final report

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Prepared by: Greg Palmer
Matrix Professionals

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Meat and Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

OCM review and Strategy Development

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1 Table of Contents

2 Introduction

Meat and Livestock Australia Ltd (MLA) and the Australian Meat Processor Ltd (AMPC) have been introducing new technologies into the Red Meat processing sector. These technologies have been generally aimed at reducing labour, since labour has been difficult to source; reducing cost and improving efficiencies.

One of the ways that all of these can be achieved is by knowing more about the raw material, in this case lamb and beef carcasses that are being supplied. The more that is known about a carcass before it is processed; its value; its health status; its best market to be allocated to so as to maximise returns; its most efficient use of the cuts and their specifications then the greater efficiency that will be gained and the least cost expended and margins maximised.

New technological advances in the Medical arena as well as Security and other technological breakthroughs has meant that there is now a plethora of potential measurement and sensing technologies that are able to measure various attributes of a carcass and achieve these greater efficiencies. This project has been about reviewing the available measurement technologies across the Electromagnetic wavelength spectrum and providing sufficient information on those technologies that are thought to have some opportunity so that the processing sector could see where the technology may fit within their business and bring a benefit.

The Meat Processing sector were provided the information on the selected technologies and had the opportunity to review the preliminary technology summary reports and the opportunity to provide comments via a survey. This survey was developed to allow Processors to have input and identify those areas of their business that would benefit from using a particular technology to deliver information that would bring a benefit.

The results of this Survey from the Processors who responded are included in Appendix 2 and the Actual Survey is included in Appendix 3.

3 Executive Summary

Whilst the bulk of this project was focussed on identifying technologies that have some chance of delivering information that brings a benefit to a processor, input from processors was vital to identify the areas of information need. What emerged from the survey results was one common need from all respondents. This common need was for some mechanism of hot fat trimming on a carcase, to a specified depth across the carcase, located after the grading station and prior to despatch of the carcase to the chillers.

It is recommended that the Industry give consideration to examining in more detail the opportunity to develop such a system. Initial research has been done utilising Terahertz or Millimetre Wave technology and there were signs of promise. More funds, although not considered to be large amounts, are needed to develop this technology to a proof of concept stage.

Other technologies that were identified and were particularly exciting and promising and are worthy of further review are:-

3.1 Near Infrared Spectroscopy or NIRS

This technology has the potential to measure:-

- Meat Colour
- Tenderness
- pH
- Marbling

Whilst the industry has invested some research funding into this arena already with mixed results, new hardware that has been recently developed will resolve many issues of the past.

New developments in Time Domain NIRS mean that the potential to measure Meat Colour and other eating quality attributes such as juiciness and tenderness are closer to a reality.

3.2 Raman Spectroscopy

Again the industry has invested funding in this technology often with disappointing results but more economical instruments are being developed as a result of the uptake of this technology in the Security industry. This gives the potential to measure:-

- Tenderness
- Juiciness
- ph. and
- Cooking loss

3.3 X-Ray Technologies

There are several levels of X-Ray technologies. Single Energy X–Ray (SEXA) has already made an impact with use in automated processing within the lamb industry and commercial SEXA units becoming more common in modern meat processors. Dual Energy X-Ray (DEXA) is approaching a commercial product showing benefits in predicting yield with high levels of statistical significance.

3-Dimensional X-Ray or Computer Tomography (CT) is also rapidly developing with activities in the aviation security area providing the potential to have a full CT Carcase scan at production speeds in a 24/7 environment delivering outputs such as individual cut weights. This has potential for Grading and sorting as well as payment and feedback systems. Other measurements derived from a full 3 dimensional computer model of a carcase are available for use as well.

Other exciting advances in CT are the Spectral Molecular Imaging technology spearheaded by the Otago University in Christchurch. This technology will be comparable to the quantum change brought about by colour television compared to a black and white television. This potentially will enable an improvement by an order of magnitude in the image quality and contrast and allow much greater definition of the different densities of tissue and organs. This potentially will allow for the automatic finding and inspection of specific organs such as lymph node and other glands that are mandatory inspection during slaughter or anomalies such as abscesses or bruising.

These technologies are all changing, evolving and developing rapidly and the potential benefits that can be brought to the red meat industry are very large indeed.

4 Results from the Processor Survey.

The Survey results as received from those Processors who responded are discussed below. Each processor member of the AMPC Technical Committee was contacted and requested that a survey be completed based on their interest in the various areas of their business where benefits were thought to be achievable. The Survey aimed to look at areas of the business where there was a need rather than the benefits of the technology itself at this stage. The next step is to consider which technology is the most suitable to improve the various areas of identified need within the processors businesses and at what cost to deliver these benefits.

4.1.1 Results – Discussion

The results of the survey, albeit a small sample who responded, surprisingly suggest that there is one common need for both Lamb and Beef. This was for automated hot fat trimming to a specified fat depth over the carcase prior to chilling and post grading which in the survey scored the highest score of 24 out of a possible 24 points.
If automated hot fat trimming could be achieved this would allow the processors to scan a carcase and then using automated systems, trim the fat from the carcase to a specified fat depth after grading and payment had occurred. This would allow the carcase to be de-fatted while the fat was soft and would reduce:-

- Chilling requirements because of the reduced volume and reduced insulation thickness
- Would increase the efficiency of boners by reducing workload in removing the solidified fat prior to boning.

The technology to achieve this was based on using Terahertz or Millimetre waves in the Electromagnetic Spectrum. Some small scale trials of the technology had been undertaken but more work is needed to achieve a proof of concept success.
The second area of interest identified with 21 out of 24 points was the automatic carcase breakdown based on 3-Dimensional data. This requires automated boning of a carcse hence the full 3-D skeleton and the position of all of the Meat fat and Bone needs to be known. This would require some form of 3-Dimensional image most likely supplied by a modern CT scanner
The third area of interest with 20 out of 24 points was "Saleable meat yield (in primal kg or $). This requires the knowledge of where the meat is on the carcase and how much in weight there is on which primal. This would allow for sorting into boning rooms based on the end primal weight so that like lines of carcasses could be sorted and are boned together and the processor had confidence that the carcase would be suitable to comply to the weight requirements of the specification for a particular customer. It would also allow the feedback of the carcase performance to be provided to producers as well as the basis for a robust value based payment system should a processor require.
The requirement to achieve such an outcome would need the generation of a full 3-Dimensional image of the carcase most likely using the technology of CT Scanning
None of these solutions to the identified problem have as yet been reviewed to determine neither the realistic viability of the technology nor the likely costs of investing in the suggested technology that is likely to deliver the benefit nor any cost benefit estimate to demonstrate that there is a realistic investment pathway.
These studies were to be part of another project which is yet to be implemented once general support from the processing sector had been secured...

4.1.2 Results Summary

The Table in Appendix 2 has the results from all 4 processors with the data amalgamated and a score allocated. The scoring was based on a score per level of interest. A high score achieved 3 points, a Medium level of interest scored 2 points and a low score achieved 1 point.

Scores were allocated to both the Interest level held by the processor as well as the benefit to the business. The total Score value was a numerical combination of both of these. Score is out of a possible24

The table below shows the areas that had the most level of interest.

Table 1: Ranking Of Areas Of Interest By Most Popular

Area of Interest	Total Score
Automated hot fat cutting to a specified depth over the carcase	24
Automatic carcase breakdown based on 3-Dimensional data	21
Measurement of saleable meat yield (in primal kg or $)	20
Automatic Inspection and health status of Viscera and Offal such that Inspection can be more effective and productive	17
Marbling Score on a hot carcase at a single site as per AUS-MEAT rules (or at multiple sites)	16
Auto sorting of stock based on: MOB or RFID	15
Auto sorting of stock based on: Muscle size and weight	14

Detailed summary of the highest score areas of interest are listed below.

Note scoring is based on 3 points for High Interest, 2 points for Medium Interest and 1 point for Low interest

Area of Interest			High	Medium	Low	Summary Score	Total Score for Area of Interest
Automated hot fat cutting to a specified depth over the carcase	Interest Level	Beef	2			6	
		Lamb	2			6	
	Benefit to The Business	Beef	2			6	
		Lamb	2			6	**24**
Automatic carcase breakdown based on 3-Dimensional data	Interest Level	Beef	2			6	
		Lamb	1	1		5	
	Benefit to The Business	Beef	2			6	
		Lamb		2		4	**21**
Saleable meat yield (in primal kg or $)	Interest Level	Beef	1	1		5	
		Lamb	1	1		5	
	Benefit to The Business	Beef	1		1	4	
		Lamb	2			6	**20**
Automatic Inspection and health status of Viscera and Offal such that Inspection can be more effective and productive	Interest Level	Beef	1	1		5	
		Lamb		2		4	
	Benefit to The Business	Beef		2		4	
		Lamb		2		4	**17**
Marbling Score on a hot carcase at a single site as per AUS-MEAT rules <or at multiple sites	Interest Level	Beef	1	1	1	6	
		Lamb		1	1	3	
	Benefit to The Business	Beef	1		1	4	
		Lamb		1	1	3	**16**
Auto sorting of stock based on: MOB or RFID	**MOB**	OR	**RFID Number**			6	
	Beef	**1**	**Beef**	**1**			
	Lamb	**1**	**Lamb**		2		
	Interest Level	Beef	2			6	
		Lamb			2	2	
	Benefit to The Business	Beef	1	1		5	
		Lamb		2		4	**15**
Automated hot fat cutting to a specified depth over the carcase	Interest Level	Beef	2			6	
		Lamb	2			6	
	Benefit to The Business	Beef	2			6	
		Lamb	2			6	**24**
Automatic carcase breakdown based on 3-Dimensional data	Interest Level	Beef	2			6	
		Lamb	1	1		5	
	Benefit to The Business	Beef	2			6	
		Lamb		2		4	**21**
Saleable meat yield (in primal kg or $)	Interest Level	Beef	1	1		5	
		Lamb	1	1		5	

5 Technologies Considered

The following technologies have been considered as being at a sufficiently advanced stage to be considered for inclusion within this review:-

5.1 Spectroscopic Technologies

- Single-photon emission computed tomography (SPECT)
- Near Infrared Spectroscopy (NIRS)
- Nuclear magnetic resonance (NMR) and Magnetic Resonance Imaging (MRI)
- Raman Spectroscopy
- Terahertz and Millimetre Waves

5.2 X-Ray Based Technologies

- X-Ray Single Energy
- X-Ray Dual Energy Absorptiometry (DEXA)
- Computer Tomography (CT) or 3-D X-Ray
- Computer Tomography- Medical
- Spectral Molecular Imaging
- Phase Contrast or Diffraction Enhanced Imaging
- Micro CT and Nano CT.

5.3 Other Technologies

- Vision based systems
- Ultrasound

6 Summary of The Technologies

6.1 Spectroscopic Technologies

Spectroscopic Technologies formally includes the study of the interaction between electromagnetic radiation and matter. Whilst this would include technologies such as X-Ray and Light or Vision systems, these have been specifically dealt with separately because of their many spinoffs within the technological group e.g. X-Ray and CT, familiarity and well known attributes as has Ultrasound. In this instance, spectroscopic technologies include all technologies utilising electromagnetic waves apart from these 3.

6.1.1 Single-photon emission computed tomography (SPECT)

- This technology uses ionizing radiation and is not suitable for a production facility. It has some potential in research.

6.1.2 Near Infrared Spectroscopy (NIRS)

- Appears that NIRS can:-

(I) Predict fat content in beef trimmings (R=0.98, RMSEP=2.8%)
(II) Measure pH pre and post rigor could be measured with a similar accuracy of a pH meter
(III) Has the ability to measure objective colour, intramuscular fat and pH at 24 hours post slaughter

- robust method to noninvasively predict LM tenderness of grain-fed beef carcasses
- Whilst some of these claims still need to be verified on Australian cattle and processing conditions the outlook seems promising. It needs to be noted that these measurements are taken on the chilled carcase and not before it leaves the slaughter floor.
- The Meat Quality attributes relating to the sensory side of meat such as taste; juiciness and flavour appear to need additional research before a useful tool is available.

6.1.3 Nuclear magnetic resonance (NMR) and Magnetic Resonance Imaging (MRI)

- NMR is an emerging technology with many areas of opportunity yet to be fully explored.
- At this stage of it technological development it does not meet the needs of a modern meat processing facility except for research.
- Heavy laboratory apparatus are being replaced with efficient NMR portable devices making the availability of equipment to undertake trials more accessible.
- It potentially has the potential to measure:-
    - Flavour
    - Juiciness and tenderness
    - Cooking loss
    - Fat and moisture content
    - Instrumental tenderness (Warner Bratzler shear force)

6.1.4 Raman Spectroscopy

- Raman Spectroscope shows some promise in measuring attributes of meat that may be useful as a grading or market allocation tool.
- These attributes include tenderness, juiciness, and flavour, cooking loss, pH and lactate.
- There still appears to be significant work needed before this is a useful commercial production tool.

6.1.5 Terahertz and Millimetre Waves

- The trials undertaken with this technology were very low key. They showed promise to predict subcutaneous fat thickness but additional structured trials are needed.
- The technology has developed substantially since this project as undertaken.
- Potential to develop an automatic hot fat trimmer to a set thickness all over a side prior to chilling.

6.2 X-Ray Based Technologies

6.2.1 X-Ray Single Energy

- This technology has remained fairly stationary except for software and detectors such that the X-Ray dosage can continued to be reduced

6.2.2 X-Ray Dual Energy Absorptiometry (DEXA)

- This technology is improving all of the time as different energies of X-Ray are experimented with; detectors are improved.
- In the medical arena dosage reduction is always paramount. Opportunities are available to work with higher energies and currents on carcasses.
- This may deliver segmentation of carcases to provide percent of bone, meat and fat over a carcase and with appropriate software, provide this information on the fore or hind quarter in beef and on the shoulder, middle and legs with lamb.
- Potentially less expensive than CT but depends if the outputs that are generated provide a benefit that reflects the cost

6.2.3 Computer Tomography (CT) or 3-D X-Ray

6.2.3.1 Computer Tomography- Medical

- Whilst this technology in itself is of little use as a production tool, mainly because of the duty cycles and suspected costs to purchase, it does however drive the direction of the software.
- Software now has more sophisticated reconstruction algorithms for greater contrast images
- Image analysis software moving towards more automation and semi-automated tasks.
- Medical fraternity using more contrast agents (dyes) that enable more clarity of certain organs but not suitable for carcasses.
- Dose again is one of the key drivers but this is of no consequence to carcasses.

Spiral CT could predict very accurately estimates of tissue weights with high accuracy:-

- subcutaneous fat (R_2, RMSECV=0.94, 34.60 g and 0.92, 34.46 g)
- intermuscular fat (R_2, RMSECV=0.81, 161.54 g and 0.86, 42.16 g)
- total fat (R_2, RMSECV=0.89, 65.96 g and0.93, 48.35 g)
- Muscle content (R_2, RMSECV=0.99, 58.55 g and 0.97, 57.45 g) in Angus and Limousin samples, respectively.

Accurate CT predictions were found for:-

- fatty acid profile (R_2=0.61–0.75)
- Intramuscular fat content (R_2=0.71–0.76) in both sire breeds.

Low to very low accuracies were obtained for technological and sensory traits with R^2 ranged from 0.01 to 0.26.

6.2.3.2 Computer Tomography- Aviation- Baggage Scanners

- This technology is basically the same as medical as far as operation of the hardware and the image reconstruction.
- Is the most robust in construction and most suited to industrial applications

- Have large throat diameters of 1000+ mm
- Use dual energy as standard
- Software native to these machines is designed for security outcomes – to detect guns, knives etc. and or explosives.
- Medical Software can run on these machines.
- Have the advantage of operating 24 hours a day and 7 days a week.
- **Medical or Aviation CT** systems have the capability (with modifications to software) to deliver
  - Lean Meat Yield
  - Saleable Meat Yield
  - Weight of individual cuts
  - Marbling or Intramuscular fat
  - Eye Muscle Area
  - Hump Height
  - Produce sufficiently detailed images to allow automated cutting between primals
  - Produce sufficiently detailed images to all cutting between bones
- Future improvements will allow the ability to identify organs in the animal prior to evisceration

6.2.4 Spectral Molecular Imaging

- This is a new area of imaging that is underdevelopment. Still in early stages but technological hurdles appear to be few.
- Developed on our back door in Christchurch.
- Will provide a quantum change in image quality.
- Will have the capability of multi images allowing identification of objects significantly easier.
- Will provide a 'colour' image where every colour is a different material
- Will be doing trials on lamb as a precursor to trialling on humans

6.2.5 Phase Contrast or Diffraction Enhanced Imaging

- A technology that can deliver high contrast images of soft tissues.
- Other versions can produce very high resolution images below 1 angstrom.
- Suitable for research tool only at current level of development.

6.2.6 Micro CT and Nano CT.

- These are both able to deliver very high levels of magnification CT images.
- Used predominantly for research and not in any production environment
- Sample preparation is critical to restrict blurring

6.3 Other Technologies

6.3.1 Vision based systems

- Several vision systems around the world in commercial use.
- They are reliable and perform to the best available predictive capacity for an objective system
- Have a major detriment in that re-calibration must occur regularly as the herd population changes based on the signals being fed back to producers. This is expensive.
- Payment systems based on the output of this technology is happening in New Zealand
- Can predict cut weight yield.
- Slow uptake by processors. More successful in New Zealand presumably because of way industry is dominated by producer ownership and the 2 major lamb and beef processors.
- Significant advances in cameras and statistical analysis of images allows for accurate tracking of cuts

6.3.2 Ultrasound

- Is used now extensively on live animals.
- Has a major problem with carcases as a result of the air bubbles induced in the subcutaneous layer during hide removal

7 Other Industries Approach to Sensing and Scanning

7.1 Chicken Processing

Chicken processors have installed an imaging system to check for defects. [1] on the chicken carcass. Initially it was only a vision system "to ensure that the carcasses are free of visible quality defects, such as bruising, overscalds, tumours, air sac, and a host of other quality variables."

Later a spectral imaging system was developed for "the identification of faecal matter and ingesta (partially digested food from the ruptured crops of chicken carcasses) that can contaminate the surfaces of poultry carcasses. Specific spectral properties have been identified and algorithms developed that enhance the identification of faecal contamination. These features are being transferred to an imaging system that can scan carcasses at line speeds. In initial development tests, hyperspectral imagery has demonstrated the ability to recognize spectral signatures associated with contaminated poultry carcasses even in shadowy regions of the carcasses.

The system is operating at 180 birds a minute but can expand to 200 birds per minute.

In another system "in the broader area of systemic defect and OCPs detection, researchers with ARS's laboratory in Beltsville, Md., have developed a prototype of a four-camera multispectral imaging system and a near-infrared light probe for reflectance scans of chicken carcasses on the processing line. Led by Yud-Ren Chen, the developer of the system, the team also has a cooperative research and development agreement with Stork Gamco. Stork has agreed to test the system on a 140 bird per minute line (however, according to researchers, the system could handle up to 180 birds a minute.).

In a processing plant, the test equipment will be mounted alongside a processing line at the point right after the chickens are killed and de-feathered. The equipment takes two complementary readings of the carcasses' condition.

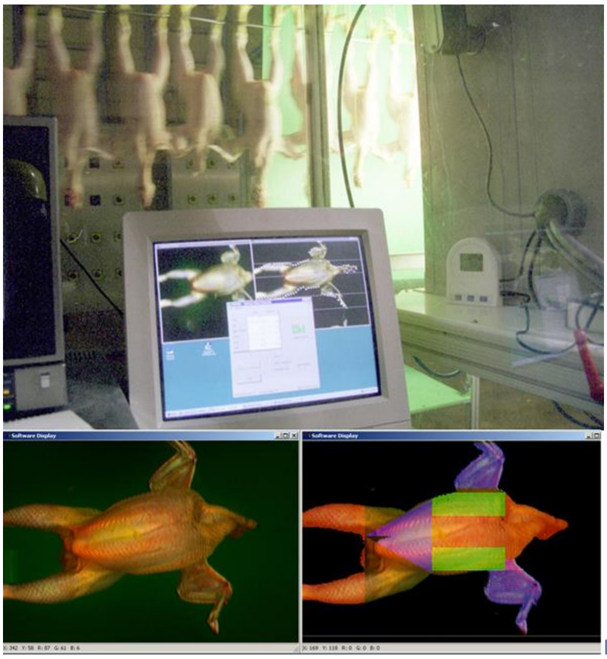


Figure 1 Researchers with Georgia Tech's Agricultural Technology Research Program have developed a state-of-the-art machine-vision system for detecting systemic defects in poultry carcasses. Installed on the kill line, the system's digital camera captures an image of each bird, that image is then processed by the system's computer, which automatically makes a decision about what it sees, thus determining whether or not the bird has a systemic defect. In addition to identifying the most common systemic defects, such as septox, overscalds, and cadavers, the system also detects small birds, broken wings, bruising, mishung birds, and empty shackles.

For the first reading, a probe bounces light off the carcasses. The reflected light goes to a spectrophotometer and then a computer — which is in a room away from the moist conditions of the processing line — for analysis. Differences between light shining on the chicken and light reflected back are due to variations in external skin colour and meat tissue composition that are clues to problems.

For the second reading, a camera takes three spectral images of each chicken through different colour filters. Then the computer reads the spectral images and decides if the carcass is wholesome or not, as well as identifying local tears, bruises, or tumours and carcass size.

Together, the equipment pieces quickly diagnose physical or biological conditions causing inspectors to reject chickens. They spot both definitely unwholesome carcasses for rejection and suspect ones requiring closer human inspection.

This information regarding this automatic detection of defects was first published in Agricultural Research Magazine May 1998 - Vol. 46, No. 5

7.1.1 Bone Detection

Major equipment manufactures supplying the poultry industry have developed X-Ray systems to automatically detect bone. Supplies such as Marel [2] have their SensorX product that:-

"scans the product using advanced X-ray technology.

Product with bone is rejected to a workstation with a display showing the precise location of the bone. The bone (or other contaminant) is removed by the operator before the product is re-scanned for added safety.

In addition to bone detection, the SensorX can detect other contaminants such as metal, stone and glass."

Marel also has a higher end and greater capacity product called the SensorX 25 – This product reportedly has a 500 X-ray scanning area and can handle larger sized product as found with turkey breast.

7.1.2 Faecal Contamination

Other companies are doing similar things. [3] and believe that :-

"To quickly identify faecal contamination or contaminants that should not be in a product, engineers are building a prototype multispectral imaging apple-inspection system. It uses the reflectance from apples in the invisible near-infrared and visible colour light bands, as well as fluorescence techniques, to detect dirt, fly specks, fungi, rot and other diseases that can cause illness or negatively impact quality. The system can potentially be used on other products as well."

It would appear that this same technology would apply to beef, lamb and goat carcass inspection particularly for Faecal contamination

7.2 dental

The dental industry has made major advances in 3 Dimensional measurement particularly as a result of advances in manufacturing and dental implants. CAD/CAM technology has allowed the rapid development of the measurement of and the manufacture and fitting of porcelain Crowns in the dentists surgery in a single sitting. To do this an accurate and precise 3-Dimensional image is needed to allow the manufacturing of the Porcelain Crown.

There are multiple methods to be able to undertake the measurement within the intraoral space all of which utilise the physics of various wavelengths of light.

A major manufacturers such as 3M [4] and others have commercial equipment available that links the measurement technology with the 3 dimensional model generation and with the Computer Aided Manufacturing machinery to generate the Crown or the tooth to be attached to the implant.

Papers by S Logozzo et al [5] and A.J. Ireland et al [6]identify many differing methods where very fine measurements with in the oral cavity can be made and a 3 dimensional model generated. These methods generally use light or laser as the medium to enable the measurements to be captured.

Some of the light methods need the teeth to be coated with a reflective coating so as to provide uniformity in the reflectivity of the surfaces to be modelled.

Others use monochromatic light such as infrared laser of blue light emitting diodes with the shorter wavelength allowing for greater precision with accuracies around 20 microns.

These accuracies are far in excess of what is generally required within the Red Meat Industry and the existing laser scanning technologies in use by organisations such as Scott technology on their Lamb automated cutting equipment is well developed and commercially available and will provide the accuracy required for most applications.

The Dental industry has also had access to Cone beam CT hard scanners for some time and this has allowed the development of very detailed 3 Dimensional reconstructions of the teeth, gums and mouth. The Cone Beam technology has been successful in this application because of the small distances that the X-Rays of the CT scanner have to travel and the availability of digital detectors of an appropriate size.

The maximum detector size that is commercially available is approx. 4500 mm x 450 mm. Most dental scanners use only a 300 mm x 300 mm detector which is sufficient to capture high quality images of the head and mouth.

As the diameter of a body to be scanned increases (in humans it is approximately 700 mm diameter although there are now CT scanners with 1000 mm throat diameters) so does the size of the detector because of the geometry configurations.

As the diameter increases so does the power required to generate enough photons to produce a clear and detailed image. A "distance squared" relationship exists. i.e. if the distance from the detector increases from 400 to 800 mm then 4 times the power (i.e. 4 times the number of photons) is required to produce the same quality image./

The dental technology has this remained fairly static and the focus has been on utilising other compatible technologies such as PET to provide specific outcomes such as tumour identification. Other technologies such as MRI of the head only have been specifically developed for head and dental imaging.

8 Technology Matrix

The tables below summarise the available technologies and where they may be applicable within a modern meat processing facility:-

8.1 Lamb

	Potential for Whole of Processing - Lamb / Sheep			Potential Enabling Technology		✔	Can be done		?	might be able to be done with this technology More R&D needed						✖	Cannot be done with this Technology			☞	Possibly can be done in combination with other Technologies			
	Task: Lamb/ Mutton	Current Measurement method	Ultrasound	Laser Scanning	*SEXA	**DEXA	NMR or MRI	CT - Medical Spiral	CT Cone Beam	CT Aviation Bgge'Scan	NIR Spect.	Futuretech	Raman S[pectroscopy	Conventional Robotics	VIAscan or Equivalent	Other Vision Systems	Terrahertz Waves	Spectral Molecular Imaging	Timeframe till developed: 1 to 5	6 to 10	11+	Impact on Industry (1-10)	Ease to Implement (1-10)	Comments
SLAUGHTER	Stun																							
	Stick																							
	Shackle																							
	Head removal																							
	Breast strip & tail removal																							
	Legging																							
	Socks																							
	Y cut																							
	Breast roller																							
	Inversion																							
	Hind feet																							
	Punch																							
	Rodding																							
	Pelt puller																							
	Gambrel re-invert																							
	Front feet																							
	Anus and belly split																							
	Throat removal																							
	Throat trim																							
	Brisket Cut																							
	Eviscerate																							
	Pluck removal																							
	Viscera Recovery /Sorting																							
	Inspect Viscera																							
	Offal trim																							
	QC trim																							
GRADING	Dentition	Visual			☞			?	?	✔									✔					
	Rib Fat P8	Ruler															?			✔				
	Saleable Meat Yield %					✔													✔			6	6	Based on not using VIAscan or euivalent system
	Prediction of individual Cut Weights							✔	?	✔										✔		8	6	
	Market Allocation optimisation							✔	?	✔										✔		8	6	
	Hide / Pelt Assessment	Visual																						
	Fat Cover Assesment /Removal							?		?							?		✔	✔		6	5	
CHILL	**Chilling**																							
	Transfer to chillers													✔										
	Chiller selection	Manual												✔										
	Tenderstretch Hook Swap	Manual												✔										
	Carcase Chilling																							
OFFAL	**Offal Processing**																							
	Sorting; cleaning salting of Casings																							
	Grading																							
MEAT QUALITY	Inspection																							
	Meat Colour																							
	Marbling Intramuscular Fat %						?	✔	?	✔			?							✔		9	6	Measure on Hot Carcass
	Eye Muscle Area							✔	?	✔										✔		3	6	Measure on Hot Carcass
	Ultimate pH	pH probe					?																	
	Tenderness	Warner Bratzler					?						?							✔		4	7	
	Juciness	Consumer					?						?							✔		4	7	
	Flavour	Consumer					?						?							✔		4	7	
BONING	Seperate Shoulder Middle and Leg	Band Saw			☞									✔					✔					Can be done now with Scott Technology "Leap" Series
	Square Cut shoulder				☞									✔					✔					Can be done now with Scott Technology "Leap" Series
	Neck Chops				☞									✔					✔					Can be done now with Scott Technology "Leap" Series
																								Can be done now with Scott Technology "Leap" Series
	Middle Processing			☞										✔					✔					Can be done now with Scott Technology "Leap" Series
	Leg Processing			☞										✔					✔					Can be done now with Scott Technology "Leap" Series
	Location of major seams on cutting lines							?		✔										✔		3	6	
PACKING	Trim Sorting CL																							
	Trim Packing																							
	Trim Assesment for CL	Smith Heiman, Foss etc				✔													✔					In existence as a commercial product
	Carton Stacking																							
	Carton despatch to Cooling																							
	Carton Retrieval																							
	Container Packing																							

8.2 Beef

Potential for Whole of Processing - BEEF

Potential Enabling Technology: ✔ Can be done; ? might be able to be done with this technology More R&D needed; ✖ Cannot be done with this Technology; ☞ Possibly can be done in combination w

	Task Beef	Current Measurement method	Ultrasound	Laser Scanning	*SEXA	**DEXA	NMR or MRI	CT - Medical Spiral	CT Cone Beam	CT Aviation Bgge'Scan	NIR Spect.	Futuretech	Raman S[pectroscopy	Conventional Robotics	VIAscan or Equivalent	Other Vision Systems	Terahertz Waves	Spectral Molecular Imaging	Timeframe till developed 1 to 5	6 to 10	11+	Impact on Industry (1-10)	Ease to Implement (1-10)	Comment
SLAUGHTER	Lead-up Race											✔							✔			3	2	
	Restraining											✔							✔			3	2	
	Captive Bolt Stun											✔							✔			3	2	
	Slaughter- Sticking Bleeding																							
	Rodding and Tie Weasand																							
	Remove Front Feet			☞										☞										
	Attach Legging chain and connect to slaughter rail			☞										☞										
	Rear Hock removal			☞										☞										
	Attach Second Leg to main rail																							
	Hide opening - Workup first Leg																							
	2nd Rear Leg Hock Removal																							
	Tail Removal																							
	Ring and seal the bung																							
	Udder and Pizzle Removal																							
	Flanking																							
	Hide removal																							
	Head removal																							
	Sever Brisket				☞																			
	Eviscerate													☞		☞								
	Viscera Recovery /Sorting																							
	Inspect Viscera							?		✔								✔	✔			7	8	
	Split Carcase																							
	Spinal Cord removal																							
	Trimming																							
	Final Inspection																							
	Skin head																							
	Bone head																							
	Inspect Head																							
	Carcase (Side) Grading Weighing																							
GRADING	Dentition	Visual			☞			?	?	✔								✔						
	Rib Fat P8	Ruler															?			✔				
	Saleable Meat Yield %					✔													✔			6	6	Based on not using VIAscan or euivalent system
	Prediction of individual Cut Weights							✔	?	✔										✔		8	6	
	Market Allocation optimisation							✔	?	✔										✔		8	6	
	Hide / Pelt Assessment	Visual																						
	Fat Cover Assesment /Removal							?		?							?		✔	✔		6	5	
CHILL	**Chilling**																							
	Transfer to chillers	Manual												✔					✔			5	8	Commerical prototype nearing completion
	Chiller selection and rail selection	Manual												✔					✔			5	8	Commerical prototype nearing completion
	Tenderstretch Hook Swap	Manual												✔					✔			5	8	Commerical prototype nearing completion
	Carcase Chilling																							
OFFALL	**Offal Processing**																							
	Sorting; cleaning salting of Casings																							
	Grading																							
MEAT QUALITY	Inspection Site Prep/ Quartering																							
	Meat Colour	Manual Aus-Meat Chips/ VIAscan									?					*?								*Replace VIAscan with I"- phone" size system
	Marbling	Manual Aus-Meat Chips/ VIAscan					?	✔	?	✔			?							✔		9	6	Measure on Hot Carcass
	Eye Muscle Area	Grid / VIAscan						✔	?	✔										✔		3	6	Measure on Hot Carcass
	Ultimate pH	pH probe					?																	
	Tenderness	Warner Bratzler					?						?							✔		4	7	
	Juciness	Consumer					?						?							✔		4	7	
	Flavour	Consumer					?						?							✔		4	7	
BONING	Scribing	Manual			✔									☞					✔			3	4	
	Location of major seams on cutting lines							?		✔										✔		3	6	
	Robotic Boning							?		☞				☞		☞				✔		9	8	
	Automatic Primal Packing	Manually												☞		☞			✔			7	6	
PACKING	Trim Sorting CL																							
	Trim Packing																							
	Trim Assesment for CL	Smith Heiman, Foss etc				✔													✔					In existence as a commercial product
	Carton Stacking																							
	Carton despatch to Cooling																							
	Carton Retrieval																							
	Container Packing																							

9 What are The Needs of Processors?

In a previous strategy development workshop [7] "A formal industry engagement workshop (Workshop 1) identified the following attributes should be considered under the OCM strategy"

1	Skeletal positioning	9	Cut size & weight	17	Dentition
2	Eye muscle area	10	Ossification	18	Meat colour
3	Rib fat (GR)	11	Cysts	19	Hide/pelt quality
4	Muscle seams	12	Abscess	20	Glycogen
5	Marbling	13	Disease (i.e. liver)	21	Juiciness
6	Lean meat yield	14	Eating quality	22	Sex
7	Hump height	15	Ext. contamination	23	Live animal growth
8	Saleable meat yield	16	Tenderness		

Table 1: Sought after attributes for OCM strategy (not in any order of priority)

A presentation of all of the technologies researched was delivered to the processors followed by a question and answer session. A Beef and Lamb Processor Survey was then developed and circulated to core processors on the Technical Committee. The results of this survey are listed in Appendix 2.

10 Appendix 1: details of the Technologies Considered.

10.1 Spectroscopic Technologies

10.1.1 Single-photon emission computed tomography (SPECT)

According to Wikipedia [8] SPECT "is very similar to conventional nuclear medicine planar imaging using a gamma camera, however, it is able to provide true 3D information. This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required.

This technology uses ionising radiation in the form of Ionising Gamma rays and is therefore not considered suitable for the Meat industry as a production tool.

10.1.2 Near Infrared Spectroscopy (NIRS)

10.1.2.1 Introduction

NIRS is a well-established technology and has been utilised in many industries for determining physical properties and quality measurements. Such industries include grains, milk, timber and supplements to name a few. According to Nilsson [9] "Near infrared spectroscopy is used in the meat, dairy and seafood industries for proximate analysis."

According to Marco Ferrari, [10] (2012) the main advantages of the optical methods or NIR methods are: - "non-invasive, no side-effects, good temporal and spatial resolution, real-time functional information, cost effective and portable. Optical methods rely on different types of interactions between visible or NIR light and biological tissue to provide structural, biochemical, physiological and morphological information. There are two main tissue optical properties which characterise light–tissue interactions and determine therapeutic or diagnostic outcome: absorption coefficient and reduced scattering coefficient."

He also says that

"The penetration depth of visible and NIR light in tissue ranges from microns to centimetres depending on wavelength, source/detector separation, light delivery/collection geometry etc. The major tissue absorbers include: haemoglobin, lipids, melanin, water and proteins. Oxygenated and de-oxygenated haemoglobin (O_2Hb; HHb) preferentially absorb visible and NIR light of different wavelengths, as evidenced by the more reddish colour of oxygenated blood and the more bluish hue of deoxygenated blood. O_2Hb and HHb have distinct spectra, therefore optical measurements can provide information on tissue oxygenation, oxygen consumption and blood haemodynamics."

Berzaghi [11] also lists the following advantages over other analytical techniques:-

(I) "the spectral measurements is really rapid one sample can be scanned in less than 1 min;
(II) less expensive because there isn't any use of chemical reagents and a single operator can analyze a large number of samples;
(III) several scans can be made on the same object, which permits to obtain a more representative sample composition and a more accurate result of analysis;
(IV) sample requires minimal (drying and grinding) or no preparation;

(V) several constituents of the same sample can be measured at the same time;
(VI) easily applicable in different environments (like industry, laboratory, harvesters, etc.);
(VII) measurements can also be carried out on/in/at line;
(VIII) the opportunity to use optical probes makes it possible to analyse the sample in-situ;
(IX) the availability of portable instruments permits to obtain spectra directly in the field, useful to follow process like ripening. "

On the downside he suggests that NIR spectroscopy has some disadvantages to take into account:-

(I) low sensitivity of the signal which can limit the determination of substances with concentration below 0.1%;
(II) it is a secondary analytical method, so it requires an accurate chemical and physical analysis as reference samples;
(III) development of calibration models require high trained personnel;
(IV) accurate and robust calibration require a large data set incorporating large variation, which is often difficult to obtain;
(V) it requires a continuous maintenance of the calibration data set;
(VI) with some hardware it is difficult to transfer calibration between instruments to the same manufacture or between different manufactures (Manley et al, 2008);
(VII) Although NIR technique has low measuring cost, the initial high financial investment for the instrumentation represents an important obstacle for the purchase.

This suggests that the opportunity to measure key attributes of meat will with time, be measurable using this technology.

10.1.2.2 Industry Projects

MLA and AMPC have undertaken a number of projects to examine NIR and have done several projects starting in 2006. In the project P.PSH.0229 [12] undertaken by MF North et al. (2006) it was believed that Many studies have shown that NIR readings can be calibrate against accepted meat quality attribute measures; however a key problem that has restricted the use of NIR in industry has been the ability to transfer calibrations.

The conclusion from this project suggested that:-

1. pH pre and post rigor could be measured with a similar accuracy of a pH meter
2. There was a relationship between NIR and shear force with further calibration needed for DFD and cold shortened meat.

A continuation project A.MQT.0016 by Baud et al. [13] (2007) expanded the previous work to cover the Visible Spectrum (which is the next range down on the electromagnetic wavelength spectrum) and called VISNIR. Vis-NIR technology provides information about the molecular bonds (chemical constituents) and tissue ultra-structure in a scanned sample. This project concluded that :-

"The results provide strong support for the continued development of VISNIR spectroscopy to accurately measure and classify carcasses on a number of commercially important traits of red meat. These include the ability to measure objective colour, intramuscular fat and pH at 24 hours post slaughter, muscle glycogen and/or glycolytic potential and muscle heme pigment levels at 30 minutes post slaughter."

This report concluded that "VISNIR spectroscopy did not provide a reliable prediction of objective tenderness"

This report by Kapper et al. [14] recommended further research and this was commenced in Project A.TEC.0064 by Hosen [15] (2009) This report looked at the performance of using NIR technology QVision probe to measure the Chemical Lean (CL) of fat trimmings. This project found that :-

1. "Good calibration models for fat content in beef trimmings (R=0.98, RMSEP=2.8%) have been produced "
2. "A test with the QVision scanner using 3 big batches of 145, 164, and 170Kg gave the same fat estimates as the inline microwave system on ground meat."
3. "For the concept to work properly it is a requirement that the trimming or layers of trimmings on the belt are not too thick. In this study maximum thickness was about 80 mm. Thicker trimmings might be used, but careful hardware adjustments might then be required."

10.1.2.3 Other Research

Research papers on NIRS have covered a wide range of applications from the performance of monitoring the performance of aerobically packaged beef fillet spoilage at different storage temperatures [16]to measuring colour, pH and tenderness, respectively.

In other work undertaken, researchers such as Shackelford (2004) [17] have found that in his paper entitled "Development of optimal protocol for visible and near-infrared reflectance spectroscopic evaluation of meat quality" Shackelford found wanting the technology and the protocols to measure beef repeatably using the technology at that time.

However in a later paper by Shackelford et al, [18] in 2011, "Field Testing Of A System For Online Classification Of Beef Carcasses For Longissimus Tenderness Using Visible And Near-Infrared Reflectance Spectroscopy" Shackelford concluded that;-

"present experiments resulted in development and independent validation of a robust method to noninvasively predict LM tenderness of grain-fed beef carcasses. This technology could facilitate tenderness-based beef merchandising systems."

In a paper presented at the First Annual Conference on Body and Carcass Evaluation, Meat Quality, Software and Traceability in in Ireland in 2012, a poster by Prevolnik [19] concluded that:-

"the prediction errors approached the repeatability of the reference methods which points to the main limitation of NIRS being that its predictive ability is limited by the accuracy of the reference method"

However in 2009 Prieto [20] in a reasonably large on-line trial of 194 carcasses found that there was a high predictability using VIS-NIR for colour "Vis-NIR calibrations, tested by cross-validation, showed high predictability for L*, a* and b* (R2 = 0.86, 0.86 and 0.91; SECV = 0.96, 0.95 and 0.69, respectively)." Whereas the other more subjective sensory measurements (flavour, juiciness,

tenderness and overall liking) were much less correlated. It was argued that in a production run of cattle there is likely to be greater variation where the VIS-NIR would be perform better.
In contrast Berzaghi, [11] in 2009, found much poorer correlations with colour components of L* a* and b*(R^2 = .585; 0.008; 0.345) which is significantly different from Prieto's findings. However on young cattle the results were much better (R2= 0.869; 0.707; 0.901). Berzaghi also reported on inconsistencies between various papers regarding the measurement of Warner Bratzler shear force, pH and tenderness.

Price [21] (2008) on the other hand, found that "The VIS-NIR system correctly classified 26 of the 28 (92.9% accuracy) tough carcasses " on a sample of 100 carcases.

He concluded that "In an attempt to improve efficiency in processing facilities, carcasses that were predicted as tough could be accurately sorted onto specific rails in holding coolers, thus benefiting the fabrication process. In addition, identification of tough carcasses in-plant could benefit beef producers that produce cattle that generate tender carcasses, which could possibly lead to incentives for specific degrees of tenderness."

Also, in 2008 Rust [22] in a trial of 292 Choice and select USDA graded carcases that "It was concluded that NIR scanning offers an in-plant opportunity to sort carcasses into tenderness outcome groups for guaranteed tender branded beef programs. "

Shackelford in a later paper 2012 [23] developed some prediction correlations on line during the grading process in a large US plant. Using custom made spectroscopy units using detectors in the 350 to 1,050 nm range. He concluded that "The present experiments resulted in development and independent validation of a robust method to noninvasively predict LM tenderness of grain-fed beef carcasses.

pH has also been measured using NIR.
In a subsequent paper by Shackelford [24] in 2012 as well, a trial is described where more carcasses were measured with Vis-NIR at line speed in a processing plant. The goal was to provide a validation of the previous trial and to see if more measurements post-mortem aging could improve the prediction of tenderness. It was concluded that "this technology for non-invasive tenderness prediction can be robust across time when applied under a similar situation (i.e., the same packing plant)."

A paper by ElMasry et. al (2012) [25] images were collected for beef samples in an Irish processing facility. The spectral footprint derived from these images was compared to the accurately measured pH, Colour L*A*B* and tenderness values and following some data and statistical manipulation then "By using these important wavelengths, image processing algorithm was developed to transfer the predicting models to every pixel in the image for visualizing colour and pH in all portions of the sample."
They found that "NIR hyperspectral imaging system is a potential technique for non-destructive prediction of beef quality attributes, thus facilitating identification and classification of beef meat in a simple and fast way. With more improvement in terms of speed and processing, the hyperspectral imaging system could be effectively implemented in commercial meat product processing plants for non-destructive and rapid quality measurements."

The researchers noted that the use of fewer wavebands in the spectral measurements is preferable so as to reduce the interband correlation which can lead cause convergence stability in the prediction models. Something the Australian projects seem to have suffered from. They note that "such PLSR model remains less robust in case of pH and tenderness prediction which requires further studies including external validations and analyses of a bigger number of samples"

On the more positive side "it seems feasible to use hyperspectral imaging technique as a reliable and rapid alternative to traditional colorimeter, standard pH electrodes and universal testing machines for measuring colour, pH and tenderness, respectively".

Xiong (2014) [26]also notes the pending improvements in both hardware and software. With hardware advances such as optical grating allows "more precise spectral ranges in practical applications" and new CCD cameras have been developed to "reduce production cost and improve performance". With software it was identified that "Advances in software mainly focus on developing new algorithms for hyperspectral data processing". These algorithms will allow for the removal of redundant data. Improved statistical analysis is alos adding to the developments all of which combine to improve the ability of Hyperspectral imaging systems to predict quality attributes of red meat in the future.

The researches noted that Kobayashi et al. could predict in intact raw beef cuts total fat, total saturated fatty acid and total unsaturated fatty acid with correlation coefficients (R^2) of 0.9, 0.87, 0.89 respectively.

It was identified that with Lamb, Kamuruzzaman et al. could predict water, fat and protein contents, with an R^2 of 0.84, 0.87 and 0.82 and Standard Error of Prediction of 0.57%, 0.35% and 0.47% respectively.

In another paper by Kamuruzzaman et al [27] pH in lamb can be measured using NIR hyperspectral imaging technique with an R^2 of 0.65 and Reis et al. (2014) [28] believed that they were able to segregate the high pHu carcases (pHu $\geq$ 5.8) from low pHu carcases within 20-40 minutes post mortem, 90% of the time at line speed in a hot boning beef plant.

Colour and marbling could also be predicted with good correlations (R of 0.96, 0.96, 0.07 for L*, a*, b* for colour by Wu et al. and R^2 of 0.92 for marbling by Li et al.) but noting that this was not across the whole rib-eye section of the quartered carcase as is required by AUS-MEAT. It is wondered why this would be any better than an efficient system of a Chiller Assessment vision system as is now available.

In a more recent paper by Toohey, [29] (2014) which reviewed much of the objective measurement technology including the papers by rust and Shackleford, concluded that :-

"Thus far the only real commercial application of this technology in terms of carcase traits has stemmed from the work in the USA by Shackelford, *et al.* (2005; 2012) and similarly Rust *et al.* (2008) where the technology has been found robust under commercial conditions and useful for classifying beef carcases based on their predicted sliced shear force allowing sorting of carcases into different tenderness groups. Additionally a similar concept has also been proposed for lamb carcases (Kamruzzaman, ElMarsy, Sun & Allen, 2013) where they could be sorted into tender and tough with reasonable accuracy. However with refinement of more recent techniques where VIS-NIR spectroscopy measurements have been taken on the surface of carcases (De Marchi, 2013; McDonagh, 2014, Unpublished data) the technology could be even more applicable and attractive for industry. Clearly more work on this technology to move it from concept to application is required."

10.1.3 Summary

From all of the above it appears that NIR can:-

(IV) Predict fat content in beef trimmings (R=0.98, RMSEP=2.8%)

(V) Measure pH pre and post rigor could be measured with a similar accuracy of a pH meter

(VI) Has the ability to measure objective colour, intramuscular fat and pH at 24 hours post slaughter

(VII) robust method to noninvasively predict LM tenderness of grain-fed beef carcasses

Whilst some of these claims still need to be verified on Australian cattle and processing conditions the outlook seems promising. It needs to be noted that these measurements are taken on the chilled carcase and not before it leaves the slaughter floor.

The Meat Quality attributes relating to the sensory side of meat such as taste, juiciness and flavour appear to need additional research before a useful tool is available.

10.1.4 Nuclear magnetic resonance (NMR) and Magnetic Resonance Imaging (MRI)

As quoted by the University of Tennessee Physics department [30]**"**Magnetic resonance imaging (MRI) is an imaging technique used primarily in medical settings to produce high quality images of the inside of the human body. MRI is based on the principles of nuclear magnetic resonance (NMR), a spectroscopic technique often used to obtain microscopic chemical and physical information about molecules.

The medical imaging technique was called magnetic resonance imaging rather than nuclear magnetic resonance imaging (NMRI) because of the negative connotations associated with the word nuclear in the late 1970's. MRI started out as a tomographic imaging technique (imaging by sections), that is it produced an image of the NMR signal in a thin slice through the human body. MRI has advanced beyond a tomographic imaging technique to a volume imaging technique.

MRI and NMR are technologies that have the same basis. Both technologies rely on applying a strong magnetic field to a person (MRI) or a sample (NMR), and then applying another oscillation magnetic field at a specific frequency and measuring the electromagnetic frequency response from the sample or human being tested. Toohey [29] notes that "the most widely explored NMR in meat science is proton relaxometry. The use of relaxometry has been highly successful due to its ability to characterise water and structural features in heterogeneous system like meat"

"Over the past fifty years Nuclear Magnetic Resonance Spectroscopy, commonly referred to as NMR, has become the preeminent technique for determining the structure of organic compounds"

And, in the application to food andin particular meat, Marcone [31] “Due to the fact that many foods are proton-rich, with protons originating, e.g., from water, fat, carbohydrates, and proteins; proton NMR becomes the most common type of NMR to determine these abundant food components. The components are essential for human nutrition and also influence the intrinsic properties of food during processing, storage, and transportation”.

In the report undertaken by Starling and Palmer in 2006 [32] the available, commercial MRI technology was reviewed. Whilst this technology was certainly capable of generating very high quality 3 dimensional images of a beef or lamb carcass, It was concluded then that this technology was going to be:-

- too slow to operate for a modern processing facility
- too costly to own and operate
- and the potential dangers of such large magnetic forces in a meat processing facility will cause significant safety concerns.

These concerns have not changed and hence mean it is not a technology at this point that has merit in a production arena. Since that time, the technology has improved and strength of the magnetic forces has been reduced somewhat to produce a similar quality image at less than 3 Teslars. Whilst the MRI technology has continued to develop [33] “MR imaging has become the preferred diagnostic imaging method for imaging the central nervous system, particularly for detecting brain tumours, spine lesions, imaging blood vessels, and stroke affected areas of brain. This technology has gained impetus from the keen interest shown in it by technology developers and manufacturers that wish to make it more patient friendly”

And,

“Moreover, changing healthcare reforms from early 2013 in the U.S. also resulted in 20-25% reimbursement cuts for MRI, affecting the global clinical OEMS, physicians and healthcare payers. Nevertheless, once market barriers of tight R&D budgets, high costs of MRI scans and alternate cooling systems are resolved, the industry is expected to grow considerably. With technology developers exploring many new applications, especially those involving cardiac and breast imaging, it was inevitable that magnetic resonance imaging would evolve into a highly sophisticated medical imaging tool.”

This suggests that the technology will continue to develop. At this stage of the technology it does not meet the needs of a modern processing plant. There are however some exciting opportunities in the research arena regarding the NMR technology.

Generally with NMR a sample is taken and inserted in a container around which the magnetic fields operate. This means that the size of the system and hence to cost to operate is much less. However having said that, NMR is considered a costly method of analysis. It’s applicability as an online measurement tool is limited since it needs a “Sample” to measure.

Massimo et al [31] notes that since many foods are proton rich “with protons originating e.g. from water, fat, carbohydrates, and proteins; proton NMR becomes the most common type of NMR to determine these abundant food components. The paper goes on to talk about the ability of NMR “to determine water content and water distribution in foods" and the capability of visualising the water distribution within a compound.

There have been several recent studies [34] [31] illustrating the ability of NMR to simultaneously measure sensory properties such as :-

- Flavour
- Juiciness and tenderness
- Cooking loss
- Fat and moisture content
- Instrumental tenderness (Warner Bratzler shear force)

This is done using time domain NMR which monitors the electromagnetic signals generated by the sample after the magnetic field is turned off.

Other studies [35] were able to discriminate breed "allowed the classification of muscle type according to the breed. In the case of Buffalo and Chianina the discrimination capability was very high, while for the other two breeds the model's goodness and predictive ability was lower."

Marcone [31] in this 2013 paper says "The use of MRI permits the quantification of the above mentioned parameters, which has been used not only to determine chemical composition, muscle structure, and quality of meat, but also to study carcass composition, adipose tissue distribution, connective tissue, and muscle fibre type. These parameters have also been correlated with meat properties including pH, water-holding capacity, moisture, texture and sensory attributes

He also says that "Modifications of NMR instruments are also needed to improve the sensitivity to enable improved detection and quantification of food components."
He believes that "Research applications described above illustrate that NMR and MRI are valuable tools to study metabolic processes, composition, structural, and physical states of foods, as well as tools for food quality and process control."

Regarding new equipment development he goes on to note that "and other workers proposed that low-field NMR technologies along with polarization techniques can contribute to the development of stable, robust and portable NMR devices"

Low field NMR is important because "In food science, barriers to development of NMR spectroscopy instruments are primarily due to high cost, the expertise involved, and safety issues related to magnetic field maintenance. Low-field NMR and MRI are relatively more accessible to food researchers due to lower cost and easier maintenance, but their applications are still limited. It should also be noted that all applications of NMR and/or MRI appears to be research oriented at the present time"

Li et. al [36] (2012) suggested that low field NMR and colour evaluation could differentiate water holding capacity in pork.
Water holding capacity and its interaction with eating quality seem to be important hence the importance of the ability to measure it. Pearce et. al [37] (2011) in their paper note the importance of this. ". This review identifies the critical stages which affect the translocation of water into the extra-myofibrillar space and thus the potential for decreased WHC during proteolysis (the

conversion of muscle to meat). This review discusses how the intrinsic properties of the water held within the meat could contribute to juiciness and tenderness."

As stated by Toohey, Proton NMR uses relaxometry. This is a process whereby the protons return to their equilibrium state after being disturbed by a radiofrequency pulse. This time to retune to equilibrium can be measured and the Paper by Pearce et. al [37] suggest that tenderness is correlated with this response time. The paper cautions that "breed and species differences made it difficult to draw firm conclusions. Further understanding of the inherent water properties of fresh meat and the factors affecting water distribution and mobility using NMR technologies will increase the understanding of WHC and tenderisation of fresh meat."

This confirms earlier work by Pearce et. al in 2008 [38] using a prototype bench top NMR machine on lambs. It concluded that "This research indicates that an increase in the concentration of water with a fast relaxation time (K21) and a decreasing T21 time constant is associated with more tender meat. The opposite result has been observed in pork. This result needs to be further confirmed with red meats."

It seems that despite more work being done an easy measurement of the key eating quality parameters still eludes the industry. However there seems to be sufficient evidence that the research is close to unlocking the secrets using NMR and eith technological advance in equipment development, the time and cost will reduce to make this continues research more feasible.

10.1.4.1 Summary

- NMR is an emerging technology with many areas of opportunity yet to be fully explored.
- At this stage of it technological development it does not meet the needs of a modern meat processing facility except for research.
- Heavy laboratory apparatus are being replaced with efficient NMR portable devices making the availability of equipment to undertake trials more accessible.
- It potentially has the potential to measure:-
    - Flavour
    - Juiciness and tenderness
    - Cooking loss
    - Fat and moisture content
    - Instrumental tenderness (Warner Bratzler shear force)

10.1.5 Raman Spectroscopy

10.1.5.1 Introduction

"Raman spectroscopy is a spectroscopic technique based on inelastic scattering of monochromatic light, usually from a laser source. Inelastic scattering means that the frequency of photons in monochromatic light changes upon interaction with a sample. Photons of the laser light are absorbed by the sample and then reemitted. Frequency of the reemitted photons is shifted up or down in comparison with original monochromatic frequency, which is called the Raman effect. This shift provides information about vibrational, rotational and other low frequency transitions in molecules. Raman spectroscopy can be used to study solid, liquid and gaseous samples." [39]

The interest in the Meat industry regarding Raman Spectroscopy appears to be growing with the greater availability of economical instrumentation. The greater availability of lower cost instrumentation is probably as a result of Raman technology being used extensively in the Security and law enforcement arenas because "Raman spectroscopy offers the advantage of identifying potentially hazardous substances by a unique fingerprint, based on the chemical structure of the unknown, and can do so through the walls of sealed plastic bags and transparent bottles, vials, and ampoules without opening the container. Therefore, Raman spectroscopy can be an ideal tool to aid in substance analysis during arrests for possession, seizures of clandestine manufacturing laboratories, large seizures at borders and ports of entry, and in first responder situations." [40]

There has been earlier work in meat with Font-i-Furnols et al. identifying [41] "Since 2000, Raman spectroscopy has been used in pork, lamb and beef to estimate various meat characteristics. Results were promising, Wang *et al.* (2012) obtained an R_2 of 0.98 to predict chewiness, tenderness and juiciness and Olsen *et al.* (2007) R_2=0.83-0.98 to predict SFA and MUFA directly from fat tissue. Iodine Value (IV) was calculated from the fatty acid profiles in order to determine the degree of unsaturation of the adipose tissue."

Toohey, in 2013 [29] identified research in 2004 that claimed "a rapid non-destructive technique for prediction of tenderness and juiciness for beef.

Damez, et. al in 2008 [42] suggests that Raman technology can predict the water holding capacity of meat as well. The paper also suggests that using polarised light depth dependent selective information can be gleaned.

Recent work on pork reported in 2013 by Berhe et al. [43] claims it is "It is easy, fast, non-destructive and not sensitive to water. The objective of this study was to use Raman spectroscopy to characterize fatty acid composition of pork back fat. Berhe suggests that "Thus, the meat industries can make measurements and classify carcass and/or product rapidly."

The most recent research in sheep was in 2013 by Beattie et. al [44] who took Raman measurements on samples from two sheep flocks of different origins which had been aged and frozen. They found high correlations (Approx. 0.8 R^2) of Raman Spectra values with shear force and cooking loss. Raman spectra measurements for the prediction of quality traits such as tenderness and cooking loss can be collected and recorded during meat processing.

A poster presented in March 2014 [45] describes research "Based on raw Raman spectra of 10 pork semimembranosus muscles a range of data pre-pro-cessing and multivariate calibration methodology have been used to develop online predictive models for the meat quality parameters: the lactate and pH"

In this work correlations for pH and Lactate were achieved; "Identifying the best "efficiency "evaluation procedure represented the final milestone of the present study. Thus with a cross-validated r^2 value for both pH and lactate of 0.97, a RMSECV of 4.5 mmol/l for the lactate prediction and 0.06 units for the pH prediction."

Other recent papers with pork also suggest that Raman Spectroscopy can be used to measure pH. [46] There appears to be elaborate sample preparation required which suggests this is far from an on-line tool. However the correlations with Raman Spectra suggested" demonstrate the usefulness of Raman spectroscopy to observe qualitative metabolic changes in a pork muscle and to quantify the pH value between 0.5 and 24 h post mortem."

In a recent web site article in "The Meating Place" [47] Ramaon Spectroscopy is being used to detect single bacteria and pathogens, although the article notes that the equipment is bulky and the process slow.

How this technology would be then used by Meat processors is yet to be determined. Toohey [29] suggest that "Further research into the effects of Raman Spectra for sheep and beef would be required before we could accurately determine the effectiveness of this technology for the commercial use in the red meat industry."

In another paper by Schmidt (2013) [48] trials were undertaken on 140 lambs. Ramon Spectroscopy measurements were taken as well as shear force, cooking loss % pH and Drip loss. It was concluded that "The results show the potential of Raman spectra for the prediction of quality traits such as tenderness and cooking loss

10.1.5.2 Summary

Raman Spectroscope shows some promise in measuring attributes of meat that may be useful as a grading or market allocation tool.
These attributes include tenderness, juiciness, flavour, cooking loss, pH and lactate.
There still appears to be significant work needed before this is a useful commercial production tool.

10.1.6 Terahertz and Millimetre Waves

Terahertz and Millimetre waves are an emerging form of electromagnetic waves. They have jumped to prominence with their capability to "see" through normal clothing and detect items such as weapons hidden beneath clothing without causing any harm to the person.

In 2008, MLA undertook a review of the opportunities with Terahertz and Millimetre wave radiation technology [49]

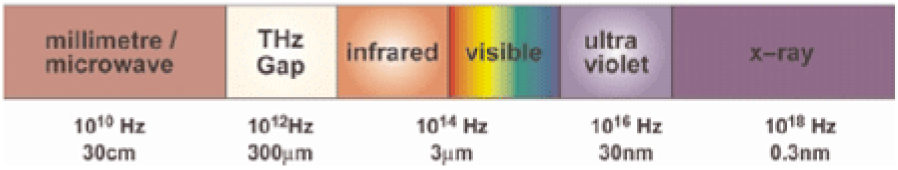
From that report:-

"The expression "Millimetre wave" and "Terahertz wave" are basically interchangeable. The terahertz refers to the number of cycles per second or "Hertz" that the waves vibrate at and the "millimetre" part refers to the wavelength which is approximately 1 mm.

Terahertz waves are intrinsically safe, non-invasive and non-ionizing and shares with microwaves the capability to penetrate a wide variety of non-conducting materials. It can pass through clothing, paper, cardboard, wood, masonry, plastic, ceramics and other items such as fog clouds. It will not penetrate water or metals.

Terahertz radiation is non-ionizing electromagnetic radiation in the frequency from 0.1 to 10 THz or $1x10^{11}$ to $1x10^{13}$ hz (Terra Hertz = 10^{12} Hertz or cycles per second) and corresponds to wavelengths between 30 µm and 1 mm These waves occupy a portion of the electromagnetic spectrum between infrared and microwave radiation. Terahertz radiation is also called, **terahertz waves**, **terahertz light**, **T-rays**, **T-light**, **T-lux** and **THz**

Millimetre waves are I the range from 30- 300 Giga Hz ($3x10^{10}$ -$3x10^{11}$). They are therefore at the bottom end of the terahertz range, closer to the microwave region. . .



”

This report [49] noted that “Terahertz waves are now finding applications in a wide range of applications, many which are still being discovered and unfortunately there has been little work undertaken in the biological area.”

Subsequent to this work contact was established with CSIRO at their CSIRO ICT Centre, Multi-Spectral Imaging Project who had used Terahertz waves previously. This project was to undertake a brief trial using established equipment on the potential for Terahertz waves to measure subcutaneous fat depth across a carcase. For these initial trials easily available cuts of meat were used. If successful, the goal would have been to develop an automatic robotic, subcutaneous fat cutter that would pre-trim a hot carcase to a specified depth

The following from the report summarises the potential of the technology:-

“The CSIRO ICT Centre has proposed a technique based on the reflection of microwaves from the air-fat and fat-meat interfaces of the carcass. This report details some preliminary calculations and measurements on five samples carried out in May and June 2007. The measurement results are summarized in Table 2 which compares invasive and microwave measurements of fat thickness on the five samples.

	Fat thickness	
Sample	Microwave meas’t (mm)	Invasive meas’t (mm)
Pork 1	15.7	11 ± 2
Pork 2	15.7	15 ± 5
Lamb 1	unclear	2 ± 2
Lamb 2	11.3	7 ± 3
Beef	unclear	8 ± 2

Table 2. Microwave measured fat thicknesses of the five samples.

Based on these studies, it is concluded that the technique should work in principle; however there are a number of practical difficulties which would need to be addressed:

(i) Measurements would need to be made at a relatively large number of discrete frequencies (>10) or the instrument would need to scan or “chirp” over a frequency range. Unfortunately, instruments designed to generate and receive microwaves over a large frequency range are expensive (tens of thousands of dollars). Also, there are significant licensing issues with operating equipment over a large frequency range. The rural location of most abattoirs and the indoor nature of the measurement would help in acquiring a license; however this would still not be a straightforward task.

(ii) A fan, or a similar airflow mechanism, would be needed to remove blood and water from the surface of the carcass for the duration of the measurement. Water and blood are strong absorbers of microwaves and their presence would result in significant errors in the estimate of fat thickness.

(iii) The alignment of the carcass and microwave horn is crucial. The shape and size of the pork samples enabled them to present a relatively flat surface to the measurement equipment. This resulted in much higher reflected powers and a sounder estimate of fat thickness. In comparison, the reflected powers from the Lamb 1 and Beef samples were too low for a reasonable estimate of fat thickness to be made. However, the samples used in this study were much smaller than the whole carcasses which would be measured in an abattoir, and hence this problem might not be as significant as it first appears. Future refinements of the technique should be tested on more realistic samples. Also, in its final implementation, the microwave horn would ideally be mounted on a robotic arm which could adjust its orientation to maximize the reflected signal.

(iv) A lens or other focusing element is required to increase the reflected power and reduce the area of subcutaneous fat under measurement. However, the combination of multiple frequencies (suggested in (i)) and a lens would increase the similarity of the technique to that patented by Holme. It is recommended that a second phase of work be undertaken. This phase of work would involve further testing of the technique at Marsfield on at least three larger samples provided by MLA.

Most of these considerations were thought to have been easily dealt with. Due to changes of personnel within CSIRO and a lack of interest from the researchers, this next phase never progressed.

At a recent conference in 2013 [50] International Conference on Infrared Millimetre, and Terahertz Waves, there was much more interest in all things biological From the referenced Table of Contents the following were relevant papers.

"P3-81 Pharmaceutical, Biological And Industrial Applications Of Terahertz Spectroscopy And Imaging 984, Edward King; Eiji Kato; Mark Sullivan; David Heaps Advantest America, Inc, United States. The terahertz range of the electromagnetic spectrum falls between the more familiar microwave and infrared regions. Advances in pulsed terahertz technology over the past decade have led to the development of commercial instrumentation for spectroscopy and imaging. Terahertz analysis is non-destructive for materials as well **as living tissue and its high depth of penetration offers many advantages over other techniques**. Terahertz spectroscopy is well suited for the identification of crystalline polymorphs and for real time monitoring of solid form changes in-situ. Terahertz imaging is ideal for measuring the thicknesses and properties of multilayered structures such as tablet and paint coatings. Terahertz techniques for measuring bulk physical properties (e.g. electric field permittivity) also have the potential to determine the efficacy of drugs and to **detect**

disease states in cell cultures. In this poster, we present the background of terahertz analysis and instrumentation and provide examples of several recent applications from our laboratory.

And

"Mo P1-39 Linac Based Broadband Source Of THz Coherent Smith-Purcell RadiationIvan Konoplev[1]; Alexander Aryshev[2]; Junji Urakawa[2]; Konstantin Lekomtsev[2]; MikhailShevelev[2]; Andrei Seryi[1] [1]JAI, Department of Physics, University of Oxford, United Kingdom; [2]High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Japan Development of compact source of high-intensity, coherent, broadband, THz radiation is still at its initial stage. Such sources are required for a broad range of the researches including metrology, **biology**, security and etc. Here we discuss one of the schemes for generating the THz coherent radiation."

And

"**Th P3-11** Analysis On THz Applications For DNA NanomachinesMiki Hirabayashi[1]; Ibuki Kawamata[2]; Masami Hagiya[2]; Hiroaki Kojima[3]; KazuhiroOiwa. **Biological ICT Lab**., Advanced ICT Research Institute, National Institute of Information and Communic, Japan; [2]Univ. Tokyo, Japan; [3]NICT, Japan We present an analysis on bond-dissociation dynamics of DNA-based molecular machines under terahertz radiation. Our goal is to control micro/nanoworld utilizing artificial molecular machines. In this work we aim to provide fundamental findings to construct platform technologies to **control artificial molecular systems** using terahertz waves."

And,

"Th P3-80 Identification Of Tissue Interaction Of Terahertz Radiation Toward Functional Tissue Imaging By Terahertz Spectroscopic Imaging Seongsin Margaret Kim; Hamdullah Yokus; Soner Balci; David Wilbert; Patrick Kung University Of Alabama, United StatesIn this study, we utilize Terahertz imaging to study the effects of hydrofluoric acid on both compact bone tissue and cartilage. We compare the differences observed in the exposure for formalin fixed and raw, dried, tissue as well as those resulting from a change in Hydrofluoric (HF) concentration. Measurements are performed with THz-TDS, and a variety of spectroscopic based image reconstruction techniques are utilized to develop contrast in the features of interest."

And

"Th P3-09 Real-time THz Imaging Of Human Tissue Characteristics And Cancer Margins Woon-Gi Yeo[1]; Niu K. Nahar[2]; Charles L. Hitchcock[3]; Ogan Gurel; Sungchan Park;Kubilay Sertel[1] [1]ElectroScience Laboratory / The Ohio State University, United States; ElectroSicence Laboratory / The Ohio State University, United States; Davis Heart & Lung Research Institute / The Ohio State University, United States; Samsung Advanced Institute of Technology and Samsung Advanced Institute for Health Sciences & Techno, Korea, Republic of; Samsung Advanced Institute of Technology, Korea, Republic of We investigate the use of real-time THz camera imaging for differentiating between benign and malignant tissues in major human tissue groups. Using broadband time domain THz spectroscopy, we discriminate between tumour and nerve margins on the basis of different THz refractive indices and reflectivity. Particular focus is given to easily accessible malignancies, such as skin, larynx, oesophagus, and colon cancers. Time domain THz response due to tissue chemistry and morphology is recorded and tabulated to create a "THz tissue database" that can be used as a reference for diagnosis as well as tumour and nerve margin differentiation using THz waves."

Whilst this is hardly a major change in the direction of the application of the technology, it does indicate that there are some applications within the biological arena and a watching brief maintained on Terahertz wave technology would be beneficial.

10.1.6.1 Summary

- The trials undertaken with this technology were very low key. They showed promise to predict subcutaneous fat thickness but additional structured trials are needed.
- The technology has developed substantially since this project as undertaken.
- Potential to develop an automatic hot fat trimmer to a set thickness all over a side prior to chilling.

10.2 X-Ray Based Technologies

10.2.1 X-Ray Single Energy (SEXA)

10.2.1.1 Introduction

The RMI has been involved with assistance on X-Ray projects for a number of years. These projects have used conventional X-Ray to identify skeletal positions in Lamb and the use is identical to the way X-Ray is used in the medical industry.

X-Ray has proved successful albeit somewhat troublesome in trying to find the correct location in 3 Dimensions from a 2 Dimensional image. If the task was to locate a particular cutting line based on a numbered rib position, counting the ribs can be difficult because of the numbers of bones around where the first rib starts. The opportunity for error is obvious.

The Single Energy X-Ray technology world wide does not seem to have changed apart from the push for lower dose and a better image from the lower X-Ray dose.

More recently there has been some development work utilising Hyperspectral imaging techniques utilising X-Ray Scattering

10.2.2 X-Ray Dual Energy Absorptiometry (DEXA)

Dual Energy X- Ray or DEXA has been commercially available for some time. The technology uses the information from data captured at 2 different energy levels. The higher energy is better at discriminating harder, denser Bone material whilst the lower energies are better at discriminating the software tissues.

Applied Sorting [51] undertook a study in 2006 Approximately. They summarised that based on work done in a separate Monash University study undertaken for Applied Sorting, accuracies of measuring meat thickness in lamb with a DEXA system could be achieved of precision of less than 3%

Furthermore, new detection technology being driven by the security industry is using photon counting techniques incorporated into the detectors which means that, “fat and lean quantification can be done with newly available detectors in practical equipment”. It noted that experimental confirmation was needed.

Toohey in the Milestone 1 report [29] noted that previous referenced reports had “demonstrated the efficacy of DEXA as a non-destructive method for determining the composition of sheep half carcasses based on the high accuracies made for total tissues mass, lean mass, fat tissue mass and bone mineral content”

There is also reference to a 2009 report lead by Pearce [52] was undertaken using lamb carcasses and not sides as the previous report. This report found that “DXA is an accurate tool to measure carcass composition in both live and dead animals and carcasses.”

It found that DEXA could predict the boned saleable meat weight with an R^2 of .93 and RSD of 0.47. This was done excluding the carcass weight as a co-predictor.

The report also noted that “despite the positive results for the DEXA to estimate boned out muscle weight, it is difficult to predict whether the DXA will be used as an online carcass grading tool due to the compatibility of the long scanning time (approx. 2 minutes per carcase) and the chain speed of the abattoir.”

At these slow speeds the DEXA technology will still be a useful tool for researchers and the opportunity is there to undertake cross sectional scanning to fit in with chain speed and extrapolate those results to the whole carcass. New technologies such as Fan beam or wide angle bam are likely to improve scan times.

It must be remembered however, that all of these DEXA trials have been done using medical DEXA machines where the patient X-Ray dose is a high consideration and this is one of the factors limiting the speed of capturing an image.

Apart from the speed of image capture Stone and Turner [53] Also note that “Despite the plethora of potential and realized uses for DXA in veterinary research, the use of DXA remains restricted, primarily, to the human health industry or animal research. Currently, a number of limitations exist that prevent the widespread use of DXA in veterinary medicine. Most notably, the high purchase and maintenance costs and relatively short life-span of DXA units, combined with their size, are major limitations for DXA and hinder its widespread use in traditional veterinary practice. Until these limitations are resolved, DXA will continue to be restricted to human-based clinical settings or with animal research institutions.”

This technology appears to be an acceptable tool for research when applied to the appropriate use. It seems to be a long way away from use as a production tool however; the technology in this area is being driven by the security industry [54]and is advancing rapidly. A watching brief would be wise to monitor advances.

Scholz’s paper [55] (2012) at the Farm Animal Imaging Conference agreed generally with the results of Pearce on lambs although the accuracies were not nearly as good. It was noted that the move toward the Dual Energy CT might be the better path forward.

DEXA has also been reported as a tool for the objective measurement of eating quality.

Font-i-Furnols [41] "DXA has been reported to be able to determine the chemical composition of pork and beef (R_2=0.5- 0.9) (Brienne *et al.*, 2001). Recently, Lopez-Campos *et al.* [56] (2013) evaluated IMF of beef using this technology (R_2=0.43) and meat tenderness evaluation was also reported to be feasible(R_2=0.69) (Kroger *et al.*, 2006). Although it was concluded that "results from this preliminary study suggest that dual energy X-ray absorptiometry technology may have the potential to estimate beef quality traits, such as marbling. However, further studies to obtain calibration curves are needed to increase prediction accuracy for use in beef populations."

A recent discussion with Professor Rob Lewis [57] seems to dispel a lot of the concerns about slow speed and DEXA's ability to be a useful objective measurement tool capable of operating at modern meat processing chain speeds. Rob is a Professor at Monash University in Melbourne at the School of Medical Imaging and Radiation Sciences. The lower energy output of the existing medical machines has been driven by minimising the X-Ray dosage that a patient receives. He supports the belief that with the right energy output from the X-Ray generator and the appropriate detectors, a dual energy system could be built to image t a beef carcase at the speeds required. There would be implications for the cost of the X-Ray shielding areas to cope with the higher energy levels.

Whilst dual energy systems are still a @ dimensional system and some shadowing effect occurs as a result of bones hiding the tissue below, it is feasible to use a purpose built DEXA system that gave the amount of meat fat and bone of a beef hindquarter and forequarter and meat fat and bone amounts for the leg; middle and shoulder for a lamb carcass.

10.2.3 Computer Tomography (CT) or 3-D X-Ray

10.2.3.1 Introduction

In 2008 a project was undertaken by Matrix Professionals [58] to ascertain the emerging technologies that would have the potential to deliver benefits to the Red Meat Industry (RMI) in the area of Objective Carcass Measurement (OCM). At that stage the measurements of overall carcass yield; cut weight yield and measurement of Intramuscular fat or marbling were high on the agenda.

This study determined that of the technologies reviewed, Computed Tomography or CT, had the greatest opportunity to deliver the best outcome in the shortest time. At this time there had been little research into CT for use in a commercial meat processing facility.

As a result of the early work in this study there was hoped that using Cone Beam CT where one rotation of a carcase could collect data on that carcase over a large swath of area would have been successful. If it had been, it would have been a potentially very elegant solution. The work undertaken by Scott Technology [59]at the Siemens facility in Munich however, demonstrated conclusively that with the current Cone beam CT technology, it was never going to be a success.

This process of investigation has taken MLA some years. Initially it sourced a number of Industrial CT companies with whom to partner with. Imtec Corp. [60]was the original Company that MLA worked with having considered a number of other industrial CT companies as well.

The trials undertaken with Imtec Inc. using their industrial Cone bean CT machines provided a good grounding in the technology and industry contacts even though the Technical results were disappointing and Imtec's performance on delivering to their outcomes was also disappointing.

Unfortunately not long after MLA engaged with Imtec, Imtec was subject to a merger that changed the focus of the business away from Industrial CT systems and prevented the work continuing.

10.2.3.2 R&D Projects Relating To CT

Following this work with Imtec and the relatively disappointing outcome, further work was undertaken with Siemens at their facility in Munich Germany by Scott Technology [59]. Scott worked with Siemens to conduct trials on both Cone Beam CT and Fan Beam CT.

The results of this work were more successful particularly with Fan Beam CT the same technology used in conventional spiral Medical CT scanners.

This report shows that with Fan Beam CT the following are potentially capable:-

	Sheep /Lamb	Beef
USE	Fan Beam (Medical)	Fan Beam (Medical)
Automated cutting between bones	✓	✓
Automated cutting between primals	✓	✓
Lean Meat Yield	✓	✓
Saleable Meat Yield	✓	✓
Marbling or Intramuscular fat	N/A	✓
Eye Muscle Area	✓	✓
Hump Height	✓	✓
Subcutaneous Fat and GR	✓	✓

This table should not suggest that these actions are available now. Much more needs to be done to develop the algorithms to make these a reality. What this table is suggesting is that the image quality was of sufficient contrast to enable software to be able to extract reliably from the image that information needed to generate these outcomes.

The other consideration is that these were a one off scan. That is it was much like a medical scanner where one patient (or Lamb) was scanned and then another patient was set up. This means that the X-Ray units have time to cool down which would not be the case for a production unit.

Other research projects that MLA has sponsored have delivered the following:-

1. [61]That hot or cold carcase temperature does not impact the ability of CT to measure marbling within the muscle. More work is needed to confirm this across a range of all Marble Scores.
2. [1]That CT can predict the Marble score irrespective of the temperature of the carcase. This means that potentially the marble score of a carcase can be known before the carcase leaves the slaughter floor.

Summary

10.2.3.3 Computer Tomography- Medical

There continues to be large volumes of specific research into CT in the medical arena. Much of the research revolves around specific techniques to find specific organs from the collected and reconstructed images or specific techniques to improve the image quality; contrast and image reconstruction.

The major manufacturers continue to develop their hardware and most of these developments are kept within the company doing the development.

There are however several companies that manufacture the Kernel of the system, i.e. the rotating machinery, the X-ray generator and the X-Ray detector for several of the main players.

Apart from the hardware research there have been two main areas of research. Software that undertakes the reconstruction of the images and the better this becomes the clearer and greater contrast is the image.

Clearer images means that smaller items that could not be detected before can now be seen' by the radiologist reading the image or detected automatically on a consistent basis using image processing software.

10.2.3.4 Dual Energy CT

This is now almost a mainstream tool available to radiologist with CT manufacturers mounting 2 X-Ray generators and 2 detectors onto the rotating gantry. . [62] "Dual Source CT (DSCT) is a relatively new technique used for diagnostic imaging purposes which uses two different x-ray tubes in a single CT unit. With the additional tube comes the advantage of exposing the patient with two different energy spectrums"

Unless imaging high atomic numbers such as calcium (bone) contrast agents such as iodine are added via injection or Xenon gas for lung airway differentiation enable the 2 different energies to produce better quality images.

Injection of contrast agents is not an option for meat processing and further discussion on DECT is included with the discussion on Aviation CT systems

[1]

10.2.3.5 Software Developments

10.2.3.5.1 Reconstruction Algorithms

There is a continued development with CT Software. CT Software comprises 2 areas. The first relates to the quality of the image that is captured and the predominant research involves improvements in the image reconstruction algorithms

Other software developments relate to improving the contrast of the image so that more detail can be viewed in the image.

10.2.3.5.1.1 Recent Improvements in Reconstruction Algorithms

The main CT equipment suppliers have invested thousands of man-hours in developing robust reconstruction algorithms. These algorithms take the raw X-Ray image of each 'snapshot' and joins them together in a manner that accounts for many of the geometrical and spatial artefacts.

According to Lifeng et. al. [63] "Image reconstruction in CT is a mathematical process that generates images from X-ray projection data acquired at many different angles around the patient. Image reconstruction has a fundamental impact on image quality and therefore on radiation dose. For a given radiation dose it is desirable to reconstruct images with the lowest possible noise without sacrificing image accuracy and spatial resolution. Reconstructions that improve image quality can be translated into a reduction of radiation dose because images of acceptable quality can be reconstructed at lower dose."

Most modern Medical CT systems and Aviation CT systems have now migrated to the improved forms of reconstruction algorithms.

One example is G.E. Health care [64] "This robust, full Model-Based Iterative Reconstruction (MBIR) was designed from the ground up to enable improved image quality and to enhance imaging performance even under very low mA scenarios.

More recent research [65] covers an overview of the different reconstruction techniques. 3 of the 5 authors are employed by GE Healthcare, one of the major manufacturers of medical CT systems.

The authors make the point that MBIR whilst significantly more computationally intensive, and "provides superb image quality in terms of spatial resolution, noise reduction and artefact correction, the time delay in the image generation is not negligible."

Fortunately, the meat industry applications do not have the same pressing time constraints as intensive surgery based CT applications where there is a requirement to reconstruct the image between heartbeats as in the case with operations concerning the heart.

10.2.3.5.2 Software - Image Analysis

Most research that is undertaken in the Meat Science arena is still being undertaken on older CT systems which are still using the Filtered Back Projection (FBP) method of reconstruction. According to GE Health care and Thjibault, [64] this method of reconstruction "ignores that the projection data are corrupted by quantum and electronic noise during acquisition. Instead, it may propagate and sometimes amplify noise into patient images, creating streaks and artefacts, which may hide pathology and valuable diagnostic information."

There has been for over a decade research papers presented that have been using CT systems to measure the live [32, 66]animal or carcass attributes. [67] [68] [69]

The Mayo Clinic however is continuing to improve its Medical Image Analysis Software called Analyze [70]. This software was reported on by Palmer [58] after first seeing this software at the RSNA exhibition in Chicago. A program is running Called 'CORE' which [71]"For analysis services, the core offers **semi-automated** magnetic resonance (MR) and computed tomography (CT) image and volumetric analyses of polycystic kidneys and liver. Additionally, it offers functional assessment of the kidneys and heart, including measurements of renal blood flow."

The software to undertake this semi-automated analysis has been incorporated into the Analyze software as developed by the Mayo Clinic and is available to any radiologist interested in acquiring the software.

It will probably never happen that this kind of software becomes fully automatic since the risks to human life are too great and there will always be an involvement of the very highly skilled radiologist to interpret the image.

However, in non-human applications, it is a much smaller jump to automatically analyse a Beef kidney for example and report any exceptions of disease.

10.2.3.6 Medical CT Manufacturers

The major manufacturers of medical CT systems have slowed their advances in the quest for speed. It is reported that the Siemens Somatom which uses a Tungsten Anode within the X-Ray generator, and operates at such a high temperature that it is operating at close to the melting point of tungsten. It is only the long breaks between data acquisition, as is common in a medical CT application that enable the cooling of this system to be successful. This system would not in its current form be capable of a continuous operation as is the requirement in a meat processing facility.

The big 4 manufacturers released their latest versions in March in Vienna Austria at the European Congress of Radiation (ECR) [72] 2014 conference and exhibition.

10.2.3.6.1 Siemens Healthcare

"This German multimodality vendor made Somatom Scope an ECR 2014 highlight, with the CT scanner making its global debut at the conference. The 16-slice scanner is designed for budget-conscious sites, with a particular emphasis on low total cost of ownership: as much as 35% lower.

The work undertaken by Scott technology with Siemens in Munich I 2011 [73] used the Siemens Somatom system. This machine was similar to the recently released Somatom Force system [74]. This system has the capability of imaging the heart in less than a heartbeat and is capable of dual energy CT images. This machine can capture detailed images with a field of view of 50 cm and at a traverse speed of 40 cm/second or a beef side in approximately 8 seconds. But not in a continuous operation.

10.2.3.6.2 GE Healthcare

“GE is making its new Dose Blueprint radiation dose reduction initiative a major focus at this year's congress. Dose Blueprint combines CT dose reduction technologies such as iterative reconstruction with dose tracking software to give sites a better idea of the dose their patients are receiving.”

“The company is giving ECR attendees a look at the Revolution CT scanner launched at RSNA 2013; the system is designed to give users spatial resolution, 16 cm of anatomic coverage per rotation and dose reduction all in one package.”

10.2.3.6.3 Toshiba Medical Systems

“Like the other multimodality vendors, Toshiba is demonstrating a mix of brand-new technologies and products seen previously at RSNA 2013.

Among the new introductions is a faster version of its Astelion/Advance 16-slice multislice helical CT scanner, with a souped-up gantry speed of 0.6 seconds per rotation”

10.2.3.6.4 Philips Healthcare

“a technology seen at RSNA 2013 that Philips is talking up this week is SkyFlow, a new algorithm for digital radiography that removes scatter radiation, enabling users to acquire mobile radiography images without a grid”.

All of the above suggests that the research is no longer on improving the image or with scanning speed but the focus is more on dose reduction, integration with other technologies such as PET scans and lowering the cost of ownership.

10.2.4 Computer Tomography- Aviation

The aviation industry has adopted technology focussing on security and explosive detection in an accelerated way since the events of 11 September 2001 in the US. Legislation meant that screening and security measuring systems were mandated and required all airline checked baggage to be scanned for Explosives Detection Systems (EDS). Most US airports have adopted the use of CT systems to do this task. [75]

The National Academies Book [75] on Engineering Aviation Security Environments makes the point that

“This development fostered intensive research and development by vendors of medical imaging instruments, with relatively few contributions being made by the academic community. Much of the engineering development in medical CT was therefore considered proprietary and has remained unpublished.”

This explains why there is a large gap in the research market place of what technology is being utilised within the machinery to generate the CT Images along with the software to undertake the image analysis.

A similar approach has occurred within the Aviation explosives detection and threat identification businesses.

One saving grace has been the common data format that all CT systems have standardised on. "Digital Imaging and Communications in Medicine (DICOM) format was adopted in 1993 as the industry standard through promulgation by a committee of the National Electrical Manufacturers Association."

This then allowed vendors of 3rd party image processing software and other add-ons to flourish. The Aviation use of CT suffers from the same problem that the medial CT industry suffers in that CT is measuring a density in 3 dimensions. In medical CT a tumour can have a very similar density to a gland for example and in Aviation, Semtex explosives has a similar density to soap. Hence there can be many false positives where soap is identified in a travellers luggage requiring the bag to be further examined.

The improvements in image quality and close proximity of the CT slices has made the level of detail in both Medical and Aviation CT systems has provide significantly more opportunities for development.

Medical CT has a number of differences compared to Aviation CT:-

- The first is that every image is reviewed by a highly trained professional radiologist who is highly skilled in interpretive analysis.
- The live patient mans that the X-Ray dose is important to be minimised and sets upper thresholds on energy levels
- A low operational duty cycle of the CT systems since it would be unusual to see more than 20 patients per day over 8-10 hours per day and only 5 days per week. This impacts heavily on cooling system design and life of the X-Ray generators

Aviation CT by contrast has:-

- no maximum dose restrictions and can increase the energy without recriminations.
- the time available to analyse an image is very short with the number of bags being processed per day increasing at airports. This also means that there is neither time nor the funding available to have every image reviewed. Hence automatic software is fundamental to the success of any CT analysis.
- Very high duty cycles of the CT system being required at most airports to operate for the majority of a 24 hour period and 7 days a week

The Australian RMI requires the duty cycle, energy input and automation software of the aviation CT systems coupled with the medical diagnostics of the Medical CT systems.

10.2.4.1 Equipment Manufacturers of Aviation CT Systems

The manufacturers of the CT equipment are also developing their machinery to achieve better image contrast so as to deliver sharper and clearer images thus enabling greater opportunities for analysis.

There are 4 major manufacturers of Aviation CT systems.

They are all standalone (Conveyor in-feed and Exit) are self-shielding i.e. no need for any additional lead shielding protection and are designed for a continuous 7 days a week operation.

The table below summarises their capability

Manufacturer	Model	Production Speed m/sec	Production Speed Bags/hour	Physical Size Lx W x H	Latest Reconstruction Software	Dual Energy CT capability	Max Bag Weight kg	Fully Shielded	Max Throat dia. mm
Rapiscan [76]	MVXR5000	0.5 m/sec	1800	5379 x 1969 x 2003	?	Yes			990
L3 Security and Detection Systems [77] [78]Manufactured by Analogic	Examiner XLB		1200	5280 x 2160 x 2060	yes	yes		Yes	1000
GE Morpho Detection LLC [79]	CVTX 9400 DSi				Yes				1000
Leidos [80]	Reveal CT-120 Baggage Inspection System		1000	3600 x 2390x 2420		Yes	50		900

10.2.4.1.1 Reconstruction Software in Aviation CT systems

In the report of the RSNA conference in 2011, Palmer [58] reported that the CT Reconstruction algorithms had been ported to both the medical and the Aviation CT systems. This will mean that the image quality in some brands (i.e. those that have the Model based Iterative reconstruction algorithms) will provide images of very high quality and would be the best platform to attempt any developmental work.

10.2.4.1.2 Image Analysis Software

It is yet to be confirmed if these aviation systems are able to utilise the standard medical image analysis software but the expectation is that this will be the case. Unfortunately whilst the medical software provides the best opportunity to differentiate and measure those attributes of a carcass that are important to a Meat Processor, the automation of this software is also as discussed elsewhere in this report.

Merherbi et Al [81] reviewed several common medical methods that are used in medical Ct systems and found that "Experiments show that the current 3D CT medical image segmentation methods can be successfully applied to the CT security screening problem domain but that the results are significantly limited by the presence of noise, the complexity of the target imagery within this context and the lack of prior domain knowledge that underpins a range of leading medical domain approaches."

Mouton et. al [82] have also prepared papers where traditional denoising methods were used to reduce the inherent 'noisy' image of a 3D baggage CT scan with good results. They tested a number of different de-noising methods and reported each's performance.

10.2.4.2 Dual Energy Systems

One of the approaches to reduce the number of false positives in Aviation CT systems has been to adopt Dual Energy CT (DECT).

[83]"Dual-energy CT provides information about how substances behave at different energies, the ability to generate virtual unenhanced datasets, and improved detection of iodine-containing substances on low-energy images. Knowing how a substance behaves at two different energies can provide information about tissue composition beyond that obtainable with single-energy techniques."

"In the abdomen and pelvis, dual-energy CT may be used in the liver to increase conspicuity of hypervascular lesions; in the kidneys, to distinguish hyperattenuating cysts from enhancing renal masses and to characterize renal stone composition; in the adrenal glands, to characterize adrenal nodules; and in the pancreas, to differentiate between normal and abnormal parenchyma."

DECT techniques involves scanning an object a 2 different energy levels, typically 140 Kev and 40 Kev. By subtracting the data from the 2 scans more information can be gleaned.

. [84]. "The use of Dual Energy CT "provide atomic number of scanned objects in addition to density measurements."

"The atomic number measurement provides an additional dimension to the density measurement for characterising the physical properties of scanned materials"

"For example water and the explosive ANFO can have similar physical densities. However, they differ significantly in effective atomic numbers"

A dual energy system applied to a beef or lamb carcase would definitely increase the resolution of any bone component where there was discrepancy regarding what was bone, meat or fat. The DECT would mean that the atomic number of Calcium would be detected where the density of bone was blurred with say cartilage.

It appears that most equipment manufacturers have moved to DECT systems to reduce the quantity of false positives for explosive detection.

An example is Reveal Imaging Technologies Inc. who have been approved by the TSA for the use of their [85] CT80DR EDS.

[86] "January 25, 2011 – Reveal Imaging Technologies Inc. and Science Applications International Corporation provide the CT-80 and CT-80DR Explosives Detection Systems (EDSs). The Technology is used to screen items, such as checked airline baggage, for the presence of explosives. It is based on compact, dual-energy computed tomography (CT). Additionally, algorithms used in the Technology software reconstruct an item's contents and analyze the contents for the presence of explosives in an automated manner"

10.2.5 What others are doing around the world Using CT In Meat

Much of the research work being undertaken is occurring in academic institutions around the world with researchers focussing on specific areas of interest. This research generally reflects the specific Institution and the researchers areas of interest rather than any 'Meat Industry' approach.

There are significant volumes of work looking at Image Segmentation, both semi-automatic and automatic. [87], [88]

Until recently, much of this work has been conducted on older, ex medical CT machines which did not have the latest image reconstruction algorithms incorporated. This has meant that much of the research would show significant improvements when undertaken on the newer machines.

Some research has identified that CT can deliver more than just composition. Prieto (2010) [89] found that spiral CT could predict very accurately estimates of tissue weights. The results were able to predict with high accuracy:-

- subcutaneous fat (R_2, RMSECV=0.94, 34.60 g and 0.92, 34.46 g)
- intermuscular fat (R_2, RMSECV=0.81, 161.54 g and 0.86, 42.16 g)
- total fat (R_2, RMSECV=0.89, 65.96 g and0.93, 48.35 g)
- muscle content (R_2, RMSECV=0.99, 58.55 g and 0.97, 57.45 g) in Angus and Limousin samples, respectively.

Accurate CT predictions were found for:-

- fatty acid profile (R_2=0.61–0.75)
- intramuscular fat content (R_2=0.71–0.76) in both sire breeds.

Low to very low accuracies were obtained for technological and sensory traits with R^2 ranged from 0.01 to 0.26.

10.2.6 New Developments in CT

10.2.6.1 Spectral Molecular Imaging

This technology will deliver a quantum improvement in image quality of CT images. As reported by Palmer [58] a new form of CT development based on Spectral Molecular Imaging (SMI or Spectral CT) is being researched. This work is being spearheaded by Otago University in New Zealand with some of the core technology coming from the European Organisation for Nuclear Research. This technology will eventually replace conventional CT. Conventional CT suffers from the issues a s discussed previously in the section on dual energy, where 2 very different materials can have the same Hounsfield number or density. It is therefore very difficult to segment a 3D image and correctly segment individual components where the densities are similar.

Dual Energy CT goes some way to solving this problem and gives an indication of the density as well as the atomic number of the substance. This technology will be capable of 4- 8 different energies hence giving greater information on any substance that the X-Rays pass through.

The Medipix All Resolution System or MARS website describes the technology thus:-

[90]" x-rays are also produced in a range of wavelengths called a spectrum. These different wavelengths are not visible to, or distinguished by, the human eye but they are able to be detected with film and digital devices. Standard radiographs use x-rays over a wide spectrum. They measure how much of the x-rays are attenuated by the object they pass through. Attenuation is a reduction in the total intensity of the x-rays as they pass through an object. They cannot measure how each different wavelength is being individually attenuated (this is equivalent to being able to measure the brightness but not the colour). The Medipix3 detector is able to measure how specific energies of x-rays are being attenuated. While these are outside of the range of wavelengths the human eye can see, they are 'true colour.'"

The same website continues on:-

"All materials attenuate the various wavelengths differently. This is because the atomic structure of materials is different. For example, on a regular x-ray image bone (predominantly calcium) highly attenuates the x-rays and appears white. Iodine, a common contrast agent, also highly attenuates the x-rays and appears white. However, across the spectrum the two materials are behaving very differently. Therefore during processing of the colour CT image, these two materials can be separated. The image below is of the same sample. In the colour image the back bone is green (calcium) and the stomach (filled with iodine contrast) is yellow. In the black and white image these two objects both appear white."

“The MARS scanner incorporates the Medipix detector chip, a new generation x-ray detector. It is both energy resolving and photon counting which allows true colour images. It has been developed by the Medipix3 Collaboration, which comprises CERN in Geneva and 18 research institutions worldwide.”

“True colour imaging offers to revolutionise the field of CT and provide a significant new technology platform for diagnostic imaging. The MARS imaging system promises not only images with new and improved diagnostic information, but allows faster and lower cost radiological procedures while working with significantly lower radiation dose. This will significantly broaden both the value and use of CT as a diagnostic tool.”

The researchers in Otago believe [91] “Spectral molecular imaging (SMI) - sometimes called spectral CT –is a new X-ray-based non-invasive molecular imaging technique that combines high-energy resolution with high spatial resolution to provide quantitative 3D images of tissue components, biomarker labels, and pharmaceuticals (1–4). It can differentiate multiple tissue components and contrast materials or molecular imaging probes simultaneously “See Fig. 1 below

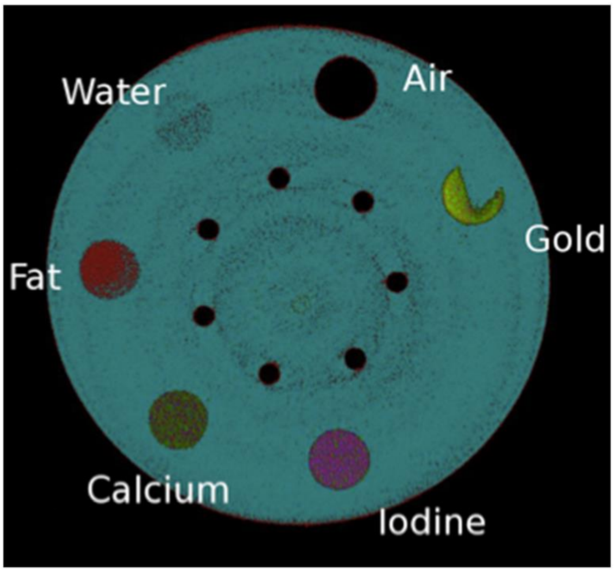


Figure 1. A MARS spectral image of a five-material decomposition obtained using Medipix3.1 GaAs detector assembly. Clockwise from 1 o’clock: black, air; yellow, gold (30mgml$_{-1}$); purple, iodine (20mgml$_{-1}$); green, calcium (338mgml$_{-1}$); red, fat; cyan, Perspex and water. Commercially available dual energy systems measure two materials and some dual energy research machines measure up to three materials.

“Hounsfield units (HU) are energy dependent (11), but this dependence is disguised in conventional CT because the HU measurement is a weighted average of the beam absorption over the entire range of beam energies. In spectral molecular imaging, multiple narrow sections of the energy spectrum are sampled simultaneously, providing a range of energy-dependent Hounsfield units across the spectrum. As each material has a specific measurable X-ray spectrum, spectroscopic imaging allows for multiple materials to be quantified and differentiated from each other simultaneously.”

This means that in future, there is a path forward for a significant improvement in CT image quality and the ability to see anatomical items more clearly. The ability to inspect lymph nodes and other glands, tasks now done by meat inspectors, may be able to be undertaken using this improved CT technology and using automatic image processing software suites.

The researchers have been able to achieve this by bringing together all of the components that make up a system. They have a relationship with the European Organization for Nuclear Research, known as CERN for the date readout; they identified the latest Detectors with CZT crystals [92] and have developed their own control systems.

They are now working on developing in-house the reconstruction algorithms based on the algorithms in the current Dual Energy medical dual energy CT systems to be applied to their multi energy system. Recent discussions with the researchers [93] at Otago University it was noted that GE health care had signed on as a partner to work collaboratively to develop both a human CT System based on the Medipix technology. Lincoln University is involved as a resource with agricultural animal science experience and with the system to be tested on lamb before humans.

A recent paper on the Spectral Imaging system [94] presents some images that were captured of a small lamb chop. These images of a 23 mm Diameter sample are presented below.

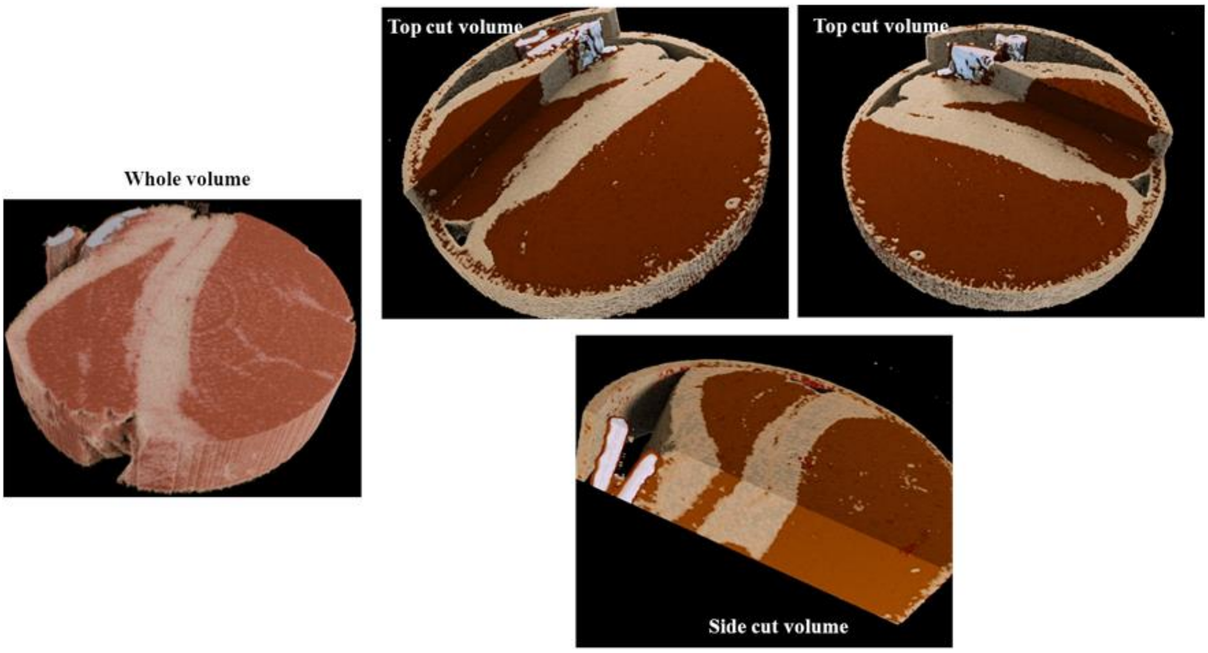


Figure 2 Figure 6. 3D volume rendering of lamb meat using the MARS system. A clear separation within meat structure between fat (off white colour scheme) fat marbling and bone (showing calcium in white) can be seen.

A grant application for funding is expected to be successful which will mean that a system for imaging lamb may be available within 3-4 years with full software development in 5- 10 years.

The same technology is expected to be applicable to Beef sides since they are no thicker than a large human. Beef carcasses will require greater current levels and this capability has yet to be thought through.

This technology will in time, deliver the capability to be able to discriminate and identify and potentially automatically inspect small components of a lamb carcass. Items such as livers, kidneys, glands will be able to be inspected for disease.

10.2.6.2 Phase Contrast or Diffraction Enhanced Imaging

This Technology uses a number of different techniques to convert the changes in phase of an X-Ray which occurs after passing through an object, into intensity variations which can then be collected in an image via an X-Ray detector. The changes in phase are highly sensitive to weak absorbing materials of conventional X-Ray such as soft tissues. In a conventional X-Ray these parts of the anatomy generate little contrast and are difficult to discriminate. More recently phase Contrast Tomography has also becoming more prevalent.

Initially this technology needed a very powerful and intense focussed beam such as could be found in a Synchrotron but has the technology has progressed where conventional X-Ray systems are used as the source of X-Rays. This has applications in achieving higher contrast images on soft tissue thus making their inspection and diagnosis easier.

It is also being applied to the security industry where [95] "the method both increases the visibility of all details in an image and allows the detection of features invisible to conventional absorption-based methods. This will enable easier recognition of the objects contained in a piece of luggage, as well as the detection of fine details with little or no absorption."

What this means is that higher quality images of some soft tissue parts will be available for [96] "In particular, the results showed that phase contrast can provide additional and complementary information and visualization of soft tissue structures that are invisible to conventional x-ray methods. For instance, various kinds of soft tissue, i.e., fat, tendon, muscle, can be identified by means of phase contrast. However, in the slices from the absorption contrast they are normally indistinguishable either mutually or from the surrounding media. From that, we conclude that phase contrast imaging provides a substantial dose reduction and/or image quality enhancement for small specimens".

This technology has been used in looking at the changes during cooking of meat. [97] "Phase contrast tomography offers the possibility to study structural changes of meat caused by cooking. The non-destructive characteristics of the method made it possible to study the exact same sample before and after heat treatment. The high contrast in the data set made it possible to both visualise and quantify structural variation within the meat structure"

A watching brief over the development of this technology would be of benefit. Its immediate use in a processing line is unclear but potentially .as an online inspection tool for viscera. In another form of Phase Contrast namely Transmission Electron Microscopy, according to Wikepedia [98] "phase contrast enables very high resolution (HR) imaging (at resolutions below one angstrom), making it possible to distinguish individual atoms from each other by their different refractive indices." Not something to be seen on a processors' facility any time soon, but as a research tool it may be invaluable.

10.2.6.3 Other Types of CT

Other systems using the basic CT concept exist, namely Micro CT and Nano CT. These systems uses a similar technique as X-ray tomography systems used in CT Scans but with much finer resolution and with special X-Ray sources and detectors to suit the small size and large magnifications. Normally the part is rotated through the X-Ray beam. Micro CT acquires images with a pixel size of 0.5 micron. [99] and Nano CT have a pixel size 150 nanometres [100] or 300 times smaller than a human hair.

These technologies have not been explored fully in this paper since it requires very careful specimen preparation as the magnification is so large that blurring occurs unless the sample being images has been cooled substantially. Typically samples are embedded in resin [101] to rigidise the sample structure when micrometer or submicrometer resolution is required. Phase contrast agents can also be added in live animals to highlight the area of interest and increase the Signal to noise ratio [102].

These tools are destined for research only in the next 10 years and may have applicability into understanding the chemical changes within the microstructure of red meat and the links to the physical make-up of the meat.

10.2.7 CT As A Reference For Determination Of Body Composition

There has been significant research across many academic institutions using CT as a reference for the body composition. There has been comparisons of the CT measurements with animal dissections. This has always been a difficult area since the dissection has traditionally been the "Gold Standard Reference". Animal dissections or "Bone-outs" in themselves have some inherent error. Scale errors, fat left on muscle and included in the muscle weight etc. will all contribute to an error in the bone-out.

CT has slowly moved into the position as being more "accurate" than the bone-out but this is a hard thing to verify. There are several issues associated with using CT as the Standard.

What is the definition of yield? In Australia, the general specification for the reference bone-out for Lamb has been a lean meat yield specification where the muscles are denuded of fat before weighing. This is relatively easily achieved in a CT image.

In Beef, the general "Yield" specification is for a "Saleable Meat Yield" which is where the cuts are trimmed to an 8 mm fat thickness over the primal. As the fat thickness increases up to 8 mm so does yield increase as more weight is included in the cut. After 8 mm, the yield will decrease with fat thickness

A CT system will find it difficult to measure and compute the yield for a carcass with an 8 mm trim.

Other issues arise such as what to do with the trim? In a bone-out, the trim is usually collected and then sampled and the fat content adjusted by adding more fat in or taking fat out of the 'fat pile' to adjust to a standard 70% CL value of the trim.

Other variables associated with the CT machine can also influence the values that is generated by the software that is prediction an outcome such a meat yield.

Some of these variables include:-

1. The kind of CT system and how many slices per unit length are captured. The greater the number of slices then the closer the approximation to the real meat yield is obtained.
2. The type of image reconstruction algorithm employed within the system.
3. The energy of the X-Ray
4. The variation of Hounsfield units across a consistent section of the carcass. E.g. What is the variation if Hounsfield unit across the rump of a beef carcass. Is this variation significant enough so that there is the density value falls below the meat/ fat threshold?

The same carcass images on 2 different machines is likely to give a different result.

Researchers at the Danish Meat Research [103] Institute have identified this and commented on why the work was needed thus:-

"The idea of using objective classification to support transparency and a harmonized market is basically the right thing to do. However, the "objective classification" is not completely objective. It is dependent on the calibration method, the sample of data and the people carrying out the calibration experiment."
They summarised their findings as:-
"There is potential to make a precise reference standard based on CT. However, more experience is needed. In particular, there is a need to determine how differences between scanners (brands and types (spiral or single slice images) and measuring protocols) can be managed. Effective and reliable reference materials (phantoms) might solve some of the problems. However, the type of image analysis also needs to be managed, i.e. how the data is modelled, the type of software and type of algorithms. "

They recommended the following next steps:-

"The future work addressing the topic of obtaining an instrumental reference method based on CT independent of manual dissection can be condensed into two items:

- Establishing a protocol for scanner parameters, which allows comparison of results from different brands of scanners? The work includes the development of phantoms and reference material.
- Developing a common method and algorithm to analyse data without any use of results from manual dissection."

In another paper presented at the same conference [104] and in recognising that CT has the potential to be the standard then one of their goals was "Building an international CT based reference would improve the comparisons, the market and the efficiency of the whole chains."

And,

"To build a primary CT reference for measuring body/ carcass composition is one of the main aims of COST Action FAIM. To identify possible and relevant post mortem reference methods for carcass composition is one of the milestones for FAIM in 2013."

As part of this project a number of trials, mostly involving pigs, were reviewed. The focus was then on the method of image analysis since this was seen as the main area for discrepancies in the overall analysis.

They found a variation range within the trials reviewed of :-

"The median relative difference of muscle weight and LMP ranged from -18 % to 9 %."

They concluded that: - "Further studies should assess the impact of CT scanners parameters. A harmonized procedure of CT scanning and of analysing CT images should be proposed for measuring carcass composition. Then, the accuracy of this proposed CT reference should be documented."

10.3 Other Technologies

10.3.1 Vision based systems for OCM

10.3.1.1 Introduction

The Red Meat Industry has been investing in Vision based systems for objective measurement for over a decade. The development of the VIAscan technology was successful and resulted in a sale of the rights to the technology to Sastek which has now been taken over by Cedar Creek Company. The uptake of the technology in Australia has been less than what was expected however that is not a result of the technology itself.

There are 2 basic vision systems;-

- A carcase system that measures the carcass colour and dimensional attributes very accurately; undertakes some image analysis and image segmentation and predicts a yield related number. This system is applicable to both beef and Lamb (and in New Zealand, this has also been tested on Venison)

And

- A Chiller Assessment System (CAS in Australia and "Cold Camera" in the US) that looks at the cross section of the quartered site of the Side of Beef. This system is only applicable to Beef.

Toohey [29] provides an overview of the technology as well as the competing technologies around the world.

10.3.1.2 The VIA Carcass System

For the Carcass systems the general opinion is that for lamb "The VIAscan technology offers significant potential to automatically predict meat yield"

And for Beef "VIA technology is a useful tool to evaluate carcass composition"

The Australian developed VIA technology is arguably the best technology in the world at the time. Because it was completely in control of the environment there were no external influences impacting the image and hence produced extremely good comparisons on the same carcass across different sites. A fact that was not fully appreciated by the Europeans during the trials conducted in Ireland.

The Australian technology was trained to predict a saleable meat yield in the case of beef and a Lean Meat Yield (LMY) in the case of lamb.

Other countries do not trade on a specified “Yield Basis” as has happened in Australia and New Zealand. America has a “Yield Grade” and the Europeans have a EUROP Yield Score. Both of these systems have guidelines as to their interpretation of what a particular grade but in the end it is a subjective assessment by a trained grader.

The VIAscan system as developed in Australia had as its reference a carcase dissection by a trained boning team following predetermined procedures and protocols.

The ability to predict a subjective end point as in the US and Europe, adds one more complexity to the development task.

10.3.1.3 The VIA Chiller Assessment System

When measuring a cross section of the carcass this system is able to measure the Attributes of :-

- Meat Colour’
- Fat Colour
- Marbling
- Eye Muscle Area

Again Toohey provides a summary of the CAS and the developments and performances across the globe. In Australia this system has been granted AUS-MEAT approval and can therefore report on the AUS-MEAT grades of:

- Meat Colour
- Fat Colour
- Marbling

The system is seeing a cross section of the carcase and thus can use this information to predict yield such that [29] “it was concluded that VIAscan predicted fabrication yield more accurately than the current online grading system used in the US and in the latter study it was also found that the ribeye (EMA) measurement replaced estimated ribeye area in the determination of yield grades. Shackelford, et al. (2003) & Steiner, et al. (2003b) both supported this outcome concluding that the beef industry could more accurately determine beef yield grades using VIA and this could be operated at line speeds.”

Shackelford et al. [105] in 2003 used the equivalent of an Australian Chiller Assessment system, a “Meat Animal Research Centre’s (MARC) beef carcass image analysis” system to predict calculated yield” The paper concluded that it could assist in allocating more accurate yield grades but “this system does not provide an accurate enough prediction of marbling score to be used without USDA grader interaction for USDA quality grading”

A more recent paper by McEvers et. al in 2012 [106] was “was focused on the use of VIA technology to improve the prediction of saleable red meat yield.”

Whilst this study used the German developed E+V system the E+V - VBG 2000 [107] This paper supported the good predictability of the VIA system “Prediction equations developed in this study indicate that the use of VIA technology to quantify measurements taken at the 12th/13th rib separation could be used to predict saleable meat yield more accurately than those currently in use by U.S. and Canadian grading systems.

10.3.1.4 Future for the Technology

In Australia, despite the technology being well credentialed as being accurate and reliable it has not been the success that perhaps it could have been. The reasons for this could are many.

10.3.1.4.1 Carcass System

These systems only output was originally an overall yield % number. A processor could then use this only in a limited way. Either:

- Feedback to producers to advise of the performance of their livestock

Or

- Payment systems based on a yield or the amount of meat that a processor could expect to retrieve from the carcase. (See comments on payment systems below)

Later, further development resulted in a "predicted cut weight" basis yield system whereby a weight of an individual cut could be predicted with a reasonable degree of accuracy. Certainly the accuracy was high enough to be capable of grading cattle into their best market allocation based on the weight of the cut.

This however was not an attractive commercial proposition for processors to adopt. A cost benefit on this basis was difficult to justify and relied on the processor working hard to derive the benefit.

One of the other significant reasons why this was not successful was the way the VIAscan systems were sold. They were not sold on an outright purchase model, something the processors were accustomed to, but on a fee for service basis or so much per carcass imaged, a model that was not familiar to nor attractive to processors.

It should be noted that the same commercial model was adopted in new Zealand and was dramatically successful

The major difference in New Zealand is that the processing industry is dominated by 2 large players who are shareholder owned by the producers. This 'Loyalty' factor was used to ensure that producers would benefit from a payment system based on yield. Those that received less under this system did not have an incentive to go to the opposition but rather had an incentive to improve their animal genetics and other management practises to raise the carcass yield to achieve a higher payment. This model was supported with the appropriate extension services to support the producers during the early periods.

Comparatively in Australia, the producer who was paid less under a yield based payment system did not return to that processor and sold the next lot of livestock via the saleyards or to the next closest meat processor who was trading on a 'non yield' based payment system. This would have been a disaster to a processor since the processing sector is geared to proses a minimum number of head per day no matter what and with 50% of the producers on average being paid less for their cattle (potentially), the processor would have struggled to obtain cattle numbers.

The second major issue with any vision system or any other system which is not truly 'Objective' is the need for a reference "re-calibration"

A vision system measure dimensional and colour attributes about the image under the lens. These measurements are then related to the measurements in a carcass dissection using a statistical analysis. A prediction algorithm is developed and tested on another set of data for validity and it is the used to predict or "infer" a yield number. A truly objective system by comparison, always had the information about the object. In a CT image, the image will show where the muscles are larger and how much larger despite what changes are occurring on the surface of the carcase which is where the vision system is measuring.

With time and with feedback to producers, change occurs. This is what is wanted as the average meat yield is hoped to increase. With change, there is potential for a change in the measurements that the visions system collects compared to the values of the dissection. Hence another calibration trial with a detailed carcass dissection is required to re-calibrate the instrument.

The time between calibrations or "re-calibration" will vary depending on the rate of change but a 5 year period would seem reasonable. This is a very costly exercise which is unlikely to engender support from the processor or the producers in the medium term.

10.3.1.4.2 The Chiller Assessment System

In the early stages of this instruments development there was difficulty encountered in measuring colour correctly. This problem was rectified and since then the major development work on the technology itself, went into algorithms to improve the capability of segmenting out the ribeye muscle and the identification of marbling.

The complete system has always been larger than is comfortable for an operator to use and this is believed to be one of the main reasons that it has not been adopted more widely. When initially developed, an image grabber card was of the order of 5 Kgs and $10,000. An electronic card now that has more than that capability is smaller than the size of an iPhone and costs less than $200. A "backpack" version was developed that allowed a person undertaking the process of Chiller Assessment to take the system into a chiller. Unfortunately, even in a backpack format, the system was still too large and cumbersome for the wearer to be able to easily move within a chiller packed full with carcases.

The system has not changed greatly in the last 10 years and certainly does not reflect the opportunity available for miniaturisation of camera and screens and dramatically reduced costs that are now available thanks to the advance in and the rapid technological changes in mobile phone technology..

It is feared that unless the owners of the technology begin to develop the technology to take advantage of the modern mobile phone like technology and the simple ways of capturing images, then the use of this technology within the industry will disappear.

10.3.1.5 Summary

The Vision Systems that are commercially available are capable (with continued re-calibration) of delivering prediction numbers around % yield of a whole beef or lamb carcass or a cut weight yield in Kg of individual cuts.

The technology has failed to be taken up by the industry in Australia and this should heed as a warning for other technologies.

10.3.2 Vision Systems for Product Identification

Some recent research has been done on tracking cuts of meat throughout a factory and being able to correctly re-identify them at some stage later in the process.

Larson (2014) [108] describes a system where pork loins are tracked and are able to be re-identified after time with a subsequent photo. This has applications in traceability and because of the improved image analysis, there is an opportunity to use this system to identify different cuts and place into cartons.

The Chicken industry in the US through Georgia Tech. University [109] [110] [111] has developed a Vision System to enable them to bone out a chicken using robotics. The system copes with the variability of the chicken carcases because of the vision system and some smart software and in the finished machine is capable of exceeding the current processing line speeds.

10.3.3 Ultrasound

10.3.3.1 Introduction

Ultrasound as an objective measurement tool has been in use for many years in other industries. MLA has done trials on the use of ultrasound to measure fat depth on the hot and cold carcass with limited results.

Ultrasound has been used and still is used successfully on live animals for both beef and sheep.

There is a problem using ultrasound on a beef or lamb carcase since the action of "pulling" off the hide or pelt induces air bubbles under the surface of the subcutaneous fat. These air bubbles act as points of 'echo's' to the ultrasound wave and result in false or very noisy readings making ultrasound unsuitable for the carcass after the hide is removed.

There is still the opportunity to do objective measurements on the carcase after stunning but prior to the hide removal in the area of interest.

The Pork Industry has developed a semi-automatic ultrasound measurement system that captures an image from the centre of the spine around to the end of the belly at a specific location across the carcase.

This image that is captured is then processed with image analysis software to generate relevant information about each carcase based on the cross sectional ultrasound image. His works well in pigs because the hide or in fact the outer skin of the animal is not removed with the hair only being removed. There is thus a clean and undisturbed surface and pathway for the sound waves to travel.

10.3.3.2 New Advances in Ultrasound

Ultrasound applications within the medical industry has advanced primarily with the driver of better images for the detection of breast cancer.

One of the new technologies is Ultrasound CT or USCT. This technology [112] "is very similar to x-ray tomography. In both cases a transmitter illuminates the object and a line integral of the attenuation can be estimated by measuring the energy of the far side of the object"

Continued development in auto segmentation of the USCT image is also progressing [113]"At the Institute for Data Processing and Electronics at Karlsruhe Institute of Technology we develop a new imaging modality for early breast cancer detection. The 3D Ultrasound Computer Tomography provides three-dimensional volume images with a significantly higher image quality than conventional sonographic systems. The current prototype was tested in first clinical examinations."

11 Appendix 2: Processor Survey Results- Summary

Below is the completed and amalgamated results of the Surveys as received from the Beef and lamb Processors. Whilst there were 18 processors requested contacted and asked for feedback on the benefit of these technologies, there were only 4 respondents. -2 beef and 2 lamb.

The number of beef or lamb processors responding has been recorded under the area of interest as **1xB** reflects 1 Beef Processor or **2xL** reflects 2 Lamb Processors scored this item at that level of interest.to this item. A simple scoring system was applied whereby aa low level of interest received a score of 1; a medium level of interest 2 and a high level of interest a 3.

Their results to all of the survey questions appears below

									Note"-	**Score is calculated by allocating 1 point for a Low, 2 for Medium and 3 for High**
Area Of Interest:- Lairage/Lead up	**Auto sorting of stock based o**		MOB	or	RFID Number					Comments
		Beef	1	Beef	2					
		Lamb	1	Lamb						
			Interest Level			High	Medium	Low	Total Score	
			Beef			2			6	
			Lamb					2	2	
			Benefit to The Business			High	Medium	Low		
			Beef			1	1		5	Flexible retrofit applications to all industry configurations.
			Lamb					2	2	

	Auto Capture / Stun	Interest Level	High	Medium	Low		
		Beef	1		1	4	
		Lamb	1	1		5	
		Benefit to The Business	High	Medium	Low		
		Beef	1		1	4	Clarification required for ' Auto Capture ' – currently commercially available.
		Lamb		2		4	
Processing							
	Auto Identification of abscesses; major defects; bruising in the carcase prior to Hide removal	Interest Level	High	Medium	Low		
		Beef			2	2	
		Lamb		1	1	3	
		Benefit to The Business	High	Medium	Low		
		Beef			2	2	
		Lamb			2	2	
Evisceration							
	Automatic Inspection and health status of Viscera and Offal such that Inspection can be more effective and	Interest Level	High	Medium	Low		

	productive						
		Beef	1	1		5	
		Lamb		2		4	
		Benefit to The Business	High	Medium	Low		
		Beef		2		4	Assume AQIS Officer retained for final disposition.
		Lamb		2		4	
Grading Station prior to ownership changing	**Feedback systems to producers**	Interest Level	High	Medium	Low		
		Beef	1		1	4	
		Lamb		1	1	3	
		Benefit to The Business	High	Medium	Low		
		Beef	1		1	4	Total solution for indexing and continuous rail systems
		Lamb		1	1	3	
	Payment of Carcase based on Objective Measures						
		Interest Level	High	Medium	Low		
		Beef		1	1	3	

		High	Medium	Low		
	Lamb		1	1	3	
	Benefit to The Business	High	Medium	Low		
	Beef		1	1	3	
	Lamb		1	1	3	
Marbling Score on a hot carcase at a single site as per AUS-MEAT rules or at multiple sites-						
	Interest Level	High	Medium	Low		
	Beef	1	1	1	6	
	Lamb		1	1	3	
	Benefit to The Business	High	Medium	Low		
	Beef	1		1	4	Beef- Potential cost saving for chilling, grading, segregation. Amendments to refrigeration chiller regime.
	Lamb		1	1	3	
Ultimate pH						
	Interest Level	High	Medium	Low		
	Beef	1	1		5	
	Lamb		2		4	
	Benefit to The Business	High	Medium	Low		Improvement of in-line pH measurement technology.
	Beef	1	1		5	2. Interested in hosting

						factory trials.
	Lamb		1	1	3	
Subcutaneous Fat Depth on key Primals (single site measurement or 3d profile)						
	Interest Level	High	Medium	Low		
	Beef	1		1	4	
	Lamb		2		4	
	Benefit to The Business	High	Medium	Low		
	Beef	1		1	4	
	Lamb	1	1		5	
Intermuscular Fat content as a %						
	Interest Level	High	Medium	Low		
	Beef	1	1		5	
	Lamb			2	2	
	Benefit to The Business	High	Medium	Low		
	Beef	1	1		5	
	Lamb			2	2	
Intramuscular Fat % of key Primals						
	Interest Level	High	Medium	Low		
	Beef		1	1	3	
	Lamb			2	2	

		High	Medium	Low		
	Benefit to The Business	High	Medium	Low		
	Beef		1	1	3	
	Lamb			2	2	
Muscle size and weight						
	Interest Level	High	Medium	Low		
	Beef	2			**<u>6</u>**	
	Lamb	1	1		**<u>5</u>**	Beef -Allowance to pre-sort prior to boning
	Benefit to The Business	High	Medium	Low		2. Pilot factory for industry trials.
	Beef	1	1		5	
	Lamb		2		4	
Total Fat % of a Carcase or Side						
	Interest Level	High	Medium	Low		
	Beef	1		1	4	
	Lamb		1	1	3	
	Benefit to The Business	High	Medium	Low		Total carcase break - bone, primal muscle, trim, fat.
	Beef	1		1	4	Represented as % of carcase.
	Lamb		1	1	3	
Lean Meat yield as % or weight						
	Interest	High	Medium	Low		

	Level					
	Beef	1		1	4	
	Lamb		2		4	
	Benefit to The Business	High	Medium	Low		Total carcase break - bone, primal muscle, trim, fat.
	Beef	1		2	5	Represented as % of carcase.
	Lamb		2		4	
saleable meat yield (in primal kg or $)						
	Interest Level	High	Medium	Low		
	Beef	1	1		**5**	
	Lamb	1	1		**5**	
	Benefit to The Business	High	Medium	Low		Total carcase break - bone, primal muscle, trim, fat.
	Beef	1		1	4	Represented as % of carcase.
	Lamb		2		4	
Eye Muscle areas as per AUS-MEAT rules on hot carcase						
	Interest Level	High	Medium	Low		
	Beef	1		1	4	
	Lamb		2		4	
	Benefit to The Business	High	Medium	Low		Higher interest if included MC and FC.
	Beef	1		1	4	
	Lamb		2		4	

Hump Height

Interest Level	High	Medium	Low	
Beef	1		1	4
Lamb				0

Benefit to The Business	High	Medium	Low	
Beef			2	2
Lamb				0

Not Applicable to lamb Processors

Post Slaughter and pre chilling

Automated hot fat cutting to a specified depth over the carcase

Interest Level	High	Medium	Low	
Beef	**2**			**6**
Lamb	**2**			**6**

Benefit to The Business	High	Medium	Low	
Beef	**2**			**6**
Lamb	**2**			**6**

Chilling, Cold Grading and Pre-Boning

Measurement of Flavour

Interest Level	High	Medium	Low	
Beef	1		1	4
Lamb		1	1	3

		High	Medium	Low		
	Benefit to The Business	High	Medium	Low		
	Beef	1		1	4	
	Lamb			2	2	
Tenderness (shear force, or Sarcomere length)						
	Interest Level	High	Medium	Low		
	Beef		1	1	3	
	Lamb		1	1	3	
	Benefit to The Business	High	Medium	Low		
	Beef		1	1	3	
	Lamb		1	1	3	
Predict Cooking Loss						
	Interest Level	High	Medium	Low		
	Beef			2	2	
	Lamb			2	2	
	Benefit to The Business	High	Medium	Low		
	Beef			2	2	Achieved by pH and colour grading
	Lamb				0	
Predict Fat% and Moisture Content of Cuts						

		High	Medium	Low	
	Interest Level	High	Medium	Low	
	Beef	1		1	4
	Lamb		1	1	3
	Benefit to The Business	High	Medium	Low	
	Beef	1		1	4
	Lamb			2	2
Tenderness - Warner Bratzler Shear Force	Interest Level	High	Medium	Low	
	Beef			1	1
	Lamb		1	1	3
	Benefit to The Business	High	Medium	Low	
				1	1
			1	1	3
Visible fat content in eye muscle (fat depth uniformity)					
	Interest Level	High	Medium	Low	
	Beef	1		1	4
	Lamb		1	1	3
	Benefit to The Business	High	Medium	Low	
	Beef	1		2	**5**
	Lamb			1	1

Value adding product in pack consistency benefit

Boning

Automatic carcase breakdown based on 3-Dimensional data	Interest Level	High	Medium	Low		
	Beef	2			6	
	Lamb	1	1		5	
	Benefit to The Business	High	Medium	Low		
	Beef	2			**6**	
	Lamb		2		4	

Further Processing

Analysis of fat level in trim cartons (or in trim for sorting)	Interest Level	High	Medium	Low		
	Beef	1		1	4	
	Lamb		1	1	3	
	Benefit to The Business	High	Medium	Low		Currently commercially available.
	Beef	1		1	4	
	Lamb			2	2	

12 Appendix 3: Processor Survey on Objective measurement Technologies

A survey was developed and sent to a core of key Lamb and Beef Processors. This survey was designed to glean feedback from Lamb and Beef Processors as to the key areas within their processing facilities where emerging technologies in the Sensing and Scanning arena can deliver an advantage to their businesses.

12.1 Processor Survey on Objective Technologies

This survey is the next Milestone in the Project A.TEC.0110 OCM Review and Technology Strategy Development. It serves to glean feedback from processors as to what are the key areas within their processing facilities where emerging technologies in the Sensing and Scanning arena can deliver an advantage.

At the presentation to the Technical Committee in Melbourne in September 2014, information on a range of emerging potential technologies were presented.

A summary of the technologies presented is:-

12.1.1 SPECTROSCOPIC TECHNOLOGIES

- Single-photon emission computed tomography (SPECT)
- Near Infrared Spectroscopy (NIRS)
- Nuclear magnetic resonance (NMR) and Magnetic Resonance Imaging (MRI)
- Raman Spectroscopy
- Terahertz and Millimeter Waves

12.1.2 X-RAY BASED TECHNOLOGIES

- X-Ray Single Energy
- X-Ray Dual Energy Absorptiometry (DEXA)
- Computer Tomography (CT) or 3-D X-Ray
- Computer Tomography- Medical
- Spectral Molecular Imaging
- Phase Contrast or Diffraction Enhanced Imaging
- Micro CT and Nano CT.

12.1.3 OTHER TECHNOLOGIES

- Vision based systems
- Ultrasound

In order to prioritise the development of the appropriate technologies, an understanding of the processor need is required and the importance and potential that these technologies may deliver within the processing plant.

The attached survey, when completed, is designed to provide guidance for some ranking on the priority of the future development of systems or equipment based on these technologies.

It would be appreciated if you could complete these surveys by marking the boxes to reflect where you believe benefits may lie in the future for your establishments. A brief comment as to why you believe this is the case would also be beneficial.

12.2 Area Of Interest:- Lairage/Lead up

12.2.1 Auto sorting of stock based on:

MOB	❑	RFID Number	❑

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.2.2 Auto Capture / Stun

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.3 Processing

12.3.1 Auto Identification of abscesses; major defects; bruising in the carcase prior to Hide removal

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business			

❑ ❑ ❑

Comments	

12.4 Evisceration

12.4.1 Automatic Inspection and health status of Viscera and Offal such that Inspection can be more effective and productive

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.5 Grading Station prior to ownership changing

12.5.1 Feedback systems to producers

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.5.2 Payment of Carcase based on Objective Measures

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.5.3

12.5.4 Marbling Score on a hot carcase at a single site as per AUS-MEAT rules <or at multiple sites>-

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.5 Ultimate pH

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.6 Subcutaneous Fat Depth on key Primals (single site measurement or 3d profile)

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.7 Intermuscular Fat content as a %

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.8 Intramuscular Fat % of key Primals

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.9 Muscle size and weight

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.10 Total Fat % of a Carcase or Side

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.11 Lean Meat yield as % or weight

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

12.5.12 saleable meat yield (in primal kg or $)

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.5.13

12.5.14 Eye Muscle areas as per AUS-MEAT rules on hot carcase

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.5.15 Hump Height

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low
	❑	❑	❑

Comments	

12.6 Post Slaughter and pre chilling

12.6.1 Automated hot fat cutting to a specified depth over the carcase

Interest Level	High	Medium	Low
	❑	❑	❑
Benefit to The Business	High	Medium	Low

❑ ❑ ❑

Comments	

12.7 Chilling, Cold Grading and Pre-Boning

12.7.1 Measurement of Flavour

Interest Level High Medium Low

❑ ❑ ❑

Benefit to The Business High Medium Low

❑ ❑ ❑

Comments	

12.7.2 Tenderness (shear force, or Sarcomere length)

Interest Level High Medium Low

❑ ❑ ❑

Benefit to The Business High Medium Low

❑ ❑ ❑

Comments	

12.7.3 Predict Cooking Loss

Interest Level High Medium Low

❑ ❑ ❑

Benefit to The Business High Medium Low

❑ ❑ ❑

Comments	

12.7.4 Predict Fat% and Moisture Content of Cuts

Interest Level High Medium Low

❑ ❑ ❑

Benefit to The Business | High | Medium | Low

❑ ❑ ❑

Comments	

12.7.5 Tenderness - Warner Bratzler Shear Force

Interest Level | High | Medium | Low

❑ ❑ ❑

Benefit to The Business | High | Medium | Low

❑ ❑ ❑

Comments	

12.7.6 Visible fat content in eye muscle (fat depth uniformity)

Interest Level | High | Medium | Low

❑ ❑ ❑

Benefit to The Business | High | Medium | Low

❑ ❑ ❑

Comments	

12.8 Boning

12.8.1 Automatic carcase breakdown based on 3-Dimensional data

Interest Level | High | Medium | Low

❑ ❑ ❑

Benefit to The Business | High | Medium | Low

❑ ❑ ❑

Comments	

12.9 Further Processing

12.9.1 Analysis of fat level in trim cartons (or in trim for sorting)

	High	Medium	Low
Interest Level	❑	❑	❑
Benefit to The Business	❑	❑	❑

Comments	

Other General Comments and Feedback to assist technology strategy development, or areas where further information would be useful:

Comments	

13 Appendix 4: List of Processors contacted to Complete Survey

The following list details the processors who were sent the survey.

13.1 AMPC technical Committee – Details

Name	Company	Position	Mobile	Email	Coy Phone	Fax	Address
Justin Gathercole	G & B Gathercole Pty Ltd	Commercial Manager	0412 251 397	justin@gathercole.com.au	03 9772 2533	03 9776 0137	1 Learmonth Road, Patterson Lakes VIC 3197
Graham Treffone	JBS Swift Australia	Innovation Manager	0407969315	gtreffone@jbsswift.com.au	07 38102170	0732823941	1 Lock Way, Riverview QLD 4303
Murray Miller	Australian Lamb Co PTY Ltd.			Not sure but guess mmiller@alcolac.com.au	03 9310 2726	03 9310 2377	0-34 Strezlecki Avenue, Sunshine West VIC 3020
Nekta Nicolaou	Thomas Foods International	Group Engineering Project Manager		nekta.nicolaou@thomasfoods.com	08 8532 1955		Lagoon Rd, Murray Bridge SA 5253
John Hart	*John Dee* Pty Ltd	Director	+61 419704698	jehart@johndee.com.au	0 7 4660 2200		97 Rosehill Road Warwick QLD 4370
Greg Williams	Northern Co-Operative Meat Company	Chief Engineer	0427534717	gwilliams@cassino.com.au	02 6662-2444		10615 Summerland Way, Casino NSW 2470
Dean Goode	Kilcoy Pastoral Company	CEO	+61 4 4816 2327	dgoode@kpc.com.au	07 5497 1277	+61 7 5497 1572	4830 D'Aguilar Highway, Winya QLD 4515

Bernard Smith	Teys Brothers Ltd			bernards@teysaust.com.au	07 3198 9000		Building 3 Freeway Office Park 2728 Logan Road Eight Mile Plains QLD 4113
Sam Barton	Gundagai	Director	+61 419 470 077	sbarton@gmpgundagai.com.au	02 6944 1001	02 6944 1859	2916 Gocup Road South Gundagai NSW 2722
Tony Bessell	Wammco International Western Australian Meat Marketing Co-operative Limited (*WAMMCO*).	Plant Manager - Katanning	0438 722771	bessell@wammco.com.au	08-9821 2000	08 9821 2731	3 De Vlamingh Avenue, East Perth WA 6004
James Ralph	Wagstaff Food Services Pty Ltd	Director	0419 036 904	jhralph@bigpond.net.au	03 5996 0488	03 9686 4366	500 Thompsons Rd Cranbourne East VIC 3977 PO Box 214, Altona North Victoria 3025 Australia
Terry Nolan Or Mike Nolan	Nolan Meats Pty Ltd	Director	0428714888	twn@nolan.com.au	07 5489 6888	07 5482 1972	Nolan Meats Pty Ltd PO Box 389 Gympie QLD 4570 East Deep Creek Rd, Gympie QLD 4570
Peter Cody	V&V Walsh Pty Ltd	Operations Manager	0417175841	pcody@vvwalsh.com.au	08 9725 4488	08 9791 4077	
Farron Fletcher	Fletcher International	General Manager,	0419 010 384	f.fletcher@fletchint.com.au	02 6801 3100		Lot 11 Yarrandale Road, Dubbo NSW

	Exports						Locked Bag 10, Dubbo NSW 2830 Australia
Paul Gibson	Australian Country Choice	Research and Innovation Manager	0419158599	pgibson@accbeef.net.au	07 3902 4141		Colmslie Road, Cannon Hill QLD 4170
	Stanbroke Pastoral Company				07 4697 6188	07 4697 6806	Stanbroke PO Box 81 Gatton, QLD 4343 AUSTRALIA
Len Jones	GMScott Pty Ltd or Manildra Meat Company Pty Ltd	Chief Executive Officer	0408 628 990	len@gmscott.com.au	02 6940 1501		Manildra Meat Company Pty Ltd Lot 572 Temora Road Cootamundra NSW 2590 Australia
Andrew Triance	NH Foods	Innovations Manager	0409 342 802	atriance@nh-foods.com.au			

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