgrading ($300,000) and insurance premium savings ($100,000) were approximately US$400,000. • Given 1 tag was used in every pallet, the total cost of implementation was approximately 16-20% of the saving (note that these savings do not include the reduction in labour cost for handling defective product, or brand enhancement) Tanner, D. (2016). You can't manage it well if you don't measure it: RFID technologies for improving your supply chain. Presentation made at the 4th IIR International Conference on Sustainability and the Cold Chain, Auckland, New Zealand. April 7-9, 2016.
Danfoss, Denmark: Cool.it cloud-based platform for collecting temperature sensor data In September 2016 Danfoss commenced trialling Cool.it, a cloud-based platform that collects temperature and product data from multiple silo sources such as producers, transport operators and supermarkets. Cold chain participants are able to view and track temperature data for stock in a simple and easy to use dashboard as it proceeds though the cold chain, promoting transparency and traceability. Cool.it includes a real time alert facility that sends an email to users if temperatures exceed limits set by users and identifies any point in the process where temperature is at risk. http://www.danfoss.com/ http://cool.it/
Walmart, US: cold supply chain inventory tracking system Walmart investigated the use of RFID technology and digital temperature recorders in its cold supply chain inventory tracking system. The state-of-the-art technology and network design allows Walmart to accurately forecast demand, track and predict inventory levels, create high efficiency transportation routes, monitor and manage the effects of various temperature conditions on

perishable produce.

The aim of the combined RFID and digital temperature recorder tracking is to decrease shrinkage due to food spoilage and to have faster response to equipment failure. This design allows the user to access both the traceability and sensor information.

Benefits:

- Supply chain optimisation, waste reduction and increased availability of perishable products through efficient inventory management.
- Reduced shrinkage (water loss) translates into higher sales revenue for product sold by weight.
- Monitoring assists with identification of faulty cold chain equipment, reducing energy and product wastage.

http://www.freshplaza.com/article/114875/Wal-Mart-approves-digital-temperature-recorder

http://www.iifiir.org/userfiles/file/publications/notes/notefood_04_en.pdf

Asda supermarket group, UK: chilled distribution depot upgrades

Asda introduced Silvertree Engineering's IceSpy System5 advanced wireless temperature monitoring and alarm system to improve the efficiency of cold storage facilities and maintain the quality of products. The system is designed to ensure optimum temperatures are maintained. It also saves time previously spent by staff doing manual checks by automatically recording and transmitting temperature data. The system can be used throughout the supply chain and data viewed through the web.

Benefits:

- 7% reduction in annual energy costs after introduction of advanced monitoring system
- Part of wider energy-saving initiative which resulted in an overall cost reduction of approx. £85,000 (17%)

https://www.the-imcgroup.com/app/uploads/AsdaDistribution.pdf

Tesco Stores, Malaysia: refrigerated transport management system

Tesco, one of the largest supermarket chains in Malaysia, have installed the Astrata fleet, driver and cold chain management system in their trailers. The system will be used to manage temperature and also prevent fuel theft and excessive fuel consumption, reducing operational loss and increasing efficiency through automation. The system includes: live remote temperature monitoring; multiple temperature zones and warnings; compressor status alarms and SMS alerts; excessive cargo door opening alerts; and, audit trail and data dashboards.

Benefits:

- Improved food quality
- Reduced food waste
- Reduced fuel use and cost

http://astratagroup.com/tesco-malaysia-chooses-astrata-to-provide-premium-cold-chain-solutions/

http://astratagroup.com/wp-content/uploads/2015/07/A4-March-2015-v1.4-Cold-SAFE.pdf

Art of Meat butchery, UK: wireless temperature monitoring system for chiller and refrigerated display units

Gourmet butcher installed IceSpy's Notion Lite wireless temperature monitoring kit to record real-time data 24/7 for meat chiller and two refrigerated display unit to cloud-based software accessible from a PC, tablet or smart phone. Alerts are issued if temperature issues are experienced.

Benefits:

- Continuous monitoring, including out of hours.
- Assists butcher with HACCP compliance requirements.
- Reduces risk of damage to stock caused by refrigeration failure.

https://www.the-imcgroup.com/case-study/butchers-haccp/

School of engineering and natural sciences, University of Iceland: fish cold chain trials

Operation of field trials and follow up activities to test functionality of technologies to improve quality, safety and traceability in fish supply chains.

Benefits:

- Establishment of standard operating procedures.

Barriers:

- Many steps in the supply chain.
- Different motivations of participants in the supply chain.
- Cultural and language barriers.

http://www.chill-on.com/images/pdf/4_3_Haflidason.pdf

Chill-on project, Europe: cooperative projects

European Union funded project to improve the quality and safety, transparency and traceability of the chilled/frozen supply chain by developing cost-effective novel technologies, devices, and approaches for continuous monitoring and recording of relevant data and processing the data for information management throughout the entire supply chain.

Benefits:

- Co-ordinated approached to improving the cold chain.

Barriers:

- Cost.
- Difficulties calculating return on investment.
- Need to develop global RFID standard.
- Need to develop transparency and collaboration across the cold chain.

http://www.chill-on.com/

Agreement on the International Carriage of Perishables Foodstuffs and on the Special Equipment to be Used for Such Carriage (ATP), Europe

The ATP is a UN agreement relating to the international carriage of perishable foodstuffs and the equipment to be used for such carriage. It has been signed by 48, mainly European, countries and has set performance standards for approximately 30 years. Europe sets the gold standard on transport of perishables and has the critical mass to have enough testing stations to ensure compliance.

• Text of ATP agreement: http://www.unece.org/trans/main/wp11/atp.html • Cemafroid (http://www.cemafroid.fr/index-en.htm) is a French organisation that provides testing services to ensure compliance with the ATP and other certification programs.
Fraunhofer IVV, Germany: active packaging materials Innovative sustainable packaging that provides protection against microbial contamination, which adversely affects shelf-life and food safety. Benefits: • Improved shelf life and food safety. • More sustainable packaging https://www.ivv.fraunhofer.de/en/forschung/-materialentwicklung/forschungsprojekte.html
GS1, international: standards for data capture GSI is an organisation focused on the development of common standards for barcodes and other forms of data capture, including specifically for the transport and logistics industry and foodservice industry. Benefits: • Increase speed to market and supply chain efficiency. http://www.gs1.org/transport-and-logistics http://www.gs1.org/foodservice
Sainbury's supermarkets, UK: testing cryogenic refrigeration for delivery trucks Sainsbury is the first customer to use Carrier Transicold's prototype natural refrigerant trailer unit that uses carbon dioxide refrigerant as part of a three year trial commencing in 2016. While this is not an IoT technology, it is relevant to improving the energy productivity/efficiency and carbon emissions of refrigerated transport. http://www.globalcoldchainnews.com/sainsburys-tests-cryogenic-refrigeration/
Carrefour supermarkets, France: carbon-dioxide refrigeration systems Huge French supermarket chain Carrefour is switching to carbon dioxide-based refrigeration systems in its stores to reduce emissions. http://www.globalcoldchainnews.com/carrefour-turns-to-co2-refrigeration/
Olivo Cold Logistics, Australia and internationally: insulated shipping containers Reusable insulated shipping containers that keep products chilled or frozen during delivery without the need for a refrigerated truck, allowing chilled, frozen and dry goods to be transported in a single truck. In Australia, used by Laurent Patisseries to transport delicate cakes daily and by seafood wholesalers to deliver product to restaurants. http://coolpac.com/transport-chilled-frozen-product-in-non-refrigerated-truck/

D.2 Implementation of cold chain optimisation measures – pharmaceutical

Cryopack – Mirador, Canada and Europe: innovative insulated packaging and real-time temperature monitoring

Cryopak produces packaging incorporating innovative materials such as phase change materials. Phase change materials provide advanced thermal protection when shipping temperature sensitive products. When PCMs melt and freeze, or change phases of matter between solid and liquid, they maintain a constant temperature equal to their melting/freezing point. They are specially formulated to change phases at specific temperatures to match the payload requirement.

Cryopak also supplies the Mirador real-time monitoring system for tracking temperature, humidity, differential pressure and other environmental conditions. Access to data via internet and/or intranet. Alert notifications via text to mobile phone, email or pager.

http://www.cryopak.com/temperature-monitors/mirador-real-time-monitoring/
http://www.cryopak.com/packaging-and-refrigerants/phase-change-materials/what-is-phase-change/

MNX Global logistics, international: real time shipment monitoring using SenseAware technology

Tracks location and sensor tracking includes humidity, temperature, light and shock.
www.mnx.com/gps_tracking_service.aspx

DHL SmartSensor GSM, international: near real time monitoring

Near real time tracking of temperature, humidity, shock, light and location.

http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/smartsensor.html

ThermoSafe and Cardinal Health, US: phase change panels

A project to standardise cold chain practices led to a 50% reduction in spoiled product being returned from local pharmacies to Cardinal Health, a major US healthcare products distributor. The project expanded and led to the development of Sonoco's ThermoSafe PureTemp phase change panels, which provide temperature-specific cooling in tote bags Cardinal uses to ship products to pharmacies. The PureTemp panels are cost-effective if they can be used at least eight times. In reality they are being used up to 87 times. Spoiled product returns have been reduced by 85%, over a period where the volume of cold chain product grew 50%, approaching $21 billion per year. The project has been expanded again with reusable containers using PureTemp panels being developed.

http://pharmaceuticalcommerce.com/supply-chain-logistics/enterprise-solutions-for-cold-chain-management/

Inmark, US: custom designed temperature controlled packaging

Engineer-designed temperature-controlled packaging manufactured to meet compliance with regulations and customers' precise specifications.

http://www.inmarktcp.com/services/packagedesign

World Health Organisation: the vaccine cold chain

Vaccines are very temperature sensitive and permanently lose their potency if exposed to inappropriate temperatures. Vaccines typically require transport and storage temperatures to be maintained between 2°C and 8°C. Examples of vaccine vial monitors are provided in section 3.1 and examples of temperature logging devices are provided in section 3.2.

http://www.who.int/immunization/documents/IIP2015_Module2.pdf

D.3 Research into cold chain optimisation

Wageningen University, The Netherlands: Internet of Food and Farm 2020

A four year, 30 million EUR project co-funded by the EU, Dutch government and Wageningen University launched in February 2017. IoF202 project fosters the large-scale uptake of IoT technologies in the European food and farming sectors with a view to strengthening competitiveness and sustainability. Of particular interest will be two trials conducted as part of the project: the internet of fruit and the internet of meat.

Benefits:

- Objective of drastically improving agricultural production, while demonstrating the added value of smart webs of connected objects.

https://iof2020.eu/iof/iof2020

United States Department of Agriculture: supermarket shrink

Supermarket shrink, i.e. estimated food lost in handling and display, including theft, in the US were been found to be in general higher in 2011-12 compared to previous estimates in 2005-06. These higher shrink estimates represent lower per capita food availability and sales value where product is sold by weight.

Benefits of research:

- Research adds to the body of knowledge in trends in supermarkets shrink

Detriment associated with supermarket shrink in US:

- Average 2011-12 shrink:
    - Fruit 12.6%
    - Veg 11.6%
    - Meat, poultry, seafood 12.7%

Limitations of research:

- Difficulty differentiating between food waste and theft
- Survey methodology

Buzby, J.C., Bentley, J.T., Padera, B., Campuzano, J. & Ammon,C. (2016). *Updated Supermarket Shrink Estimates for Fresh Foods and Their Implications for ERS Loss-Adjusted Food Availability Data*. EIB-155, U.S. Department of Agriculture, Economic Research Service, June 2016.

Frisbee project, EU: cold chain database

Frisbee is an EU funded project to provide new tools, concepts and solutions for improving refrigeration technologies along the European food cold chain. The project will develop new innovative mathematical modelling tools that combine food quality and safety with energy, environmental and economic aspects to predict and control food quality and safety in the cold chain.

Benefits: • Increased ability to model and control food quality and safety in the cold chain http://frisbee-wp2.chemeng.ntua.gr/coldchaindb/index.php http://frisbeetool.eu/FrisbeeTool/about.html
School of Air Transport, Transportation & Logistics, Korea Aerospace University, South Korea: improving shelf life Research paper examining: • Clustering temperature zones for multi-temperature cold storage. • The relationship between deterioration rate, shelf life and freshness. • Methods to assess quality of perishable food in real time using a Wireless Sensor Network in a Smart Cold Chain Management system. Benefits: • Creating different temperature zones for chilled goods allows each category of goods to be stored at its optimal temperature, prolonging shelf life and quality. Barriers: • Complex method of establishing optimal temperature range. Myo Min Aung, Yoon Seok Chang. (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control*, Volume 40, 2014, 198–207.
Department of Electronics, Universitat de Barcelona, Spain: RFID smart tag in fish cold chain Research paper to validate use of RFID smart tag developed for real-time traceability and cold chain monitoring. The project monitored fresh fish transported from South Africa to Europe. The smart tag, attached to the produce to be tracked, integrates light, temperature and humidity sensors, a microcontroller, a memory chip, low power electronics and an antenna for RFID communications. The results of this work found this system had advantages over conventional temperature data loggers such as more memory, reusability, no human participation, no tag visibility needed for reading, possibility of reading many tags at the same time and more resistance to humidity and environmental conditions. Benefits: • Continuous monitoring allows action to be taken if issues occur with temperature levels. • Information logged can be obtained without opening boxes • Data can be used to estimate product freshness and lifetime, reducing food waste and risk of exposing consumer to unsafe foods. Costs: • Data not available, but paper asserts 1 tag per box of high value product, such as seafood, is affordable. Barriers: • Tag cost, though prices are going down continuously • Lack of standardisation, but efforts to define standards of operation are being made.

- Need for robust tags able to withstand exposure to water, salt and ice

Abad, E., Palacio,F., Nuin,M., Gonzalez de Zárate, A., Juarros, A., Gómez, J.M., Marco, S. (2009). RFID smart tag for traceability and cold chain monitoring of foods: demonstration in an intercontinental fresh fish logistic chain. *Journal of Food Engineering, 93* (4) (2009), pp. 394–399

Institute of Animal Science, Universitat Bonn, Germany: innovative systems for supporting cold chain management

- Temperature monitoring systems e.g. time temperature indicators
- Predictive models for shelf life and food safety e.g. shelf life models for meat
- Rapid methods for food freshness and safety analysis e.g. biosensors
- Packing and storage systems to prolong shelf life and increase food safety e.g. oxygen scavengers and indicators

Benefits:

- Add further value to high quality produce
- Product safety by combining innovative solutions e.g. temperature monitoring systems and microbial growth models.
- Minimise economic losses.

Barriers:

- Lack of guidelines for integration of innovative solutions.
- Cost
- Need for user friendly implementation
- Integration of existing and new technologies.

http://www.chill-on.com/images/pdf/Preface_new.pdf

Wessex Institute of Technology, Southampton, UK: heat transfer model

Research paper outlining the development of a mathematical model for heat transfer from surrounding environment to a single food package. To be used for estimating the effects of temperature abuse on food product inside a single packing unit. Model was validated by comparison with experimental results.

Benefits:

- Improved ability to estimate the impact of temperature abuse on microbial growth and chemical properties of food products, and hence shelf life and risk of illness.

Barriers:

- Commercial availability of model
- Technical ability to use model

GospaviA, R., Margeirsson, B., & Popov, V. (2012). Mathematical model for estimation of the three-dimensional unsteady temperature variation in chilled packaging units. *International Journal of Refrigeration, 35*(5), 1304

Faculty of engineering, science and the built environment, London South Bank University, UK: cold store efficiency

Research paper investigating reasons for the large variation in cold store energy efficiency. Energy savings of between 8 and 82% were identified, with service, maintenance and **monitoring** the areas with the greatest potential to save energy. Payback periods to implement energy efficiency options and technologies varied and 71% of the issues identified had paybacks of less than 3 years. Benefits: • Improved energy efficiency of cold storage facilities, resulting in lower energy costs. Costs: • Costs for specific methods were not specified, but it is stated that 71% of the issues identified had paybacks of less than 3 years. Barriers: • Costs associated with some methods • Expertise Evans, J.A., Hammond, E.C., Gigiel, A.J., Reinholdt, L., Fikiin, K. & Zilio, C. (2013). Assessment of methods to reduce the energy consumption of food cold stores. *Applied Thermal Engineering*. 697 - 705.
The National Food Centre, Ireland: food quality impacts of fluctuating versus constant frozen storage temperatures Impact on a range of food quality indicators of freezing, super-freezing and fluctuating below zero temperatures on a range of food products. Gormley, R., Walshe, T., Hussey, K., & Butler, F. (2002). The effect of fluctuating vs. constant frozen storage temperature regimes on some quality parameters of selected food products. *LWT-Food Science and Technology*, 35(2), 190-200.
Food Climate Research Network, UK: reducing greenhouse gas emissions in the food system Refrigeration's contribution to UK greenhouse gas emissions, and how emissions related to refrigeration could be reduced by both improving the greenhouse gas efficiency of refrigeration equipment and reducing dependence on the cold chain. Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)?. *Food policy*, *36*, S23-S32.
Global Food Cold Chain Council, International: reducing GHG emissions related to food loss and waste in the cold chain Report exploring if there is there a net benefit, in terms of GHG emissions, from expanding cold chains in developing countries. The study found the benefits of expanding the cold chain and reducing food waste outweighed the newly created emissions by a factor of ten approximately. Global Food Cold Chain Council. (2015). *Assessing the potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction.* Retrieved from: http://www.foodcoldchain.org/wp-content/uploads/2016/07/Reducing-GHG-Emissions-with-the-Food-Cold-Chain-NOV2015.pdf

International Institute of Refrigeration, France: document database Database of documents related to refrigeration. http://www.iifiir.org/ClientBookline/toolkit/p_requests/formulaire.asp?GRILLE=IIFRRECHFRIDOC&PORTAL_ID=portal_model_instance__fridoc_search_en.xml&INSTANCE=exploitation&SETLANGUAGE=EN
Massey University, New Zealand: temperature control and energy efficiency in cold storage Presentation discussing the following aspects of food cold storage facilities: temperature variability; air flow distribution; and, energy efficiency. Cleland, D. (2010). Temperature control and energy efficiency in cold storage. Presentation made at the 1st IIR International Cold Chain Conference, Cambridge, UK. 31 March 2010
Food Chain Intelligence & Science and Technology Council, Australia: RFID technologies for cold chain applications Articles discussing the principles, advantages and disadvantages of radio frequency identification (RFID)-based monitoring technologies for the food cold chain. Estrada-Flores, S. & Tanner, D. (2008). RFID technologies for cold chain applications. *EcoLibrium.* March 2009. 34-37.
Food Science Australia: Australian standard for thermal testing of refrigerated road vehicles Discussion of Australian refrigerated vehicle standards, comparison with international standards, and recommendations for improvement. Estrada-Flores, S. & Tanner, D. (2005). Interpretation of the Australian standard for the thermal testing of refrigerated road vehicles. *EcoLibrium.* November 2005. 24-31
Food Chain Intelligence, Australia: Achieving control and efficiency in the cold chain Paper discussing opportunities to improve temperature control and efficiency in the food cold chain. Estrada-Flores, S. (2012). Achieving control and efficiency in the cold chain. *Climate Control News.* January 2012. 18-21.
Food Chain Intelligence, Australia: modeling of relationship between shelf life and temperature Report prepared for the CSIRO discussing food quality factors during cold storage and presenting the theory of shelf-life modeling for a range of products. Predicted shelf-life of selected horticultural products, raw beef, raw poultry, raw fish fillets and raw and pasteurized milk are presented for a range of temperatures. Estrade-Flores, S. (2010). *Quality characteristics, factors of spoilage and shelf-life models for selected foods*.
Food Science Australia: temperature variability and prediction of food storage during urban delivery of food products Investigation into temperature variations of food products home delivered in small vans and

prediction of pseudomonads and *Escherichia coli* growth as a result of temperature variations experienced. Estrada-Flores, S., & Tanner, D. (2005, May). Temperature variability and prediction of food spoilage during urban delivery of food products. In *III International Symposium on Applications of Modelling as an Innovative Technology in the Agri-Food Chain; MODEL-IT 674* (pp. 63-69).
Food Science Australia: temperature variability during shipment of fresh produce Paper presenting measured temperature data from typical container and refrigerated vessel shipments, monitored throughout voyages from Australasia to markets in Europe and Japan. Tanner, D. J., & Amos, N. D. (2002, June). Temperature variability during shipment of fresh produce. In *International Conference: Postharvest Unlimited 599* (pp. 193-203).
Australian Seafood Cooperative Research Centre: supply chain temperature profiles of Australian oysters Evaluation of Australian oyster cool-chain processes as they related to food safety and optimizing commercial quality. Madigan, L. (2008). *A critical evaluation of supply-chain temperature profiles to optimize food safety and quality of Australian oysters*. Australian Seafood CRC
AIRAH: issues and solutions related to transitioning to low-emission HVAC&R Discussion paper on issues and solutions related to the transition to low emissions heating, ventilation, air-conditioning and refrigeration. http://www.airah.org.au/Content_Files/UsefulDocuments/AIRAH_Transition_to_low_emission_HVACR_Issues_and_solutions.pdf

2xEP

Doubling Australia's
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