MEAT & LIVESTOCK AUSTRALIA

final report

Project code: B.FLT.0377

Prepared by: SG Wiedemann, DJ Cottle, JG Valentine, PJ Watts and EJ McGahan
Feedlot Services Australia Pty Ltd

Date published: 9 August 2019

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

CFI Methodologies for the Feedlot Sector – Scoping Study

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Executive summary

The Australian Government's Carbon Farming Initiative (CFI) provides economic rewards for farmers and landholders who take steps to reduce emissions or store carbon in the land. Under the CFI, they can earn credits that can be sold to businesses wanting to offset their carbon emissions. The Government's planned Emissions Reduction Fund will use the CFI as a key source for purchasing abatement so as to reach Australia's emissions reduction target by 2020.

The CFI also provides a number of co-benefits, such as increasing resilience to the impacts of climate change, protecting the natural environment, and increasing farm productivity and food production. The Government's planned Emissions Reduction Fund (Fund) will use the CFI as a key source for purchasing abatement so as to reach Australia's emissions reduction target by 2020.

The feedlot sector of the beef industry is currently investigating methods to mitigate greenhouse gases (GHGs) in order to participate in the CFI. This report outlines the scientific basis for emissions mitigation. The aim of the paper is to inform the feedlot industry and the Department of Environment (formerly the Department of Climate Change and Energy Efficiency, or DCCEE) of the most suitable mitigation options available for developing CFI methodologies.

For mitigation approaches to be suitable for development into CFI methods, they must be underpinned by robust science, and must not be common practice in the industry already. Each mitigation must also take into account leakage issues, or the risk of inadvertent increases in GHG emissions elsewhere in the production system when applying a given mitigation method. This paper addresses the first requirement; the scientific basis for mitigation. We have also provided some comment regarding common practice, cost effectiveness and the risk of leakage. However, these issues will be dealt with in more detail during a second phase of this project which may involve an industry workshop.

The CFI provides proponents with the opportunity to earn credits by reducing direct agricultural emissions. For a feedlot, this means that methane emissions associated with rumen function and nitrous oxide and methane from manure management can be reduced to earn carbon credits. Depending on the project type/management action other potential emissions sources such as from feed production or emissions from transport and feedlot management may be within the project emissions boundary and may need to be calculated. This report provides data both for direct agricultural emissions and the total GHG profile for feedlots from recent life cycle assessment (LCA) research completed for the industry.

The direct agricultural emissions from feedlots include; enteric methane (about 60% of emissions) and manure emissions, the largest of which is nitrous oxide. There is a degree of uncertainty surrounding the exact magnitude of these emission sources, particularly with regard to the manure emissions. Despite this, new methodologies may be developed using default values from the National Inventory Reports (NIR) where better data are not available. Consequently, manure mitigation strategies will be more difficult to achieve without further research under Australian conditions.

Several of the most promising mitigations identified for enteric methane are already practiced by at least some of the feedlot industry. Mitigations such as the feeding of fats/oils, improved techniques for processing grain and high starch rations, and feeding monensin are all practiced by some feedlots. However, there may be opportunities to make small changes to feedlots already applying these practices and improve mitigation potential. In some cases, practices may be applied in some regions and not others (for example, feeding oil/fat is less common in WA) and some practices may be more common to some sectors of the industry. Because these mitigations are some of the most attractive options that are likely to be taken up by the industry, further investigation of what is deemed 'common practice' will be required. Currently, the definition of common practice and the rules regarding additionality are under review. Readers are encouraged to keep a watching brief on these changes.

This review has identified a wide range of mitigation options that could technically be adopted by feedlots. The review of research in this field showed that enteric methane mitigations are, in general, more advanced and are likely to be more readily adopted under the CFI because they are technically robust enough. These are summarised with a qualitative feasibility analysis in Table 1. Manure mitigations are less well understood scientifically and are therefore harder to adopt. With the high degree of uncertainty that exists regarding the baseline emissions from manure management, it is very difficult to promote CFI methods that rely on reducing manure emissions. One exception to this is the adoption of covered ponds, as have been adopted in other industries successfully under the CFI. These are only likely to be feasible for larger feedlots and will require a long term investment perspective. Manure management mitigations are summarised in Table 2.

Table 1 – Qualitative feasibility assessment of enteric methane mitigation options

	Cost	Mitigation Potential	Ease of meeting CFI requirements	Ease of applying commercially	Leakage risk	Commonly used in Australian feedlots
Rumen manipulation and ecology						
Defaunation	H	L	L	L	L	N
Ionophores	L	L	H	H	L	Y
Bacteriocins	H	L	L	L	L	N
Feed additives - fats and oils	L	M	H	H	M	variable
Distiller's grains	NA	M	L	L	H	variable
Micro-algae	L	L	L	H	?	N
Synthetic chemicals	M	M	H	H	L	N
Natural chemicals	H	L	L	H	L	N
Vaccination	H	L	L	H	L	N

Enhancing non-methanogens - diet manipulation						
Forage quality, grain type/processing	H	L-M	M	H	L	variable
Inoculants	H	L	L	H	L	N
Breeding	H	M	L	L	L	N
Management						
Reduced age to market weight (supply chain and feedlot)	M	H	L	H	?	n.a

Of the options assessed for mitigating enteric methane, several of the most promising (feed additives, monensin, improved feed processing) are already practiced in the industry to some extent. However, this does not automatically exclude these options for all feedlots. Further analysis may be required after the revision of the common practice and additionality tests to assess these options.

Three promising management options that all focus on increased ADG were identified; reduced days on feed (DOF) in the feedlot, reduced DOF during backgrounding, and diversion of additional cattle from grass finishing to grain finishing. These methods offer the greatest opportunity for mitigation and productivity enhancement. However, they may be difficult to apply under the CFI guidelines in their present form because each is common practice and may not be considered additional. We recommend a more detailed investigation of these approaches to map a path for uptake in the CFI in the future.

Table 2 – Qualitative feasibility assessment of manure emission mitigation options

	Cost	Mitigation Potential	Ease of meeting CFI requirements	Ease of applying commercially	Potential leakage	Commonly used in Australian feedlots
Low protein (nitrogen) diets	M	H	M	H	L	N
Feed pad						
Acidification	M	M	M	M	H	N
Sorbers	M	M	M	M	M	N
Rapid cleaning	?	M	L	M	H	N
Nitrification inhibitors	M	L-M	M	L	H	N
Solid manure handling						
Acidification	M	H	M	M	M	N
Sorbers	M	L	M	M	M	N

Short duration stockpiling	L	L	L	L	M	variable
Covers	L	L	M	L	M	N
Liquid manure handling						
Pond cover and methane destruction	H	L	H	L	L	N
Short retention time	M	L	L	L	L	N

A simple cost-benefit analysis of three potential methods showed that feeding high-fat diets could be cost effective for mid to larger feedlots. Nitrate feeding was not cost effective at expected costs for calcium nitrate. Covering effluent ponds could be cost effective in some situations, based on a recent analysis of a 9000 SCU feedlot, but this requires significant up-front investment and the contribution to returns from the CFI were relatively small. None the less, the presence of CFI credits would improve the cost effectiveness of this approach and may increase uptake across the industry. It is likely that a number of CFI methods will need to be applied as part of a suite of actions to improve the cost effectiveness of participating in the CFI for the feedlot industry.

Table of contents

1 Introduction

1.1 Background

The Carbon Farming Initiative (CFI) became operational after legislation was passed by Parliament in 2012. Under the CFI, Australian Carbon Credit Units (ACCUs) will be issued for every tonne of CO2-equivalent abatement generated by CO2 reduction activities. The CFI scheme allows farm owners and land managers to earn carbon credits through carbon sequestration in soils and vegetation or by reducing greenhouse gas emissions from farming activities. These credits can be sold to people and businesses wishing to offset their carbon emissions. The CFI is voluntary and intends to help both rural communities and the environment by supporting sustainable farming. Offset projects established under the CFI must use government approved methodologies and these contain the rules for implementing and monitoring specific abatement activities and generating carbon credits under the scheme.

CFI abatement activities can be conducted by individual feedlot owners, provided methodologies can be developed to ensure industry specific, greenhouse gas mitigation outcomes are achieved. In the feedlot industry, reducing emissions directly from livestock and associated manure management may be suitable approaches to mitigation. However, to date no feedlot specific methods have been developed and there is a lack of consensus on which methods should be pursued.

This report outlines the processes that lead to greenhouse gas (GHG) emissions at the feedlot, and also notes a range of mitigation options that may be suitable for developing further into CFI methodologies. It is intended to inform the feedlot industry and interested parties of the scientific basis for GHG mitigation of feedlot specific emissions. It should be noted that subjective judgements have been included for some but not all mitigation options (see Table 11 and Table 12). These are for indicative purposes only. These are to be fully reviewed and revised in the second stage of the project. Key elements of the CFI are described in the next section as context for the report.

1.2 Key Aspects of the CFI

The key concepts related to development of CFI methodologies are covered in 'The Carbon Farming Initiative Handbook' (DCCEE 2012). There are two key components of approved CFI methodologies that help deliver the integrity of CFI credits, offsets integrity standards and measures to minimise fraud and dishonest conduct. Of these, the integrity standards are relevant to this report, which is focussed on the scientific basis for mitigation.

The CFI offsets integrity standards are based on internationally accepted principles to ensure that CFI credits are only issued for activities that genuinely mitigate greenhouse gas emissions from farming activities or carbon through sequestration. Through this system, the integrity of CFI credits is upheld. The offsets integrity standards are as follows:

- Abatement must be measurable and verifiable (DCCEE 2012).
- Measurement methods must be supported by peer reviewed science and consistent with Australia's international accounts (DCCEE 2012).
- Measurement methods must account for variability and leakage and use conservative assumptions (DCCEE 2012). Some abatement activities can result in increased emissions

that may inadvertently arise elsewhere in the production system. These emissions are referred to as leakage. Leakage emissions that can be directly attributed to the abatement activity need to be estimated and deducted from the overall project abatement to prevent over-crediting (DCCEE 2010a). For this reason, abatement cannot involve simply transferring emissions from one entity to another, as would be the case if a feedlot 'reduced' manures application emissions by selling their manure to another farmer. In this case, the emissions would still occur at a different location and there would be no net mitigation. In some cases, the increased emissions may occur outside the project boundary (off-farm). This would be the case if a feedlot reduced emissions by reducing total stock numbers; assuming the market demand remained, similar numbers of cattle would be produced elsewhere and there would be no net reduction in GHG.

- Abatement activities must be additional to what would occur in the absence of the project (i.e. they must not be considered common practice for the industry). Only activities that are additional provide a net environmental benefit that can offset emissions that occur elsewhere and have value in an offsets market (DCCEE 2012).
- Any carbon sequestration project must be permanent. Carbon in vegetation or soils can only offset emissions if it is stored permanently. The internationally accepted timeframe for ensuring sequestration is equivalent to emissions is 100 years (DCCEE 2012).

This report is divided into two broad mitigation areas; mitigation of enteric methane from feedlot cattle, and mitigation of manure emissions from feedlot cattle. We have not addressed any carbon sequestration approaches.

2 Greenhouse Gas Emissions from Feedlot Cattle

2.1 Greenhouse Gas Emissions from Beef Cattle

The Australian Government, under the United Nations Framework Convention on Climate Change (UNFCCC) collates a National Greenhouse Gas Inventory (NGGI) of total net emissions annually from all sectors. Emissions are collated primarily by source (i.e. carbon dioxide emissions from stationary energy) and are reported by economic sector. As part of this assessment, direct agricultural emissions are determined from all agricultural industries including beef cattle production.

Australian agriculture contributed 14.9% of net national emissions in 2011 (DCCEE 2013). Of these emissions, the beef industry contributed approximately 48%, of which the vast majority was enteric emissions from cattle at pasture. Consequently, the beef industry is a significant contributor to national emissions, and is a major focus point for mitigation from the farming sector under the Carbon Farming Initiative (CFI). The feedlot sector contributed 7.6% of net emissions from beef cattle when averaged over the five years to 2011. This amounted to ~3.5% of total agricultural emissions; a small but not insignificant contribution. While the contribution of the feedlot sector to total agricultural emissions may be relatively small, mitigation of these emissions may be more readily achieved than in the extensive beef cattle or sheep industries because of the intensive management and the nature of the emissions from lot feeding.

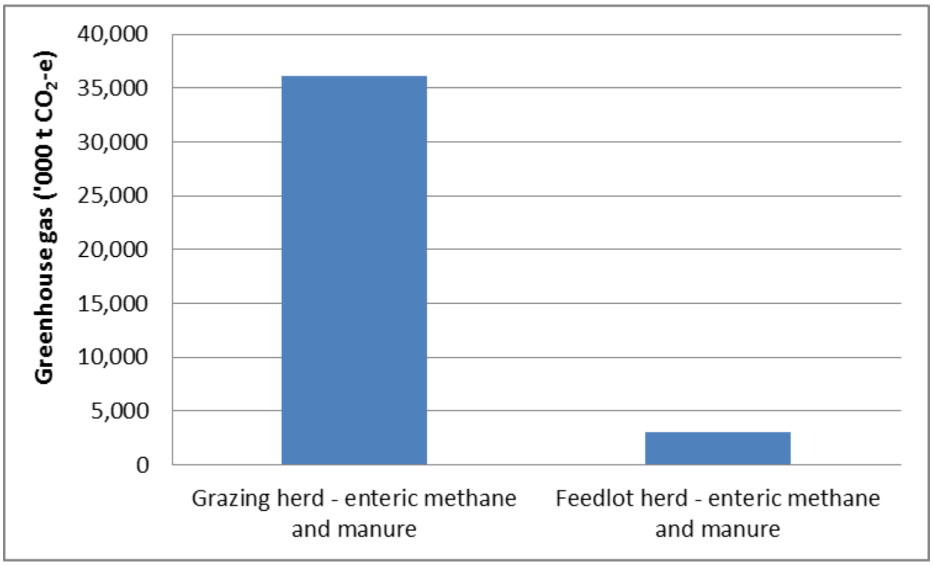

Figure 1 – Direct Agricultural greenhouse gas emissions from the beef industry (average of 5 years to 2011: source (DCCEE 2013))

Estimation of agricultural GHG emissions is not straight forward, and the scientific understanding of emission rates is often lacking. To develop the NGGI, a manual for estimating emissions has been developed (referenced here as DCCEE 2010) using a mix of country-specific and internationally agreed default methods provided by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 1997, 2000). However it should be noted that this manual may not reflect the best understanding available for specific emissions. Partly this is because of the long time frame for reviewing the IPCC guidance and updating the NGGI manual. In the aim of targeting the most effective mitigation strategies for the feedlot industry, this report has taken into account the 'best science' available for emission factors when determining emission sources. In some cases, this differs significantly from the NGGI values. Additionally, parties to the UNFCCC have agreed to adopt new global warming potential (GWP) values for use in NGGIs from 2015. These will result in slight changes to the relative importance of methane and nitrous oxide (see Table 3).

Table 3 – The global warming potential of major greenhouse gases

Greenhouse Gas	**Kyoto compliant 100 yr. GWPs (1990 baseline) applied by the Australian National Inventory (DCCEE 2010c)**	**100 year GWPs – IPCC (2007) [a]**
Carbon Dioxide	1	1
Methane	21	25
Nitrous Oxide	310	298

[a] Solomon et al. (2007)

2.2 Overview of Feedlot Emission Sources

The NGGI only assesses greenhouse gas emissions from direct agricultural sources in feedlots (i.e. enteric methane and manure emissions). In some cases, small emission sources are either aggregated or excluded. However, lot feeding also generates GHG emissions through the use of energy, services and feed. When assessing mitigation potential, these factors also need to be taken into account to address the leakage considerations under the CFI unless covered by the Carbon Price Mechanism (CPM). Leakage refers to the possible increase in emissions that may inadvertently arise elsewhere in the production system when applying a specific mitigation practice.

To avoid confusion, emission sources will be discussed in terms of direct agricultural emissions, and indirect emissions in this report. Table 4 shows direct agricultural emission sources for Australian feedlots and indicate those covered by the NGGI. Sources that are likely to be significantly greater or smaller than assessed by the NGGI are also noted. Table 5 shows the main indirect emission sources and their relative contribution assessed using LCA (Wiedemann et al. unpublished).

Table 4 – Direct agricultural emissions sources associated with feedlot beef production

Direct Agricultural Emission Sources	**Included in the NGGI**	**Comments**
Enteric methane	Yes	NGGI method tends to over-estimate emissions by 20-25% compared to measured data (i.e. McGinn et al. 2008)
Feed pad and stockpile nitrous oxide	Yes	NGGI factor likely to over-estimate emissions (in the order of 50%) – Muir (2011), M. Redding pers. comm.
Feed pad and stockpile methane	Yes	Few data available to compare with NGGI.
Ammonia volatilisation	Yes	NGGI factor for ammonia likely to underestimate true emissions by 2.5 times (Watts et al. 2012).
Indirect nitrous oxide emission from ammonia (above)	Yes	NGGI factor for indirect nitrous oxide likely to over-estimate emissions considerably
Manure land application	Yes	Attributed to the land sector, not the feedlot. NGGI emission factor is considerably higher than the fertiliser emission factor and the validity of this emission factor has not been validated with Australian research.
Effluent pond	No	Expected to be a small source of total direct emissions (<3%)
Stockpile	Yes – but not separated from feed pad	NGGI includes this in the feedpad and stockpile emission factor under the heading ‘drylot and storage’. This makes targeted mitigation difficult without using a manure mass balance approach and separate emission factors for the feed pad and the manure stockpile
Composting	No	Not identified as a separate activity.

Table 5 – Indirect emission sources associated with feedlot beef production

Indirect Emission Sources	**Comments**
Feed grain production	Significant contribution (~18%) to total feedlot emissions* as a result of fossil fuel and agricultural emissions from growing and transporting grain to the feedlot.
Feed milling (steam flaking)	<5% contribution to total feedlot emissions
General feedlot energy use and services (excl. feed milling)	<5% contribution to total feedlot emissions
Cattle transport	<1% contribution to total feedlot emissions

* Note: 'total feedlot emissions based on a gate-to-gate life cycle assessment (LCA) excluding emissions associated with the breeding and growing of cattle on grass prior to entry into the feedlot

2.2.1 Direct Agricultural Emissions

As noted in Table 4, several direct agricultural emission sources may produce lower emissions under Australian conditions than predicted using the NGGI methods. Figure 2 shows the contribution of direct GHGs from the feedlot sector as a five year average (2007-2011) as estimated by the NGGI. The red columns are an indicative estimate of emissions when taking into account revised (but not yet approved) emission factors for different emission sources. Further research is underway to quantify emissions from various sources at the feedlot and these will be incorporated into the NGGI when the evidence is sufficient to revise emission factors.

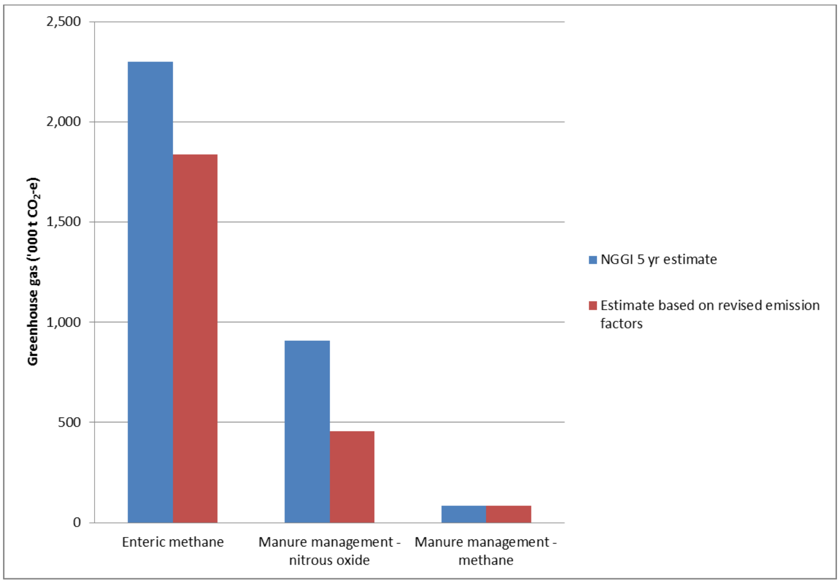

Figure 2 – Feedlot GHG emissions by source (direct emissions only) showing the NGGI emission estimates and revised 'best science' estimates

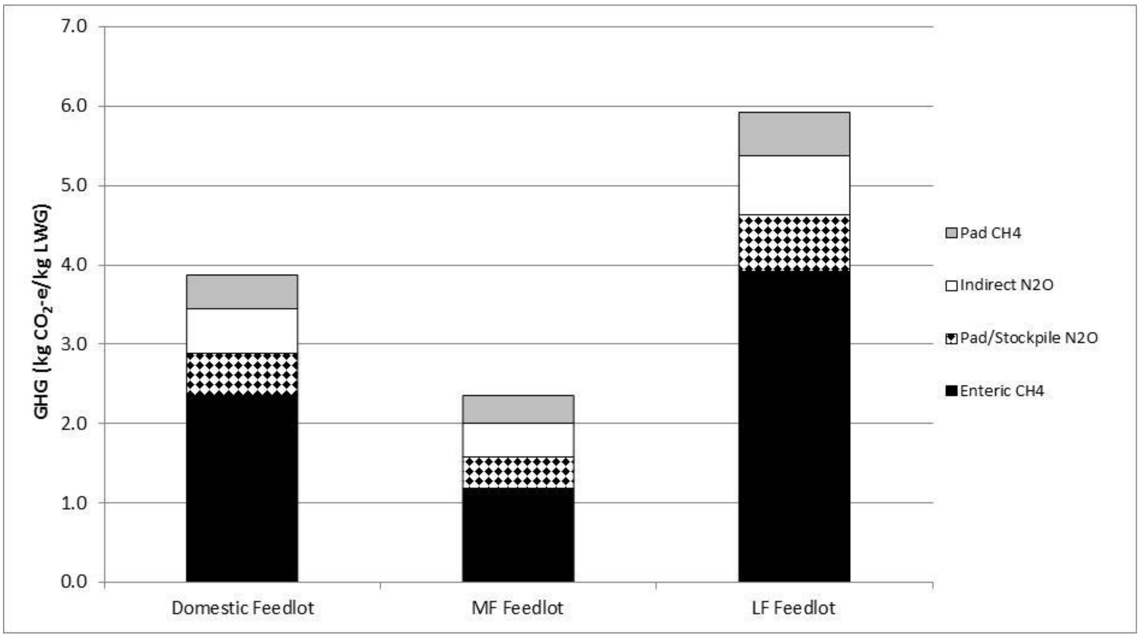

Figure 3 – Direct Greenhouse gas emissions per kilogram of live weight gain in three grain feeding scenarios and rations (Wiedemann et al. unpublished data)

Figure 3 shows the relative emissions per kilogram of live weight gain (LWG) for cattle in three specific feedlots in Australia (Wiedemann et al. unpublished data). The feeding period for each of these feedlot classes was as follows: domestic feedlot – 63 days on feed (DOF); Mid Fed feedlot – 115 DOF; Long fed feedlot – 335 DOF. The large differences reflect differences in the feeding period, productivity and feed rations. The lower enteric methane from the mid fed feedlot reflected a higher proportion of grain in the ration and a high proportion of lipids.

2.2.2 Direct and Indirect Emissions from Feedlot Beef Production

Figure 4 shows the direct and indirect emissions from three feedlots and relative contributions from each source.

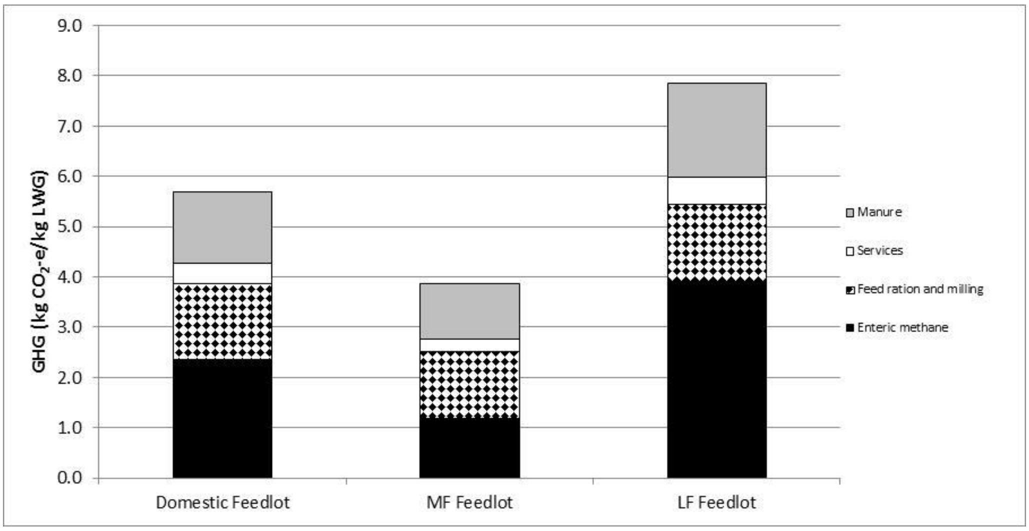

Figure 4 – Greenhouse gas emissions per kilogram of live weight gain in three grain feeding scenarios (Source: Wiedemann et al. unpublished data)

2.3 Enteric Methane Processes

Enteric methane is the largest direct emission source from feedlots and therefore needs to be understood in detail. This section explains enteric methane processes in the rumen as a precursor to exploring mitigation options.

In the aerobic metabolism of living cells, excess electrons and H2 can combine with O2 to form water, but this reaction is not possible in anaerobic environments. Anaerobic microorganisms such as ruminal bacteria, protozoa and fungi ferment dietary organic matter (OM) components (starch and plant cell wall polysaccharides, and proteins and other materials) and release end-products that include volatile fatty acids (VFA), CO2, H2 and CH4. Fermentation also occurs in the caecum and colon of ruminants but the amount of OM fermented is usually much less than in the rumen. Even hind gut CH4 in ruminants is mostly released via the lungs.

Fermentation reactions use the coenzyme NAD+ to oxidise dietary carbohydrates and NADH/H+ is formed from NAD+.H2 is generated when the protons associated with the NADH/H+ are reduced by the action of hydrogenases of the microbial ferridoxin oxidoreductase systems. The H2 diffuses out of microorganisms and is either used by other microorganisms, or accumulates in the rumen gas space. In the final stages of fermentation, H2 is used as a reducing agent and NAD+ is regenerated. In particular, methanogens oxidise the H2 (energy content 143 MJ/kg) to reduce CO2 to CH4 (energy content, 55 MJ/kg), thereby gaining energy for their growth (McAllister & Newbold 2008). This H2 removal is extremely important because, if H2 accumulates, reoxidation of NADH to NAD+ is restricted, and this inhibits carbohydrate degradation, ATP production and microbial growth. Forage digestion and the resultant production of VFA are then restricted (Joblin 1999).

2.4 Predicted and Measured Enteric Methane Emissions from Feedlot Cattle

The Australian NGGI (DCCEE 2010b) methodology for predicting enteric methane emissions from feedlot cattle is based on Moe and Tyrrell (1979). The equations for methane emission require some detail regarding dietary components, specifically, the proportion of soluble residue, hemicellulose and cellulose in the diet.

The formula for enteric methane yield (Y_{ij} – MJ CH4/head/day) is as follows:

$Y_{ij}=3.406+0.510SR_{ij}+1.736H_{ij}+2.648C_{ij}$ Equation 1

Where:

SR_{ij} = intake of soluble residue (kg/day)

H_{ij} = intake of hemicellulose (kg/day)

C_{ij} = intake of cellulose (kg/day)

Each of SR, H and C are calculated from the total intake of the animal, the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates and the soluble residue, hemicellulose and cellulose fractions of each of these components.

The DCCEE provide default values for daily feed intake and feed properties for Australian feedlot cattle. However, these may not accurately reflect commercial conditions in all cases. Table 6 shows the assumptions used by the NGGI for different classes of cattle and the enteric methane prediction based on these assumptions.

Table 6 – Daily feed intake and feed properties for short-fed feedlot

	Units	Feed intake and properties	Enteric Methane (kg / hd d)
Short fed (75d) cattle	kg/hd/d	9.8	0.196
Mid fed (140d) cattle	kg/hd/d	11.7	0.207
Long fed (250d) cattle	kg/hd/d	11.0	0.213
Dietary components (not differentiated by cattle class)			
Proportion of grains in feed		0.779	
Proportion of concentrates in feed		0.048	
Proportion of grasses in feed[1]		0.138	
Proportion of legumes in feed		0.035	

[1] forage hay / silage classified under grasses

Research by Wiedemann et al. (unpublished) showed that when the assumptions used in this method were altered to more accurately reflect feed intakes and composition at Australian feedlots, emissions tended to be lower for the mid-fed and long-fed cattle (-8.5 to -11.5%), while domestic cattle (63 days) were similar to the NGGI assumptions.

Several Australian studies have been conducted to measure enteric methane from grain fed cattle under controlled or commercial conditions. McCrabb and Hunter (1999) measured CH_4 emissions of 160g/head/day in Brahman cattle fed high grain diets in a chamber. Using open path lasers, McGinn et al. (2008) and Loh et al. (2008) reported the measured methane emissions of a 13,800 head south-east Queensland feedlot (27.1 south, 151.2 east) at the same level (161g/hd/day). The measured values were compared with those estimated via a number of prediction methodologies. These methods, in summary, were:

1. IPCC 2006 Tier I – constant
2. IPCC 2006 Tier II – intake
3. Blaxter and Clapperton (BC) - digestibility and relative intake
4. Moe and Tyrrell (MT) - diet composition and intake

The predicted emissions were 90 (Tier I), 109 (Tier II), 199 (Blaxter and Clapperton model) and 196 g/hd/day (Moe and Tyrrell model). McGinn et al. (2008) noted that the models did not account for the possible effects of dietary lipids on CH4. When taking these effects into account (5% reduction per 1% DM as oil – see section 3.1.4) the Moe and Tyrrell method estimated emissions of 172 g/hd/d, or 7% more than the total methane measured from the feedlot.

Summary: Australian enteric methane measurement trials suggest that the NGGI over predicts enteric methane when using default feed intake and composition data. However, this may be largely rectified by using actual feed intake and composition data, and by taking into account commonly used feed ingredients known to reduce enteric methane (i.e. lipids). CFI methods will require reporting standards for actual average feed intake (i.e. feed offered-refusals) and diet composition to be maintained.

2.5 Nitrogen Loss Pathways at a Feedlot

Nitrogen enters the feedlot system as crude protein or non-protein-nitrogen in the ration. Cattle utilise protein for growth and maintenance, and excrete excess nitrogen in urine and faeces. Post excretion, nitrogen may exist in numerous forms and can transfer between different forms rapidly. As manure moves around the feedlot (from the feedlot pad, to the stockpile, to land application, and to the effluent pond) transformations and emissions may take place. To follow the flow of nitrogen, a mass balance must be used throughout the system in order to quantify and predict emissions of relevant gases. While nitrous oxide is the only direct emission source, losses of ammonia may also generate indirect nitrous oxide after deposition to land. Therefore, both direct nitrous oxide and indirect ammonia emissions are relevant. This is presented diagrammatically in Figure 5.

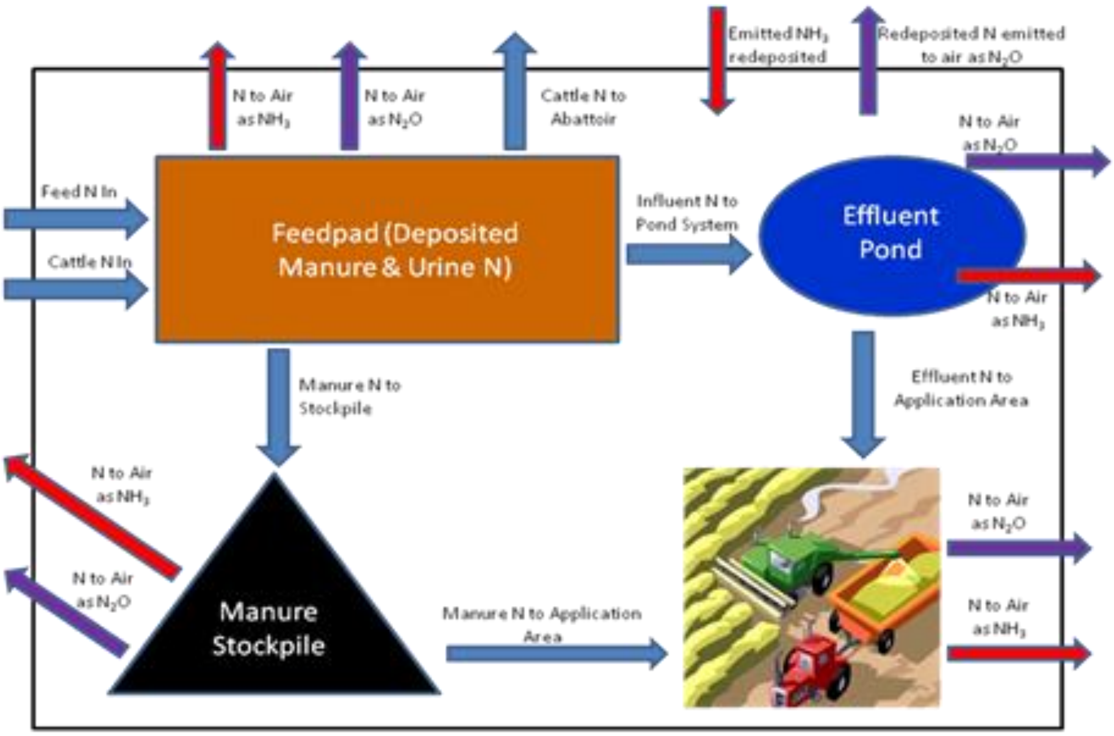

Figure 5 - Theoretical mass flow for excreted N in Australian feedlots

Research into nitrogen losses from feedlots has been done using both direct measurement and by mass balance. Losses of ammonia have been investigated in more detail than nitrous oxide. Mass balance research (Watts et al. 2012) can only determine total losses rather than losses of individual gas species. However, it is a useful measure of total losses. Table 7 details reported values of N loss (NH3), as a percentage of N excreted. Both the measured data and mass balance data suggest that ammonia losses from Australian feedlots are considerably higher than the default IPCC value used in the NGGI. A more appropriate value would be in the order of 70% (NH3-N per unit of N excreted), as suggested by Watts et al. (2012).

Table 7 - Reported values of ammonia (NH3-N), as a per cent of N excreted

Value or Range (% of excreted N)	**Comments**	**Reference**
	Australian measurement studies / predictions	
59	Measured values from two Australian feedlots	Denmead et al. (2008)
45	Based on measured values from a Victorian feedlot in summer, % determined based on average diet CP and intake	Loh et al. (2008); feed data and calculation by authors.
80	Review of literature for Australian NPI	FSA Consulting (2006)
70	Estimate for Australian feedlots based on literature and measured manure N values	Watts et al. (2012)
30	IPCC (1997) default value	DCCEE (2010)
	International measurement studies / predictions	
57.0 - 67.0	6 to 12 months cleaning intervals	Bierman et al. (1999)
50.0 - 55.0		Flesch et al. (2007)
47.0 - 69.0	18 harvesting experiments	Kissinger et al. (2006)
25.2 - 47.9	Bran supplemented treatments	Farran et al. (2004)
55.5 - 78.4	Varying pen cleaning frequency	Wilson et al. (2004)
62.0 - 64.0	10 week study - Texas, USA	Todd et al. (2006)
63.0 - 65.0	2 month study - Texas, USA	Flesch et al. (2007)
20.0 - 50.0	Suggested values	IPCC (2006)

Fewer studies report nitrous oxide emissions from feedlots. This is largely because measurement is more difficult (nitrous oxide can't be measured with lasers and small chambers are problematic on feedlot pads). However, Muir (2011) summarised previously unpublished data from the University of Melbourne and recommended that total emissions may be closer to 1% of excreted N, compared with the default IPCC emission factor of 2% of excreted N used in the NGGI. Research currently underway with Qld DAFF also suggests that nitrous oxide emissions are much lower than the default factor (M Redding pers. comm.).

Globally, there have been no studies under conditions that are similar to feedlots in Australia. Hence, the recommended value from the IPCC (2006) should be viewed with caution.

Table 8 - Reported emission factors for predicting nitrous oxide (N_2O-N) emissions from the feed pad and stockpile, as a percent of N excreted

Value or Range	Comments	Reference
1.0	Australian research	Muir (2011)
1.0 - 4.0	'Expert judgement' – not based on research that reflects Australian conditions	IPCC (2006)
2.0	Based on IPCC 1997 – not based on research that reflects Australian conditions	DCCEE (2010)

Summary: Manure nitrous oxide and ammonia have received less research attention in Australia than enteric methane. However, results from the few studies completed, together with modelling using mass balance principles, suggest that ammonia emissions are much higher than the recommended emission factor in the NGGI. Conversely, recent research findings show nitrous oxide emissions may be lower than predicted using the NGGI emission factors at the feedlot pad and stockpile. These findings suggest mitigation of manure emissions via CFI methods is constrained by the current scientific understanding.

2.6 Manure Methane

A significant proportion of the excreted manure carbon (most commonly termed volatile solids, or VS) is lost from manure as a result of bacterial oxidation, predominantly in the forms of CO_2 and CH_4. The carbon loss pathways within a feedlot are presented diagrammatically in Figure 6. The percentage that is lost will be dependent on the pad conditions (pH, moisture content, temperature), type of solids storage system and duration that manure is kept in storage, and the effluent treatment system. Manure management practices that could be used to reduce emissions are covered in more detail in sections 4.2, 4.3 and 4.4 of this paper.

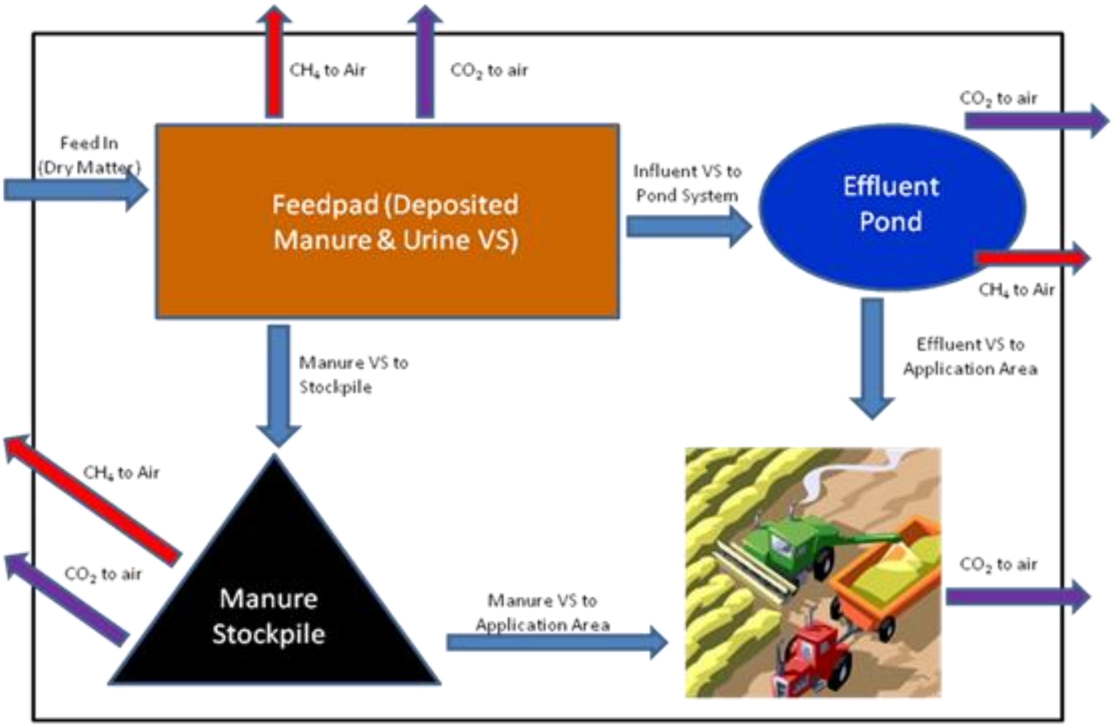

Figure 6 - Theoretical mass flow for carbon (VS) in Australian feedlots

The NGGI estimates CH4 emissions from manure using the default IPCC (1997) factor for 'drylots'. It is unclear if the one factor is intended to cover the whole feedlot (feed pad, stockpile and pond) or only the feed pad. The reference to 'drylot' implies other sources have not been considered.

Following the NGGI calculation, CH4 production is in the range of 1.69 – 5.63 g of CH4 per kg of VS excreted. The variation is in response to the different methane conversion factors (MCF) used for southern Australia (1.5%) and northern Australia (5%). This is equivalent to 1.3 – 4.2 kg CH4 / hd. yr (i.e. for one standard cattle unit (SCU) over a whole year, excreting 750 kg VS annually).

No studies have been completed in Australia that independently undertake a quantification of manure methane emissions from feed pads, stockpiles or effluent ponds, though all are likely to generate methane emissions.

Methane losses from stockpiled and composting manure from feedlots have been researched in North America and Europe. A review of the research was done by Watts et al. (2012) and calculations done by these authors are repeated in Table 9 to provide approximate emission rates in kilograms per head per year. The following assumptions were used to enable the comparison:

- VS excretion rate = 750 kg/hd/yr.
- Bo of 0.17 m3 CH4 / kg VS
- VS:TS ratio of fresh manure = 0.80
- Percentage VS lost to pond = 2%
- Pad losses of VS = 50%.

Table 9 - Methane emission rates from manure calculated per SCU

Reference	Comments	Methane emission rate ($kg\ CH_4$/hd/yr)
IPCC (2006) – 'drylot'	Temperate – MCF = 1.5%	1.3
	Warm – MCF = 2.0%	1.7
Boadi et al. (2004) – Feed pad	Low forage	0.3
	High forage	0.5
IPCC (2006)- Composting	Cool – MCF = 0.5%	0.2
	Temperate – MCF = 1.0%	0.5
	Warm – MCF = 1.5%	0.7
IPCC (2006)- Stockpile	Cool – MCF = 2.5%	0.9
	Temperate – MCF = 4.0%	1.9
	Warm – MCF = 5.0%	2.4
Sommer et al. (2004)- Stockpile	Continuous measurement	9.7
	Continuous measurement	5.8
	Continuous measurement	0.6
Kulling et al. (2003) – Bucket storage experiment	Grass low protein; liquid manure	0.5
	Grass low protein; solid manure	0.5
	Grass high protein; liquid manure	0.1
	Grass high protein; solid manure	0.4
Hao et al. (2001)	Passive composting	18.9
	Active composting	24.3
Hao et al. (2004)	Straw bedding	26.8
Pattey et al. (2005) – Beef cattle	Stockpile (mixed)	2.3
	Composted (aerobic)	0.11
Pattey et al. (2005) – Dairy cattle	Stockpile (mixed)	6.5
	Composted (aerobic)	1.3
	Wood chips	26.8

The only feed pad emissions reported were 0.3-0.5 kg CH_4/hd. yr from Boadi et al. (2004). The IPCC (2006) recommend an MCF value of 1.5-2% for 'drylot' conditions, which would correspond to 1.3-1.7 kg CH_4/hd. yr.

Stockpile emissions ranged from 0.6-9.7 kg CH_4 / hd. yr (excluding trials that included bedding), though none of these trials were carried out in conditions similar to Australia. Higher losses were reported for studies that applied bedding (not a common practice in Australia). Taking the IPCC (2006) recommendation would result in emissions between 0.9-2.4 kg CH_4 / hd. yr, which is of a similar order to the current estimated pad emissions from the NGGI.

Some very high emission rates were reported for some composting processes. In theory, methane emissions should be low from composting because this is an aerobic process, though actual conditions can be quite variable depending on the amount of water added and the turning frequency. Further research is required in this area under Australian conditions.

Emissions from effluent ponds depend on the total mass of VS entering the pond annually. Because feedlot ponds capture runoff only after rainfall events, inflows are highly variable. While there are no data available to quantify the VS transfer to effluent ponds in Australia, Watts et al. (2012) estimated it to be 2% of excreted N based on a review of the literature and runoff/mass balance calculations. This translates into 15 kg of VS entering the effluent pond per SCU / yr. Assuming an MCF for the effluent treatment pond of 80%, methane emissions from effluent ponds may be in the order of 1.4 kg CH_4 / hd. yr.

Based on the above review, manure methane emissions from all sources at the feedlot may be in the order of 3.6 – 5.5 kg CH_4 / hd. yr from all sources for feedlots that stockpile manure. This is slightly higher than the NGGI values.

Summary: Manure methane is thought to be a minor emission source from feedlots, though it has received very little research attention in Australia.

From a review of the literature and application of the IPCC methods, there are three sources that are likely to be relevant for feedlots; feed pad emissions, stockpile/composting emissions and pond emissions. Total manure methane emissions from all sources are likely to be higher than predicted by the NGGI and the potential for mitigation may be subsequently greater. Development of CFI methods would require extrapolation of research from other sectors in the absence of NGGI default values.

3 Enteric Methane Mitigation Strategies

Mitigation strategies for ruminants have been recently reviewed (Cottle et al. 2011, Patra 2012). The potential of these mitigation options for use with feedlot cattle are updated and summarized in this section.

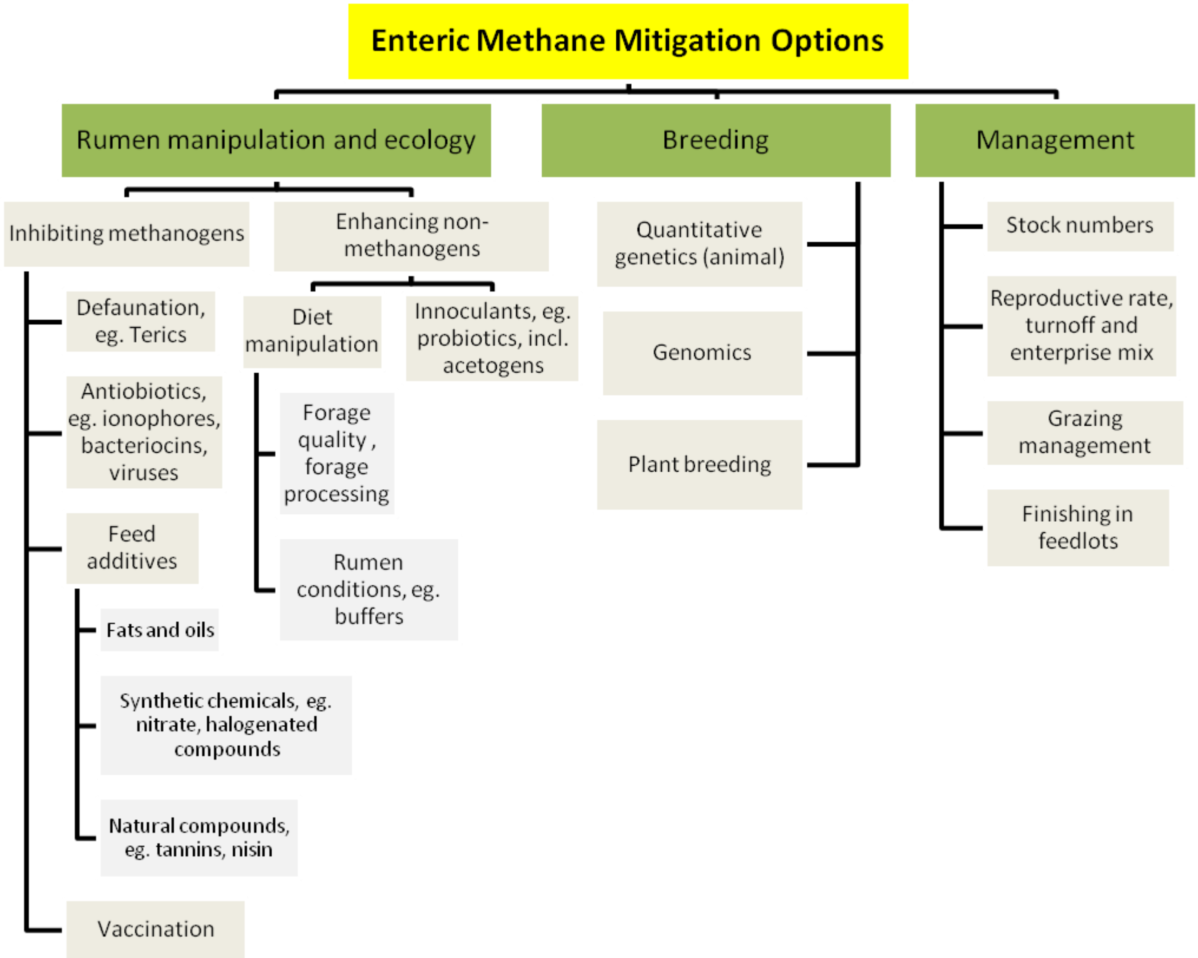

Figure 7 – Enteric Methane Mitigation options for ruminants (Cottle et al. 2011)

Hristov et al. (2013) recently reviewed over 900 grazing and feedlot references and ranked the enteric methane mitigation potential of feed additives and feeding strategies (reproduced in Table 10). The mitigations identified in Figure 7 and Table 10 is explored in detail in the following sections.

Table 10 - Ranking of the enteric methane mitigation potential of feed additives and feeding strategies. source: (Hristov et al. 2013)

Category	Potential enteric methane mitigating effect
Inhibitors	
Bromochloromethane and 2-bromo-ethane sulfonate (BES)	**High**
Chloroform	**High**
Cyclodextrin	Low
Electron receptors	
Fumaric and malic acids	No effect to High
Nitroethane	Low
Nitrate	**High**
Ionophores	Low
Plant bioactive compounds	
Tannins (condensed)	Low
Saponins	Low?
Essential oils	Low?
Exogenous enzymes	Low
Defaunation	Low
Manipulation of rumen archaea and bacteria	Low
Dietary lipids	Medium
Inclusion of concentrate feeds	Low to Medium
Improving forage quality	Low to Medium
Grazing management	Low
Feed processing	Low
Mixed rations and feeding frequency	?
Processing and supplementation of low-quality feeds	
Macro-supplementation (when deficient)	Medium
Alkaline treatment	Low
Biological treatment	?
Breeding for straw quality	Low

3.1 Rumen Manipulation and Ecology

In the aerobic metabolism of living cells, excess electrons and H_2 can combine with O_2 to form water, but this reaction is not possible in anaerobic environments. Anaerobic microorganisms such as ruminal bacteria, protozoa and fungi ferment dietary organic matter (OM) components (starch and plant cell wall polysaccharides, and proteins and other materials) and release end-products that include volatile fatty acids (VFA), CO_2, H_2 and CH_4. Fermentation also occurs in the caecum and colon of ruminants but the amount of OM fermented is usually much less than in the rumen. Fermentation reactions use the coenzyme NAD^+ to oxidise dietary carbohydrates and $NADH/H^+$ is formed from NAD^+.H_2 is generated when the protons associated with the $NADH/H^+$ are reduced by the action of hydrogenases of the microbial ferridoxin oxidoreductase systems. The H_2 diffuses out of microorganisms and is either used by other microorganisms, or accumulates in the rumen gas space. In the final stages of fermentation, H_2 is used as a reducing agent and NAD^+ is regenerated. In particular, methanogens oxidise the H_2 (energy content 143 MJ/kg) to reduce CO_2 to CH_4 (energy content, 55 MJ/kg), thereby gaining energy for their growth (McAllister and Newbold 2008). This H_2 removal is extremely important because, if H_2 accumulates, reoxidation of NADH to NAD^+ is restricted, and this inhibits carbohydrate degradation, ATP production and microbial growth. Forage digestion and the resultant production of VFA are then restricted (Joblin 1999).

Options for reducing methane production include: (i) inhibiting H_2-producing reactions; (ii) promoting alternative reactions which accept H^+ during reoxidation of reducing equivalents; (iii) promoting alternative H_2-using reactions, and iv) promote anaerobic CH_4 oxidation in the rumen. Mitigation strategies aimed at reducing populations of methanogens usually involve inhibition of methanogens and include alternatives for removal of H_2 so that fermentation is not impeded.

3.1.1 Defaunation

Defaunation (removal of protozoa from the rumen) has been used to investigate the role of protozoa in rumen function, and also to study their effect on methane production. Defaunation treatments have included using copper sulphate, acids, surfactants (environmentally safer alternates to nonyl phenol ethoxylate (Teric GN9) include sodium 1-(2-sulfonatooxyethoxy) dodecane (10% Empicol ESB/70AV), sodium lauryl sulphate, linear alcohol ethoxylates and sorbitan esters), triazine, lipids, tannins, ionophores and saponins (Hobson and Stewart 1997; Hook et al. 2010). Interestingly, Eadie et al. (1970) noted that rumen ciliate protozoa disappeared with a decrease in rumen pH in 3 heifers given ad lib. access to an all-concentrate diet but were established in large numbers when the same diet was fed below ad lib. Some of these chemicals are reviewed in more detail below.

Defaunation decreases methane production as indicated by many authors (Jouany et al. 1981, Kreuzer et al. 1986, Whitelaw et al. 1984, Williams & Coleman 1997). Defaunation treatments may also decrease the protozoa-associated methanogen population and therefore decrease methane production. Rumen protozoa share a symbiotic relationship with methanogens, participating in interspecies hydrogen transfer, which provides methanogens with the hydrogen they require to reduce carbon dioxide to methane (Machmuller et al. 2003). The methanogens associated with the ciliate protozoa, both intracellularly and extracellularly, are responsible for 9-37% of the methane production in the rumen (Machmuller et al. 2003, Newbold et al. 1995a). The formation of both acetic and butyric acids is accompanied by the production of H, whereas propionic acid production involves a net uptake of H (Cottle et al. 2011). The relative rates of formation of these three VFAs thus largely determine the amount of excess H available in the rumen. Thus differing proportions of VFA observed under ciliate-free conditions in grain fed cattle would be expected to result in much lower quantities of CH_4 produced (Whitelaw et al. 1984). Moss et al. (2000) showed that a good relationship exists between (C2 + C4)/C3 ratio and methane production. These results are logical as the protozoa are also an important site for methanogens (Newbold et al. 1995a, Ushida & Jouany 1996). Indeed, the C3/C4 ratio greatly increased as a consequence of defaunation, which may reveal an excess of hydrogen (Sauvant et al. 1995). When methanogenesis decreases, hydrogen production may be oriented in propionic acid production, at the expense of methane production (Demeyer & Van Nevel 1979). This suggests that higher OM digestibility, and therefore higher energy digestibility, observed in the rumen and in the total tract in faunated animals is partly lost in methane emission.

Mathison et al. (1998) stated the absence of protozoa reduced rumen methane emissions by 20 to 50% depending upon diet. Hegarty (1999) found that defaunation reduced methane output on average by only 13%, noting that the magnitude of reduction varied with diet. Hegarty et al. (2008) also found that there was no main effect of protozoa on rumen methane production, when investigated in chemically-defaunated, defaunated from birth, and faunated lambs. The greatest reduction in methane production with defaunation has been measured on high-concentrate diets. This is likely because protozoa are the predominant source of hydrogen for methanogenesis on starch-based diets and many starch-fermenting bacteria do not produce H_2. The relative methane production of defaunated versus faunated animals was 0.8 on hay: concentrate (1:1) (Rowe et al. 1985), 0.58 on 85% barley (Whitelaw et al. 1984), 0.69 in vitro concentrate (Demeyer & Van Nevel 1979) and 0.5 on steam flaked starch (Kreuzer et al. 1986). Whitelaw et al. (1984) intensively studied 12 Friesian steers fed pellets containing barley/soybean meal and fish meal. Another consideration is whether there are long-term effects of defaunation on methanogenesis. In the sheep study of Morgavi et al. (2008), the lower CH_4 emission in defaunated animals was maintained for more than 2 years indicating that the changes induced were stable. However, a study of ionophore supplementation (monensin at 33mg/kg DM or lasalocid at 36mg/kgDM) by Guan at al. (2006) found that reductions in rumen methanogenesis only lasted 4 weeks and hypothesized that this was due to adaptation of ciliate protozoa. Maintenance of defaunated animals can be difficult. A recent sheep study found that transfer of viable protozoa to defaunated animals does not occur readily through contact with feed or faeces of faunated animals, nor with direct contact with faunated animals, but does occur through contaminated water (Bird et al. 2010), which would be expected to occur in feedlot pens.

3.1.2 Ionophores

Monensin. This is a naturally occurring polyether ionophore antibiotic that is isolated from Streptomyces cinnamonensis and widely used as a rumen modifier, especially for cattle given concentrate diets (Grainger et al. 2008). Monensin reduces methane mainly by reducing voluntary DMI by 5-6%, which is not desirable in a feedlot, and decreasing the C2: C3 ratio (Goodrich et al. 1984). Monensin promotes selection for succinate-forming Bacteroides and S. ruminantium, the latter being a propionate producer that decarboxylates succinate to form propionate (Chen & Wolin 1979). Monensin also results in selective reduction of acetate formation and associated H_2 production by inhibiting the release of H_2 from formate (Slyter 1979, Van Nevel & Demeyer 1977).

The decrease in methane production ranges from slight (e.g. McGinn et al. (2004) found when CH4 emissions were corrected for differences in energy intake, the loss of GE to methane was decreased by 9%) to about 25% (Johnson & Johnson 1995). The persistency of the decrease in methane production with continual use has been variable among studies from a few days to 6 months, with methane production per unit of diet in cattle returned to initial levels within about 2 weeks in most studies (Johnson & Johnson 1995, Mbanzamihigo et al. 1995, Odongo et al. 2007, Waghorn et al. 2008). When delivered by controlled release devices, monensin was not effective in reducing methane in New Zealand dairy cattle (Waghorn et al. 2008). Beauchemin et al. (2008) reviewed the effect of monensin on CH4 emissions and found evidence of a dose response. Monensin doses of <19 mg/kg DMI did not reduce CH4 emissions, but higher doses (24-35 mg/kg DMI) reduced CH4 (g/kg DMI) by 3-8%. There has been no further work published on monensin added to Total Mixed Rations (TMR) since 2008.

Ionophores, such as monensin, have been banned in many countries, including the European Union (Ferme et al. 2008), so their use can restrict market access.

3.1.3 Bacteriocins

These are naturally occurring peptide toxins that inhibit the growth of closely related strains of bacteria. Nisin A (asparagine at position 27 in 34 amino acid peptide) or Nisin Z (histidine at position 27) powder, produced by fermentation using the bacterium Lactococcus lactis, has been used in processed foods and during their production to extend shelf life by decomposing Gram-positive bacterial spoilage and pathogenic bacteria, since the 1950s. Its use is licensed in over 48 countries (Deegan et al. 2006). Nisin is more broad spectrum than most other bacteriocins and has been used to treat dairy cow mastitis (Cao et al. 2007). Nisin has some effects on ruminal fermentation that are similar to monensin. It appears that mixed ruminal bacteria are able to degrade nisin (Russell & Mantovani 2002). Nisin has been shown in vitro to reduce MP by 36% (Callaway et al. 1997). Kišidayová et al. (2009) found nisin significantly increased the population of ciliate protozoa in vitro, while monensin decreased the protozoal population.

As well as exogenous bacteriocins, there are bacteriocins released within the rumen itself. Kalmokoff et al. (1996) surveyed 50 strains of Butyrivibrio and found about half exhibited a wide range of inhibitory activities. Because many lactic acid bacteria produce bacteriocins, it is possible that part of the reduced MP observed at low pH is due to bacteriocins rather than a direct effect of pH. Teather and Forster (1998) have suggested that ruminally produced bacteriocins could represent a new type of rumen modifier. Archaea, like bacteria, produce substances referred to as archaeocins that also inhibit microbial growth (O'Connor & Shand 2002) but whether archaeocins produced by one archaeal organism can inhibit the growth of other archea is unclear. Klieve and Hegarty (1999) suggested the use of archaeal viruses to decrease the population of methanogens, but, to our knowledge, no bacteriophages active against rumen methanogens have been isolated so far.

3.1.4 Feed Additives – Fats and Oils

Inclusion of lipids in the diet reduced methane emissions by 5.6% for each 1% of added lipid in the review of Beauchemin et al. (2008) and by 3.5% for each 1% of added lipid (10 g/kg) in the work of Moate et al. (2010, 2011). In a more detailed review, Martin et al. (2010) compared a total of 67 in vivo diets with beef, sheep and dairy cattle, and reported an average of 3.8% (g/kg DMI) less enteric

CH_4 with each 1% addition of fat. Assuming that most TMR have some fat content and that DMI may be suppressed at fat intakes above 6%–7%, CH_4 abatements of 10%–25% are possible with the addition of dietary oils to the diets of ruminants (Beauchemin et al. 2008), with 37–52% abatement possible in individual studies (Martin et al. 2010).

Assuming beef steers produce ~0.2 kg/hd/day of methane (Eckard et al. 2010) then a 5% reduction from 1% added lipid is equivalent to 10 g/hd/day less methane. Grainger and Beauchemin (2011) reviewed the most promising dietary and farm system strategies to mitigate enteric methane emissions from ruminants. They considered dietary supplementation with fat as the most promising dietary strategy. A meta-analysis using data from all published cattle studies was conducted using covariance analysis and the approach outlined by Sauvant at al. (2008). For diets containing up to 130 g fat/kg DM there was a significant linear relationship between total fat content of the diet and CH_4 yield (g/kg DMI). The analysis was re-run restricting diets to a practical feeding range of < 80 g fat/kg DM. For cattle (59 studies) a 10 g/kg increase in dietary fat decreased CH_4 yield by 1 g/kg DMI (i.e. ~10 g/hd/day). In the practical range of fat feeding the relationship between concentration of fat in the diet and CH_4 yield was not affected by the form of added fat (oil versus seed), major fatty acid in the added lipid (C12:0 and C:14, C18:1, C18:2, and C18:3), or fat source (canola, coconut, fatty acid, linseed, soya, sunflower and base diet without added fat).

Recent reviews have noted a lack of data on the long-term effect of fat supplementation on CH_4 yield (Beauchemin et al. 2008, Martin et al. 2010). In four published studies of dairy cattle (Grainger et al. 2010, Holter et al. 1992, Johnson et al. 2002, Woodward 2006) and one of beef cattle (Jordan et al. 2006) the average decrease in CH_4 was 3.4 ± 1.4% per 10 g fat added to the diet/kg DM with a range of 1.7 to 6.7% (Grainger & Beauchemin 2011). In two experiments, the decrease in CH_4 increased with time on treatment (Grainger et al. 2010, Holter et al. 1992). Grainger et al. (2010) concluded that adding fat to the diet of cattle reduces CH_4 yield and that the effect is persistent.

This mitigation strategy was adopted in Alberta, Canada (Quantification protocol for including edible oils in cattle feeding regimes, 2011) but it is no longer listed on the Offset Credit System website (http://environment.gov.ab.ca/info/library/8793.pdf). Feeding edible oils is a mechanism for increasing weight gain in beef cattle in feedlots and this activity is being incorporated into the Quantification protocol for reducing days on feed of beef cattle (see below). The cost: benefit of feeding lipids needs careful consideration. If carbon is valued at A$23/t CO_2-e and methane is assumed to have a GWP of 21, then 10g/day less methane is only worth 0.5 cent. It costs about 6 cents to provide the lipid that produces this methane effect, so it is not worth feeding for this effect alone.

Useful lipids can be found in a variety of feeds including coconut oil and whole crushed oilseeds (rapeseed, sunflower seed and linseed). Both long-chain fatty acids (LCFA) and medium chain-fatty acids (MCFA) reduce MP (Blaxter & Czerkawski 1966). Research has been mainly focussed on unsaturated LCFA because they take up H_2 as they become more saturated. However, LCFA also reduce fibre digestion (Broudiscou et al. 1990) and are less effective in reducing MP than MCFA (C10–C14), with C12 : 0 and C14 : 0 being most effective (Dohme et al. 2000). High dietary calcium or high dietary fibre content can reduce the level of CH_4 suppression in response to MCFA (Machmuller et al. 2003). Adding coconut oil, sunflower seed and linseed in vitro reduced MP and completely eliminated protozoa from rumen fluid after 4–9 days (Machmüller et al. 1998). However, the reduction in MP was thought to be due to a direct inhibition of methanogenesis by archaea rather than to the effects of MCFA on protozoa (Soliva et al. 2003). Understanding the biosynthetic pathway of the omega-3 polyunsaturated fatty acid, eicosapentanoic acid (Sayanova & Napier 2004), raises the prospect of producing it in transgenic plants.

Fat supplements can be relatively easily added to TMR diets. Use of agricultural/food processing industries by-products, that contain fat, can reduce both enteric CH4 emissions and global GHG emissions, as emissions arising from producing the by-product are, in essence, already accounted for by the primary product. By-product examples include whole cottonseed, brewers grains, cold-pressed canola, and hominy (maize) meal.

Osborne et al. (2008) reported that drinking water could be used to supply fish oil to dairy cows using an on-line dispenser for the supplements and a pressure tank. This approach could also be used in a feedlot.

3.1.5 Distillers Grains

Any expansion of ethanol fuel production will increase the supply of co-products such as distillers grains with soluble (DGS). The DGS from maize grain contain about 100 to 150 g crude fat/kg DM, and are a good source of CP (> 300 g/kg DM) and UDP (550 g/kg CP). Cost per tonne and cents/MJ ME is ~33% that of canola meal. Predominantly sorghum DGS are produced in Australia. In beef cattle diets, up to 400 g/kg DM of DGS has been fed without decreasing animal performance (Klopfenstein et al. 2008). McGinn et al. (2009) fed growing beef cattle a diet in which barley grain (350 g/kg DM) was replaced by maize dried DGS. Incorporating DGS in the diet increased the dietary crude fat content by 31g (20 to 51)/kg DM and enteric CH4 decreased by 4g (23.8 to 19.9) CH4/kg DMI, consistent with other fat sources (Grainger & Beauchemin 2011). When adjusted for GEI, Benchaar et al. (2013) found CH4 losses decreased linearly as dried maize DGS proportion increased in the diet of dairy cows by 5, 8, and 14% for 10, 20, and 30% dried DGS diets, respectively. Similar decreases (up to 12% at 30% dried DGS) were also observed when CH4 production was corrected for DEI.

The concentration of fat in the DGS from various grain sources usually reflect proportionately increased concentrations of those components relative to the starting grain after starch removal (Lodge et al. 1997, Mustafa et al. 2000), so DGS from sources other than maize are lower in fat content (e.g. 40-50 g fat/kg DM for wheat DGS). Klopfenstein et al. (2008) found less apparent feeding value for dry DGS compared with wet DGS and suggested the fat in DGS may be partially protected from ruminal degradation leading to greater proportion of unsaturated fatty acids at the duodenum and greater total tract fat digestibility. Bremer et al. (2011) suggested feeding corn wet DGS to feedlot cattle was the optimum feed use of distillers grains plus soluble based on feeding performance and GHG reduction using the Biofuel Energy Systems Simulator; www.bess.unl.edu).

Hales et al. (2013) reported that CH4 production as a proportion of GE increased linearly when the amount of wet DGS in maize diets was increased. DGS may increase nitrogen excretion from cattle so an LCA analysis is necessary to calculate the net effects of using DGS on the GHG budget of feedlots.

3.1.6 Micro-Algae

Fish oil and micro-algae are rich in omega-3 fatty acids, which have been shown to reduce CH4 in in vitro studies (Fievez et al. 2007). Micro-algae are suited for efficient, industrial-scale production, e.g. MDB Energy Limited to use waste CO2 gases from coal-fired power plants combined with sunlight and waste water. The by-product algae meal is a potential livestock feed (MDB 2013).

3.1.7 Synthetic Chemicals

Many synthetic feed additives (mainly antimicrobial compounds) are known to have direct or indirect effects on MP (Van Nevel & Demeyer 1977). These include halogenated CH4 analogues, e.g. 2-bromoethanesulfonic acid (BES) (Immig et al. 1996); dicarboxylic acids, e.g. fumarate (Asanuma et al. 1999); fatty acids, e.g. myristic acid (Odongo et al. 2007); galacto-oligosaccharides and nisin (Santoso et al. 2003); ionophores, e.g. monensin and lasalocid (Guan et al. 2006); nitrite reducers (Sar et al. 2005) and hydroxymethylglutaryl-SCoA reductase inhibitors (Miller & Wolin 2001). None of these compounds is used routinely in commercial livestock industries to reduce CH4 emissions, however Hristov et al. (2013) considered chloroform, BES and nitrate to have the best potential for methane mitigation of all feed additives or feeding strategies reviewed (Appendix 1).

3.1.7.1 Halogens

Halogenated compounds such as chloroform and BES have direct inhibitory effects on methanogenic bacteria and reduce MP both in vitro and in vivo (Bauchop 1967, Clapperton 1974). Martin and Macy (1985) found that 30 mM BES reduced MP by 76% in mixed cultures of rumen fluid. Though often effective in the short term, these compounds may lose their inhibitory effects with repeated administration (Van Nevel & Demeyer 1977). For example, Immig et al. (1996) observed in a rumen fistulated wether continuously infused with a BES solution (2 g/d), after a 2 g pulse dose, methane concentration in rumen gases was lowered from 40% to less than 1%, but after 4 days, despite repeated pulse dosage of BES, methane concentration in rumen gases returned to 20%.

3.1.7.2 Dietary nitrate

Nitrate and sulphate supplements in ruminant diets compete successfully for H2 and electrons and decrease MP. The reducing effects of nitrate and sulphate are claimed to be independent and additive (Van Zijderveld et al. 2011b). In addition to inhibiting MP, the end-product of nitrate reduction in the rumen is ammonia – a major source of the N for microbial protein synthesis in the rumen. Nitrate has a greater affinity for H2 than does CO2 and most other potential precursors (Ungerfeld & Kohn 2006) and so, when nitrate is present in the rumen, nitrite formation is favoured over MP. Nitrite reduction to ammonia is also more favourable than CO2 reduction but is often less favourable than nitrate reduction (Iwamoto et al. 1999). As well as reducing MP, the nitrate-reducing microorganisms obtain more energy and so achieve higher rates of microbial growth (Guo et al. 2009). Calcium nitrate needs Mg levels to be managed. The ionic nitrate can be supplied as sodium nitrate, potassium nitrate, calcium nitrate, or ammonium nitrate. Complex inorganic nitrate salts such as 5.Ca (NO3)2.NH4NO3.10H2) are commercially available and safer but are more expensive.

Much of the recent nitrate work in cattle has, not surprisingly, been sponsored by Provimi (Cargill) the holder of a patent on nitrate use for mitigation. For example, dietary nitrate persistently decreased methane production in lactating dairy cows fed restricted amounts of feed (Van Zijderveld et al. 2011b) and in beef cattle fed sugarcane based diets (Hulshof et al. 2012). Nitrate has been shown to reduce DMI and liveweight gain by ~7% in some feeding scenarios with dairy cattle, so it is thought that nitrate should be fed with sorghum to achieve higher energy levels in the diet to maintain liveweight gains (H. Perdok pers. comm.). This concern may be less apparent with low dietary nitrate inclusion rates, but would need to be monitored under any proposed feedlot scenario to ensure negative impacts on production did not occur.

McAllister et al. (1996) have cautioned that nitrate supplementation might be impractical because of the risk of (nitrite) toxicity but Leng (2008) suggested that nitrite accumulation and absorption, the reason for toxicity, may be avoided if (a) the rumen microbial population has been acclimated to nitrate, and (b) sulfur:nitrate ratios in the diet are appropriate to maintain the activity of sulfur-reducing bacteria that also play a role in reducing nitrite to ammonia. The level of nitrate provided in TMR in feedlots is easily controlled so the risk of toxicity in individual animals is more easily controlled than in grazing situations. Currently, urea-N is less expensive than nitrate-N, so farmers or graziers would not be likely to adopt nitrate supplementation without a financial benefit arising from increased rumen microbial protein production, or from carbon credits, or both.

3.1.7.3 Other chemicals

There are other electron 'sinks' that remove H2 in the rumen; e.g. dicarboxylic acids such as malate, fumarate and succinate that can use H2 to provide the energy for propionate synthesis. As a result, some of the energy of H2 is captured and made available for animal production. In vitro studies with fumarate or malate have usually resulted in reduced MP (Asanuma et al. 1999) but this has not always been the case (Callaway & Martin 1997). In vivo data are scarce and do not always match in vitro results. For example, van Zijderveld et al. (2011a) found none of diallyl disulfide (56mg/kg DM, from garlic oil), yucca powder (3g/kg DM), calcium fumarate (25g/kg DM), an extruded linseed/rapeseed/sunflower meal product (100g/kg DM), or a mixture of the MCFAs, capric and caprylic acid in a silica carrier (20.3g/kg DM) reduced MP in dairy cows on a silage/concentrate diet. Foley et al. (2009) found DL-malic acid (fed at 7.5% DMI) decreased total daily CH4 emissions by 16%, which corresponded to a 9% reduction per unit of DMI in beef cattle, as DMI decreased. Wood et al. (2009) reported that growing lambs fed a concentrate diet with straw ad libitum produced 24.6 L/d of methane, whereas a 100 g/kg addition of fumaric acid or encapsulated fumaric acid decreased methane production by 60% and 76% (9.6 and 5.8 L/d), respectively. When Bayaru et al. (2001) included 2% fumaric acid in diets for cattle given silage, MP decreased by 23% from 180 to 139 L/day. Unfortunately, dicarboxylic acids are expensive to synthesise and are unlikely to be affordable in the foreseeable future. MP was markedly inhibited in in vitro cultures treated with nitropropanol, nitroethane, nitroethanol, sodium laurate, Lauricidin or a finely ground product of the marine algae, Chaetoceros, or combinations of these compounds (Anderson et al. 2003). However, these compounds also inhibit fermentation to varying degrees (Božic et al. 2009) and so may reduce DMI and animal production. Administration of 2-nitro-1-propanol and nitroethane has been shown to reduce MP in mature ewes by as much as 94%, but the mechanisms are unclear (Anderson et al. 2003). Two hydroxymethylglutaryl-SCoA reductase inhibitors, mevastatin and lovastatin (drugs used in human medicine) have been found to inhibit the growth in vitro of strains of Methanobrevibacter isolated from the rumen, and to reduce their production of CH4 (Miller & Wolin 2001).

3.1.8 Natural Chemicals

3.1.8.1 Essential Oils

Essential oils antimicrobial activities were reviewed by Benchaar and Greathead (2011). Essential oils derived from thyme, oregano, cinnamon, garlic, horse radish, rhubarb and frangula have decreased CH4 production in vitro in a dose dependent manner. However, this inhibition occurred at high doses (>300 mg/L of culture fluid). Some essential oils, such as garlic, cinnamon, rhubarb and frangula, may exert a direct effect on methanogens. Thus these authors suggested the challenge remains to identify essential oils that selectively inhibit rumen methanogenesis at practical feeding rates, with lasting effects and without depressing feed digestion and animal productivity.

3.1.8.2 Yeast Cultures

Yeast cultures based on Saccharomyces cerevisiae are widely used in commercial dairy production in North America and Europe to improve milk yield and production efficiency (Desnoyers et al. 2009, Robinson & Erasmus 2009). Newbold and Rode (2006) suggested some strains of yeast may produce less CH4 due to a shift in partitioning of hydrogen between microbial cells and fermentation products. However, McGinn et al. (2004) earlier evaluated the effects of two commercially available strains of yeast on CH4 production (g/kg DMI) in beef cattle and reported no effects. Grainger and Beauchemin (2011) reported a novel yeast strain reduced CH4 emissions by 7% but also dramatically decreased rumen pH and increased the risk of acidosis, which is no use in a feed lot.

3.1.8.3 Bacterial Direct Fed Microbials

Bacterial direct fed microbials (DFM) are being used increasingly in commercial cattle operations to reduce ruminal acidosis (Krehbiel et al. 2003). The main bacterial species used in DFM products for cattle either produce or use lactic acid. Those that use lactic acid (e.g., Megasphaera elsdenii, Selenomonas ruminantium, Propionibacterium spp.) convert it directly to propionate or to succinate that can then be converted to propionate. Increasing ruminal synthesis of propionate should decrease the production of CH4. This is yet to be tested in vivo.

3.1.8.4 Commercial Enzyme Feed Additives

Commercial enzyme feed additives might reduce CH4 emissions (Beauchemin et al. 2008). These are concentrated fermentation products such as cellulases, hemicellulases, proteases, and ferulic acid esterase activities. Adding enzymes to ruminant diets has the potential to improve fiber digestion, thereby enhancing feed utilization and animal performance, although responses are highly variable depending on the product used and the conditions of the experiment (Beauchemin et al. 2008). Little work has been published.

3.1.8.5 Condensed Tannins

Condensed Tannins (CT) have been shown to reduce CH4 production by 13%–16% (DMI basis) (Eckard et al. 2010), mainly through a direct toxic effect on methanogens. However, high CT concentrations (>55g CT/kg DM) can reduce voluntary feed intake and digestibility (Beauchemin et al. 2008; Grainger et al. 2009).

3.1.8.6 Plant Saponins

Plant saponins also potentially reduce CH4, and some saponin sources are clearly more effective than others, with CH4 suppression attributed to their anti-protozoal properties (Beauchemin et al.

2008). Although extracts of CT and saponins are commercially available, their cost is currently prohibitive for routine use in feedlots.

3.1.9 Vaccination

Sheep work has been undertaken, mainly in Western Australia and NZ, with the aim of producing vaccines that trigger the animal's immune system to generate antibodies against enteric methanogens. So far vaccine formulations (using crude methanogen cultures to provide antigenic materials) have been virtually ineffective when tested in practical situations (Wright et al. 2004). In New Zealand, workers are using genomic screening to identify microbial proteins specifically involved in methanogenesis that could be used to develop antisera and broad-spectrum vaccines (Buddle et al. 2011). Wedlock et al. (2010) found antisera from NZ sheep vaccinated with fractions of methanogens have a significant impact on these organisms, inducing cell agglutination, and decreasing growth of methanogens and production of methane.

However, poor results similar to those in WA have occurred in the USA (Williams et al. 2009). A commercial proven vaccine does not exist yet.

3.2 Enhancing Non-Methanogens – Diet Manipulation

3.2.1 Forage Quality, Grain Type and Processing

Grain-based feedlot diets result in lower enteric CH_4 emissions (g/kg DMI) compared with grazed pastures (Johnson & Johnson 1995). Starch fermentation promotes propionate production creating an alternative hydrogen sink (Murphy et al. 1982), lowers ruminal pH and inhibits the growth of rumen methanogens (Kessel & Russell 1996). Grain diets reduce protozoa and the transfer of hydrogen from protozoa to methanogens (Williams & Coleman 1997).

Methane production per unit cellulose digested has been shown to be three times that of hemicellulose (Moe & Tyrrell 1979). Cellulose and hemicellulose ferment at slower rates than do non-structural carbohydrates, thus yielding more CH_4 per unit substrate digested (McAllister et al. 1996). Consequently, higher grain rations in a feedlot will increase starch and reduce fibre intake, reduce the rumen pH and favour the production of propionate rather than acetate in the rumen (McAllister & Newbold 2008). Improving roughage quality in a TMR also tends to increase the voluntary intake and reduce the retention time in the rumen, promoting energetically more efficient post-ruminal digestion and reducing the proportion of dietary energy converted to CH_4 (Blaxter & Clapperton 1965). Improving diet quality reduces CH_4 emissions per unit of animal product. Because cereal forages require fertilization, harvest and preservation prior to feeding and will incur additional N_2O and transport emissions during the grain production processes, leakage effects may also need to be taken into account.

Beauchemin and McGinn (2005) found methane emissions were not affected by grain source during the 42-d backgrounding phase (24.6 g CH_4/kg of DMI; 7.42% of GE), but were less for maize than for barley during the 32-d finishing phase (9.2 vs. 13.1 g CH_4/kg of DMI; 2.81 vs. 4.03% of GE). All diets contained monensin (33 mg/kg of DM) in these beef feedlot studies.

McGeough et al. (2010) found cattle fed a high concentrate diet (starch content of 369 g/kg DM) produced 19% less CH4 (g CH4/kg DMI) than cattle fed maize silage diets. CH4 output relative to DMI declined linearly in response to increasing starch to NDF ratio. McGeough et al. (2010) found methane (adjusted for DMI) decreased by 14% as starch content of wheat silage diets increased from 192 to 387 g/kg DM due to differing ratios of grain to straw plus chaff. However, CH4 production of cattle fed the high concentrate diet was 45% lower than that for cattle fed the wheat silage diets.

Lower methane emissions can also be due to a shift in the site of digestion from the rumen to the intestines, and rolled maize is typically less extensively digested in the rumen than rolled barley (Yang et al. 1997). Fermentation acids produced in the rumen are toxic to methanogenic bacteria at pH less than 6 (Kessel & Russell 1996). Zinn et al. (2002) reported steam flaking increased the performance of feedlot cattle on maize by 18%. Digestibility of starch from corn grain is limited by the protein matrix that encapsulates starch granules, and by the compact nature of the starch itself. Disruption of the protein matrix (by shear forces on hot grain during flaking) is the first limiting step toward optimizing starch digestion. Five critical production factors influence the quality of steam-flaked corn: steam chest temperature, steaming time, roll corrugation, roll gap and roll tension. For optimal shear, it is important that rolls be hot and that kernels be hot when flaked. Steam flaking reduced methane energy loss by up to 30% (Zinn et al. 1995). Corona et al. (2006) found the percentage of fermented energy loss as methane (predicted from VFA profiles) accounted for a mean of 17.7% with diets based on dry rolled maize vs. 11.0% with steam flaked maize, despite having more OM truly digested in the rumen. That is, the favourable effect of steam flaking on methane energy losses was not offset by a lower energy recovery from starch digested in the rumen versus the small intestine. Pattanaik et al. (2003) on the contrary found that raw and thermally processed maize had no impact on CH4 production in crossbred calves.

Zinn (1993) estimated that steam -rolled, thin flaked oats (0.44 mol/mol glucose) produced less methane than coarse flaked oats (0.56), dry rolled oats (0.52) or steam flaked maize (0.48). Plascencia and Zinn (1996) evaluated maize flaked to 390, 320, and 260 g/L vs. dry rolled maize. As flake density increased, a linear reduction in methane production was observed in the lactating dairy cows. Zinn et al. (1996) compared a hull-less barley variety (Condor) with a conventional covered barley variety (Leduc). The seed coat of hull-less barley is loosely attached and easily removed during harvesting, resulting in a feed grain with a bulk density and physical appearance similar to wheat. Methane (mol/mol glucose fermented) was 18% lower on Condor than Leduc barley.

High amylose starches are poorly digested and absorbed compared with starches containing mainly amylopectin which is more branched (⍰ 1-6 linkages). Maize and sorghum have more branched chain starches than wheat (J Hill pers. comm.). In a large US review of grains, not including sorghum, Owens et al. (1997) reported that rates of liveweight gain were higher on dry rolled oats, barley and maize than on wheat, while feed efficiency was best on steam rolled maize and wheat.

Thus there is evidence that choice of grain type and how it is processed can reduce methane production. These choices are usually dictated by relative cost and availability rather than their impact on methane production. To qualify for carbon credits changes to existing feeding practices have to be documented. Larger feedlots probably already steam flake their grains. The more likely mechanism for earning carbon credits would be via reduced age to slaughter or days on feed.

3.2.2 Inoculants

3.2.2.1 Probiotics

Probiotics are microbial feed additives that influence rumen fermentation directly. The most widely used probiotics are yeast and Aspergillus oryzae. Some available products guarantee high numbers of live yeast cells and are sold as live yeast while other products are sold as yeast cultures containing both yeast cells and the media on which they are grown. It is assumed that yeast cultures reduce methane production in four ways: (1) by increasing butyrate or propionate production; (2) by reducing protozoan numbers; (3) by promoting acetogenesis; and (4) by improving animal productivity (Iqbal et al. 2008). In a review of in vitro studies, Wallace and Newbold (1993) found that probiotics improved productivity by 7– 8% resulting in reduced methane production per unit of product (milk or meat) in dairy cows and growing cattle. Periods longer than 1-2 days are probably required to fully realise the effects of yeast. Methane suppression effects of probiotics are not consistent (Newbold et al. 1995a, 1995b) and there is a need to identify the dietary situations in which daily fed probiotics would give consistent results.

3.2.2.2 Acetogens

Research into acetogenesis as a CH4 abatement option is still largely conceptual, with extensive research still required to understand the physiology and ecology of acetogens, and their relative dominance in some environments but not in the rumen. A challenge for rumen microbiologists is to find ways of creating the conditions in ruminants that match those present in macropods.

Reductive acetogenesis, in which H2 and CO2 form acetate rather than CH4 as a source of energy, has been suggested as an alternative to methanogenesis (Joblin 1999). However, methanogens effectively out-compete acetogens for H2 in the rumen, because the reduction of CO2 to acetate is thermodynamically less favourable than the reduction of CO2 to CH4 (Cottle et al. 2011). When methanogenesis is inhibited, reductive acetogenesis can be increased in the ruminal fluid, with a possible energy gain of about 13%–15% (Nollet et al. 1997).

MP is different between sheep and kangaroos (Kempton et al. 1976) and can also differ between individual sheep (Joblin 1999). Eastern grey kangaroos and tammar wallabies (Von Engelhardt et al. 1978) produce less CH4 per unit digestible DMI (DDMI) than ruminants even though they ferment fibrous feeds and generate VFA in a manner similar to ruminants (Dellow et al. 1983). Ouwerkerk et al. (2006) found that forestomach contents of kangaroos had appreciable numbers of acetogens but few methanogens. The situation is similar in the hind gut of pigs, humans and rats (Joblin 1999), ostriches (Fievez et al. 2001) and termites (Breznak & Switzer 1986), all of which have acetogen populations that apparently compete effectively with methanogens.

3.3 Breeding

Breeding programs to genetically select lower methane emitting cattle (Herd et al. 2002) is not done within the confines of a feedlot, so this is not covered in this review. It would be possible for lot feeders to source cattle that have been selectively bred for reduced methane per DMI and/or for feed use efficiency on properties supplying feeder stock. These two traits are interrelated (Cottle et al. 2011).

RFI is not on the Australian DCCEE positive action list yet (DCCEE 2013) and no Australian carbon credit methodology has been developed for it yet. Alberta Province, Canada has a protocol for selection of low residual feed intake (RFI) in beef cattle (Alberta Government 2013c). Cattle operations that have incorporated a new genetic merit trait procedure known as selecting for low RFI cattle in their breeding program after January 1, 2002, and where sufficient records exist to quantify the baseline and project condition, are eligible to claim offset credits in the Alberta offset system.

The project developer (feedlot operator) must be able to demonstrate that cattle included in the project condition have a low RFI value. This requires that the sires be tested by an approved testing facility that is able to establish an estimated breeding value according to a standardized process. The baseline condition for this protocol is defined as the greenhouse gas emissions from a grouping of animals across the full life span of the animal including the cow-calf operation, backgrounding operation and feedlot operation resulting from normal dry matter intake of feed prior to the selection for low RFI animals. All cattle included in the project must have documentation showing that at least one parent animal was certified as low RFI breeding stock. Reductions can be claimed for animals with low residual feed intake-estimated breeding values and their first generation progeny only. A project developer can claim credits for a maximum of 8-years with a possible 5-year renewal where they can demonstrate low RFI cattle being claimed to meet the requirements of the protocol. Genomics and plant breeding are not relevant to feed lots.

3.4 Management

3.4.1 Reduced days on Feed and Age to Market Weight

Various studies have concluded that finishing cattle on grain-based rations in feedlots can be less GHG intensive than forage-finishing (Pelletier et al. 2010, Phetteplace et al. 2001). Two mechanisms operate to achieve this; i) higher quality diets reduce enteric CH_4 emissions per kilogram of feed consumed compared to forage rations, and ii) increased growth rates reduce days to market and total GHG emissions per finished animal.

This mechanism can function at two levels. For cattle already in the feedlot system, it may be possible to increase average daily gain (ADG) in either the backgrounding or finishing phases to reduce the age of the animal at finishing weight. In the full cattle supply chain, it may be possible to increase the number of cattle finished on grain rather than grass in order to achieve finished weights at an earlier age. These approaches find a predicant in the Alberta GHG Reduction Program. Alberta has two approved protocols, 1) reduced days on feed (Alberta Government 2013a) and 2) reduced age at harvest (Alberta Government 2013b).

The protocols are very generic. The reduced days on feed protocol (Alberta Government 2013a) does not prescribe any one technique or combination of techniques needed to reduce the days on feed of cattle because it is recognized that different techniques will be used by different feedlot operators and several techniques may be used at once and may vary over time. In all cases, the project developer must demonstrate through feedlot documentation and records that cattle in the project condition are finishing sooner than the baseline condition. The 3-year average baseline emissions, once determined, are held constant and compared to the annual project emissions.

The project activities are new feeding practices and/or feed additives that increase the feed conversion efficiency of cattle during the later stages of finishing. Examples in the Alberta protocol include some of the mitigation options described above: 1) electron acceptors that compete for hydrogen (e.g. fumarate, malate, oxaloacetic, beta hydroxybutyric acid, propionic acid and butynoic acid); 2) compounds that inhibit uptake of electrons and hydrogen by ruminal methanogens, 3) growth promotants (e.g. monensin and tylosin) and beta-agonists (e.g. ractopamine hydrochloride, (Winterholler et al. 2008)) that improve the efficiency of lean tissue growth, 4) genetic marker panels that reduce days on feed and/or to improve feed efficiency, e.g. leptin genetic marker, (Nkrumah et al. 2004), 5) phenotypic selection for animals with higher feed use efficiency (lower RFI), and 6) increasing concentrates in the diet sooner than under the baseline conditions.

The offset is calculated using IPCC (2006) models, i.e.:

Enteric methane (kg CH4/feeding periods) = Σ [Number of head * DOF * DMI * GE Diet * (EF Enteric / 100%) / EC Methane]

where:

DOF (Days on Feed) = number of days that the animal grouping is being fed a specific diet.

DMI = total kg DM delivered to the pen for the days on that diet divided by the animal head days for that diet.

GE Diet is a default factor, depending on the concentration of edible oils/fats. 19.10 MJ per kg of DM feed is assumed if the edible oil concentration is between 4.0 - 6.0%. 18.5 MJ per kg DM fed to each head is used if the edible oil/fat concentration is less than 4%.

EF Enteric (Enteric Emissions Factor) is a default factor, depending on level of concentrates in the diet and edible oil/fat content: 3.2% is used for diets with 85% concentrates and edible oils/fats as per above; and, 5.2% is used for diets with less than 85% concentrates and edible oils/fats as per above.

EC Methane is a default factor of 55.65 MJ per kg of methane.

The reducing age at harvest Alberta protocol boundary encompasses the pasture, backgrounding and feedlot operation where the cattle are raised and fed. This protocol does not prescribe the harvest age or production practices for raising beef cattle. Emission reductions are measured on a common metric of emissions per kilogram of carcass weight for both the baseline and project condition. The project developer for this protocol is designated as the operation where the animal spends the final stage prior to harvest (i.e. the feedlot operator) though it could also be structured to allow feeder cattle producers to apply the methodology if, for example, the cattle were fed on contract (custom fed) rather than being sold to the feedlot operator. As with the baseline calculations, regression curves for a range of typical feeding regimes over the life of cattle in various production stages typical to Alberta were constructed to derive emission factors based on age of cattle at harvest, normalized to a standard carcass weight of 345 kg. Project developers must use these regression equations to calculate an annual emissions intensity per kilogram of cattle produced (kg CO2e/kg carcass weight) for each animal grouping. The total number of animals in production for each grouping is used to calculate the total annual project emissions.

kg enteric CH_4 produced/kg carcass beef/yr = $0.162\ e^{0.079\ x}$ (R^2 = 0.99)

where x represents the average age of young cattle sent to harvest, in months

Using the equation above, substitute the 3 year average lifespan (in months) for the baseline as x , multiply by 0.079 and use the product of these to take the natural log power for deriving enteric methane emissions/kg carcass beef for the baseline condition - the functional unit.

This approach holds promise in Australia and the mitigation potential is clear; reductions of 1 t CO_2-e per finished animal are achievable for cattle diverted from grass finishing to grain finishing (author's calculations). However, feedlot finishing is already common practice in the industry, making compliance with the CFI difficult under the current application of the common practice and additionality guidelines.

3.4.2 Growth Promotants

Hormonal growth promotants (HGPs) can be used by the feedlot industry and given to cattle as slow-release implants (under the skin of the ear) to increase feed-conversion efficiency. Hormones are naturally present in infinitesimal amounts in all meat, whether from implanted animals or not (Thomason 2007). Hormone levels in the meat from animals implanted with growth promotants are much lower than those occurring naturally in beef produced from cows and bulls. For instance, cow meat contains natural female hormones at levels up to 60 times the amount in beef from implanted steers. Bull beef contains around 40 times the amount of naturally occurring male hormone than the amount of hormone found in implanted heifer beef. The amount of oestrogen in plant-source foods is greater than in meat. The human body produces hormones in quantities much greater than would ever be consumed by eating beef. Exhaustive scientific tests carried out over many years have not shown growth promotants pose any risk to human health or safety (Thomason 2007).

Use of HGPs may enable a reduction in emissions by reducing the reducing the days on feed and age to slaughter, or conversely increasing the weight gain resulting in fewer animals to produce the same amount of beef. Basarab et al. (2012) reported that growth implants reduced the carbon footprint of Canadian calf-fed production systems by 5%. The improved average daily gain, DMI and feed conversion in response to anabolic implants depends on the type of implants, amount and duration of exposure, age of animals and combination of implants (Song & Choi 2000). Anabolic implants include zeranol, trenbolone acetate, estradiol with testosterone or prgoesterone and bovine somatotropin.

Similarly, some b-agonists may be legally used to increase feed growth rates and different β-agonists are not equally potent (Strydom et al. 2008). They are analogues of a natural group of compounds called catecholamines, e.g. zilpaterol, ractopamine and (banned) clenbuterol. They bind to certain receptors on fat and muscle cell surfaces and thereby modify biochemical processes of tissue growth by increasing lipolysis, decreasing lipogenesis, decreasing protein degradation and increasing protein synthesis.

4 Mitigation Strategies for manure Emissions

A variety of options exist for the mitigation of greenhouse gas emissions from manure. Mitigation strategies can work via a number of mechanisms; reduction of substrate (N and VS), alteration of the chemical properties of the manure, alteration of the management conditions under which manure is handled, and using alternative treatment systems compared with common practice. The mitigation strategies in the following sections are summarised with reference to the part of the feedlot where they target as shown in Figure 8.

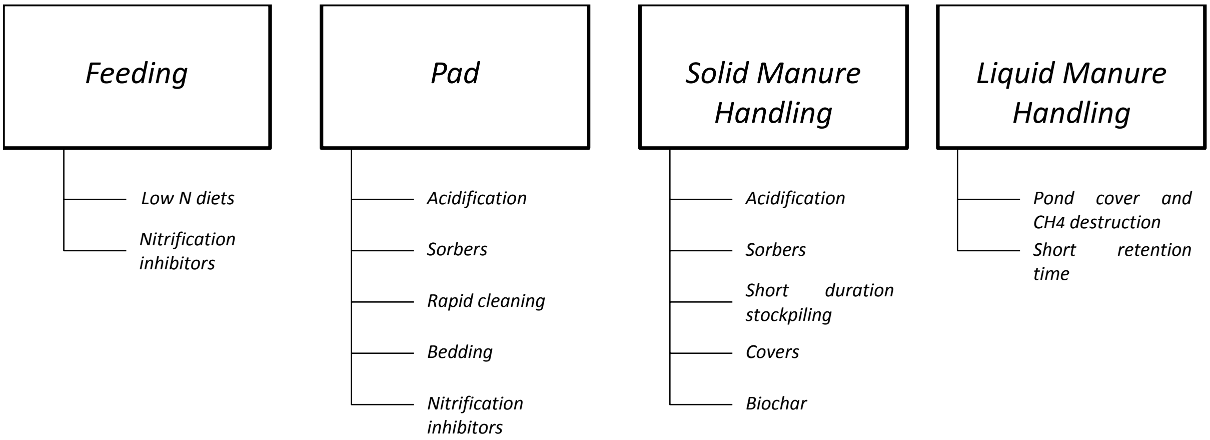

Figure 8 – Mitigation strategies that may be applicable for reducing manure emissions

Emissions from land application have not been covered. These emissions are less specific to lot feeding and could be developed as generic methods applicable across multiple livestock industries. Land application emissions should be taken into account with respect to leakage however.

4.1 Feeding

4.1.1 Reduced Protein (N) Diets

Reducing the level of protein in cattle diets has been shown to reduce N excretion in manure and urine (Cole et al. 2005, James et al. 1999, Misselbrook et al. 2005, Todd et al. 2006). Eckard et al. (2010) noted that reducing excess urinary N and improving N efficiency is an effective strategy for reducing nitrous oxide emissions, and can be achieved by having higher energy-to-protein ratios, or by balancing high-protein forages with high-energy supplements. Cattle are relatively inefficient at utilising protein compared to monograstrics. Nitrogen retention is commonly in the order of 10-15% of feed N, with the remaining N being excreted. Reducing N levels in the diet is an attractive mitigation option, because it should result in lower emissions throughout the manure management system. Despite the uncertainty surrounding the likely emissions from direct N2O from the feed pad and stockpile and indirect N2O via ammonia volatilisation, these are still expected to be the largest manure emission sources at the feedlot.

Emissions reductions are achieved by lowering N excretion rates in urine and faeces and as such, leaving less substrate for emissions.

There have been several studies on the effect of diet/ration manipulation on ammonia emissions from feedlots. Bierman et al. (1999) tested diets with neutral detergent fibre contents of 10% (all concentrate), 13% (7.5% roughage), or 28% (wet corn gluten feed, 41.5% of diet DM). Bierman et al (1999) found that 45 to 57% of the N fed was volatilised, with the proportion decreasing with increasing dietary roughage content. Adams et al. (2004) had a similar study that found that direct additions of organic matter, in the form of sawdust, to the pen surface, reduced N volatilisation losses and led to a higher N content in manure.

Todd et al. (2006) and Cole et al. (2005) noted that in vitro NH3 losses from a mixture of faeces and urine increased exponentially as the dietary crude protein concentration was increased. In a similar study, James et al. (1999) found that NH3 volatilisation decreased by 28% when Holstein heifers were fed a diet containing 9.6% crude protein as opposed to 11% crude protein. Similarly, Misselbrook et al. (2005) showed that a 14% crude protein diet as opposed to a 19% crude protein diet fed to dairy cows led to a 45% reduction in urinary N excreted. Cole et al. (2008) and Todd et al. (2009) examined the effect of feeding distillers' grains on N volatilisation losses from feedlot pens. It was found that feeding lower concentrations of distillers' grains led to a shift of N excretion from urine to the faeces, a decrease in faecal and manure pH, and additional organic matter on the pen surface. Feed timing management can also have an effect on ammonia emissions from the pen and stockpile. Cole et al. (2005) noted that ammonia emissions from faeces and urine increased with days on feed. This was due to increased urinary N excretion. Cole et al. (2006) also showed that N volatilisation losses were decreased by 25% in cattle phase-fed steam-flaked corn-based diets.

This research suggests that lowering crude protein in feedlot diets may reduce ammonia emissions. This may be a GHG mitigation strategy for Australian feedlots via the indirect relationship between ammonia and nitrous oxide. We note that higher ammonia emissions have been measured from Australian feedlots (Denmead et al. 2008, Loh et al. 2008) than are currently accounted for in the NGGI, increasing the mitigation potential via this pathway. However, mitigation via reduction of ammonia depends on the emission factor for indirect nitrous oxide, which may be overestimated in the current NGGI methods (R. Eckard pers. comm.). This should be taken into account for all mitigations targeting ammonia.

No research projects were found that directly measured reductions in feed pad nitrous oxide as a result of lower N levels in rations. However, Velthof et al. (2005) examined the effects of crude protein content, addition of a urine acidifying salt and fermentable NSP contents on potential nitrous oxide emissions from swine manure and found that reduced crude protein had the greatest potential to decrease nitrous oxide emissions in soils. Considering the lack of direct research, predicting mitigation of nitrous oxide would require an assumption that similar reductions to ammonia would result from lower N in the ration.

Practically, reduced protein levels may be feasible in the Australian industry where excess protein is fed. This can be the case where ration commodities such as whole cotton seed or wet/dry distillers grains are included in the ration and ration CP can exceed 15% compared to common CP levels which are closer to 13%. The cost of this is likely to be governed by the cost of alternative lower N feed components that allow a similar level of cattle performance.

4.1.2 Nitrification Inhibitors

Nitrification inhibitors such as dicyandiamide (DCD) and 3, 4-dimethylpyrazole phosphate (DMPP) are known to reduce nitrous oxide emissions from fertilisers and animal slurries applied to land (Pain et al. 1990). Trials have been proposed in New Zealand to feed DCD in dairy cattle rations to reduce post-excretion nitrous oxide emissions (Stewart Ledgard pers. comm.). However, this research is still in very early stages and no such research has been done to quantify the potential for nitrification inhibitor feed additives under feedlot conditions to the authors knowledge. This may be a useful strategy in the future depending on the results of subsequent research, but is not commercially viable at the present.

4.1.3 Ration Additives

Sherwood et al. (2005) undertook a N mass balance study of feedlot pens to analyse the effect of feeding clinoptilolite zeolite clay to cattle. The hypothesis was that the addition of zeolite to the ration would bind the NH3 on the feedlot pen surface thus reducing NH3 losses and increasing the N content of the manure. They found that a 1.2% inclusion of clinoptilolite in the feedlot ration did not affect the N balance of the feedlot pen (Sherwood et al. 2005) and therefore does not appear to be a viable mitigation strategy.

4.2 Feed Pad

Mitigation of GHG emissions at the feed pad can be done mainly by applying additives to the feed pad surface or by changing manure management. Manure additives work in numerous ways but there are several concerns with their use as mitigation strategies, namely: they may have a short term and/or reversible effect; most focus on ammonia rather than nitrous oxide directly; they may inhibit emissions at the feed pad, but emissions may subsequently increase during manure handling, stockpiling/composting and land application. For these reasons, on-site emissions associated with the project action would require careful analysis.

A summary of the mechanisms for reducing and estimating ammonia and nitrous oxide emissions from the feed pad is provided in Appendix 1.

4.2.1 Acidification

The pH of the manure determines the equilibrium between NH4+ and ammonia in aqueous systems, with a lower pH leading to a lower proportion of aqueous ammonia and as such, a lower potential for ammonia volatilisation (Ndegwa et al. 2008). Therefore, acidification of manure on the feed pad should lead to a mitigation of ammonia volatilisation. Several studies have been undertaken on the effect of acidification on ammonia emissions from manure. Safley et al. (1983) found that the addition of phosphoric acid to cattle and pig manure led to a 50% reduction in ammonia emissions while Al-Kanani et al. (1992) found that addition of phosphoric acid to pig manure led to a reduction of ammonia emissions by 90%. A number of studies found that the addition of sulphuric acid to cattle and pig manure led to a reduction in ammonia emissions between 14-100% respectively (Al-Kanani et al. 1992, Frost et al. 1990, Jensen 2002, Molloy & Tunney 1983, Pain et al. 1990, Stevens et al. 1989). Similarly, a study by Husted et al. (1991) showed that the addition of hydrochloric acid to cattle manure led to a 90% reduction in ammonia emissions. The research shows that strong acids have the potential to reduce ammonia emissions from manure. However, it should be noted that strong acids can be hazardous to other farming activities.

While acidifying agents can reliably reduce ammonia, the effect on feed pad nitrous oxide is not known. Additionally, losses during later stages of the manure management system may offset gains.

4.2.2 Sorbers

Several studies have shown that ammonia emissions from the feed pad can be potentially decreased through the use of additives such as alum, calcium chloride, adsorbents (zeolite, humate) or urease inhibitors (Parker et al. 2005, Shi et al. 2001, Varel et al. 1999). Sorbers work by binding to ammonia and other compounds in manure, reducing losses. Urease inhibitors work by inhibiting ammonium production as per the equations shown in Appendix 1. However, it should be noted that there may be disadvantages associated with these methods such as increased manure mass, short effect period and increased sulphate emissions.

Chemical additives such as calcium chloride and alum have been shown to decrease ammonia emissions by a combined process of lowering the pH of the manure and through cation exchange. The cation exchange process releases hydrogen ions and replaces them with calcium or aluminium ions and as such decreases pH levels and results in reduced ammonia emissions (Shi et al. 2001). Studies on composted chicken manure have also shown that chemical amendments such as alum and calcium chloride have significantly reduced ammonia volatilisation (Kithome et al. 1999, Moore et al. 1995). Shi et al. (2001) undertook an experiment to test the effect of a range of chemical additives on ammonia emissions from a simulated beef cattle feed pad. Two samples each of alum (aluminium sulphate) and calcium chloride were applied to the simulated feed pad at application rates of 4500 kg/ha and 9000 kg/ha respectively. The two alum treatments were found to reduce the 21 day cumulative ammonia emissions by 91.5 and 98.3% when compared against the control sample. The two calcium chloride treatments were found to decrease the 21 day cumulative ammonia emissions by 71.2 and 77.5%. These results suggest that alum and calcium chloride can be used as chemical additives to reduce ammonia emissions from the feed pad.

Shi et al. (2001) also examined the effect of the adsorbents brown and black humate on ammonia emission rates from a simulated beef cattle feed pad. The humates were added at application rates of 9000 kg/ha. The research found that ammonia emissions from the feed pad were reduced by 67.6 and 60.2% for the brown and black humate respectively when compared against the control sample.

Varel et al. (1999) investigated the effect of two urease inhibitors on ammonia emissions from the feed pad, namely N-(n-butyl) thiophosphoric triamide (NBPT) and cyclohexyl-phosphoric triamide (CHPT). The results showed that topical application of both CHPT and NBPT increased the surface concentration of the feed pad manure above untreated concentrations. This suggests that urea was retained in the manure and as such, ammonia emissions are expected to decrease. Parker et al. (2005) undertook a similar experiment where the effect of NBPT application for minimising ammonia emissions from beef cattle feedlots was examined. The urease inhibitor was applied at concentrations of 0, 1 and 2 kg/ha to simulated beef cattle feed pad at frequencies of 8, 16 and 32 days respectively. The results showed that NBPT applied at concentrations of 1 and 2 kg/ha every 8 days led to a reduction in ammonia emission rates between 49 and 69% respectively. These results suggest urease inhibitors such as NBPT and CHPT can successfully be utilised to reduce ammonia emissions from beef cattle feed pads.

Cole et al. (2007) concluded that a combination of compounds that utilise different mechanisms in order to mitigate ammonia emissions may be more effective when compared against using individual compounds on their own.

It is not clear at this stage whether sorbers could be used effectively and economically at Australian feedlots. Some sorbers (notably alum) will bind phosphorus and are likely to result in lower fertiliser value of the manure, which is not preferable. Further research and practical application trials would be beneficial prior to pursuing a CFI method based on these technologies.

4.2.3 Increased Frequency Pen Cleaning

Feedlots clean manure from pens on a rotational basis with variable intervals between cleaning. Intervals may range from 6 weeks to several months, and may also be dependent on climatic conditions. During the period following cleaning, manure nitrogen and VS accumulates, providing a larger mass of substrate for emissions to occur. There are two potential mitigations that may arise from increasing the frequency of pen cleaning. Firstly, increasing the frequency of pen cleaning may reduce the overall N losses from the feed pad. Secondly, if pens are cleaned more frequently and a lower mass of N and VS are present on the feed pad during wet conditions, emissions may be reduced.

Wilson et al. (2004) conducted a trial over two summer feeding periods to determine if more frequent pen cleaning reduced N loss from pens. The study showed that monthly pen cleaning (rather than cleaning at the end of the feeding period) reduced N loss by 18-19%. The reduction was not large, suggesting that much of the N volatilised is likely to occur rapidly. Considering the differences between the conditions studied by Wilson et al. (in Nebraska, USA) and Australian conditions, this mitigation is not likely to be effective unless the cleaning frequency was greater, which is unlikely to be economically feasible.

The feasibility of changing the frequency of pen cleaning would need to be explored further, but will be most heavily influenced by the cost of additional cleaning compared to the return from sales of carbon credits.

4.2.4 Bedding

Bedding has been included among other factors as having dramatic influence on reducing NH3 emissions from dairy facilities in North America. For housed dairy systems, factors influencing NH3 emissions include barn design, ambient temperature and ventilation, diet composition, bedding and frequency of manure removal (Hristov et al. 2011). For feedlot cattle, ammonia volatilisation from the feedlot surface and manure storage can potentially be decreased through the use of additives such as bedding (Parker et al. 2005, Shi et al. 2001, Varel et al. 1999).

Misselbrook and Powell (2005) examined the influence of bedding material on ammonia emissions from cattle excreta. Six different bedding materials were used in the experiment, namely chopped wheat straw, sand, pine shavings, chopped newspaper, chopped corn stalks and recycled dairy manure solids. Equal volumes of dry bedding were added to six chambers containing cattle excreta.

Urine and diluted faeces were then added. Emission from all treatments, with the exception of sand, increased over the first 12 to 24 hours after urine application. Ammonia emissions were least from the sand and pine shavings compared against chopped newspaper, chopped corn stalks, and recycled manure respectively (Figure 9).

The use of bedding material such as woodchips may in fact assist in maintaining a dry pen surface. Additionally, increasing the surface area with woodchips is likely to increase the rate of drying and oxygen permeability. In this circumstance, the overall emission intensity would be lower, and the length of malodour events would be reduced.

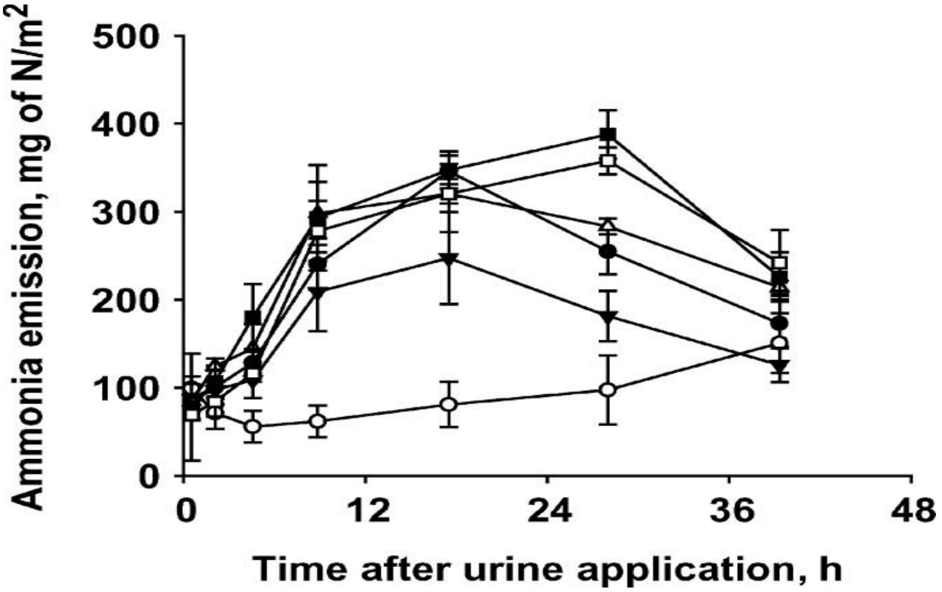

Figure 9 notes: Ammonia emission rates following urine application to different dry bedding materials: chopped straw, ● ;sand, ○; pine shavings, ▼; chopped newspaper, ; chopped corn stalks, ■; recycled manure solids ■ Error bars show ±1 SE (n = 3).

Misselbrook & Powell (2005) concluded that pine shavings reduce ammonia emissions when compared with recycled manure as may be found on a typical pad surface. In a similar study, Powell et al. (2008) reported that heifer ammonia emissions (g/heifer/day) from bedding that contained manure solids (20.0 g/heifer/day), newspaper (18.9 g/heifer/day), and straw (18.9 g/heifer/day) were similar and significantly greater than emissions using pine shavings as bedding (15.2 g/heifer/day).

Adams et al. (2004) undertook an experiment to investigate the application of sawdust to the feedlot pens in addition to feeding diet high in roughage (bran). Adams et al. (2004) observed that in winter, the volatilisation loss from the control pen (no sawdust, high concentrate diet) was 49.4% and this decreased to 29.1% for the bran treatment and 26.8% for the sawdust treatment. This indicates that the addition of carbon decreases N volatilisation markedly. However, the average temperature during the winter experiment was only 0.6°C, which are conditions never encountered in Australia. For the summer experiment, the mean temperature was 22°C. The volatilisation loss from the control pen in summer was 62.2% and this decreased to 56.4% for the bran treatment but increased to 64.8% for the sawdust treatment. Adams et al. (2004) concluded that the increase in volatilisation due to temperature increase dominated the N balance. Regardless, the addition of carbon to the pen surface, either through the ration or the addition of bedding, has the potential to reduce N volatilisation from pen surfaces.

The use of bedding will alter porosity and aeration on the feed pad and the influence on nitrous oxide emissions are not clear. Some research also suggests that manure methane emissions may be higher (see Table 9).

Considering these mixed results, further research is required to understand the mechanisms altering emissions when different bedding substrates are applied, prior to development of a CFI method.

4.2.5 Housing

While not a readily applied option, it is worth noting that changing from a manure based system to a slurry-based system may reduce nitrous oxide emissions (Groenestein & Van Faassen 1996, Thorman et al. 2003). Most of this research has been on European style dairy barns which may be flushed daily to carry manure to an effluent pond. Provided leakage issues could be addressed (i.e. manure methane would need to be captured and destroyed) this may reduce nitrous oxide and ammonia. Clearly, this is not a readily applied mitigation strategy as it would essentially require construction of a new feedlot.

4.2.6 Nitrification Inhibitors

Nitrous oxide production only occurs under specific conditions where combined processes of the aerobic process of nitrification and the anaerobic process of denitrification take place.

As mentioned previously, nitrification inhibitors can reduce nitrous oxide emissions from soil (Pain et al. 1990). New Zealand research has investigated using nitrification inhibitors on grazing land with some success (Di & Cameron 2003). This suggests further investigation may be worthwhile for feedlot pens, though it would not be suitable for further investigation as a CFI method at this stage.

4.3 Solid Manure Storage

Many approaches discussed in the feed pad section may also apply to manure storage. These will be discussed briefly with comments provided on the applicability to manure storage. Manure may be handled in several ways at a feedlot. Compacted stockpiles, uncompacted stockpiles and composted windrows (where manure is mechanically turned frequently) are all common. These methods in themselves may alter emissions and this is discussed below.

4.3.1 Acidification

Few studies were found that investigated acidifying manure stockpiles, though this method is frequently applied to reduce emissions from cattle slurry in Europe (Kai et al. 2008, Stevens et al. 1992). It may be feasible to acidify manure as it is stored in a stockpile or to the surface of the stockpile. However, as acidification preserves more N in the manure and as nitrous oxide production favours lower pH conditions, acidification may cause an increase in direct nitrous oxide emissions (VanderZaag et al. 2011). More research is required at Australian beef cattle feedlots to test the feasibility of acidification as a mitigation technique for reducing ammonia emissions before it can be utilised.

4.3.2 Sulphur Compounds

Hao et al. (2005) examined the effect of treating solid manure stockpiles with sulphur compounds such as phosphogypsum. It was found that methane emissions decreased with increasing sulphur content. The sulphur compound was found not to have an effect on nitrous oxide emissions. However, other studies have shown that sulphur additions reduce N losses during composting by decreasing the manure pH level without decreasing the level of decomposition (Mahimairaja et al. 1994). Again, more research would be required before sulphur compound addition can be considered as a potential mitigation strategy for the Australian beef cattle industry.

4.3.3 Altered Manure Storage Management

Monteny et al. (2006) suggested that emissions could be reduced by storing manure for shorter periods under conditions conducive to emissions. By reducing residence time, emissions are expected to decrease. This could be achieved by spreading manure directly from the feedlot pad onto fields. There are some practical challenges with this however, as pen cleaning may not correspond with ideal application times, particularly if pen cleaning occurs frequently. A mitigation based on this approach would require quantification of emissions from baseline (stockpile) conditions.

Management of manure heaps by minimising compaction as well as the frequent addition of straw/litter has been shown to significantly decrease methane and nitrous oxide emissions in Europe (Hüther et al. 1997as cited in, Monteny et al. 2006).

There is evidence to suggest that emissions vary depending on whether manure is stored under aerobic or anaerobic conditions. Monteny et al (2006) also showed that compaction of manure heaps to reduce oxygen levels and maintain anaerobic conditions has the potential to reduce nitrous oxide emissions from the storage of solid manure. However, it should be noted that methane emissions would be expected to increase with the compaction of manure heaps. Conversely, several studies have found that active composting (turning and wetting windrows) may increase nitrous oxide emissions considerably (see references in Appendix 1, Table 27). This suggests that stockpiling or rapid spreading of manure may be a mitigation option where composting was common practice. This would need to be determined on a ‘feedlot-by-feedlot’ basis however which is unlikely to be feasible for baseline calculations under the CFI.

4.3.4 Covers

Covers for solid manure stockpiles have been built in Europe in an attempt to reduce emissions and capture biogas. This is achieved by trapping any emissions, by preventing wind from removing the gas and by increasing the vapour pressure difference that would bring more gas to diffuse from lower depths in the manure tank toward the surface (Miner et al. 2000). Hansen et al. (2006) examined the effects of covering solid manure separated from pig slurry on the production and emission of GHGs and ammonia. Emission levels from solid manure can be expected to depend on the oxygenation level inside the bulk of the stored solid manure. Covering the solid manure was found to decrease aeration, reduce internal heat production, degrade organic matter and decrease the emissions of GHGs and ammonia. Approximately 15% of the initial nitrogen content of the solid manure was lost when the solid manure was stored uncovered, with 5% lost as nitrous oxide and

0.3% lost as ammonia. The higher nitrous oxide emissions found in this study may be explained by the high density of solids separated from slurry, relative to that of deep litter from dairy cattle production or of green manure. Higher density of solid manure reduces ammonia emission and subsequently leads to a higher rate of nitrous oxide emissions (Sommer 2001). Covering the solid manure stockpile was found to reduce nitrous oxide and ammonia emissions by 99% and 12% respectively. Covering of the solid manure stockpile was also found to reduce methane emissions by 88%.

These results are promising and show that covering solid manure stockpiles may be a potential mitigation technique for reducing emissions at feedlots. However, research would be required with Australian feedlots to determine emissions from covered and uncovered stockpiles to determine the appropriate mitigation rate prior to development of a CFI methodology.

4.3.5 Energy Generation from Manure

A number of technologies have been investigated for generating energy from manure and altering the quantity and quality of the nutrients contained in manure. These technologies may utilise wet manure (i.e. digestion) or dry manure (i.e. combustion or pyrolysis). Energy generation may be attractive to feedlots as a means of offsetting fossil fuel use, which may improve the economics of the technologies. Generation of energy per se is not eligible under the CFI because energy is covered by the carbon tax mechanism. However, there are two potential pathways in which energy generation may mitigate emissions:

- Reduction of emissions from manure storage and possibly land application by diverting manure to an energy generation process.
- Increase in the rate of carbon sequestration in soil from biochar (assuming this could be verified) compared to land application of stockpiled manure.

The DIICCSRTE have recently commenced work to develop a CFI methodology for the pyrolysis of poultry manure targeting these mitigation opportunities (N Gabay pers. comm.). The successful development of such a CFI methodology would make similar methodologies for the feedlot industry more feasible. However, there are three main challenges to establishing such a methodology.

Firstly, there are few data available to determine, with confidence, the avoided emissions from diverting manure away from stockpiles and land application. The emission estimates outlined in this report, and in Watts et al. (2012) are based on a literature review and few studies have been completed in Australia. It should also be noted that the NGGI do not identify separate emission factors for stockpiling or for effluent treatment of manure. Considering it would not be possible to measure the mitigation potential from avoiding manure handling, there would need to be a high degree of scientific rigour in the methods used for predicting emissions abatement. At the current time, there are insufficient data to confirm these emissions (and abatement potential) under Australian conditions.

Secondly, there are no studies (to the author's knowledge) that demonstrate higher rates of carbon sequestration from biochar produced from feedlot manure compared to sequestration from stockpiled feedlot manure. This would need to be established beyond scientific doubt to enable a methodology to be developed for carbon sequestration potential.

Thirdly, there are a range of leakage concerns that would need to be thoroughly investigated with respect to energy generation processes. With respect to thermal technologies (combustion and pyrolysis) the losses of nitrogen may be significant (Gaskin et al. 2008), because of the volatile nature of the nitrogen components in manure, possibly resulting in secondary emissions of nitrous oxide. Onsite rises in emissions are also likely with digestion technologies, particularly those that utilise pen manure that would otherwise have been handled in a dry system (stockpiling). These approaches aim to maximise methane yields from manure over and above what would occur if the manure is handled in a stockpile, and may have unintended losses of methane from the digester. Increased emissions may also arise from N losses associated with effluent land application after digestion.

It should be noted that there are a number of practical barriers to the uptake of combustion and pyrolysis technologies in Australia, including the high proportion of soil contamination in feedlot manure (Davis et al. 2012), the variable (and sometimes high) moisture content and subsequent low energy yield from Australian feedlot manure (Watts et al. 2013) and the reliance on high returns from the sale of biochar to ensure economic feasibility (Watts et al. 2013). None the less, such technology is likely to improve over time and the economics of adopting such technology will improve as energy prices climb.

4.4 Liquid Manure Handling

4.4.1 Pond Cover and Ch_4 Destruction

Uncovered anaerobic ponds are used to store liquid manure at feedlots. However, emissions from anaerobic ponds are likely to account for ~1% of total feedlot emissions only (Wiedemann et al. unpublished data). This emission source can be mitigated and/or used by capturing the methane in a covered anaerobic pond (CAP) system and destroying it. The methane can be captured by installing a geo-membrane cover such as high density polyethylene (HDPE), low density polyethylene (LDPE) or polypropylene (PP). Because methane is highly volatile, it can be burned with a flare, or can be used to generate heat or electricity in a generator or combined heat and power (CHP) unit. Provided the methane is destroyed, the overall GHG emissions will be reduced regardless of whether a flare or generator is used. Two methods have been approved under the CFI using this approach for the piggery and dairy industries respectively. It would be possible to develop a similar method for feedlots, though the total mitigation potential is fairly low. Figure 10 shows a typical covered anaerobic pond (CAP) in Australia.

Figure 10 – Covered anaerobic pond (CAP)

5 Review Summary

In order to assist decision makers, the findings of the literature review have been summarised here together with a qualitative analysis of technical feasibility, and the ease of application under the CFI. The analysis is indicative rather than definitive and was conducted to help identify the best opportunities at the present time. Further research and analysis are likely to change these ratings. The enteric methane mitigation options are summarised in Table 11.

Table 11 – Assessment of enteric methane mitigation options

	Cost	Mitigation Potential	Ease of meeting CFI requirements	Ease of applying commercially	Leakage risk	Commonly used in Australian feedlots
Ruman manipulation and ecology						
Defaunation	H	L	L	L	L	N
Ionophores	L	L	H	H	L	Y
Bacteriocins	H	L	L	L	L	N
Feed additives - fats and oils	L	M	H	H	M	variable
Distiller's grains	NA	M	L	L	H	variable
Micro-algae	L	L	L	H	?	N
Synthetic chemicals	M	M	H	H	L	N
Natural chemicals	H	L	L	H	L	N
Vaccination	H	L	L	H	L	N

Enhancing non-methanogens - diet manipulation						
Forage quality, grain type/processing	H	L-M	M	H	L	variable
Inoculants	H	L	L	H	L	N
Breeding	H	M	L	L	L	N
Management						
Reduced age to market weight (supply chain and feedlot)	M	H	L	H	?	n.a

Of the options assessed for mitigating enteric methane, several of the most promising (feed additives, monensin, improved feed processing) are already practiced in the industry to some extent. However, this does not automatically exclude these options for all feedlots. For example, the level of oil in rations tends to be lower in WA, and the use of steam flaking for feed processing tends to be limited to feedlots greater than 5000 head capacity. Grain inclusion rates in rations may be variable across the industry. Further analysis may be required after the revision of the common practice and additionality tests to assess these options.

Some other options, such as feeding nitrate in replacement of urea, should be relatively easy to apply commercially provided the cost-benefit is attractive.

The 'reduced days to market weight' mitigation is an attractive whole supply chain approach, leading to lower emissions for every animal marketed. There are two perspectives for this mitigation. Firstly, it could apply to cattle while they are in the feedlot. Secondly, it could apply to cattle that may be finished either in the feedlot or on grass. Of these, the second option may provide a large mitigation potential, equivalent to more than $15 / hd. While there are challenges with this approach (particularly around the tests for common practice and additionality) the large potential suggests further investigation would be warranted.

Table 12 – Assessment of manure emission mitigation options

	Cost	Mitigation Potential	Ease of meeting CFI requirements	Ease of applying commercially	Potential leakage	Commonly used in Australian feedlots
Low protein (nitrogen) diets	M	H	M	H	L	N
Feed pad						
Acidification	M	M	M	M	H	N
Sorbers	M	M	M	M	M	N
Rapid cleaning	?	M	L	M	H	N
Nitrification inhibitors	M	L-M	M	L	H	N
Solid manure handling						

Acidification	M	H	M	M	M	N
Sorbers	M	L	M	M	M	N
Short duration stockpiling	L	L	L	L	M	variable
Covers	L	L	M	L	M	N
Liquid manure handling						
Pond cover and methane destruction	H	L	H	L	L	N
Short retention time	M	L	L	L	L	N

The magnitude of manure emissions, and their potential mitigation, is subject to a much higher degree of uncertainty than enteric emissions. The degree of uncertainty surrounding mitigations is exacerbated by the open and dynamic nature of manure management systems, which are heavily influenced by temperature, rainfall and management. Because manure emissions are volatile and may remain in the management system for up to 12 months, the risk of increased on-site emissions is high. The lack of Australian research, and variation between Australian conditions and those experienced in the USA or Europe, make applying the findings from overseas research much less certain than is the case with enteric methane. As a consequence, there are fewer manure mitigation strategies that could be easily taken up in the CFI without further research. A summary of the assessment of manure emission mitigation options is given in Table 12.

The best option appears to be reduced crude protein in rations, which should reduce N emissions throughout the manure management system. It would also be relatively easy to develop a methodology for the destruction of methane from feedlot effluent ponds, though the mitigation potential is low. New research has recently been commissioned to investigate the ability of sorbers to reduce gaseous losses from feedlot manure (M Redding pers. comm.), and the results of this research may be applicable for developing CFI methods in the mid-term future.

6 Analysis of Mitigation Options for the Feedlot Industry

6.1 Industry Survey

Following completion of the mitigation review, a survey of key industry participants was undertaken with the following aims:

- To gather information on the current use of practices known to reduce greenhouse gas emissions (to address common practice criteria).
- To identify barriers and benefits from applying mitigation strategies across the industry and qualitatively rank the mitigation strategies based on perceived feasibility and likelihood of industry uptake if they were adopted as part of the CFI.

The survey consisted of a series of questions (see Appendix 2) with information provided for context. Survey participants were also provided with a brief project outline (Appendix 2). Survey participants were selected for their broad knowledge of the industry and to provide a wide coverage of the major lot-feeding regions of Australia. The survey also involved industry advisory personnel, such as nutritionists and providers of environmental services, who were able to provide information covering a broad cross section of the industry. Survey results are provided in the following sections.

6.1.1 Common Practice

For each mitigation option, survey participants were asked to report if they used this practice already at their own feedlot and others managed by their company, and if they understood the practice to be widely adopted in the region/regions where they operated. The outcomes were as follows.

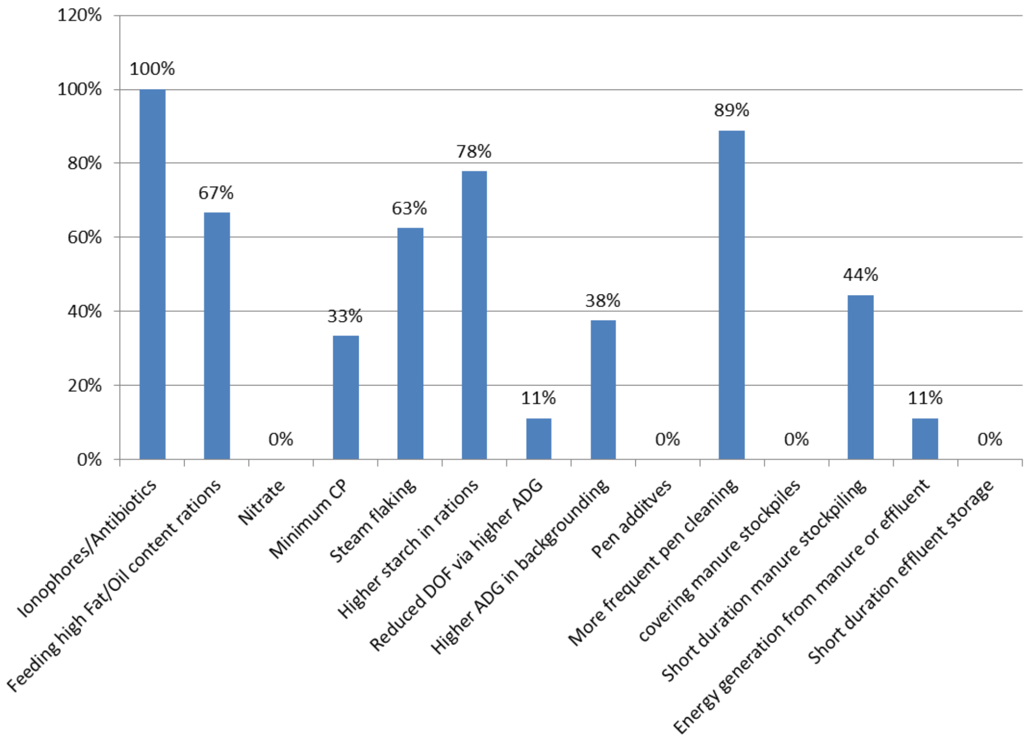

Figure 11 – Prevalence of mitigation practices in the Australian feedlot industry. 100% = all surveyed feedlots use this practice, 0% = no surveyed feedlots used this practice

The survey clearly showed differences between practices known to reduce GHG. Of the nutritional strategies, feeding ionophores (monensin) was very common in the industry. Feeding high starch rations, steam flaking and feeding high fats/oil content rations were also common, though there was a clear trend in which feedlots typically did not use these. For example, long-fed feedlots tend not to feed high starch rations because they are not aiming for high growth rates. Steam flaking is also variable; it is common in large feedlots (>5000 head) in regions where sorghum is commonly used but is not common in smaller feedlots, particularly in southern and Western Australia. However, these feedlots are unlikely to install steam flakers because of the capital outlay and marginal returns.

Feeding high fat/oil content rations was fairly common for feedlots using cotton seed, which was most of the feedlots north of central NSW. Feedlots further south, and feedlots in Western Australia typically fed lower levels of oil and this varied depending on grain prices. No feedlots surveyed fed rations with fat/oil content as high as 7% of DMI (considered a maximum level). Consequently, while this is commonly practiced, levels could be increased and it could be practiced more widely.

Feeding minimum CP levels was only common in some feedlots, but while most others did not specifically maintain low CP levels, they did not overfeed either. Only one feedlot reported a CP level (15% DMI) that was clearly well above requirements.

The only feeding strategy not used by any feedlots was feeding nitrate.

Of the cattle management strategies, reduced DOF via higher ADG had been applied at only one feedlot, which specialised in long-fed cattle for the Japanese market. This market type are typically managed to achieve growth rates well below genetic potential and therefore gains are more easily achieved if quality aspects can be maintained. Improved growth rate is an ongoing productivity objective by the industry. It is likely that a suite of strategies would need to be applied to achieve higher ADG and it may be difficult to provide guidance regarding the common practice and additionality tests. In many situations, reducing DOF is also constrained by market requirements which may limit the scope of this strategy.

Most (75%) of the feedlots surveyed backgrounded cattle prior to feedlot entry, though this varied from 3 weeks to > 6 months. Some (40%) grain assisted these cattle during backgrounding. About 40% of feedlots had used strategies to reduce the days during backgrounding. The remaining feedlots reported that they either (i) didn't need to do this because growth rates on grass were high already, or (ii) they didn't have control over cattle during the backgrounding process.

Of the manure handling practices, frequent pen cleaning was practiced by most feedlots. Many feedlots (44%) were already maintaining short stockpiling periods. Of the other strategies, no feedlots applied pen additives, used covers on their manure stockpiles or rapidly irrigated effluent. Only one feedlot was in the process of installing energy generation technology.

The strategy of feeding additional grass fed cattle in feedlots to reduce emissions could not be assessed as being common practice or not. In general, the CFI has looked to 'new' practices rather than a change in existing practices when applying this rule. Hence grain finishing would be considered common practice and not additional. The primary issue here relates to the integration of the mitigation strategy into the CFI rather than the technical viability of the strategy. Considering this, further discussion may be warranted to investigate how these issues could be overcome.

6.1.2 Industry Ranking of Mitigations

A series of questions are asked of the survey participants about the feasibility, barriers to uptake and attractiveness of the mitigations proposed if they could be used at access a payment under the CFI. These questions were summarised by asking each survey participant to provide a subjective ranking for the mitigation, as a measure of how attractive this would be to industry. The potential mitigation options surveyed were not screened to remove those already common in the industry. As a consequence, some very attractive options such as feeding ionophores (9.5) are common to the industry. Feasibility and compliance with the CFI requirements was taken into account in the following section (6.1.3).

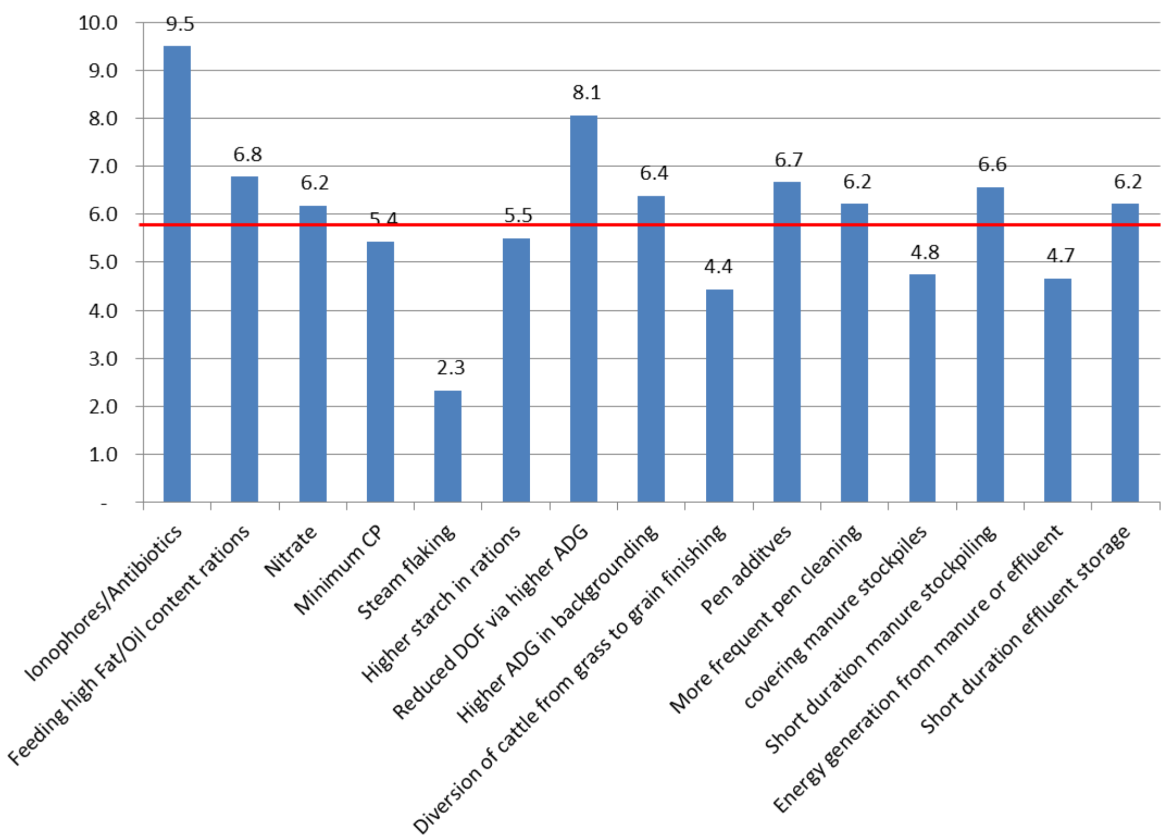

Figure 12 – Industry ranking of mitigation options (score out of 10) based on practicality and likelihood of industry uptake if a CFI payment was available

Perhaps not surprisingly, the most attractive option after ionophores was reduced DOF via higher ADG. Most participants commented that this is their primary goal already, but if there was a new approach that could increase ADG and attract a CFI payment this would be very attractive. Beta agonists were suggested as an option that could achieve this, as were improved pen conditions in winter via provision of bedding materials such as woodchip. As noted in the previous section, reducing DOF would in most cases require a change to market requirements and would therefore be difficult to establish as an industry practice.

There were a number of mitigation options ranked in the mid-range, from 6.2-6.8. These included feeding strategies such as higher fat/oil content levels, feeding nitrate, higher ADG in backgrounding, application of pen additives, more frequent pen cleaning and short duration manure and effluent handling. Interestingly, 'more frequent pen cleaning' was rated reasonably highly, despite most feedlots practicing this already. Some respondents suggested that improvements could be made more broadly across the industry in this area but not at their own feedlots.

Interestingly, diverting grass finished cattle to feedlots to reduce the days to market was not highly ranked by the survey participants. The reasons cited were varied; some indicated that markets may not be able to handle additional cattle. Others noted that capacity was constrained in their feedlots and this would limit the opportunity to feed more cattle. Others noted that the payment would not be sufficient to warrant the purchase of more cattle. Some of these issues, such as constrained capacity, may be less apparent across the whole industry than for individual operations.

Options with a score higher than 6/10 which were not common practice were considered against technical feasibility criteria in the following section.

6.1.3 Technical Feasibility and Mitigation Potential

Options that were deemed attractive to the industry and were not common practice across the whole industry were subjected to a further analysis to assess technical feasibility and mitigation potential. This analysis was done by the project team using a simple, internally developed set of criteria and is reported in Table 13. The purpose of this analysis was to identify overall scores and any significant barriers that may stand in the way of further investigation. The total score is only one part of the analysis; failure for question 1 (technical) or 3 (market barriers) automatically excluded a strategy.

Table 13 – Technical feasibility and mitigation potential of selected GHG mitigation strategies for the feedlot industry

	Technology / equipment is available	No technical / production barriers	No market barriers	Cost effective*	Mitigation calculated easily	Sufficient Mitigation Potential	Total Score
Feeding high fat/oil content rations	1	1	1	1	1	1	6
Feeding Nitrate	1	1	1	0	1	1	5
Reducing DOF via higher ADG	1	1	0	1	0	1	4
Higher ADG in backgrounding	1	0	1	1	1	0	4
Application of pen additives to reduce manure GHG	0	0	1	0	0	0	1
Short duration manure stockpiling	1	1	0	1	0	0	3
Short duration effluent storage / covered pond	1	0	1	1	1	0	4

* Cost effectiveness was a broad measure of whether the approach was high or low cost, and whether it could be cost effective in at least some situations.

Based on this analysis, feeding high fat/oil content rations, feeding nitrate, reducing DOF and increasing ADG in backgrounding were the highest rated strategies. Of these, there is a significant barrier to reducing DOF for many feedlots because of the minimum requirements for feeding periods. Also, it is unclear what exact management changes would be employed to achieve this and this could make measurement difficult. This analysis provided three options, high fat/oil rations, feeding nitrate and higher ADG in backgrounding appear the most suitable methods for progressing for the industry.

6.2 Cost benefit Analysis

A basic cost benefit analysis was performed for three promising mitigation strategies. These were chosen for being the most readily applicable for the industry using approaches that have already been considered in the CFI for other industries. The chosen mitigations were feeding high fat rations, feeding nitrate and covering effluent ponds.

6.2.1 High Fat Rations

Research indicates feeding up to 7% fats and oils (in the total diet) is an effective mitigation scenario with potentially positive impacts on production. Dietary fats and oils (referred to from here on as dietary fat) suppress enteric methane. Provided other emission sources (i.e. manure emissions) are not influenced, the mitigation potential can be significant. The effect of fats and oils on N2O and CH4 emissions from dung or urine due is dependent dietary crude protein and dry matter digestibility. Digestibility affects manure methane emissions to a very small extent, and differences between diets result in negligible changes to manure methane because of the comparatively low emission factors recommended for Australian feedlot cattle (NIR, 2010). Changes in crude protein levels have a more noticeable effect on excreted nitrogen and therefore manure nitrous oxide. In the present analysis, we used iso-nitrogenous diets to remove the impact of changed nitrogen excretion on manure emissions. Diets were formulated by a professional consulting nutritionist, Dr Rob Lawrence of Integrated Animal Production. Diets were formulated based on realistic assumptions for costs and expected production (R. Lawrence pers. comm.), but should not be taken as professional advice as costs and returns can change rapidly.

Table 14 – Standard and high fat rations formulated for Queensland, Southern NSW and Western Australia

		QLD		Sth NSW		WA	
Ingredient Detail	**$/t**	**Standard**	**with Fat**	**Standard**	**with Fat**	**Standard**	**with Fat**
Tempered (20% moisture) Wheat	254	70.0%	68.0%	71.5%	69.5%	76.0%	70.0%
Lupins	300						3.0%
Sorghum Silage	60	15.0%	15.0%				
Whole Cottonseed	275	10.0%	10.0%	10.0%	10.0%		
Cereal straw	100			3.5%	3.5%	9.0%	9.0%
Water	1			10.0%	10.0%	10.0%	9.0%
Vegetable oil	840		2.0%		2.0%		4.0%
Supplement	300	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Cost $/t	$229.30	$241.02	$227.61	$239.32	$217.14	$244.49
Nutrient Analysis DM						
Dry matter %	73.22	73.62	72.90	73.30	73.11	75.01
Crude protein %	13.40	13.07	13.28	12.95	12.14	12.16
Equiv. protein nitrogen %	1.00	1.00	1.00	1.00	1.00	1.00
Met. Energy MJ/kg	13.06	13.42	13.03	13.39	12.34	13.01
Nem Mcal/kg	2.09	2.16	2.08	2.15	1.94	2.07
Neg Mcal/kg	1.43	1.49	1.42	1.48	1.30	1.40
Effective NDF %	8.06	8.02	8.03	7.98	7.78	7.76
Fat %	4.41	7.06	4.40	7.04	1.90	7.22

Fat was increased from a base level up to 7% of the diet by including vegetable oil. Inclusion of vegetable oil is beneficial from a production perspective as this increases the energy density of the ration. This is generally cost effective provided the price differential with cereals is less than a factor of 3 (or $762 in the above ration). Above this level, the fixed cost increase for the ration may not be offset by improved performance unless feeding conditions are ideal, resulting in greater risk for the feeding operation. In Table 15 we provide predicted animal performance from the above rations, showing slightly lower feed intake, higher gain, improved feed conversion and very similar cost-of-gain for both classes of cattle.

Table 15 – Performance prediction for two classes of feedlot cattle fed with standard or high fat rations

	QLD		**Sth NSW**		**WA**	
Performance Prediction	**Standard**	**with Fat**	**Standard**	**with Fat**	**Standard**	**with Fat**
			Trade (350 to 470kg)			
Feed intake kg/head/day	12.8	12.7	13.0	12.8	12.8	12.5
Daily gain	1.94	2.05	1.93	2.03	1.71	1.90
DM Feed conversion	4.82	4.57	4.86	4.61	5.47	4.94
DOF	62.00	59.00	62.00	59.00	70.00	63.00
Cost of gain	$ 1.51	$ 1.50	$ 1.54	$ 1.50	$ 1.63	$ 1.61
			Bullocks (420 to 600kg)			

Feed intake kg/head/day	14.10	13.60	14.20	13.70	14.10	13.40
Daily gain	1.80	1.82	1.78	1.80	1.57	1.67
DM Feed conversion	5.75	5.52	5.82	5.57	6.56	5.99
DOF	100.00	100.00	100.00	100.00	114.00	107.00
Cost of gain	$ 1.80	$ 1.81	$ 1.81	$ 1.82	$ 1.95	$ 1.95

As a result of this analysis, we have assumed no difference in the cost of gain for feeding higher fat levels in the ration of feedlot cattle. The economic analysis was performed using the expected mitigation and cost of compliance with the CFI.

Expected mitigation was predicted using the following equation, after Grainger & Beauchemin (2011):

$Y = 26.50 (\pm 1.270) - 0.187(\pm 0.0430)X + 0.0007(\pm 0.00037)X2$

Y = methane production (g / kg DMI)

X = total dietary fat (g / kg DMI)

The mitigation potential for a pen of steers (100 head) over one feeding period and with a potential value of carbon credits (ACCUs) of $10 / t CO_2-e or $15 / t CO_2-e is shown below. We applied GWP values of 21 to convert methane to CO_2-e. Results are shown in Table 16.

Table 16 – Mitigation potential from high fat rations in three states

State	Scenario	Dietary fat	Feed intake	Emissions	DOF	Emissions	Abatement	Potential value of ACCU	
		%	DMI (kg)	kg CH_4/head		t CO_2-e	t CO_2-e	$10 / t CO_2-e	$15 / t CO_2-e
QLD	Standard	4.41	12.8	0.251	62	32.7			
	high fat	7.06	12.7	0.213	59	26.4	6.3	**$63**	**$94**
Sth NSW	Standard	4.4	13	0.255	62	33.2			
	high fat	7.04	12.8	0.215	59	26.7	6.6	**$66**	**$99**
WA	Standard	1.9	12.8	0.297	70	43.7			
	high fat	7.22	12.5	0.208	63	27.5	16.1	**$161**	**$242**

Potential value of mitigation varied from $63-242 per pen of steers (100 head turned off). This is easily scaled up; for a feedlot turning off 10,000 head / yr the potential return is $6274-$24,182 annually. The total returns are based on a zero net change in cost-of-gain (a sensitive assumption) and are sensitive to the price of carbon, which is expected to change in the near future under the influence of policy changes. Total mitigation potential is controlled by the current level of dietary fat being fed in the ration, and by the upper limit for maximum production which is around 7%. Baseline conditions for dietary fat should be set at the individual feedlot level, as feed types can change from feedlot to feedlot and the above assumptions for 'Queensland' or 'Southern NSW' diets will not be representative of all feedlots.

Costs of compliance and overall returns from participating in the CFI will be discussed in section 6.3.

6.2.2 Nitrate

Calcium nitrate fed as an alternative non-protein-nitrogen (NPN) product replacing urea is an effective mitigation option for livestock and is the subject of a CFI methodology currently submitted for DOIC approval (M Martin, pers. comm.). Nitrate suppresses enteric methane. Provided other emission sources (i.e. manure emissions) are not influenced, the mitigation potential can be significant. The effect of nitrate on N2O and CH4 emissions from dung or urine due is dependent dietary crude protein and dry matter digestibility. Digestibility is not expected to change by shifting from urea to nitrate as an NPN source, and this is also very small emission source which could be excluded from a CFI emission boundary. Changes in crude protein levels have a more noticeable effect on excreted nitrogen and therefore manure nitrous oxide. In the present analysis, we used iso-nitrogenous diets to remove the impact of changed nitrogen excretion on manure emissions. Diets were formulated by a professional consulting nutritionist, Dr Rob Lawrence of Integrated Animal Production. Diets were formulated based on realistic assumptions for costs and expected production (R. Lawrence pers. comm.), but should not be taken as professional advice as costs and returns can change rapidly.

Table 17 – Standard and high fat rations formulated for Queensland, Southern NSW and Western Australia

Ingredient Detail	**$/t**	**Standard**	**Nitrate**
Tempered (20% moisture) Wheat	$254	70.0%	70.0%
Lupins	$300		
Sorghum Silage	$60	15.0%	15.0%
Whole Cottonseed	$275	10.0%	10.0%
Cereal straw	$100		
Water	$1		
Vegetable oil	$840		
Supplement		5.0%	5.0%
Total		100.0%	100.0%
Cost $/t		$ 229	$ 232
Supplement			

Urea %	\$450	0.20%	
Limestone %	\$40	1.35%	1.00%
Calcium nitrate %	\$700		0.55%

The mitigation diet and the standard diet were iso-nitrogenous. Consequently, no impact on manure emissions was expected. We also assumed no negative impact on performance. As a consequence, the only change from using the nitrate ration compared to the standard was the cost of gain, which increased 1% from \$1.51 to \$1.53. Over a pen of 100 steers fed for 62 days, this amounted to \$223 or \$2.23 / finished steer.

Stoichiometrically, 1 kg NO3 saves 258.7 g CH4 However, in practice measured methane reductions are usually less than this. In beef cattle Hulshof et al. (2012) found 87% efficiency when steers consumed 22g nitrate/kg DMI. van Zijderveld et al. (2010) reported a nitrate efficiency of 89% in sheep fed a diet with 26 g dietary nitrate/kg DMI, while Nolan et al. (2010) fed dietary nitrate (25 g NO3-/ kg DMI) and found a 23% reduction in methane production per kg DMI. In dairy cattle efficiency is usually lower, with Zijderveld et al. (2011) reporting a 57% apparent efficiency when dairy cows consumed 21 g NO3-/kg DMI. This may be because of the much higher rate of digesta passage in dairy cattle. van Zilderveld (2011) summarised the different methane mitigation efficiencies across species and feed levels with the generic equation:

Efficiency of methane mitigation (0-1) = 1.13 – 0.17 * NO3- (g/kg0.75/d), r2 = 0.82

It can be shown that this equation results in a non-linear methane reduction in response to nitrate supplement levels over 1.0-1.5 g/kg0.75/d, but this was not important for the feeding levels explored here. Consequently, the efficiency factor was set at 1.

Table 18 – Mitigation potential and cost benefits for feeding calcium nitrate to a pen of 100 steers for the domestic market (62 days)

State	Scenario	Dietary nitrate	Feed intake	Emissions	DOF	Total emissions (100 hd, 62 d)	Abatement	Potential value of ACCU	
		%	DMI (kg)	kg CH4/head d		t CO2-e	t CO2-e	\$10 / t CO2-e	\$15 / t CO2-e
QLD	Standard	0	12.8	0.251	62	32.7			
	Nitrate	0.4%	12.8	0.237	62	30.8	1.8	**\$ 18**	**\$ 28**
Cost-benefit - calcium nitrate at \$700/t									
Nitrate feeding cost (additional to standard ration)								\$ 223	\$ 223
Cost-benefit								**-\$ 205**	**-\$ 195**

Cost-benefit - calcium nitrate at $230/t		
Nitrate feeding cost (additional to standard ration)	$ 18	$ 18
Cost-benefit	**-$ 0**	**-$ 9**

This analysis showed that calcium nitrate would have to be available at a very low cost (<$230/t) to make the mitigation strategy effective. Despite this approach being well advanced as a method for use under the CFI, it is difficult to see how the returns will be cost effective from a simple analysis.

6.2.3 Short Duration Effluent / Covered Ponds

While energy generation was not seen as a particularly good option in the survey, the authors are aware of several feedlots exploring this option and it is one of the few manure related mitigations that could be easily developed under the CFI. The CFI returns from covering a pond and destroying methane may also be realised by irrigating effluent rapidly, rather than holding it for a long period of time in and effluent pond. This latter option has not been explored in detail but the CFI returns provided in the net returns section would be indicative of the payments that could be received.

Beef cattle feedlots have the potential to yield a significant amount of methane (CH4) from the manure produced onsite. If this methane could be captured and utilised, the feedlot could offset on-site energy usage while potentially also claiming carbon credits under the CFI, as is the case for piggeries under the approved 'destruction of methane' methodologies legislated by the Government. The costs of this system are high and the returns are primarily driven by energy requirements and production. None-the-less, there is widespread interest in this approach so it was considered worthwhile to explore further.

The volatile solids (VS) excreted on a feedlot pad are transferred to a pond system through runoff events. Liquid manure storage systems used in feedlots are predominantly anaerobic and produce methane that is emitted during the anaerobic decomposition process. Impermeable covers can be fitted to these to capture the biogas emitted from the pond surface. A range of synthetic cover materials are available and can be fabricated from low density polyethylene (LDPE), high density polyethylene (HDPE) or similar. Covered anaerobic ponds (CAPs) are the most common method of capturing methane at intensive livestock facilities in Australia with this method being adopted at piggeries in particular.

The National Inventory Report (DCCEE 2010c) does not provide an estimate of CH4 emissions from liquid storage, since all manure management for feedlots is attributed to MMS = 4, (solid storage and drylot). Limited information exists in the literature to indicate possible CH4 emissions. To determine the CH4 production from manure, it is necessary to convert VS content to CH4 generation. This is done using the VS component of manure as a basis and applying a methane potential (Bo) and methane conversion factor (MCF). The national inventory report provides typical Bo values for beef cattle manure of 0.17 m3 CH4/kg VS.

To quantify the methane production from the effluent treatment system at a feedlot, CSIRO (Allingham et al 2013) collected methane emission rates from an anaerobic pond at Kerwee Feedlot over a 15 month time period from April 2012 to June 2013. This data was further assessed by McGahan et al (2013) to investigate the technical and economic feasibility of capturing methane at feedlots to offset fossil fuel energy use. From a twelve month period (27th April 2012 and 27th April 2013) it was estimated that 33 685 kg CH_4 was emitted from the pond surface, based on an estimated pond emitting surface of 1000 m^2. Data were also collected from the feedlot over this same twelve month period on animal production, feed usage and ration type. McGahan et al. (2013) noted this emission rate appeared high considering the expected VS runoff from the feedlot and the following results need to take this uncertainty into account. Both the measured data and theoretical methane production data was used to conduct an economic assessment of installing a covered anaerobic pond (CAP) system at the feedlot. The assessment evaluated a Combined Heat and Power (CHP) system, a CAP and CHP system with dedicated methane storage and a CAP and boiler system. It was concluded that none of the systems analysed were feasible at the Kerwee Feedlot using measured methane data or estimated methane data to predict potential energy offsets. These systems all operated with an annual loss and were found to have large cumulative net losses after 10 years of operation.

The feasibility of regularly harvesting and feeding the manure feedstock from the pad to the anaerobic pond on a regular (daily) basis was also examined to allow a greater capture of the methane potential of feedlot manure. It should be noted that this method would require regular pad cleaning which may impact farm management practices and will lead to an added handling cost when the economic feasibility of this option is assessed. It is also unclear how the leakage issues would be handled in the CFI, as a significantly greater amount of methane would be generated compared to baseline emissions, with only baseline emissions being able to be claimed under a CFI project.

Table 19 – Capital costs of the CAP and CHP system with constant feed

Capital Costs of Pond	
Earth works	104 000
Cover	210 090
Sludge removal piping	20 000
Detailed design and project management	80 000
Capital Costs of Generator Assembly	
New CHP unit	595 783
Electrical switchgear	20 000
Capital Costs of Gas Line Assembly	
Biogas blower	25 000
Biogas cooler and water knockout	5 000
Biogas transfer to energy recovery unit (installation and equipment costs)	7 500
Scrubbing vessel	25 000
Flare units	20 000
Equipment total	1 112 373
Safety and compliance ($)	10 000
Contingencies non-pond parts @ 10%	69 828
Total ($)	1 192 201

6.3 Net Returns from Participating in the CFI

6.3.1 Net Returns – Feeding High Fat Rations

The CFI requires reporting and auditing to verify mitigation. As very few farmers have participated to date, the costs are not yet well understood. However, we have estimated compliance costs in this section to provide potential net returns from participation in the CFI. Assumptions for start-up costs (one-off) and on-going compliance costs are provided below.

Table 20 – Indicative start-up costs for participating in the CFI

Indicative start-up costs	days	wages / fees	cost
Training expenses	10	$ 320	$ 3,200
Consultants	5	$ 1,200	$ 6,000
			$ 9,200

Table 21 – Indicative compliance costs for participating in the CFI

	days	wages / fees	cost
Reporting	4	$ 320	$ 1,280
Independent audit	2	$ 1,600	$ 3,200
			$ 4,480

Start up and compliance costs will vary between farmers depending on their starting level of knowledge and the availability of information. The above costs are indicative only. We have annualised the start-up costs over a 7 year period ($1,315/yr) in the analysis below. Annual returns were calculated for the high fat diets and covered pond scenarios but not the nitrate feeding, which was found to not be cost effective before compliance costs were taken into account.

Feeding high levels of fat resulted in variable rates of return depending on the initial fat level in the diet, the cost of the diet ingredients and the carbon price. We have used the $15/t price for carbon in this assessment and calculated returns based on an annual turnoff of 5000, 15,000 and 50,000 head. The descriptors note the level of fat in the current diet as this is the main factor affecting returns between feedlots. Feedlots that could show their dietary levels have historically been at 4% or 2% would comply with the below scenarios. Fixed overheads were $5,800, and annual returns are provided in Table 22.

Table 22 – Indicative net returns for feeding high fat levels

Fat level in current diet	Annual turnoff (head)		
	5000	15000	50000
4% (QLD)	-$1,088	$8,323	$41,264
4% (Sth NSW)	-$866	$8,989	$43,484
2% (WA)	$6,297	$30,479	$115,118

These indicative returns suggest that further analysis and exploration of a dietary fat CFI method would be worthwhile.

6.3.2 Net Returns – Pond Covering

6.3.2.1 Annual Operating Expenses and Compliance

The annual expenses for the CAP and CHP system are presented in Table 23.

Table 23 – Estimated annual costs for a small CAP and CHP system

Operation and Maintenance Costs	**($)**
Motor oil, filters, spark plugs	8970
Biogas filter media	1745
Safety certificates, inspections, audits and labour	5000
Total annual costs	**15 715**

In addition to these annual costs, it is assumed that each year, 6% of the initial capital investment is paid back. Net returns are shown in section 6.3.2.

The predicted revenue for CAP system is based on three cash inputs:

- replacement of grid purchased electricity with electricity generated onsite
- replacement of imported LPG with waste heat derived from the biogas generator
- CFI credits.

The price of electricity was given to be an average of $0.24 per kWh. An LPG cost of $0.75/L was given for this study. These costs were assumed to increase by 6% every year. ACCUs were valued at $15 / t and the predicted mitigation was based on measured pond emissions. The projected annual revenues for the CAP and CHP system were calculated over the lifespan of the project and the results are shown in Table 24.

Table 24 - Predicted annual revenue for the CAP and CHP System with constant feed

	Elect Internal (6% CPI/Yr)	Gas Offset (6% CPI/Yr)	CFI payment (based on pond emission data)
Y1	61 660	186 779	$10,611
Y2	65 359	197 986	$10,611
Y3	69 281	209 865	$10,611
Y4	73 437	222 457	$10,611
Y5	77 844	235 804	$10,611
Y6	82 514	249 952	$10,611
Y7	87 465	264 949	$10,611
Y8	92 713	280 846	$10,611
Y9	98 276	297 697	$10,611
Y10	104 172	315 559	$10,611

The manure handling cost has a dramatic effect on the feasibility of the system. If a manure handling cost of $10/tonne was assumed, the feasibility of the project would decrease with an increase in the payback period by approximately 2 years and a decrease of the ROI over 10 years to 11%. The results are shown in Table 25.

Table 25 – Economic feasibility of the CAP and CHP system with constant feed with assumed manure handling cost of $10/tonne

System	Payback period (years)	ROI over 10 years (%)	Cumulative net profit after 10 years ($)
Proposed CAP	9.4	11	1 432 981

The CAP and CHP system with constant feed may be economically feasible provided manure handling costs are low (<$10/t) and the returns used in this modelling are achieved in practice. The CFI credits contribute a small but significant additional revenue stream, improving the return on investment and making this option more feasible.

7 Conclusions and Recommendations

This review has identified a wide range of mitigation options that could technically be adopted by feedlots. The review of research in this field showed that enteric methane mitigations are, in general, more advanced and are likely to be more readily adopted under the CFI because they are technically robust enough. Manure mitigations are less well understood scientifically and are therefore harder to adopt. With the high degree of uncertainty that exists regarding the baseline emissions from manure management, it is very difficult to promote CFI methods that rely on reducing manure emissions. One exception to this is the adoption of covered ponds, as they have been adopted in other industries (pork and dairy) successfully under the CFI. These are only likely to be feasible for larger feedlots and would need to be viewed as a long term investment.

A number of mitigations were identified that could be explored further by the industry and the Department of Environment. Specifically, feeding high fat diets looks to be a good option for the industry and should be easily adopted. Nitrate feeding, on the other hand, is not expected to be cost effective. Covering effluent ponds may be cost-effective, but further exploration of possible leakage issues is required to understand the change in emissions from altering manure management by cleaning pens more frequently and adding this manure to a covered pond.

Three promising management options that all focus on increased ADG were not explored here because of the complex interactions with markets and the difficulty in complying with the CFI common practice and/or additionality tests. Considering the potential mitigation achievable and the co-benefits for industry as a result of improved productivity, these approaches would warrant a more detailed examination to see how they could be integrated into the CFI, the mitigation potential and possibly a broader industry survey to ascertain the likely uptake.

8 References

Adams, JR, Farran, TB, Erickson, GE, Klopfenstein, TJ, Macken, CN & Wilson, CB 2004, 'Effect of organic matter addition to the pen surface and pen cleaning frequency on nitrogen mass balance in open feedlots', Journal of Animal Science, vol. 82, no. 7, pp. 2153-2163.

Al-Kanani, T, Akochi, E, MacKenzie, A, Alli, I & Barrington, S 1992, 'Organic and inorganic amendments to reduce ammonia losses from liquid hog manure', Journal of environmental quality, vol. 21, no. 4, pp. 709-715.

Alberta Government 2013a, Quantification protocol for reducing days on feed for beef cattle, Specified Gas Emitters Regulation, April 2012, Alberta Government.

Alberta Government 2013b, Quantification protocol for reducing the age at harvest of beef cattle, Specified Gas Emitters Regulation, April 2012, Alberta Government.

Alberta Government 2013c, Quantification protocol for selection for low residual feed intake in beef cattle, Specified Gas Emitters Regulation, April 2012, Alberta Government.

Amon, B, Kryvoruchko, V, Amon, T & Zechmeister-Boltenstern, S 2006, 'Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment', Agriculture, Ecosystems & Environment, vol. 112, no. 2-3, pp. 153-162.

Anderson, RC, Callaway, TR, Van Kessel, JAS, Jung, YS, Edrington, TS & Nisbet, DJ 2003, 'Effect of select nitrocompounds on ruminal fermentation; an initial look at their potential to reduce economic and environmental costs associated with ruminal methanogenesis', Bioresource Technology, vol. 90, no. 1, pp. 59-63.

Asanuma, N, Iwamoto, M & Hino, T 1999, 'Effect of the addition of fumarate on methane production by ruminal microorganisms in vitro', Journal of dairy science, vol. 82, no. 4, pp. 780-787.

Atzeni, MG, Casey, KD & Skerman, A 2001, 'A model to predict cattle feedlot runoff for effluent reuse application', in Proceedings of MODSIM 2001, vol. 4: General Systems, Canberra, pp. 1871-1876.

Basarab, J, Baron, V, López-Campos, Ó, Aalhus, J, Haugen-Kozyra, K & Okine, E 2012, 'Greenhouse gas emissions from calf-and yearling-fed beef production systems, with and without the use of growth promotants', Animals, vol. 2, no. 2, pp. 195-220.

Bauchop, T 1967, 'Inhibition of rumen methanogenesis by methane analogues', Journal of bacteriology, vol. 94, no. 1, pp. 171-175.

Bayaru, E, Kanda, S, Kamada, T, Itabashi, H, Andoh, S, Nishida, T et al. 2001, 'Effect of fumaric acid on methane production, rumen fermentation and digestibility of cattle fed roughage alone', Animal Science Journal, vol. 72, no. 2, pp. 139-146.

Beauchemin, K, Kreuzer, M, O'Mara, F & McAllister, T 2008, 'Nutritional management for enteric methane abatement: a review', Animal Production Science, vol. 48, no. 2, pp. 21-27.

Beauchemin, KA & McGinn, SM 2005, 'Methane emissions from feedlot cattle fed barley or corn diets', Journal of Animal Science, vol. 83, no. 3, pp. 653-661.

Benchaar, C & Greathead, H 2011, 'Essential oils and opportunities to mitigate enteric methane emissions from ruminants', Animal Feed Science and Technology, vol. 166, pp. 338-355.

Benchaar, C, Hassanat, F, Gervais, R, Chouinard, P, Julien, C, Petit, H et al. 2013, 'Effects of increasing amounts of corn dried distillers grains with solubles in dairy cow diets on methane production, ruminal fermentation, digestion, N balance, and milk production', Journal of dairy science.

Bierman, S, Erickson, GE, Klopfenstein, TJ, Stock, RA & Shain, DH 1999, 'Evaluation of nitrogen and organic matter balance in the feedlot as affected by level and source of dietary fiber', Journal of Animal Science, vol. 77, no. 7, pp. 1645-1653.

Bird, SH, Hegarty, R & Woodgate, R 2010, 'Modes of transmission of rumen protozoa between mature sheep', Animal Production Science, vol. 50, no. 6, pp. 414-417.

Blaxter, K & Czerkawski, J 1966, 'Modification of the methane production of the sheep by supplementation of its diet', Journal of the Science of Food and Agriculture, vol. 17, no. 9, pp. 417-421.

Blaxter, KL & Clapperton, JL 1965, 'Prediction of the amount of methane produced by ruminants', British Journal of Nutrition vol. 19, pp. 511-522.

Boadi, DA, Wittenberg, KM, Scott, SL, Burton, D, Buckley, K, Small, JA et al. 2004, 'Effect of low and high forage diet on enteric and manure pack greenhouse gas emissions from a feedlot', Canadian Journal of Animal Science, vol. 84, pp. 445-453.

Božic, A, Anderson, R, Carstens, G, Ricke, S, Callaway, T, Yokoyama, M et al. 2009, 'Effects of the methane-inhibitors nitrate, nitroethane, lauric acid, Lauricidin< sup>®</sup> and the Hawaiian marine algae< i> Chaetoceros</i> on ruminal fermentation< i> in vitro</i>', Bioresource Technology, vol. 100, no. 17, pp. 4017-4025.

Bremer, VR, Watson, AK, Liska, AJ, Erickson, G, Cassman, K, Hanford, KJ et al. 2011, 'Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle', The Professional Animal Scientist, vol. 27, no. 5, pp. 449-455.

Breznak, JA & Switzer, JM 1986, 'Acetate synthesis from H2 plus CO2 by termite gut microbes', Applied and Environmental Microbiology, vol. 52, no. 4, pp. 623-630.

Broudiscou, L, Van Nevel, C & Demeyer, D 1990, 'Incorporation of soya oil hydrolysate in the diet of defaunated or refaunated sheep: effect on rumen fermentation in vitro', Archives of animal nutrition, vol. 40, no. 4, pp. 329-337.

Buddle, BM, Denis, M, Attwood, GT, Altermann, E, Janssen, PH, Ronimus, RS et al. 2011, 'Strategies to reduce methane emissions from farmed ruminants grazing on pasture', The Veterinary Journal, vol. 188, no. 1, pp. 11-17.

Callaway, T & Martin, S 1997, 'Effects of cellobiose and monensin on in vitro fermentation of organic acids by mixed ruminal bacteria', Journal of dairy science, vol. 80, no. 6, pp. 1126-1135.

Callaway, TR, De Melo, AMC & Russell, JB 1997, 'The effect of nisin and monensin on ruminal fermentations in vitro', Current microbiology, vol. 35, no. 2, pp. 90-96.

Cao, L, Wu, J, Xie, F, Hu, S & Mo, Y 2007, 'Efficacy of nisin in treatment of clinical mastitis in lactating dairy cows', Journal of dairy science, vol. 90, no. 8, pp. 3980-3985.

Chadwick, DR, Sneath, RW, Phillips, VR & Pain, BF 1999, 'A UK inventory of nitrous oxide emissions from farmed livestock', Atmospheric Environment, vol. 33, no. 20, pp. 3345-3354.

Chen, M & Wolin, M 1979, 'Effect of monensin and lasalocid-sodium on the growth of methanogenic and rumen saccharolytic bacteria', Applied and Environmental Microbiology, vol. 38, no. 1, pp. 72-77.

Clapperton, J 1974, 'The effect of trichloroacetamide, chloroform and linseed oil given into the rumen of sheep on some of the end-products of rumen digestion', British Journal of Nutrition, vol. 32, no. 01, pp. 155-161.

Cole, N, Brown, M & MacDonald, J 2008, 'Environmental considerations of feeding biofuel co-products', Journal of Animal Science, vol. 86, no. E-Supplement 2.

Cole, N, Todd, R & Parker, D 2007, 'Use of fat and zeolite to reduce ammonia emissions from beef cattle feedyards', in International Symposium on Air Quality and Waste Management for Agriculture 2007, Broomfield, Colorado, 16-19 September 2007.

Cole, NA, Clark, RN, Todd, RW, Richardson, CR, Gueye, A, Greene, LW et al. 2005, 'Influence of dietary crude protein concentration and source on potential ammonia emissions from beef cattle manure', Journal of Animal Science, vol. 83, no. 3, pp. 722-731.

Cole, NA, Defoor, PJ, Galyean, ML, Duff, GC & Gleghorn, JF 2006, 'Effects of phase-feeding of crude protein on performance, carcass characteristics, serum urea nitrogen concentrations, and manure nitrogen of finishing beef steers', Journal of Animal Science, vol. 84, no. 12, pp. 3421-3432.

Cole, NA, Mason, AM, Todd, RW, Rhoades, M & Parker, DB 2009, 'Chemical composition of pen surface layers of beef cattle feedyards', The Professional Animal Scientist, vol. 25, no. 5, pp. 541-552.

Corona, L, Owens, F & Zinn, R 2006, 'Impact of corn vitreousness and processing on site and extent of digestion by feedlot cattle', Journal of animal science, vol. 84, no. 11, pp. 3020-3031.

Cottle, D, Nolan, J & Wiedemann, S 2011, 'Ruminant enteric methane mitigation: a review', Animal Production Science, vol. 51, no. 6, pp. 491-514.

Culley, JLB & Phillips, PA 1989, 'Retention and loss of nitrogen and solids from unlined earthen manure storages', Transactions of the ASAE, vol. 32, no. 2, pp. 667-683.

Dalal, RC, Wang, WJ, Robertson, GP & Parton, WJ 2003, 'Nitrous oxide emission from Australian agricultural lands and mitigation options: a review', Australian Journal of Soil Research, vol. 41, no. 2, pp. 165-195.

Davis, RJ, Watts, PJ & McGahan, EJ 2012, Quantification of Feedlot Manure Output for Beef-Bal Model Upgrade, RIRDC Project No. PRJ-004377, Rural Industries Research and Development Corporation, Barton, ACT.

DCC 2007, Australian methodology for the estimation of greenhouse gas emissions and sinks 2006 - Agriculture, National Greenhouse Gas Inventory Committee, Department of Climate Change, < http://climatechange.gov.au/inventory/methodology/pubs/methodology-agriculture2006.pdf >.

DCCEE 2010a, Design of the Carbon Farming Initiative - Consultation Paper, Department of Climate Change and Energy Efficiency, Canberra, ACT.

DCCEE 2010b, National Greenhouse and Energy Reporting Technical Guidelines, Department of Climate Change and Energy Efficiency, Canberra, ACT, < http://www.climatechange.gov.au/government/initiatives/national-greenhouse-energy-reporting/tools-resources.aspx#technical >.

DCCEE 2010c, National Inventory Report 2008, vol 1, Australian National Greenhouse Accounts, Department of Climate Change and Energy Efficiency, Canberra, ACT.

DCCEE 2011, Carbon Farming Initiative - Methodology for the destruction of methane generated from manure in piggeries, Department of Climate Change and Energy Efficiency, Canberra, ACT, viewed 28 October 2011, < http://www.climatechange.gov.au >.

DCCEE 2012, The Carbon Farming Initiative Handbook, vol 1.0, Department of Climate Change and Energy Efficiency, Canberra, ACT.

DCCEE 2013, Australian Greenhouse Emissions Information System, Department of Climate Change and Energy Efficiency, Canberra, ACT, viewed 3 May 2013, < http://ageis.climatechange.gov.au/ >.

Deegan, LH, Cotter, PD, Hill, C & Ross, P 2006, 'Bacteriocins: biological tools for bio-preservation and shelf-life extension', International Dairy Journal, vol. 16, no. 9, pp. 1058-1071.

Dellow, D, Nolan, J & Hume, I 1983, 'Studies on the nutrition of the Macropodine marsupials. V. Fermentation in the forestomach of Thiogale thetis and Macropus eugenii.', vol. 31, pp. 433-443.

Demeyer, D & Van Nevel, C 1979, 'Effect of defaunation on the metabolism of rumen micro-organisms', British Journal of Nutrition, vol. 42, no. 03, pp. 515-524.

Denmead, OT, Chen, D, Griffith, DWT, Loh, ZM, Bai, M & Naylor, T 2008, 'Emissions of the indirect greenhouse gases NH3 and NOx from Australian beef cattle feedlots', Australian Journal of Experimental Agriculture, vol. 48, no. 1-2, pp. 213-218.

Desnoyers, M, Giger-Reverdin, S, Bertin, G, Duvaux-Ponter, C & Sauvant, D 2009, 'Meta-analysis of the influence of< i> Saccharomyces cerevisiae</i> supplementation on ruminal parameters and milk production of ruminants', Journal of dairy science, vol. 92, no. 4, pp. 1620-1632.

Di, H & Cameron, K 2003, 'Mitigation of nitrous oxide emissions in spray-irrigated grazed grassland by treating the soil with dicyandiamide, a nitrification inhibitor', Soil use and management, vol. 19, no. 4, pp. 284-290.

Dohme, F, Machmüller, A, Wasserfallen, A & Kreuzer, M 2000, 'Comparative efficiency of various fats rich in medium-chain fatty acids to suppress ruminal methanogenesis as measured with RUSITEC', Canadian Journal of Animal Science, vol. 80, no. 3, pp. 473-484.

Dong, H, Mangino, J, McAllister, TA, Bartram, D, Gibb, DJ & Martin, JHJ 2006, 'Emissions from livestock manure management', in IPCC Guidelines for National Greenhouse Gas Inventories, HS Eggleston, et al. (eds.), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.

Eckard, RJ, Grainger, C & de Klein, CAM 2010, 'Options for the abatement of methane and nitrous oxide from ruminant production: A review', Livestock Science, vol. 130, no. 1-3, pp. 47-56.

Eghball, B & Power, JF 1994a, 'Beef cattle feedlot manure management', Journal of Soil and Water Conservation, vol. 49, pp. 113-122.

Eghball, B & Power, JF 1994b, 'Beef cattle manure management', Journal of Soil and Water Conservation, vol. 49, pp. 113-122.

Eghball, B, Power, JF, Gilley, JE & Doran, JW 1997, 'Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure', Journal of Environmental Quality, vol. 26, no. 1, pp. 189-193.

Erickson, GE, Klopfenstein, TJ & Milton, T 2002, Corn bran level in finishing diets and N losses from open-dirt pens, Nebraska Beef Report 2002, Agricultural Research Division, University of Nebraska Extension, Institute of Agriculture and Natural Resources, University of Nebraska University of Nebraska, Lincoln, U.S.A.

Farran, TB, Erickson, GE & Klopfenstein, T 2004, Reducing diet digestibility and increasing pen cleaning frequency: Effects on nitrogen losses and compost nitrogen recovery, 2004 Nebraska Beef Report, University of Nebraska.

Ferme, D, Malneršič, M, Lipoglavšek, L, Kamel, C & Avguštin, G 2008, 'Effect of sodium monensin and cinnamaldehyde on the growth and phenotypic characteristics of Prevotella bryantii and Prevotella ruminicola', Folia microbiologica, vol. 53, no. 3, pp. 204-208.

Fievez, V, Boeckaert, C, Vlaeminck, B, Mestdagh, J & Demeyer, D 2007, '< i> In vitro</i> examination of DHA-edible micro-algae: 2. Effect on rumen methane production and apparent degradability of hay', Animal Feed Science and Technology, vol. 136, no. 1, pp. 80-95.

Fievez, V, Mbanzamihigo, L, Piattoni, F & Demeyer, D 2001, 'Evidence for reductive acetogenesis and its nutritional significance in ostrich hindgut as estimated from in vitro incubations', Journal of Animal Physiology and Animal Nutrition, vol. 85, no. 9-10, pp. 271-280.

Flesch, TK, Wilson, JD, Harper, LA, Todd, RW & Cole, NA 2007, 'Determining ammonia emissions from a cattle feedlot with an inverse dispersion technique', Agricultural and Forest Meteorology, vol. 144, no. -12, pp. 139-155.

Foley, P, Kenny, D, Callan, J, Boland, T & O'mara, F 2009, 'Effect of DL-malic acid supplementation on feed intake, methane emission, and rumen fermentation in beef cattle', Journal of animal science, vol. 87, no. 3, pp. 1048-1057.

Follet, RH & Crissant, RL 1990, Guide to fertiliser recommendations in Colorado, Fort Collins, Colorado State University Cooperative Extension, Colorado, U.S.

Frost, JP, Stevens, RJ & Laughtlin, RJ 1990, 'Effect of separation and acidification of cattle slurry in ammonial volatilisation and on the efficiency of slurry nitrogen for herbage production', The Journal of Agricultural Science, vol. 115, pp. 49-56.

FSA Consulting 2006, Reviewing ammonia emision factors for feedlots, prepared for Environment and Sustainability Reporting Section, Department of Environmental Reporting, FSA Consulting Report No. 6535/1, September 2006, Toowoomba, Qld.

Galbally, IE 1989, 'Factors controlling NOx emissions from soils', in Exchange of trace gases between terrestrial ecosystems and the atmosphere, MO Andreae and DS Schimel (eds.), Biddles Ltd., Guilford, pp. 23-27.

Gardner, EA, Watts, PJ, Tucker, RW & Moody, P 1994, 'Sizing ecologically sustainable land disposal areas for feedlots', in Designing Better Feedlots Conference and Workshop Series QC94002, PJ Watts and RW Tucker (eds.), Department of Primary Industries, Brisbane.

Gaskin, JW, Steiner, C, Harris, K, Das, K & Bibens, B 2008, 'Effect of Low-Temperature Pyrolysis Conditions on Biochar for Agricultural Use', Transactions of the Amercian Society of Agricultural and Biological Engineers, vol. 51, no. 6, pp. 2061-2069.

Goodrich, R, Garrett, J, Gast, D, Kirick, M, Larson, D & Meiske, J 1984, 'Influence of monensin on the performance of cattle', Journal of animal science, vol. 58, no. 6, pp. 1484.

Grainger, C, Auldist, M, Clarke, T, Beauchemin, K, McGinn, S, Hannah, M et al. 2008, 'Use of monensin controlled-release capsules to reduce methane emissions and improve milk production of dairy cows offered pasture supplemented with grain', Journal of dairy science, vol. 91, no. 3, pp. 1159-1165.

Grainger, C & Beauchemin, K 2011, 'Can enteric methane emissions from ruminants be lowered without lowering their production?', Animal Feed Science and Technology, vol. 166, pp. 308-320.

Grainger, C, Williams, R, Clarke, T, Wright, A-D & Eckard, R 2010, 'Supplementation with whole cottonseed causes long-term reduction of methane emissions from lactating dairy cows offered a forage and cereal grain diet', Journal of dairy science, vol. 93, no. 6, pp. 2612-2619.

Groenestein, CM & Van Faassen, HG 1996, 'Volatilization of ammonia, nitrous oxide and nitric oxide in deep-litter systems for fattening pigs', Journal of Agricultural Engineering Research, vol. 65, no. 4, pp. 269-274.

Guan, H, Wittenberg, KM, Ominski, KH & Krause, DO 2006, 'Efficacy of ionophores in cattle diets for mitigation of enteric methane', Journal of animal science, vol. 84, no. 7, pp. 1896-1906.

Guo, W, Schaefer, D, Guo, X, Ren, L & Meng, Q 2009, 'Use of nitrate-nitrogen as a sole dietary nitrogen source to inhibit ruminal methanogenesis and to improve microbial nitrogen synthesis in vitro', Asian-Australasian Journal of Animal Sciences, vol. 22, no. 4, pp. 542-549.

Hansen, MN, Henriksen, K & Sommer, SG 2006, 'Observations of production and emission of greenhouse gases and ammonia during storage of solids separated from pig slurry: Effects of covering', Atmospheric Environment, vol. 40, no. 22, pp. 4172-4181.

Hao, X, Chang, C & Larney, FJ 2004, 'Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting', Journal of Environmental Quality, vol. 33, no. 1, pp. 37-44.

Hao, X, Chang, C, Larney, FJ & Travis, GR 2001, 'Greenhouse gas emissions during cattle feedlot manure composting', Journal of Environmental Quality, vol. 30, no. 2, pp. 376-386.

Hao, X, Larney, FJ, Chang, C, Travis, GR, Nichol, CK & Bremer, E 2005, 'The effect of phosphogypsum on greenhouse gas emissions during cattle manure composting', Journal of Environmental Quality, vol. 34, no. 3, pp. 774-781.

Hegarty, R, Bird, S, Vanselow, B & Woodgate, R 2008, 'Effects of the absence of protozoa from birth or from weaning on the growth and methane production of lambs', British Journal of Nutrition, vol. 100, no. 6, pp. 1220.

Hegarty, RS 1999, 'Reducing rumen methane emissions through elimination of rumen protozoa', Australian Journal of Agricultural Research, vol. 50, no. 8, pp. 1321-1328.

Herd, R, Arthur, P, Hegarty, R & Archer, J 2002, 'Potential to reduce greenhouse gas emissions from beef production by selection for reduced residual feed intake', in Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France, August, 2002. Session 10., Institut National de la Recherche Agronomique (INRA), pp. 0-4.

Holter, J, Hayes, H, Urban Jr, W & Duthie, A 1992, 'Energy Balance and Lactation Response in Holstein Cows Supplemented with Cottonseed with or Without Calcium Soap< sup> 1, 2</sup>', Journal of dairy science, vol. 75, no. 6, pp. 1480-1494.

Hristov, AN, Hanigan, M, Cole, A, Todd, R, A., MT, Ndegwa, P et al. 2011, 'Review: Ammonia emissions from dairy farms and beef feedlots.', Canadian Journal of Animal Science, vol. 91, pp. 1-35.

Hristov, AN, Oh, J, Lee, C, Meinen, R, Montes, F, Ott, T et al. 2013, 'Mitigation of Greenhouse Gas Emissions in Livestock Production: A Review of Technical Options for Non-CO2 Emissions. FAO'.

Hulshof, R, Berndt, A, Gerrits, W, Dijkstra, J, van Zijderveld, S, Newbold, J et al. 2012, 'Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets', Journal of animal science, vol. 90, no. 7, pp. 2317-2323.

Husted, S, Jensen, LS & Jørgensen, SS 1991, 'Reducing ammonia loss from cattle slurry by the use of acidifying additives: the role of the buffer system', Journal of the Science of Food and Agriculture, vol. 57, no. 3, pp. 335-349.

Hüther, L, Schuchardt, F & Willke, T 1997, 'Emissions of ammonia and greenhouse gases during storage and composting of animal manures', Paper submitted to the International Symposium on Ammonia and odour control from animal production facilities, Rosmalen, Netherlands.

Hynst, J, Simek, M, Brucek, P & Petersen, SO 2007, 'High fluxes but different patterns of nitrous oxide and carbon dioxide emissions from soil in a cattle overwintering area', Agriculture Ecosystems and Environment, vol. 120, no. 2-4, pp. 269-279.

Immig, I, Demeyer, D, Fiedler, D, Van Nevel, C & Mbanzamihigo, L 1996, 'Attempts to induce reductive acetogenesis into a sheep rumen', Archives of animal nutrition, vol. 49, no. 4, pp. 363-370.

IPCC 2006, IPCC Guidelines for National Greenhouse Gas Inventories, HS Eggleston, et al. (eds.), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.

IPCC 2007, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S Solomon, et al. (eds.), Revised edn, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Iqbal, MF, Cheng, Y-F, Zhu, W-Y & Zeshan, B 2008, 'Mitigation of ruminant methane production: current strategies, constraints and future options', World Journal of Microbiology and Biotechnology, vol. 24, no. 12, pp. 2747-2755.

Iwamoto, M, Asanuma, N & Hino, T 1999, 'Effects of nitrate combined with fumarate on methanogenesis, fermentation, and cellulose digestion by mixed ruminal microbes in vitro', Animal Science Journal, vol. 70, no. 6, pp. 471-478.

James, T, Meyer, D, Esparza, E, Depeters, E & Perez-Monti, H 1999, 'Effects of dietary nitrogen manipulation on ammonia volatilization from manure from Holstein heifers', Journal of Dairy Science, vol. 82, no. 11, pp. 2430-2439.

Jensen, A 2002, 'Changing the environment in swine buildings using sulfuric acid', Transaction - American Society of Agricultural Engineers, vol. 45, no. 1, pp. 223-238.

Joblin, K 1999, 'Ruminal acetogens and their potential to lower ruminant methane emissions', Crop and Pasture Science, vol. 50, no. 8, pp. 1307-1314.

Johnson, K, Kincaid, R, Westberg, H, Gaskins, C, Lamb, B & Cronrath, J 2002, 'The effect of oilseeds in diets of lactating cows on milk production and methane emissions', Journal of dairy science, vol. 85, no. 6, pp. 1509-1515.

Johnson, KA & Johnson, DE 1995, 'Methane emissions from cattle', Journal of Animal Science, vol. 73, no. 8, pp. 2483-2492.

Jordan, E, Lovett, D, Monahan, F, Callan, J, Flynn, B & O'Mara, F 2006, 'Effect of refined coconut oil or copra meal on methane output and on intake and performance of beef heifers', Journal of animal science, vol. 84, no. 1, pp. 162-170.

Jouany, JP, Zainab, B, Senaud, J, Groliere, CA, Grain, J & Thivend, P 1981, 'Role of the rumen ciliate protozoa Polyplastron multivesiculatum, Entodinium sp. and isotricha prostoma in the digestion of a mixed diet in sheep.', vol. 21, no. 871-884.

Kai, P, Pedersen, P, Jensen, J, Hansen, MN & Sommer, SG 2008, 'A whole-farm assessment of the efficacy of slurry acidification in reducing ammonia emissions', European Journal of Agronomy, vol. 28, no. 2, pp. 148-154.

Kalmokoff, M, Bartlett, F & Teather, R 1996, 'Are ruminal bacteria armed with bacteriocins?', Journal of dairy science, vol. 79, no. 12, pp. 2297-2306.

Kebreab, E, Clark, K, Wagner-Riddle, C & France, J 2006, 'Methane and nitrous oxide emissions from Canadian animal agriculture: A review', Canadian Journal of Animal Science, vol. 86, no. 2, pp. 135-158.

Kempton, T, Murray, R & Leng, R 1976, 'Methane production and digestibility measurements in the grey kangaroo and sheep', Australian Journal of Biological Sciences, vol. 29, no. 3, pp. 209-214.

Kessel, JAS & Russell, JB 1996, 'The effect of pH on ruminal methanogenesis', FEMS Microbiology Ecology, vol. 20, no. 4, pp. 205-210.

Kišidayová, S, Lauková, A & Jalč, D 2009, 'Comparison of nisin and monensin effects on ciliate and selected bacterial populations in artificial rumen', Folia microbiologica, vol. 54, no. 6, pp. 527-532.

Kissinger, WF, Erickson, GE & Klopfenstein, TJ 2006, Summary of manure amounts, characteristics, and nitrogen mass balance for open feedlot pens in summer compared to winter, Nebraska Beef Report 2006, Agricultural Research Division, University of Nebraska Extension, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, U.S.A.

Kissinger, WF, Koelsch, RK, Erickson, GE & Klopfenstein, TJ 2007, 'Characteristics of manure harvested from beef cattle feedlots', Applied Engineering in Agriculture, vol. 23, no. 3, pp. 357-365.

Kithome, M, Paul, J & Bomke, A 1999, 'Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments', Journal of environmental quality, vol. 28, no. 1, pp. 194-201.

Klieve, A & Hegarty, R 1999, 'Opportunities for biological control of ruminal methanogenesis', Crop and Pasture Science, vol. 50, no. 8, pp. 1315-1320.

Klopfenstein, TJ, Erickson, GE & Bremer, VR 2008, 'Use of distillers by-products in the beef cattle feeding industry', Journal of animal science, vol. 86, no. 5, pp. 1223-1231.

Krehbiel, C, Rust, S, Zhang, G & Gilliland, S 2003, 'Bacterial direct-fed microbials in ruminant diets: Performance response and mode of action', Journal of animal science, vol. 81, no. 14 suppl 2, pp. E120-E132.

Kreuzer, M, Kirchgessner, M & Müller, H 1986, 'Effect of defaunation on the loss of energy in wethers fed different quantities of cellulose and normal or steamflaked maize starch', Animal Feed Science and Technology, vol. 16, no. 3, pp. 233-241.

Kuhlman, LR 1992, 'Value of composting feedlot manure', Paper submitted to the Australian Lot Feeders Association Conference (BEEFEX 92), Coffs Harbour, NSW.

Külling, DR, Menzi, H, Sutter, F, Lischer, P & Kreuzer, M 2003, 'Ammonia, nitrous oxide and methane emissions from differently stored dairy manure derived from grass- and hay-based rations', Nutrient Cycling in Agroecosystems, vol. 65, no. 1, pp. 13-22.

Leng, R 2008, Report to Department of Climate Change, Commonwealth Government, Canberra.

Lodge, S, Stock, R, Klopfenstein, T, Shain, D & Herold, D 1997, 'Evaluation of corn and sorghum distillers byproducts', Journal of animal science, vol. 75, no. 1, pp. 37-43.

Loh, Z, Chen, D, Bai, M, Naylor, T, Griffith, D, Hill, J et al. 2008, 'Measurement of greenhouse gas emissions from Australian feedlot beef production using open-path spectroscopy and atmospheric dispersion modelling', Australian Journal of Experimental Agriculture, vol. 48, no. 2, pp. 244-247.

Luebbe, MK, Erickson, GE, Klopfenstein, TJ & Greenquist, MA 2008, Nutrient mass balance and performance of feedlot cattle fed wet distillers grains, 2008 Nebraska Beef Report, University of Nebraska.

Luebbe, MK, Erickson, GE, Klopfenstein, TJ, Greenquist, MA & Benton, JR 2009, Effect of dietary cation-anion difference on feedlot performance, nitrogen mass balance and manure pH in open feedlot pens, 2009 Nebraska Beef Report, University of Nebraska.

Luo, Z, Wang, E & Sun, OJ 2010, 'Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: A review and synthesis', Geoderma, vol. 155, no. 3-4, pp. 211-223.

Machmüller, A, Ossowski, D, Wanner, M & Kreuzer, M 1998, 'Potential of various fatty feeds to reduce methane release from rumen fermentation in vitro (Rusitec)', Animal Feed Science and Technology, vol. 71, no. 1, pp. 117-130.

Machmuller, A, Soliva, CR & Kreuzer, M 2003, 'Effect of coconut oil and defaunation treatment on methanogenesis in sheep', Reproduction Nutrition Development, vol. 43, no. 1, pp. 41-56.

Mackie, RI, Stroot, PG & Varel, VH 1998, 'Biochemical identification and biological origin of key odor components in livestock waste', Journal of Animal Science, vol. 76, no. 5, pp. 1331-1342.

Madden, JM & Dornbush, JN 1971, 'Measurement of runoff and runoff carried waste from commercial feedlots', in Livestock Waste Management and Pollution Abatement. Proceeedings of the International Symposium on Livestock Wastes, Columbus Ohio, American Society of Agricultural Engineers, St Joseph, MI, pp. 44-47.

Mahimairaja, S, Bolan, NS, Hedley, MJ & Macgregor, AN 1994, 'Losses and transformation of nitrogen during composting of poultry manure with different amendments: An incubation experiment', Bioresource Technology, vol. 47, no. 3, pp. 265-273.

Martin, C, Morgavi, D & Doreau, M 2010, 'Methane mitigation in ruminants: from microbe to the farm scale', animal, vol. 4, no. 03, pp. 351-365.

Martin, SA & Macy, J 1985, 'Effects of monensin, pyromellitic diimide and 2-bromoethanesulfonic acid on rumen fermentation in vitro', Journal of animal science, vol. 60, no. 2, pp. 544.

Mathison, G, Okine, E, McAllister, T, Dong, Y, Galbraith, J & Dmytruk, O 1998, 'Reducing methane emissions from ruminant animals', Journal of Applied Animal Research, vol. 14, no. 1, pp. 1-28.

Mbanzamihigo, L, Van Nevel, C & Demeyer, D 1995, 'Adaptation of rumen fermentation to monensin]', Reproduction, nutrition, development, vol. 35, no. 4, pp. 353.

Mc Geough, E, O'Kiely, P, Hart, K, Moloney, A, Boland, T & Kenny, D 2010, 'Methane emissions, feed intake, performance, digestibility, and rumen fermentation of finishing beef cattle offered whole-crop wheat silages differing in grain content', Journal of animal science, vol. 88, no. 8, pp. 2703-2716.

McAllister, T, Cheng, K-J, Okine, E & Mathison, G 1996, 'Dietary, environmental and microbiological aspects of methane production in ruminants', Canadian Journal of Animal Science, vol. 76, no. 2, pp. 231-243.

McAllister, TA & Newbold, CJ 2008, 'Redirecting rumen fermentation to reduce methanogenesis', Australian Journal of Experimental Agriculture, vol. 48, no. 1-2, pp. 7-13.

McCrabb, GJ & Hunter, RA 1999, 'Prediction of methane emissions from beef cattle in tropical pasture systems', Australian Journal of Agricultural Research, vol. 50, pp. 1335-1339.

McGinn, S, Chung, Y-H, Beauchemin, K, Iwaasa, A & Grainger, C 2009, 'Use of corn distillers' dried grains to reduce enteric methane loss from beef cattle', Canadian Journal of Animal Science, vol. 89, no. 3, pp. 409-413.

McGinn, SM, Beauchemin, KA, Coates, T & Colombatto, D 2004, 'Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid', Journal of Animal Science, vol. 82, no. 11, pp. 3346-3356.

McGinn, SM, Chen, D, Loh, Z, Hill, J, Beauchemin, KA & Denmead, OT 2008, 'Methane emissions from feedlot cattle in Australia and Canada', Australian Journal of Experimental Agriculture, vol. 48.

MDB 2013, Animal Farming.

Miller, T & Wolin, M 2001, 'Inhibition of growth of methane-producing bacteria of the ruminant forestomach by hydroxymethylglutary- SCoA reductase inhibitors', vol. 84, pp. 445-1448.

Miner, JR, Humenik, FJ & Overcash, MR 2000, Managing livestock wastes to preserve environmental quality, 1st edn, Iowa State University Press, Ames, IA.

Misselbrook, T & Powell, JM 2005, 'Influence of bedding material on ammonia emissions from cattle excreta', Journal of Dairy Science, vol. 88, no. 12, pp. 4304-4312.

Misselbrook, T, Powell, JM, Broderick, G & Grabber, J 2005, 'Dietary manipulation in dairy cattle: Laboratory experiments to assess the influence on ammonia emissions', Journal of Dairy Science, vol. 88, no. 5, pp. 1765-1777.

Moate, P, Williams, S, Grainger, C, Hannah, M & Eckard, R 2010, 'Comparison of cold pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emission from lactating cows. In 'Proceedings of the 4th international conference on greenhouse gases and animal agriculture' ', pp. 137.

Moate, P, Williams, S, Grainger, C, Hannah, M, Ponnampalam, E & Eckard, R 2011, 'Influence of cold-pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emissions from lactating dairy cows', Animal Feed Science and Technology, vol. 166, pp. 254-264.

Mobley, HL & Hausinger, RP 1989, 'Microbial ureases: significance, regulation, and molecular characterization', Microbiology and Molecular Biology Reviews, vol. 53, no. 1, pp. 85-108.

Moe, PW & Tyrrell, HF 1979, 'Methane production in dairy cows', Journal of Dairy Science, vol. 62, no. 10, pp. 1583-1586.

Molloy, SP & Tunney, H 1983, 'A laboratory study of ammonia volatilization from cattle and pig slurry', Irish Journal of Agricultural Research, vol. 22, pp. 37-45.

Monteny, G-J, Bannink, A & Chadwick, D 2006, 'Greenhouse gas abatement strategies for animal husbandry', Agriculture Ecosystems and Environment, vol. 112, no. 2-3, pp. 163-170.

Moore, P, Daniel, T, Edwards, D & Miller, D 1995, 'Effect of chemical amendments on ammonia volatilization from poultry litter', Journal of environmental quality, vol. 24, no. 2, pp. 293-300.

Morgavi, D, Jouany, J-P & Martin, C 2008, 'Changes in methane emission and rumen fermentation parameters induced by refaunation in sheep', Animal Production Science, vol. 48, no. 2, pp. 69-72.

Moss, AR, Jouany, JP & Newbold, J 2000, 'Methane production by ruminants: its contribution to global warming', vol. 49, Paris: Institut national de la recherche agronomique, 1960-2000., pp. 231-254.

Muir, SK 2011, 'Greenhouse Gas Emissions from Australian Beef Feedlots', Department of Agriculture and Food Systems, Melbourne School of Land and Environment, The University of Melbourne.

Murphy, MR, Baldwin, RL & Koong, LJ 1982, 'Estimation of stoichiometric parameters for rumen fermentation of roughage and concentrate diets. ', vol. 55, pp. 411-421.

Mustafa, A, McKinnon, J & Christensen, D 2000, 'Chemical characterization and in situ nutrient degradability of wet distillers' grains derived from barley-based ethanol production', Animal Feed Science and Technology, vol. 83, no. 3, pp. 301-311.

Ndegwa, PM, Hristov, AN, Arogo, J & Sheffield, RE 2008, 'A review of ammonia emission mitigation techniques for concentrated animal feeding operations', Biosystems Engineering, vol. 100, no. 4, pp. 453-469.

Newbold, C, Lassalas, B & Jouany, J 1995a, 'The importance of methanogens associated with ciliate protozoa in ruminal methane production in vitro', Letters in Applied Microbiology, vol. 21, no. 4, pp. 230-234.

Newbold, C, Wallace, R, Chen, X & McIntosh, F 1995b, 'Different strains of Saccharomyces cerevisiae differ in their effects on ruminal bacterial numbers in vitro and in sheep', Journal of animal science, vol. 73, no. 6, pp. 1811-1818.

Newbold, CJ & Rode, L 2006, 'Dietary additives to control methanogenesis in the rumen', in International Congress Series, vol. 1293, Elsevier, pp. 138-147.

Nkrumah, J, Li, C, Basarab, J, Guercio, S, Meng, Y, Murdoch, B et al. 2004, 'Association of a single nucleotide polymorphism in the bovine leptin gene with feed intake, feed efficiency, growth, feeding behaviour, carcass quality and body composition', Canadian Journal of Animal Science, vol. 84, no. 2, pp. 211-219.

Nollet, L, Demeyer, D & Verstraete, W 1997, 'Effect of 2-bromoethanesulfonic acid and Peptostreptococcus productus ATCC 35244 addition on stimulation of reductive acetogenesis in the ruminal ecosystem by selective inhibition of methanogenesis', Applied and Environmental Microbiology, vol. 63, no. 1, pp. 194-200.

O'Connor, E & Shand, R 2002, 'Halocins and sulfolobicins: the emerging story of archaeal protein and peptide antibiotics', Journal of Industrial Microbiology and Biotechnology, vol. 28, no. 1, pp. 23-31.

Odongo, N, Bagg, R, Vessie, G, Dick, P, Or-Rashid, M, Hook, S et al. 2007, 'Long-term effects of feeding monensin on methane production in lactating dairy cows', Journal of dairy science, vol. 90, no. 4, pp. 1781-1788.

Oenema, O, Velthof, GL, Yamulki, S & Jarvis, SC 1997, 'Nitrous oxide emissions from grazed grassland', Soil Use and Management, vol. 13, no. 4, pp. 288-295.

Osborne, V, Radhakrishnan, S, Odongo, N, Hill, A & McBride, B 2008, 'Effects of supplementing fish oil in the drinking water of dairy cows on production performance and milk fatty acid composition', Journal of animal science, vol. 86, no. 3, pp. 720-729.

Ouwerkerk, D, Maguire, A & Klieve, A 2006, 'Reductive acetogenesis in the foregut of macropod marsupials in Australia', in 2nd International Conference on Greenhouse Gases and Animal Agriculture: An Update, Elsevier, pp. 98-101.

Owens, FN, Secrist, DS, Hill, WJ & Gill, DR 1997, 'The effect of grain source and grain processing on performance of feedlot cattle: a review', Journal of animal science, vol. 75, no. 3, pp. 868-879.

Pain, BF, Thompson, RB, Rees, YJ & Skinner, JH 1990, 'Reducing gaseous losses of nitrogen from cattle slurry applied to grassland by the use of additives', Journal of the Science of Food and Agriculture, vol. 50, no. 2, pp. 141-153.

Parker, DB, Pandrangi, S, Greene, LW, Almas, LK, Cole, NA, Rhoades, MB et al. 2005, 'Rate and frequency of urease inhibitor application for minimizing ammonia emissions from beef cattle feedyards', Transactions of the ASAE, vol. 48, no. 2, pp. 787-793.

Patra, AK 2012, 'Enteric methane mitigation technologies for ruminant livestock: a synthesis of current research and future directions', Environmental Monitoring and Assessment, vol. 184, no. 4, pp. 1929-1952.

Pattanaik, A, Sastry, V, Katiyar, R & Lal, M 2003, 'Influence of grain processing and dietary protein degradability on nitrogen metabolism, energy balance and methane production in young calves', ASIAN AUSTRALASIAN JOURNAL OF ANIMAL SCIENCES, vol. 16, no. 10, pp. 1443-1450.

Pattey, E, Trzcinski, MK & Desjardins, RL 2005, 'Quantifying the reduction of greenhouse gas emissions as a result of composting dairy and beef cattle manure', Nutrient Cycling in Agroecosystems, vol. 72, no. 2, pp. 173-187.

Pelletier, N, Pirog, R & Rasmussen, R 2010, 'Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States', Agricultural Systems, vol. 103, no. 6, pp. 380-389.

Phetteplace, HW, Johnson, DE & Seidl, AF 2001, 'Greenhouse gas emissions from simulated beef and dairy livestock systems in the United States', Nutrient Cycling in Agroecosystems, vol. 60, no. 1-3, pp. 99-102.

Plascencia, A & Zinn, R 1996, 'Influence of flake density on the feeding value of steam-processed corn in diets for lactating cows', Journal of animal science, vol. 74, no. 2, pp. 310-316.

Powell, E 1998, Feedlot manure - a valuable fertiliser, Evan Powell Rural Consultants, Dalby, QLD.

Powell, EE 1994, Economic management of feedlot manure, Final Report prepared for Meat Research Corporation contract M.087, Evan Powell Rural Consultants, Dalby, Qld.

Powell, JM, Misselbrook, TH & Casler, MD 2008, 'Season and bedding impacts on ammonia emissions from tie-stall dairy barns', Journal of Environmental Quality, vol. 37, no. 1, pp. 7-15.

Power, JF, Eghball, B & Lory, JA 1994, 'Utilisation of nutrients in beef cattle feedlot manure in the Northen Great Plains', in Proceedings of the Great Plains Animal Waste Conference on Confined Animal Production and Water Quality. Balancing Animal Production and the Environment, GPAC Publication No. 151, Great Plains Agricultural Council, Fort Collins CO, pp. 161-167.

Robinson, P & Erasmus, LJ 2009, 'Effects of analyzable diet components on responses of lactating dairy cows to< i> Saccharomyces cerevisiae</i> based yeast products: A systematic review of the literature', Animal Feed Science and Technology, vol. 149, no. 3, pp. 185-198.

Rowe, J, Davies, A & Broome, A 1985, 'Quantitative effects of defaunation on rumen fermentation and digestion in sheep', British Journal of Nutrition, vol. 54, no. 01, pp. 105-119.

Russell, JB & Mantovani, HC 2002, 'The bacteriocins of ruminal bacteria and their potential as an alternative to antibiotics', Journal of molecular microbiology and biotechnology, vol. 4, no. 4, pp. 347-355.

Safley, LM, Nelson, DW & Wesmann, PW 1983, 'Conserving manurial nitrogen', Trans. ASAE, vol. 26, pp. 1166-1170.

Saggar, S, Andrew, RM, Tate, KR, Hedley, CB, Rodda, NJ & Townsend, JA 2004, 'Modelling nitrous oxide emissions from dairy-grazed pastures', Nutrient Cycling in Agroecosystems, vol. 68, no. 3, pp. 243-255.

Saggar, S, Giltrap, DL, Li, C & Tate, KR 2007, 'Modelling nitrous oxide emissions from grazed grasslands in New Zealand', Agriculture Ecosystems and Environment, vol. 119, no. 1-2, pp. 205-216.

Santoso, B, Kume, S, Nonaka, K, Kimura, K, Mizukoshi, H & Gamo, Y 2003, 'Methane emission, nutrient digestibility, energy metabolism and blood metabolites in dairy cows fed silages with and without galactooligosaccharides supplementation.', vol. 16, pp. 534-540.

Sar, C, Mwenya, B, Santoso, B, Takaura, K, Morikawa, R, Isogai, N et al. 2005, 'Effect of Escherichia coli wild type or its derivative with high nitrite reductase activity on in vitro ruminal methanogenesis and nitrate/nitrite reduction', Journal of animal science, vol. 83, no. 3, pp. 644-652.

Sauvant, D, Milgen, Jv, Engelhardt, Wv, Leonhard-Marek, S, Breves, G & Giesecke, D 1995, 'Dynamic aspects of carbohydrate and protein breakdown and the associated microbial matter synthesis', in Ruminant physiology: digestion, metabolism, growth and reproduction. Proceedings 8th International Symposium on Ruminant Physiology., Delmar Publishers, pp. 71-91.

Sauvant, D, Schmidely, P, Daudin, J & St-Pierre, N 2008, 'Meta-analyses of experimental data in animal nutrition', animal, vol. 2, no. 8, pp. 1203-1214.

Sayanova, OV & Napier, JA 2004, 'Eicosapentaenoic acid: biosynthetic routes and the potential for synthesis in transgenic plants', Phytochemistry, vol. 65, no. 2, pp. 147-158.

Sherwood, DM, Erickson, GE & Klopfenstein, TJ 2005, Effect of clinoptilolite zeolite on cattle performance and nitrogen volatilisation loss, Nebraska Beef Report 2005, Agricultural Research Division, University of Nebraska Extension, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, U.S.A.

Shi, Y, Parker, DB, Cole, NA, Auvermann, BW & Mehlhorn, JE 2001, 'Surface amendments to minimise ammonia emissions from beef cattle feedlots', Transactions of the ASAE, vol. 44, no. 3, pp. 677-682.

Simek, M, Brucek, P, Hynst, J, Uhlírová, E & Petersen, SO 2006, 'Effects of excretal returns and soil compaction on nitrous oxide emissions from a cattle overwintering area', Agriculture, Ecosystems & Environment, vol. 112, no. 2-3, pp. 186-191.

Slyter, L 1979, 'Monensin and dichloroacetamide influences on methane and volatile fatty acid production by rumen bacteria in vitro', Applied and Environmental Microbiology, vol. 37, no. 2, pp. 283-288.

Soliva, C, Hindrichsen, I, Meile, L, Kreuzer, M & Machmüller, A 2003, 'Effects of mixtures of lauric and myristic acid on rumen methanogens and methanogenesis in vitro', Letters in Applied Microbiology, vol. 37, no. 1, pp. 35-39.

Solomon, S, Qin, D, Manning, M, Alley, RB, Berntsen, T, Bindoff, NL et al. 2007, 'Technical Summary', in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S Solomon, et al. (eds.), Cambridge University Press, United Kingdom and New York, USA.

Sommer, SG 2001, 'Effect of composting on nutrient loss and nitrogen availability of cattle deep litter', European Journal of Agronomy, vol. 14, no. 2, pp. 123-133.

Sommer, SG, McGinn, SM, Hao, X & Larney, FJ 2004, 'Techniques for measuring gas emissions from a composting stockpile of cattle manure', Atmospheric Environment, vol. 38, no. 28, pp. 4643-4652.

Sommer, SG, Petersen, SO & Sorgaad, HTS 2000, 'Greenhouse gas emission from stored livestock slurry', Journal of Environmental Quality, vol. 29, no. 3, pp. 744-751.

Song, M & Choi, S 2000, 'Growth promoters and their effects on beef production', Asian Australian Journal of Animal Sciences, vol. 14, no. 1, pp. 123-135.

Stevens, R, Laughlin, R & Frost, J 1989, 'Effect of acidification with sulphuric acid on the volatilization of ammonia from cow and pig slurries', The Journal of Agricultural Science, vol. 113, no. 03, pp. 389-395.

Stevens, R, Laughlin, R & Frost, J 1992, 'Effects of separation, dilution, washing and acidification on ammonia volatilization from surface-applied cattle slurry', The Journal of Agricultural Science, vol. 119, no. 03, pp. 383-389.

Stevens, RJ & Laughlin, RJ 1998, 'Measurement of nitrous oxide and di-nitrogen emissions from agricultural soils', Nutrient Cycling in Agroecosystems, vol. 52, no. 2, pp. 131-139.

Stevens, RJ, Laughlin, RJ & Malone, JP 1998, 'Soil pH affects the processes reducing nitrate to nitrous oxide and di-nitrogen', Soil Biology and Biochemistry, vol. 30, no. 8-9, pp. 1119-1126.

Strydom, P, Frylinck, L, Montgomery, J & Smith, M 2008, 'The comparison of three b-agonists for growth performance, carcass characteristics and meat quality of feedlot cattle', Meat Science, vol. 81, pp. 557-564.

Sweeten, JM 1989, Removal and utilisation of feedlot runoff and sediment, Feedlot Management Workshop, Toowoomba.

Sweeten, JM, Egg, RP & Reddell, DL 1985, 'Characteristics of cattle feedlot manure in relation to harvesting practices', in Agricultural Waste Utilisation and Management - Proceedings of the 5th International Symposium on Agricultural Wastes, Chicago, Illinois, 16-17 December American Society of Agricultural Engineers, pp. 329-337.

Sweeten, JM & Wolfe, ML 1994, 'Manure and waste water management systems for open lot dairy operations', Transactions of the ASAE, vol. 37, no. 4, pp. 1145-1154.

Teather, R & Forster, R 1998, 'Manipulating the rumen microflora with bacteriocins to improve ruminant production', Canadian Journal of Animal Science, vol. 78, pp. 57-69.

Thomason, D 2007, 'Production practices for red meat in Australia', Nutrition & Dietetics, vol. 64, no. s4, pp. S192-S195.

Thorman, R, Harrison, R, Cooke, SD, Ellis, S, Chadwick, DR, Burston, M et al. 2003, 'Nitrous oxide emissions from slurry- and straw-based systems for cattle and pigs in relation to emissions of ammonia', Paper submitted to the SAC/ SEPA Conference on Agriculture, Waste and the Environment, Edinburgh, UK, 26-28 March.

Thorman, RE, Chadwick, DR, Harrison, R, Boyles, LO & Matthews, R 2007, 'The effect on N2O emissions of storage conditions and rapid incorporation of pig and cattle farmyard manure into tillage land', Biosystems Engineering, vol. 97, pp. 501-511.

Todd, R, Cole, N, Parker, D, Rhoades, M, Casey, K & Jordan, E 2009, 'Effect of feeding distiller's grain on dietary crude protein and ammonia emissions from beef cattle feedyards', in Texas Animal Manure Management Issues Conference, pp. 29-30.

Todd, RW, Cole, NA & Clark, RN 2006, 'Reducing crude protein in beef cattle diet reduces amonnia emissions from artificial feedyard surfaces', Journal of Environmental Quality, vol. 35, pp. 404-411.

Ungerfeld, E & Kohn, R 2006, 'The role of thermodynamics in the control of ruminal fermentation. In ‘Ruminant physiology: digestion, metabolism and impact of nutrition on gene expression, immunology and stress’', pp. 55-64.

Ushida, K & Jouany, J 1996, 'Methane production associated with rumen-ciliated protozoa and its effect on protozoan activity', Letters in Applied Microbiology, vol. 23, no. 2, pp. 129-132.

Van Nevel, C & Demeyer, D 1977, 'Effect of monensin on rumen metabolism in vitro', Applied and Environmental Microbiology, vol. 34, no. 3, pp. 251-257.

Van Zijderveld, S, Dijkstra, J, Perdok, H, Newbold, J & Gerrits, W 2011a, 'Dietary inclusion of diallyl disulfide, yucca powder, calcium fumarate, an extruded linseed product, or medium-chain fatty acids does not affect methane production in lactating dairy cows', Journal of dairy science, vol. 94, no. 6, pp. 3094-3104.

Van Zijderveld, S, Gerrits, W, Dijkstra, J, Newbold, J, Hulshof, R & Perdok, H 2011b, 'Persistency of methane mitigation by dietary nitrate supplementation in dairy cows', Journal of dairy science, vol. 94, no. 8, pp. 4028-4038.

VanderZaag, A, Jayasundara, S & Wagner-Riddle, C 2011, 'Strategies to mitigate nitrous oxide emissions from land applied manure', Animal Feed Science and Technology, vol. 166, pp. 464-479.

Varel, VH, Nienaber, JA & Freetly, HC 1999, 'Conservation of nitrogen in cattle feedlot waste with urease inhibitors', Journal of Animal Science, vol. 77, no. 5, pp. 1162-1168.

Velthof, GL, Nelemans, JA, Oenema, O & Kuikman, PJ 2005, 'Gaseous nitrogen and carbon losses from pig manure derived from different diets', Journal of environmental quality, vol. 34, no. 2, pp. 698-706.

Von Engelhardt, W, Wolter, S, Lawrenz, H & Hemsley, J 1978, 'Production of methane in two non-ruminant herbivores', Comparative Biochemistry and Physiology Part A: Physiology, vol. 60, no. 3, pp. 309-311.

Waghorn, G, Clark, H, Taufa, V & Cavanagh, A 2008, 'Monensin controlled-release capsules for methane mitigation in pasture-fed dairy cows', Animal Production Science, vol. 48, no. 2, pp. 65-68.

Wallace, R & Newbold, C 1993, 'Rumen fermentation and its manipulation: the development of yeast cultures as feed additives', Biotechnology in the Feed Industry. Ed.

Watts, P, McGahan, E, Bonner, SL & Wiedemann, S 2012, Feedlot Mass Balance and Greenhouse Gas Emissions - A Literature Review, Final Report, Project B.FLT.0361, Meat & Livestock Australia, Sydney, NSW.

Watts, PJ, Bridle, T, McGahan, EJ & Ni Cheallaigh, A 2013, Thermal Energy Recovery from Feedlot Manure - Pilot Trials, Meat & Livestock Australia (MLA) Final Report, Project B.FLT.0368, FSA Consulting, Toowoomba, QLD.

Wedlock, D, Pedersen, G, Denis, M, Dey, D, Janssen, P & Buddle, B 2010, 'Development of a vaccine to mitigate greenhouse gas emissions in agriculture: Vaccination of sheep with methanogen fractions induces antibodies that block methane production in vitro', New Zealand veterinary journal, vol. 58, no. 1, pp. 29-36.

Whitelaw, F, Eadie, JM, Bruce, L & Shand, W 1984, 'Methane formation in faunated and ciliate-free cattle and its relationship with rumen volatile fatty acid proportions', British Journal of Nutrition, vol. 52, no. 02, pp. 261-275.

Williams, A & Coleman, G 1997, 'The rumen protozoa', in The rumen microbial ecosystem, Springer, pp. 73-139.

Williams, YJ, Popovski, S, Rea, SM, Skillman, LC, Toovey, AF, Northwood, KS et al. 2009, 'A vaccine against rumen methanogens can alter the composition of archaeal populations', Applied and Environmental Microbiology, vol. 75, no. 7, pp. 1860-1866.

Wilson, CB, Erickson, GE, Macken, CN & Klopfenstein, TJ 2004, Impact of cleaning frequency on nitrogen balance in open feedlot pens, 2004 Nebraska Beef Report, University of Nebraska.

Winterholler, S, Parsons, G, Walker, D, Quinn, M, Drouillard, J & Johnson, B 2008, 'Effect of feedlot management system on response to ractopamine-HCl in yearling steers', Journal of animal science, vol. 86, no. 9, pp. 2401-2414.

Wood, T, Wallace, R, Rowe, A, Price, J, Yáñez-Ruiz, D, Murray, P et al. 2009, 'Encapsulated fumaric acid as a feed ingredient to decrease ruminal methane emissions', Animal Feed Science and Technology, vol. 152, no. 1, pp. 62-71.

Woodward, S 2006, 'Supplementing dairy cows with oils to improve performance and reduce methane-does it work?', in PROCEEDINGS-NEW ZEALAND SOCIETY OF ANIMAL PRODUCTION, vol. 66, New Zealand Society of Animal Production; 1999, pp. 176.

Wright, A, Kennedy, P, O'Neill, C, Toovey, A, Popovski, S, Rea, S et al. 2004, 'Reducing methane emissions in sheep by immunization against rumen methanogens', Vaccine, vol. 22, no. 29, pp. 3976-3985.

Zinn, R, Adam, C & Tamayo, M 1995, 'Interaction of feed intake level on comparative ruminal and total tract digestion of dry-rolled and steam-flaked corn', Journal of animal science, vol. 73, no. 5, pp. 1239-1245.

Zinn, R, Montano, M & Shen, Y 1996, 'Comparative feeding value of hulless vs covered barley for feedlot cattle', Journal of animal science, vol. 74, no. 6, pp. 1187-1193.

Zinn, R, Owens, F & Ware, R 2002, 'Flaking corn: processing mechanics, quality standards, and impacts on energy availability and performance of feedlot cattle', Journal of animal science, vol. 80, no. 5, pp. 1145-1156.

Zinn, RA 1993, 'Influence of processing on the feeding value of oats for feedlot cattle', Journal of Animal Science, vol. 71, no. 9, pp. 2303-2309.

9 Appendices

9.1 Appendix 1

9.1.1 Enteric Methane Emission Equations Compared in McGinn et al. 2008

These methods, in summary, were:

a) IPCC (2006) Tier I – constant. Fixed amount for region and cattle type

b) IPCC (2006) Tier II – intake. 3% of gross energy intake (GEI) / 55.65 (kg/hd/year), where GEI = DMI x 18.4.

c) Blaxter and Clapperton (BC) - digestibility and relative intake. The GEI is the sum of the intake (I) converted into energy terms assuming a gross energy content of 18.4 MJ/kg: GE = I x 18.4. The intake of the animals relative to that needed for maintenance (L) is calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with liveweight gain is set to zero).

   L = I / (1.185 + 0.00454W – 0.0000026W2 + (0.315x0))2

   The percentage of the GEI that is yielded as methane (Y) is given by Blaxter and Clapperton (1965) as:

   Y = 1.3 + 0.112DMD + L * (2.37 - 0.050DMD)

   Where: DMD = digestibility of feed (expressed as a %)

   L = intake relative to that needed for maintenance

   The total daily production of methane (M, kg CH_4/head/day) is thus:

   M = Y / 100 x GEI / F

   Where: F = 55.22 MJ/kg CH_4

d) Moe and Tyrrell (MT) - diet composition and intake. CH_4 = [3.406 + 0.510 * I * (St + Sc + Oa + Pe) + 1.736 * I * Hc + 2.648 * I * Ce] / 4.184

   Where CH_4 =methane production (Mcal)

   I = feed dry matter intake (9.8kg/day for domestic lot-fed steers)

   St, Sc, Oa, Pe, Hc and Ce = fractions of starch, soluble carbohydrates, organic acids, pectin, hemicellulose and cellulose respectively in the feed.

   Yij = 3.406 + 0.510*SRij + 1.736*Hij + 2.648*Cij

   Where: Yij = methane production (MJ/head/day)

SRij = intake of soluble residue (kg/day), Hij = intake of hemicellulose (kg/day), Cij = intake of cellulose (kg/day)

Yij is similarly converted to Mij (kg methane/head/day) by dividing by F (55.22).

A typical feedlot ration is considered by IPCC (2006) to be 77.9% grain/molasses, 4.8% other concentrates, 13.8% grasses and 3.5% legumes, resulting in cellulose - 0.07, 0.19, 0.31 and 0.36; hemicellulose - 0.04, 0.11, 0.31 and 0.20; and soluble residue - 0.68, 0.19, 0.21 and 0.21 for the four diet components respectively.

McGinn et al. (2008) noted that Tier I and II models did not account for the possible effects of dietary lipids on CH4. When taking these effects into account (5% reduction per 1% DM as oil) the Moe and Tyrrell method overestimated measured feedlot methane emissions by 7%.

9.1.2 Nitrogen Losses

9.1.2.1 Nitrogen Losses from the Feed Pad

The N excreted onto a feed pad is partitioned to three locations. These are:

- volatilisation to the atmosphere
- transported out of the pen in runoff
- harvested out of the pen in manure.

Ammonia-N Volatilisation

N excreted by cattle is in both organic and inorganic forms. Faecal N is 50% organic-N and 50% NH_3 (Mackie et al. 1998). However, urine contains up to 97% urea-N, which is readily converted by microbial urease to NH_3 following excretion from cattle (Mobley & Hausinger 1989). Mineralisation of faecal protein N occurs mainly through the activity of proteolytic and deaminative bacteria, initially hydrolysing proteins to peptides and amino acids and finally deamination to NH_4 (Gardner et al. 1994). This process occurs at a far slower rate than hydrolysis of urea (Varel et al. 1999). The other major pathway of N excretion is via the urine. Urine contains 60–80 % of the total excreted N. About 70% of the N in urine is urea and about 30% is readily mineralised organic compounds. The ammonia transformations are outlined in the following equations. Most ammonia in the system originates from urine excretion in the form of urea (far left) which is readily converted to ammonia in the presence of the urease enzyme. Depending on a range of other conditions, this ammonia can be lost through volatilisation, or can be transformed to the aqueous ammonium ion in a pH dependent, reversible reaction (on right).

Equations 1 and 2…

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} 2NH_3 + CO_2 \qquad NH_{3\,(l)} + H_2O \rightleftarrows NH_4^{+}{}_{(aq)} + OH^{-}$$

These reactions may take place within a very short time of excretion and can result in ammonia volatilisation from the system. Strictly, ammonia loss is a temperature dependent reaction where $NH_{3\,(l)}$ is transferred to $NH_{3\,(g)}$. High temperature conditions on the feed pad will influence this relationship, as will factors influencing other pathways for ammonia (i.e. the ammonium pathway). There is scope for large N losses from the pen surface. The volatilisation loss is dependent on a range of parameters including:

- manure and air temperature
- manure moisture content
- manure pH
- C to N ratio of the manure
- manure management (e.g. pen cleaning frequency)
- use of additives in feed and pen surface to reduce volatilisation.

Gardner et al. (1994) suggested that all of the N contained in urine is lost by volatilisation at Australian feedlots, because pen manure has a poor pH buffering capacity and CEC, and because pad temperatures tend to be higher than surrounding soil temperatures resulting in high evaporation rates and conditions favouring gaseous emissions.

Nitrous Oxide Losses

Currently, there are few studies with data on N_2O emissions from the feed pad that are able to express N_2O-N loss from the feed pad as a percentage of N excreted. Further, there are no Australian data, relative to Australian feedlots. In a Canadian study, Boadi et al. (2004) measured N_2O emissions from the feed pad using chamber methodology (gas sampling and analysis). However, it is not possible to express this as a percentage of total-N excreted or fed, since total-N excreted or fed is not reported.

IPCC Prescribed Emission Factors for N_2O Loss from Drylots (Feed pad)

Currently, the IPCC estimates of N_2O emissions from a drylot are based on an emission factor of 2.0% of total excreted manure (IPCC 2006). This emission factor (as stated in the IPCC guidelines) is derived from an expert panel, and based on a manure storage experiment by Külling et al. (2003). It is unclear what conclusions were made by the expert panel regarding the results presented by Külling et al. (2003). It is however assumed that the 2.0% emission factor has been derived from N_2O-N loss from the storage (over 7 weeks) of liquid manure fraction from both dietary treatments. The methodology of Külling et al. (2003) is summarised below.

Lactating dairy cows (n = 6) were used to measure the total-N loss and gas emissions arising from manure collected under controlled conditions when fed forage based diets. The experiments were conducted within Switzerland in two time periods. The two dietary treatments (fed *ad libitum*) were (i) grass-based and (ii) hay based (11.1% crude protein (CP) DM, 6 MJ net energy /kg DM), with grain supplementation (12.8 % CP DM, 7.9 MJ net energy for lactation /kg DM). Protein content of the grass diet differed between time periods 1 and 2: 11.2 and 22.9% CP DM, and 5.8 and 5.9 MJ net energy for lactation. Manure was separated into a liquid, slurry and farmyard manure type storage, and stored for 7 weeks to determine GHG losses. Liquid and slurry manure fractions were stored at 20°C and 70% ambient humidity. The solid manure fraction was stored at heated temperature to simulate heat production during long-term stockpiling. The solid manure fraction was kept at 41°C, reducing by 2°C each week of the experiment.

The formation of a persistent crust on the liquid manure samples (Külling et al. 2003) was acknowledged as a contributor to higher N_2O emissions, when compared to previous studies in manure storage. Others suggest that covering of slurry manure storage with organic material (straw) may increase the net total N_2O emissions (Amon et al. 2006, Sommer et al. 2000), which may act similarly to the crust which formed on the liquid storage treatment by Külling et al. (2003). Külling et al. (2003) observed that the effect of differing CP within the grass diet on N_2O emission was varied according to manure storage method.

In a similar study to Külling et al. (2003), Amon et al. (2006) observed that GHG emissions from manure slurry are predominantly in the form of NH_4, and most GHG emissions from the application of manure as a fertiliser are in the form of N_2O.

The validity of assumptions made to derive the emission factors of N_2O from dry lots, by inference, from the results from Külling et al. (2003) are probably not applicable to Australia. It is believed that the differences between the described methodology implemented by Külling et al. (2003) and pen surface of feedlots in Australia raises doubt on the emission estimates of N_2O. Others have similarly expressed concerns on the uncertainty of prescribed emission factors for both manure storage (Amon et al. 2006), and livestock production systems (Kebreab et al. 2006). For manure storage systems, the emission of N_2O depends on the N and carbon content of manure, on the duration of the storage and on the type of treatment (Amon et al. 2006). Similarly, the emission from manures *in-situ* varies with the type of animal, diet, management of manure and climate conditions (Kebreab et al. 2006). This highlights the need to effectively quantify N_2O emissions (and other GHG sources) from Australian feedlots.

Drivers of Nitrous Oxide Emissions from Australian Feedlots

From an Australian agricultural perspective, there is a need to examine the emissions factors used to estimate N_2O emissions on a national level (Dalal et al. 2003). Similarly, there is a need to evaluate the emission factors used to estimate N_2O emissions from Australian feedlots. Understanding the drivers of N_2O emissions is essential to designing and conducting effective experiments to measure and quantify the potential for N_2O production from feedlots.

The relevant pathways of N_2O production for beef production are through nitrification and denitrification. For N_2O emissions from pastures, the ratio of N_2O to N_2 is determined by processes within the soil, including:

- temperature
- pH
- oxygen supply, or water-filled pore space; (WFPS, to determine anaerobicity)
- decomposable soil carbon
- nitrogen substrate supply
- salinity (Dalal et al. 2003, Eckard et al. 2010).

Currently, most of the investigations regarding N_2O within agriculture are concerned with the nitrification (and denitrification) processes within agricultural soils. The production of N_2O from pasture and grazed soils is not within the scope of this review but has been repeatedly cited as a significant source of N_2O emissions (Chadwick et al. 1999, Luo et al. 2010, Oenema et al. 1997, Saggar et al. 2004, Saggar et al. 2007). It is recognised that for the purposes of understanding N_2O emissions originating from the feed pad within Australian feedlots, the same biochemical pathways of N_2O production are relevant (Kebreab et al. 2006). However, intrinsic differences exist between a beef feed pad and a soil profile.

Cole et al. (2009) comprehensively investigated the chemical characteristics of the manure and soil layers within three feedlots in Texas (USA) over four seasons. They observed chemical, physical and microbial differences between a soil profile and feedlot pad surface (Cole et al. 2009). The causes of these differences are listed below:

- Continuous deposition of excreta and higher stocking density.
- Microbial communities are likely different to those within soil. Within feedlots, soil bacteria (as dominant within most soils) may be replaced by faecal bacteria that are more tolerant to NH_3.
- Uptake of N by plants within normal soil profiles is likely to influence N transformations (Cole et al. 2009).

In addition, the use and compaction of gravel during construction of modern Australian feedlots is likely to contribute to the physical differences. In summary, the N_2O production from the manure pack on the feed pad may have a greater similarity to manure storage systems rather than a soil profile. It is likely that these differences influence the production of N_2O on the feed pad.

Future studies would need to investigate the relative influence of these individual factors on N_2O production within the feedlot. Because the physical and chemical characteristics of the layers within the feed pad can influence N transformations, N distribution and N losses, attempts to measure N_2O losses from feedlots should (where possible) be combined with measuring the physical and chemical characteristics within the source medium.

Based on the range of values (1 to 4% of N excreted) reported in IPCC (IPCC 2006), a theoretical mass balance estimates that approximately 1.7% of excreted N is volatilised as N_2O. In the same theoretical mass balance, N_2O emissions from the feed pad are estimated to comprise approximately 3.7% of total feed intake.

Ratio of N_2O to N_2 production

Observed differences in the production ratios of N_2O to N_2 have been observed between different frequency of cattle traffic and deposition of excreta for intensively housed cattle in Europe. An over wintering area (pastures where high densities of cattle are located for relatively long periods during winter) are potentially significant sources of N_2O emissions. Overwintering management can cause a gradient of impact (accumulation of excrement) from the intensively housing of cattle, ranging from most impacted areas closest to the feed areas (and animal house) to much less impacted areas in the middle, to almost unaffected areas where animal traffic was minimal (Simek et al. 2006). In some cases, contrary to expectations, N_2O emissions were smaller in an area heavily impacted by cattle than one moderately impacted by cattle (Hynst et al. 2007, Simek et al. 2006). Nitrous oxide emissions at the site severely impacted by excreta deposition were positively correlated with soil

NO_3^- and negatively correlated to soil temperature. Most of the N_2O emissions from the highly impacted site occurred during early spring at relatively low temperatures (Hynst et al. 2007).

These observations appear logical, considering soil temperature was at or slightly below 0°C during winter months. The effect of European winter temperatures (5 to -5°C during winter months) would be a significant factor on results obtained in these studies. It is difficult to make direct comparison between Australian feedlots and winter conditions in the Northern Hemisphere, since seasonality and climate conditions can significantly affect the ash content and quality of manure (Sweeten et al. 1985). For example, Kissinger et al. (2007) report that for American feedlots, almost twice the amount of manure can be collected following a winter feeding period compared to a summer feeding period (8.8 vs 4.7 kg TS/head/day). The case in point is that the interactions between the factors influencing N_2O emissions from manure are complex.

Nitrous oxide production from stored and composted manure is contributed to by multiple processes, based on variations in oxygen availability, substrate availability, pH and bacterial processes (Hao et al. 2001). In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidised forms of N. In addition, conditions preventing reduction of N_2O to N_2, such as a low pH or limited moisture, must be present (Dong et al. 2006). Similar to manure storage and soils, the pen surface of a feedlot can vary between anaerobic and aerobic conditions (and a combination of both), such that a dynamic interaction of multiple processes are involved in the production of N_2O (Cole et al. 2009, Kebreab et al. 2006, Stevens et al. 1998). Nitrification and denitrification are likely to be occurring at the same time, and therefore probable that multiple processes are contributing simultaneously to N_2O and N_2 formation from soil and feed pad (Stevens & Laughlin 1998, Stevens et al. 1998).

Nitrification

Nitrification occurs under aerobic conditions, and involves a two-step process where ammonium is first oxidised to nitrite, and nitrite is then converted to nitrate, as seen diagram below. Nitrous oxide is a by-product of this process (Kebreab et al. 2006, Stevens et al. 1998).

$$\begin{array}{llll} NH_4^+ & \rightarrow & NO_2^- \rightarrow & NO_3^- \\ & \searrow & N_2O & \end{array}$$

Denitrification

Denitrification is the reduction of nitrate to di-nitrogen gas (N_2), which is the final end product when reduction is complete (Kebreab et al. 2006). It is well established that denitrification occurs under anaerobic conditions (Hao et al. 2001). This process is can be altered by several conditions (as listed above).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

There is a general agreement in the scientific literature that the ratio of N_2O to N_2 increases with increasing acidity, nitrate concentration and reduced moisture (Dong et al. 2006). The effect of moisture (or water filled pore space; WFPS) is a significant determining factor in the N_2O to N_2 ratio (Figure 1), although other factors mentioned previously are also important.

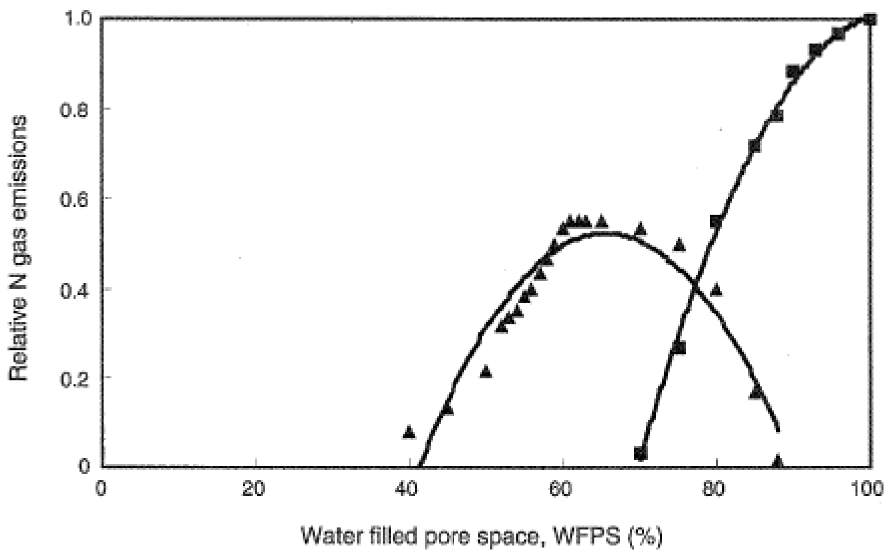

Figure 1 - Generalised relationship between water-filled pore space of soils and relative fluxes of N_2O( ) and N_2 (▪) from nitrification and denitrification TAKEN FROM (DALAL ET AL. 2003)

Temperature

The denitrification process has been observed to occur between 2 to 50°C, with every increase of 10°C causing the rate of denitrification to double (Galbally 1989, cited in Kebreab et al. 2006). For a study comparing storage types for dairy and beef manures, temperature measurements (surface and core) accounted for most of the variation in N_2O emissions from composted (aerobic) and stockpiled (balance of aerobic and anaerobic) treatments (Pattey et al. 2005). Thus, temperature is influential to the ratio of N_2 to N_2O, and is likely to be a determining factor in N_2O produced from the feed pad.

Several studies have been conducted in Canada regarding emissions from composting manure. The requirement for research in Canada may be influenced by low temperatures (particularly during winter) which have been observed to increase the volume of manure during winter compared to summer feeding periods (Kissinger et al. 2007). It is likely that more manure is removed during pen cleaning in Canada compared to Australian feedlots. Lower temperatures in Canada are likely to decrease volatilisation, thereby increasing the total volume of manure removed from the feed pad during pen cleaning. Additionally, bedding material is typically added to Canadian feedlots which would increase total manure volume, affecting the physical and chemical characteristics of fresh manure and also its composted end product (Hao et al. 2004). Straw incorporation can decrease bulk density and increase aeration (Kebreab et al. 2006). Therefore, caution should be taken when inferring data from studies conducted under winter conditions in the Northern Hemisphere to Australian conditions.

There is a deficit of Australian information and research regarding the contribution and interaction between the individual factors that influence the ratio of N_2 to N_2O on the feed pad. Of two published studies conducted in Australia to quantify GHG emissions from feedlots, only one has measured N_2O. It is not likely that findings of studies in Northern Hemisphere climates will be directly transferable to Australian conditions, due to differences in temperature and other climatic variables. This highlights the need for quantification of not only the emissions of N_2O from the feed pad, but the conditions conducive to production of N_2O over N_2.

Nitrogen Loss in Runoff

Nitrogen is lost from pens in runoff – either in solution or in the entrained manure. This loss is typically a small component of the N balance of a pen.

Erickson (2002), Farran et al. (2004), Luebbe et al. (2008, 2009) all use the same approach to determine N loss in runoff. In their experimental work, N in runoff was quantified by sampling each runoff event and measuring total runoff volume. In these experiments done in Nebraska, the feeding period ranged from 114 to 196 days with some experiments in winter and some in summer. The amount of rainfall, and hence runoff, varied between experiments. Figure 2 shows the N lost in runoff in these studies (expressed as a percentage of excreted N). It ranges from almost 0% to almost 5%. Kissinger et al. (2006) summarised the data from 18 of these manure harvesting experiments in Nebraska. As they have cold, relatively dry winters and warm, wet summers, the data was summarised into summer and winter experiments. Summer pens averaged 2.7% of N excretion in pen runoff while winter pens averaged 1.8% N loss.

Bierman et al. (1999) calculated the N lost in runoff in their feedlot study that ran over 87 days. The percentage of excreted N that was lost in runoff was 4.6%, 5.9% and 19.4% in three treatments. The third treatment had significantly more runoff thus explaining the high N loss % in the runoff.

There are no studies available in Australia that have measured N loss from pens in runoff. However, a first order estimate can be made. Assuming that 100 cattle are held in a pen at a stocking density of 15 m^2/head, with an annual rainfall of 650 mm; and assuming a runoff co-efficient of 30%, the runoff would be 0.29 ML. If the N content of the runoff was 400 mg N/L, 117 kg of N would be lost from the pen surface. If the cattle excrete 80 kg of N per head per year, the annual excretion is 8000 kg N and the runoff represents only 1.5% of this excretion. If the runoff contained significant amounts of entrained manure, the effective N concentration of the runoff would be higher, as would the percentage loss, say 2%.

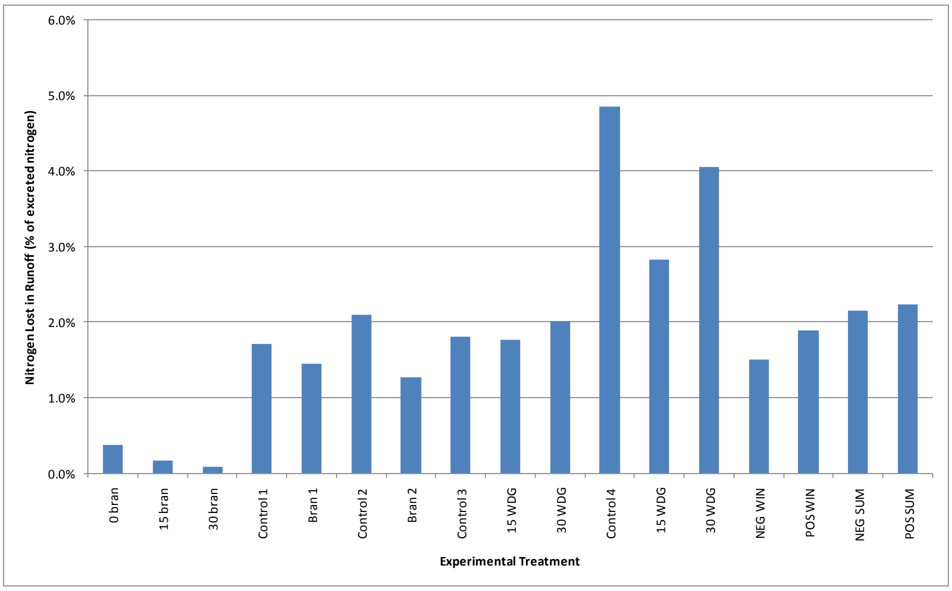

Figure 2 - Pen N lost in runoff (% of excreted N) – numerous studies

9.1.2.2 Nitrogen Losses from the Feedlot pond

Gaseous nitrogen Losses

Atzeni et al. (2001) highlighted the rate of N volatilisation as an area requiring further research. There is little experimental data on the volatilisation rates of NH_3 from Australian feedlot ponds. The reported range of values for runoff quality in holding ponds is both broad and variable within and between feedlots and difficult to predict. In the absence of published Australian data, the greatest challenge remains the prediction of runoff quality.

Sweeten and Wolfe (1994) found that well maintained settling ponds produced a total-N removal efficiency of 14 to 24%. Culley and Phillips (1989) observed that liquid storages can lose approximately 33% of the N by volatilisation. Madden & Dornbush (1971) estimated potential N reductions of around 35%.

Available research data regarding NH_3-N volatilisation from feedlot effluent ponds is limited. As such, IPCC and DCCEE estimated values of N loss (N_2O and NH_4) from liquid manure storage are used within the theoretical mass balance Table 3.

Table 3 - Reported Values of N loss (NH_3-N and N_2O-N), as a Percent of N to Pond

(Sourced from IPCC and DCCEE, and reviewed literature)

	N loss (% of N to pond)					
Emission source	Value	Range	min	max	Comments	Reference
NH_3-N emissions from N entering pond	35.0	20.0 - 80.0	20.0	80.0	Values from dairy ponds, as no data from beef feedlots	IPCC (2006)
	30.0				Value from dairy ponds, as no data from beef feedlots	DCCEE (2010)

	35.0				Review of literature for NPI Review	FSA Consulting (2006)
Range values		**20 - 80**	**20.0**	**80.0**		
	0.0				Assumes no N_20 emissions from anaerobic ponds	IPCC (2006)
N_2O-N emissions from N entering pond	**0.1**				Value for uncovered anaerobic ponds	DCC (2007)

Using a theoretical mass-balance, NH_3-N volatilisation from feedlot effluent ponds is estimated that to be in the order of 35% of total-N to pond (0.5 kg/SCU/yr).

9.1.2.3 Nitrogen Losses from Manure Stockpiles and Composting

Manure collected from Australian feedlots is commonly stored in compacted stockpiles or is composted in windrows (Kuhlman 1992, Powell 1998). Manure storages vary greatly in their ability to conserve N. Temperature, moisture, pH, and C:N ratio are important in determining the amount of N lost from the manure (Eghball & Power 1994b).

Manure stored in compacted stockpiles is subject to anaerobic decomposition, which generates a substantial amount of heat (Sweeten 1989). Current data suggests that stockpiled manure has over 90% of the total-N in the organic form, while the remainder is in the inorganic ammonium-N or nitrate-N forms. Ammonium-N levels are generally less than 5% of the total-N.

Alternatively, manure stored under predominantly aerobic conditions (or actively composted) results in greater water loss (Powell 1994) and decomposition of cellulose and fibre (Follet & Crissant 1990). Power et al. (1994) estimated up to 25% loss of N due to volatilisation, which is within the range (20-40%) recorded by Eghball and Power (1994a) during the composting process. Likewise, Eghball et al. (1997) reported N losses during outdoor composting in Nebraska over three consecutive summers ranging from 19-42%. A summary of studies measuring NH_3 and N_2O from stored and composted manure is included in Table 4. Currently, data of N_2O and NH_3 losses from manure management for Australian feedlots has not been published. Results from studies in Northern Hemisphere are likely to be of limited value for Australian conditions, largely due to lower temperatures and different manure management.

Table 4 - Reported N loss (NH_3-N and N_2O-N), as a percent of total-N to manure stockpile

(Sourced from IPCC and DCCEE, and reviewed literature)

Emission source	N loss (% of N Stored) Range	Comments	Reference
NH_3-N (% of N Stored)	10.0 - 65.0	Source: Table 10.22 of IPCC 2006	IPCC (2006)

		From dairy; no beef cattle value provided	DCC (2007)
	15.0 - 40.0	Review of literature for NPI	FSA Consulting (2006)
Range values	**10.0 – 65.0**		
N_2O-N (% of N Stored)	0.62 - 1.07	Passive storage vs. turning	Hao et al. (2001)
	0.39 - .68	Straw bedding vs. woodchip bedding material	Hao et al. (2004)
	4.3	Cattle manure. UK Straw bedding system stockpile. 12 months	Thorman et al. (2007)
	2.6	Swine manure. UK Straw bedding system stockpile. 12 months.	Thorman et al. (2007)
	12.3	**Fresh** solid dairy manure, low protein grass. 5 wks storage.	Kulling et al. (2003)
	46.0†	**Fresh** solid dairy manure, hay + grain supplement. 5 wks storage.	Kulling et al. (2003)
	7.12	**Fresh** solid dairy manure, high protein grass. 7 wks storage.	Kulling et al. (2003)
	8.45	**Fresh** solid dairy manure, hay + grain supplement. 7 wks storage.	Kulling et al. (2003)
	5.0 - 20.0	Intensive composting (frequent turning)	IPCC (2006)
	0.3 - 1.2	Static piles with forced aeration	IPCC (2006)
	0.5 - 2.0	Passive windrow - infrequent turning	IPCC (2006)
	0.25	Solid storage	IPCC (2006)
Range values	**0.27 - 20**		

† High N_2O-N (as percentage of total-N to stockpile), since freshly excreted manure was used within simulated storage experiments. Kulling et al. (2003).

9.1.2.4 Indirect Nitrous Oxide Emissions

The DCCEE (2010c) and IPCC (2006) identify further N_2O emissions associated with feedlots via the volatilisation and deposition of NH_3-N from the feedlot. These NH_3-N losses are associated with the feed pad, manure stockpile/compost, effluent pond and from application losses. These need to be added to give a total NH_3-N loss available for deposition and re-volatilisation as N_2O. DCCEE (2010c) and IPCC (2006) assume 1% of the deposited NH_3-N is re-volatilised as N_2O.

The literature suggests that indirect N_2O losses from the deposition of NH_3 are 1% of deposited NH_3-N.

9.2 Appendix 2

Table 5 – Feedlot Industry Mitigation Survey

Questions and answers in black were answered by the project team to provide background to survey participants. Survey participant questions in red

Feedlot GHG Mitigation Survey

Potential mitigation	Response	Is there likely to be sufficient scientific evidence?	Can the mitigation be directly measured OR calculated?	What basic information might be required to verify the mitigation?	Subjective mitigation potential (total reduction in emissions) (H, M, L)	Does this option appear attractive / possible to you? Please comment	Can you see any obvious barriers, including likely cost? Please note	Common practice: Do you apply it in your feed yard?	Is it common for feed yards of your size / class?	Is it common in your region/state?	Is this likely to be a high cost or low cost strategy?	Subjective rating (0-10) 0 being no value, 10 being highly likely to be of value
Feeding												
Use of antibiotics, ionophores		Y	calculated from feed intake and diet	detailed cattle and feed records, inc regular feed analysis and purchasing records	**L**							
Fat/oil content in ration (max. 7% of DMI)		Y	calculated from feed intake and diet	detailed cattle and feed records, inc regular feed analysis and purchasing records	**M - up to 20% reduction in enteric methane**							
What is the current fat/oil% in your rations (%DM)?												
Which high fat/oil products to you commonly feed?												
cotton seed												
distillers grains												
oil / recycled oil												
other												
Nitrate feeding		Y	calculated from feed intake and diet	detailed cattle and feed records, inc regular feed analysis and purchasing records	**M - 20%+ reduction in enteric methane possible**							
do you currently feed urea in the ration?												
Inclusion rate of urea? (% DM)												
do you see any concerns to feeding nitrate?												
Reduced crude protein in ration		Y	calculated from feed intake and diet	detailed cattle and feed records, inc regular feed analysis and purchasing records	**L**							
what is the current protein level in your rations (% DM)?												
Could the ration be modifed to reduce CP?												
Grain processing / ration composition												
Steam flaking to replace other feed processing		Y	one off change - ongoing mitigation	Demonstrate new equipment has been installed	**L**							
Grain inclusion rate in main ration? (% cereals)												
Higher starch in ration		Y	calculated from feed intake and diet	detailed cattle and feed records, inc regular feed analysis and purchasing records	**L**							
Cattle Management												
Reducing days on feed at same market weight (higher ADG)		Y	calculated from cattle/feed records: days on feed, ADG, feed intake etc	detailed cattle and feed records, inc regular feed analysis and purchasing records	**L**							
Same days on feed, higher market weight (higher ADG)		Y	calculated from cattle/feed records: days on feed, ADG, feed intake etc	detailed cattle and feed records, inc regular feed analysis and purchasing records	**L**							
Backgrounding												
Reduced days in backgrounding via higher ADG		Y	calculated from cattle/feed records: days on feed, ADG, feed intake etc	detailed cattle and feed records, inc regular feed analysis and purchasing records	**M**							
Do you background cattle?												
If so, do you grain assist during backgrounding?												
Grain vs Grass												
Provided with a financial incentive (i.e. $10-15/hd) are there any circumstances where you would buy **more** cattle that would otherwise be finished on grass?		Yes, but work needs to be done to show this isn't common practice based on COP	Possibly determined based on market prices for purchasing decisions	Purchasing descision matrix based on prices of grain, cattle etc	**M-H**							
Pen management												
Applying pen additives to reduce emissions of ammonia or nitrous oxide (i.e. an acidifying agent, or a binding agent)		Yes, but benefits are less assured	Model based on cattle numbers, feed intake and manure transfromations after excretion, some verification via testing	detailed cattle and feed records, manure management records, inc manure analysis	**L**							
Changing pen management to decrease manure depth substantially to reduce emissions		Unclear at this stage	Based on records of practices (cleaning frequency etc before and after the practice change)	detailed cattle and feed records, manure management records, inc manure analysis	**L**							
Stockpile management												
Covering stockpiles (plastic covers)		possibly, more research needed	Model based on cattle numbers, feed intake and manure transfromations after excretion, some verification via testing	detailed cattle and feed records, manure management records, inc manure analysis	**L**							
Reduce or remove stockpiling by rapidly applying manure to land		possibly, more research needed	Model based on cattle numbers, feed intake and manure transfromations after excretion, some verification via testing	detailed cattle and feed records, manure management records, inc manure analysis	**L**							
have you investigated options for generating energy from manure?												
if so, what barriers exist to energy generation from manure?												
Energy generation from solid manure		possibly, more research needed	Direct measurement of methane destruction	records of operation, throughput, characterisation of inflow	**L**							
Effluent management												
Do your ponds hold water for long periods of time (most of the year?)												
Est. volume of effluent on hand?												
Installing covered ponds or a digester to capture pond methane		Y	Direct measurement of methane destruction	records of flare or generator operation, possibly some measurement of inflows	**L**							
Reducing effluent storage period by more rapid irrigation		possibly, more research needed	Model based on cattle numbers, feed intake and manure transfromations after excretion, some verification via testing	Evidence of practice change, meaurement of tonnes treated, modelling to show migitation from cattle and feed data, manure measurement etc	**L**							

Feedlot CFI Survey Brief

Overview

The Carbon Farming Initiative (CFI) is a Government scheme to provide payments to farmers for reducing GHG. There is a lot of political uncertainty around the scheme so all we can say is the current situation: the scheme is up and running, and farmers are already being paid $21-23 / t CO_2-e of emissions they reduce from their farms. The feedlot industry can't participate in this scheme until mitigation options are identified and worked up into Government endorsed methodologies.

MLA and the Department of Climate Change recently commissioned a project to investigate approaches that could be used to reduce greenhouse gas (GHG) emissions from feedlots, and enable feedlots to claim saleable carbon credits from reducing these emissions. For this to be achieved, the industry must identify robust, proven ways in which GHG emissions can be reduced, using practices that aren't already in place across the industry (i.e. not common practice). The task of the current project is to identify a number of new practices that, if implemented, are likely to deliver saleable carbon credits for the industry.

We are looking for a 15-30min bracket of your time to talk through and fill out the attached spreadsheet with you. We would ask you to have a look through the accompanying spreadsheet briefly prior to this.

You are welcome to look through the report (attached) prior to the call also if you would like more detailed information. Even a quick scan of the summary, and chapters 1, 2 and 5 would provide useful background.

Background

The CFI targets direct emission sources from the animal and from manure. Emissions associated with fossil fuel use (inc. transport, milling, feedlot operations etc) and grain use are excluded. The major direct emission source is enteric methane – a by-product of ruminant digestion accounting for about 55-65% of direct emissions from feedlots. Other major sources are manure nitrous oxide from feedlot pads and stockpiles, manure ammonia (via indirect nitrous oxide) which is mainly lost from the feed pad, and manure methane which is mainly lost from the feedpad/stockpile. Smaller emissions also arise from the effluent ponds.

A review of the literature has identified a number of broad strategies and examples of potential mitigations (Figure 3).

For a mitigation to be suitable for adopting in the CFI, it needs to meet certain criteria. These criteria are outlined below, and in the accompanying spreadsheet. We are seeking your input to help identify the most promising strategies to be pursued by industry and the government.

Criteria for a successful CFI methodology:

The mitigation must be measurable and verifiable (DCCEE 2012). In many cases this can be done using calculations based on cattle/feed and management records.

Measurement methods must be supported by peer reviewed science and consistent with Australia's international accounts (DCCEE 2012). For the government to approve (and therefore to offer payment) for reducing GHG, there must be a clear scientific basis for it. At a minimum, it must comply with the state of the science outlined in the National Greenhouse Gas Inventory (NGGI). In the spreadsheet, we have filled in this column.

Measurement methods must account for variability and leakage and use conservative assumptions (DCCEE 2012). Some abatement activities can result in increased emissions that may inadvertently arise elsewhere in the production system. These emissions are referred to as leakage. For this reason, abatement cannot involve simply transferring emissions from one entity to another, as would be the case if a feedlot 'reduced' manure application emissions by selling their manure to another farmer. In this case, the emissions would still occur at a different location and there would be no net mitigation. At this stage in the process, we are looking to identify the risk of leakage for each potential mitigation we investigate.

Abatement activities must be additional to what would occur in the absence of the project (i.e. they must not be considered common practice for the industry). Only activities that are additional provide a net environmental benefit that can offset emissions that occur elsewhere and have value in an offsets market (DCCEE 2012). The government has not made all the rules clear around 'common practice' yet. We ask you to comment on whether practices are common under a few different scenarios (your feedlot, your size/class of feedlot, your region/state).

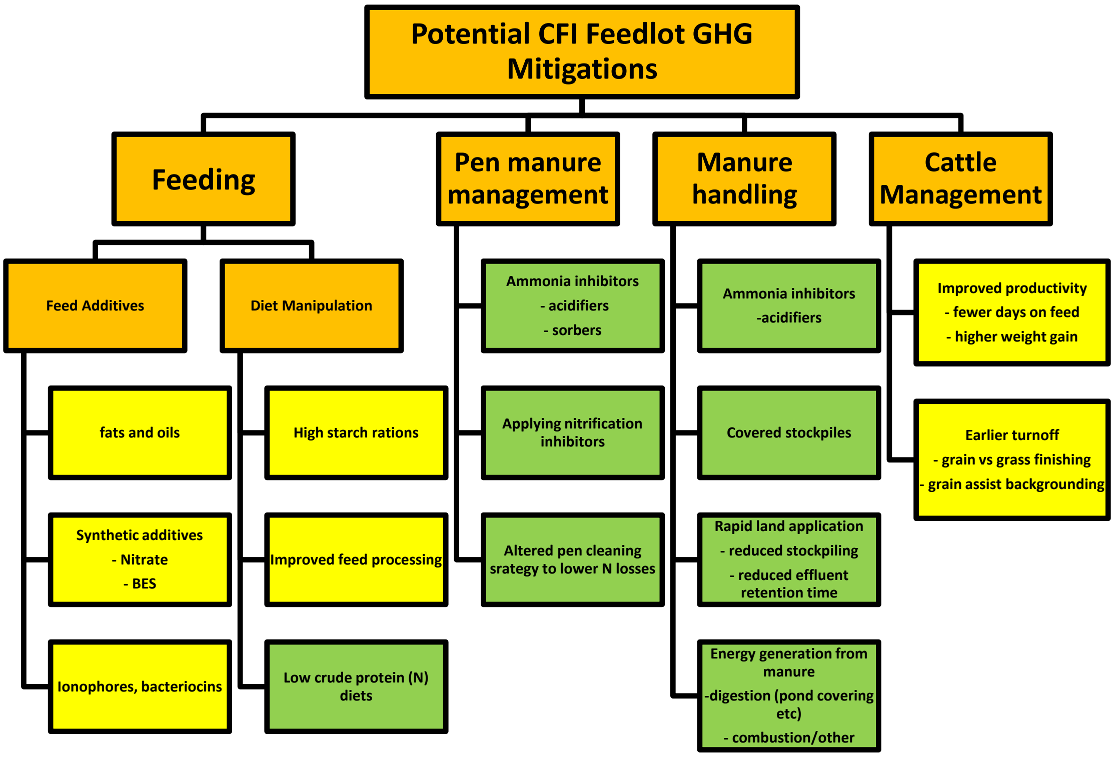

Figure 3 – Potential feedlot GHG mitigations (yellow boxes indicate mitigations targeting enteric methane, green boxes target manure emissions)

Next Steps:

We are looking for your input regarding these options, and others you may think of. These will be assessed by industry for development into CFI methodologies.