Australian Government

Rural Industries Research and
Development Corporation

Estimates of Manure Production from Animals for Methane Generation

RIRDC Publication No. 10/151

Australian Government

Rural Industries Research and
Development Corporation

Estimates of Manure Production from Animals for Methane Generation

by

Mr Eugene J McGahan, Miss Claudiane Ouellet-Plamondon and Dr Peter J Watts

September 2010

RIRDC Publication No. 10/151
RIRDC Project No. PRJ-002831

© 2010 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 978-1-74254-119-8
ISSN 1440-6845

Estimates of Manure Production from Animals for Methane Generation
Publication No. 10/151
Project No. PRJ-002831

The information contained in this publication is intended for general use to assist public knowledge and discussion and to help improve the development of sustainable regions. You must not rely on any information contained in this publication without taking specialist advice relevant to your particular circumstances.

While reasonable care has been taken in preparing this publication to ensure that information is true and correct, the Commonwealth of Australia gives no assurance as to the accuracy of any information in this publication.

The Commonwealth of Australia, the Rural Industries Research and Development Corporation (RIRDC), the authors or contributors expressly disclaim, to the maximum extent permitted by law, all responsibility and liability to any person, arising directly or indirectly from any act or omission, or for any consequences of any such act or omission, made in reliance on the contents of this publication, whether or not caused by any negligence on the part of the Commonwealth of Australia, RIRDC, the authors or contributors.

The Commonwealth of Australia does not necessarily endorse the views in this publication.

This publication is copyright. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. However, wide dissemination is encouraged. Requests and inquiries concerning reproduction and rights should be addressed to the RIRDC Publications Manager on phone 02 6271 4165.

Researcher Contact Details

Mr Eugene McGahan
FSA Consulting,
PO Box 2175, TOOWOOMBA, Q 4350
Phone: 07-46 328 280
Fax: 07-46 328 057
Email: Eugene.McGahan@fsaconsulting.net

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

Electronically published by RIRDC in September 2010
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

Foreword

Methane capture from animal manures has the potential to provide an economically viable renewable energy source for intensive livestock industries.

Accurate models that allow prediction of volatile solids (organic matter) and hence methane production will assist in the development of this technology.

This report sets out the results of a project designed to compare predictive results from models with field measurements in the existing pig, beef and dairy sectors.

The results of the project demonstrate the potential value of predictive models and highlight areas for future research to improve modelling capacity.

Funding for this project was received from the Australian Government through the Rural Industries Research and Development Program. In-kind assistance was also given by pig producers who provided valuable data to the project, along with various researchers from the Department of Employment, Economic Development and Innovation, Queensland (DEEDI) and Coomes Consulting.

This report, an addition to RIRDC's diverse range of over 2,000 research publications, forms part of our Bioenergy, Bioproducts and Energy Methane to Markets R&D program, which aims to meet Australia's research and development needs for the development of sustainable and profitable bioenergy and bioproducts industries.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

About the Author

FSA Consulting is a professional consultancy providing agricultural, environmental and engineering services to intensive livestock industries, broadacre farmers, abattoirs and industry. FSA Consulting has wide-ranging experience in environmental assessment and management. FSA Consulting also has considerable expertise in providing natural resource management services, having undertaken consultancies for industries as diverse as intensive livestock, broad acre farmers, meat processors, mushroom compost producers and sewage treatment plants.

The senior author, Mr Eugene McGahan, is an agricultural engineer who is a specialist in environmental sustainability issues for intensive livestock industries. Eugene's work areas include contracted research and development; assessing the environmental performance of individual farms and providing specific guidance for improvement; undertaking industry-specific research to provide solutions to particular environmental challenges; designing and providing environmental management training; and developing industry environmental and planning guidelines and codes of practice. He has consulted widely with the pork, egg, meat chicken, dairy and beef feedlot industries.

Acknowledgments

The authors of this document wish to acknowledge the case study participant piggeries who supplied data on feed type, feed intake and production details to the project. Their participation in the project is gratefully appreciated. The measured data on manure production supplied by Mr Scott Birchall (Coomes Consulting) and Mr Alan Skerman (Queensland Primary Industries and Fisheries) is also gratefully appreciated.

Abbreviations

AGO – Australian Greenhouse Office

ASABE – American Society of Agricultural and Biological Engineers (formerly ASAE)

ASAE – American Society of Agricultural Engineers

BOD - Biological Oxygen Demand

COD - Chemical Oxygen Demand

DAMP - Digestibility approximation of manure production

DCC – Department of Climate Change

DEEDI – Department of Employment, Economic Development and Innovation, Queensland

DMD – Dry matter digestibility

DMDAMP – Dry matter digestibility approximation of manure production

FS – Fixed solids

GHG – Greenhouse gas

GE – Gross energy

IPCC – Intergovernmental Panel on Climate Change

K – Potassium

MCF – Methane conversion factor

N – Nitrogen

NGGI - National Greenhouse Gas Inventory

P – Phosphorus

SCU – Standard cattle unit

SPU – Standard pig unit

TDN – Total digestible nutrients

TS – Total solids

VFA – Volatile fatty acids

VS – Volatile solids

Contents

Tables

Executive Summary

What the report is about

The increased costs of energy and the potential greater prices paid for renewable energy is making methane capture from animal manures more economically feasible. Combined with this is the greater intensification of the dairy industry with the use of feedpads/indoor barns, the growth in the beef cattle feedlot sector and pig production facilities generally increasing in size. With a better understanding of the manure production rates and the economically feasible size of these industries, a greater uptake of the existing technology to recover energy from these intensive animal industries will occur.

This project aimed to provide independent estimations of waste production using available methods and models, including the balance models developed by DEEDI Queensland and the National Greenhouse Gas Inventory (NGGI) documents for a series of case study farms that had measured data collected from other research projects.

Who is the report targeted at?

Accurate waste estimation techniques are required to allow developers and proponents to predict volatile solids (organic matter) and hence methane production from intensive livestock industries and to assess the economic feasibility of capturing methane from a particular enterprise. This information will also allow the size of systems to be designed to match the size of the enterprise.

Background

The waste estimation techniques commonly used in Australia used to predict manure production are not currently widely available to proponents/investors in the intensive livestock industries and have had little or no field validation.

Accurate predictions of manure production will assist industry in managing their effluent. With the greater acceptance and use of energy recovery systems with intensive agriculture, the potential benefits will be in reducing greenhouse gas (GHG) emissions, providing sustainable energy and reducing community amenity (odour) impacts.

Aims/objectives

This project was designed to allow desk-top models to be evaluated for animal manure production that will reduce the cost of more expensive measurements to provide these estimates. The outcome of this is to assist in facilitating the adoption of this technology in the intensive animal industries by providing information on the accuracy and limitations of predictive methods and models in sizing energy recovery systems from intensive animal industries. This will potentially reduce on-ground testing of individual systems before methane capture systems can be designed and installed.

Methods used

The methodology for this project was as follows:

- Undertake a review of current models used in Australia to estimate manure production for intensive animal industries including beef feedlots, piggeries and dairies. These models include BEEF-BAL, PIG-BAL, DAIRY-BAL and the manure estimate models included in the National Greenhouse Gas Inventory (NGGI) documents. Manure production is defined as total solids, volatile solids (organic matter) and nutrients per head/animal unit.

- Undertake a literature review of any new developments in the area of manure estimation for intensive livestock industries.

- Include any new developments in the existing models.

- Collect livestock herd data, feed intake and ration analysis data for a series of case study sites where actual measurements of manure production are being undertaken in other research projects funded by Australian Pork Limited and the RIRDC M2M Program. Use the various methods and models that currently exist to estimate manure production.

- Discuss the reasons for differences between predicted manure production from the various models and actual measured manure production.

Results/key findings

Three piggeries were used as case studies, with the size of the piggeries and waste output calculated in terms of the number of standard pig units (SPU).

No dairy case study was able to be reported on due to the lack of measured data on manure production for Australian dairies. At the beginning of the project, it was promised that this data existed and that other data would be collected during the course of the project. After consultation with Dairy Australia and researchers in both Queensland and Victoria, no actual reliable measured data on manure production from a dairy was available. Also, the data that was going to be collected during the course of the project at a dairy by other researchers was not available.

No beef cattle feedlot case study was able to be conducted because of the non-availability of actual measured manure production from a feedlot. The difficulty with measuring manure production from a feedlot is that manure is deposited on an outdoor pad and undergoes decomposition before it is harvested from the pad (generally between 6 and 20 weeks). Further decomposition occurs when the manure is harvested and stockpiled and/or windrow composted. To address this issue, a research project has begun under the Methane to Markets research program of RIRDC (Project No. PRJ-004377 - Quantification of feedlot manure output for BEEF-BAL model upgrade). It is proposed that this project will provide measured feedlot manure production data for comparison against predicted manure output from the BEEF-BAL model.

The evaluations conducted using the three available piggeries case studies concluded that the PIG-BAL model can provide a good estimate of VS production and hence potential methane production provided that accurate production and feed data can be supplied. The model, however, is highly sensitive to the input values of feed wastage. Other methods are also potentially useful for predicting manure production provided they are based on feed digestibility and feed intake. Methods that use standard text book values (such as the old ASAE (1988) standard) based on animal body weight are very poor at predicting manure production.

Implications and Recommendations

From this study the following recommendations can be made:

- Collect effluent production data from an intensive dairy system so that comparisons can be made against predictions from the DAIRY-BAL model and the other methods and models in this report. The dairy industry is likely to offer more potential for harvested energy from manure as it continues to expand.

- Collect manure production and decomposition data from beef cattle feedlots so that comparisons can be made against predictions from the BEEF-BAL model and the other methods and models in this report. The feedlot industry is a very large producer of organic waste and potentially offers the greatest potential for harvesting energy from manure from the intensive animal industries. (This is being done in PRJ – 004377).

- Ensure further studies that measure manure production from piggery systems also collect production and feed data to enable further validation of the PIG-BAL model. It would be worthwhile to conduct metabolic cage studies on modern genotype pigs used in Australia with varying diets to test the PIG-BAL model at an individual pig level for accuracy.

- Ensure that the balance models that are commonly used in Australia for estimating manure production (PIG-BAL and BEEF-BAL) are kept up-to-date with the latest digestibility and nutrient content of feed ingredients that are an important input to these models. It would also be useful to investigate the updating of these models with energy balance predictive methods, as this information is more readily available in the Australian literature than dry matter digestibility values for individual feed ingredients.

- Develop methane potential (B_o) standards and analysis data for Australia conditions.

Introduction

Current estimates are that manure management from animals accounts for approximately 3.2% of Australia's greenhouse gas (GHG) emissions. Using the DCC (2007) methodology, the majority of these emissions are from uncovered effluent treatment lagoons – predominantly anaerobic lagoons. Readily-available and easy-to-use models for predicting manure production from intensive animal industries will allow improved economic feasibility assessments to be conducted on methane capture and energy generation. Lagoons could be covered for methane capture and this would both reduce GHG emissions and reduce odour emissions. These odour emissions are often the cause of community amenity impacts.

Using estimates provided by GHD Pty Ltd (2008), increased costs of energy and greater prices paid for renewable energy will make methane capture and subsequent energy generation from animal manures (piggeries, dairies and beef cattle feedlots) more economically feasible. This is combined with the greater intensification of the dairy industry with the use of feedpads, as well as the growth in the beef cattle feedlot sector. Additionally, pig production facilities are generally increasing in size to where energy recovery becomes economically viable. With a better understanding of the manure production and economically feasible size of these industries, a greater uptake of the existing technology to recover energy will likely occur.

Tools are required to allow developers and proponents to predict volatile solids (organic matter) produced from intensive livestock industries and to assess the economic feasibility of capturing methane from a particular enterprise. This information will also allow the size of systems to be designed to match the size of the enterprise. These tools are not currently widely available to proponents/investors in the intensive livestock industries and the tools that do exist have had little field validation. This project, combined with PRJ-2705, will allow these tools to be tested for their accuracy in predicting manure production for various scenarios.

Methane to Markets Program

This report is part of a series of projects in the RIRDC's Australian Methane to Markets in Agriculture Research and Development Program (RIRDC 2009). The program aims to encourage and develop the use of methane capture and use technology in Australian intensive livestock industries by

i. reducing the uncertainty, risk and cost associated with installing methane capture systems

ii. facilitating the commercialization of on-farm methane systems capture and use technology and

iii. iii) effectively communicating these outcomes to intensive livestock producers.

Projects associated with this report include:

- PRJ-002705 – *Biogas production by covered lagoons; part 1 – piggery, Bears Lagoon* (Birchall 2009)
- PRJ-004377 – *Quantification of feedlot manure output for Beef-Bal Model Upgrade*
- APL Project No. 2108 – *Improved piggery effluent management systems incorporating highly loaded primary ponds* (Skerman et al. 2008)

A brief summary of each project is provided in Table 1.

Table 1: Summary of research projects associated with this report (PRJ – 002831)

Project No.	Research Organisation	Project Description	Project status
PRJ-002705	Coomes Consulting Group	A twelve month continuous monitoring program at Bears Lagoon Piggery to measure TS, VS COD, COD soluble, TKN, Ammonia and VFA's for influent and effluent and biogas methane composition of a covered anaerobic pond. The data is being used to verify an anaerobic digestion model being developed by the Advanced Water Management Centre (UQ) which aims to reduce the uncertainty, risks and costs of installing highly loaded lagoons to capture and reuse biogas (Birchall 2009).	complete
PRJ-004377	FSA Consulting	The collection of feedlot manure production data including TS, VS and moisture content to estimate losses under current production practices. This data will be used to improve the quality of BEEF-BAL outputs by validating the DMDAMP section of the model.	incomplete
APL Project No. 2108	QLD DEEDI	Performance evaluation of highly loaded piggery ponds in relation to effluent treatment (removal of solids), sludge accumulation and odour emissions. The report also provides draft recommendations for the design and management of highly loaded primary ponds (Skerman et al. 2008).	complete

Objectives

This project will provide information on the accuracy and limitations of predictive models in sizing energy recovery systems from intensive animal industries. This will potentially reduce expensive on-ground testing of individual systems before methane capture systems can be designed and installed. Accurate predictions of manure production will also assist industry in managing their effluent. With the greater acceptance and use of energy recovery systems with intensive agriculture, the potential benefits will be in reducing GHG emissions, providing sustainable energy and reducing community amenity (odour) impacts.

Methodology

The methodology for this project is as follows:

1. Undertake a review of current models used in Australia to estimate manure production for intensive animal industries including beef feedlots, piggeries and dairies. These models include BEEF-BAL, PIG-BAL, DAIRY-BAL and the manure estimate models included in the National Greenhouse Gas Inventory (NGGI) documents. Manure production is defined as total solids, volatile solids (organic matter) and nutrients per head/animal unit.

2. Undertake a literature review of any new developments in the area of manure estimation for intensive livestock industries.

3. Include any new developments in the existing models.

4. Collate livestock herd data, feed intake and ration analysis data for a series of case study sites and use the various digestibility / mass balance models and methods to predict manure production.

5. Compare the predicted manure production estimation (from 4 above) with actual data on waste produced measured by others (including RIRDC Project PRJ-2705 and APL Project 2108).

6. Discuss the reasons for differences between predicted manure production from the various models and actual measured manure production data supplied by others.

7. Prepare a Final Report.

Literature Review

To estimate the methane generation potential of manure, it is necessary to estimate the organic content of the manure and predict the production rate. Organic content can be measured by various parameters but the most common is volatile solids (VS). Methane production can be related to VS by using the maximum methane producing capacity (B_o) for manure produced by livestock (m^3 CH_4/ kg VS) and the Methane Conversion Factor (MCF). This report will review manure prediction models and methods for estimating VS and will identify any new developments that might lead to improvements in the models.

Historical Development of Manure Prediction Models

Over the past 40 years, there has been a progression in the development of methods and models to predict manure production from intensive livestock facilities. This progression has been driven by the environmental issues prevailing at the time. The manure prediction models have changed in scope and complexity (and assumed accuracy) as the breadth and detail of the environmental issues have increased over time.

Components of Manure

Manure constitutes urinary excretions as well as the fraction of the diet consumed by an animal that is not digested and excreted as faecal material, i.e. manure is urine plus faeces. Manure is composed of total solids (TS), which contains macro and micro nutrients, and water. TS which is composed of organic matter (measured as VS) and ash or fixed solids (FS). Total solids is determined by drying a sample at 105°C until a stable weight is achieved. The method to measure VS in the laboratory is to burn dried manure samples at 550 ºC (APHA 1989) or 440°C or 750°C (ASTM 2008). The VS portion of the sample is burnt off and only the ash or fixed solids (FS) remains. The VS are determined by mass balance.

Pond Organic Loading Rate Models

The first environmental issue that required a manure prediction model was the organic loading rate design for intensive livestock waste treatment ponds (or lagoons as they are referred to in the USA). The objective was to size the pond so that the organic matter – characterised as BOD or VS – was adequately treated in the pond prior to discharge or disposal by irrigation. The need for these models followed the adoption of various “clean water” regulations by the EPA in the USA. The earliest methods for estimating manure production were simply to express manure production as a fixed amount (kg VS/head/day) or as a percentage of liveweight. For example, manure production from feedlot cattle was estimated to be about 6% of body weight (ASAE 1988). However, these methods did not take account of feeding regime, growth rates and ration content. These “models” simply linearly related manure production to animal liveweight. Typical examples were ASAE (1988) and MWPS (2000).

Experience with these models indicated that the manure production estimates were too crude and that many treatment ponds either had serious odour problems or filled quickly with sludge.

DAMP Model

The most significant improvement in the prediction of livestock manure production came when Clyde Barth published three papers in 1985 (Barth 1985a, Barth 1985b, Barth and Kroes 1985) .The aim of this work was to provide a design methodology for livestock ponds that would overcome the odour and sludge accumulation problems.

Barth (1985a) proposed the Digestibility Approximation of Manure Production (DAMP) technique, which was arguably, the first technique that aimed to predict the organic content of excreted manure using animal performance data. Digestibility Approximation of Manure Production (DAMP) is a systematic approach to estimate the TS, VS and FS or ash component of animal manure based on known diet and digestibility data. This technique applies to any class of animal or bird. It assumes that FS and VS components of concentrates and protein supplements were available according to the reported value for percent total digestible nutrient (TDN). For each subclass of animal, DAMP requires, as input, the amount fed and percent wastage, percent dry matter, ash content, percent TDN, and percentage of the fixed solids available in the organic and mineral component of the diet of each feed component offered.

Barth (1985a) found that, in general, for pigs, the data of ASAE and the USDA SCS estimated greater waste production for breeding stock than DAMP. Data of MWPS (1985) was similar to DAMP for breeding animals. For growing animals, ASAE, SCS and MWPS data estimated greater waste production for larger animal sizes and less waste production for smaller animal sizes than DAMP. For dairy cattle, ASAE, SCS and MWPS manure production characteristics compared favourably with DAMP for cows at higher levels of milk production when an allowance of 5% waste was included. DAMP produced lower estimates of manure production for cows at low and intermediate levels of milk production. For beef cattle, the MWPS estimate of grower animal (159 to 340 kg) manure production compared favourably with DAMP with a 5% feed wastage included. All other estimates of beef manure production by ASAE, SCS and MWPS were much greater than DAMP estimates.

As historical background, the TDN system was developed in the early 1900s (Dumas et al. 2008). The evolution of the TDN system is described in detail in Maynard (1953). All nutrients (crude protein, crude fibre, nitrogen-free extract, crude fat) are scaled to the energy equivalent of carbohydrate. In non-ruminant animals, TDN is a measure similar to metabolic energy and not to digestible energy. In ruminants, the net energy also has a component related to the methane and fermentation heat lost. The reference system of the TDN does not take into consideration the metabolisability of the diet. This means that all feedstuffs are assumed to be used equally efficiently for maintenance and lactation, regardless of TDN composition.

For many years, Barth (1985a) was the standard technique of estimating organic load on effluent treatment ponds and was the initial digestibility method for the mass-balance models developed in Australia.

Nutrient Mass Balance Models

The DAMP model only predicts organic matter production in manure. In Australia in the later 1980s and early 1990s, there was a need to not only understand organic matter excretion but also nutrient excretion. Environmental regulators were asking for explanations of sustainable nutrient (N, P, K) utilisation at intensive livestock facilities. This led to the development of mass-balance models for manure production (e.g. Watts et al. 1994, Watts et al. 1992).

These models applied a mass-balance approach to nutrients (N, P, K) and included DAMP to estimate the organic matter component of manure production. These models typically characterised the animal ration by including individual percentages of ration ingredients and typically characterised the herd by modelling the full range of animal types, growth rates, feed intakes and liveweight. An important improvement was that the PIG-BAL model included provision for the estimation of feed wastage as this waste feed became part of the manure load on the waste treatment system.

In Australia, these models were known as PIG-BAL for pigs (QPIF 2004c), BEEF-BAL for feedlots (QPIF 2004a) and DAIRY-BAL for dairy (QPIF 2004b).

DMDAMP Model

Over time, it became apparent that the DAMP model needed improvement. Sinclair (1997) concluded that the DAMP technique, using TDN values was inadequate in being able to provide accurate estimates of the basic manure characteristics of TS, VS and FS. van Sliedregt et al. (2000) developed a new digestibility model which uses the dry matter digestibility (DMD) of each feed ingredient, not the TDN value. The DMD approximation of manure production (DMDAMP) predicts the amount of TS, VS and FS excreted by animals using DMD instead of TDN values of individual ingredients (McGahan et al. 2000, McGahan and van Sliedregt 2000, van Sliedregt et al. 2001). DMD data is also more readily available in Australia for feed ingredients compared to TDN. With data on the digestibility of each feed ingredient, the digestibility of the whole diet is used to predict the TS, VS, and FS or ash excreted by an animal using mass-balance principles. Equations 1 to 4 are the basis of the new BEEF-BAL, DAIRY-BAL and PIG-BAL models.

TS excreted = DMI x (1 - DMD of the ration) **Equation 1**

where:

DMI is the dry matter intake (kg/head/day)

The amount of FS excreted is calculated by mass balance as the difference between the amount in the diet and the amount retained by the animal as liveweight gain.

FS excreted = FS fed – FS retained **Equation 2**

DMD is a coefficient or percent of the fed dry matter that is digestible. In Equation 3, DMD prediction requires laboratory analysis (peptin cellulose technique), digestion trial or it is available for many feed ingredients in Australia.

DMD = (Feed DM – Faeces DM) / Feed DM

Equation 3

VS is calculated with Equation 4:

VS excreted = TS – FS **Equation 4**

McGahan et al. (2001a) conducted measurements of manure production at a commercial piggery to validate the developed DMDAMP model.

ASABE Models

Although Clanton et al. (1988) recognised the value of mass-balance models for nutrient estimation, it has only be in recent years that manure prediction models in the USA have been modified to improve the estimates of nutrient content and to include mass-balance principles (Erickson et al. 2003, Fulhage 2003). Consequently, the old ASAE manure standard (ASAE 1988) has been significantly updated (ASABE 2005). The new ASABE standard has also improved the digestibility model to improve VS predictions. This model determines “as-excreted” manure and does not include a component for wasted feed or bedding material.

This standard:

- characterises typical manure, “as-excreted” based on typical diet,
- estimates manure excretion based on animal performance, dietary feed and nutrient intake according to individual life stage situation,
- provides typical data on manure when removed from manure storage or animal housing.

The standard characteristics of typical manure provides information on total solids (TS), volatile solids (VS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Nitrogen, Phosphorus, Potassium, Calcium, total manure and moisture per kg/finished animal. Table 2 presents the estimated typical manure as excreted.

Table 2: Estimated typical manure (urine and faeces) as excreted (ASABE 2005)

Animal Type and Production Grouping	Total solids	Volatile solids	Nitrogen	Calculated VS/TS ratio
	kg/finished animal (f.a.)			
Beef – Finishing cattle	360	290	25	0.81
Nursery pig (12.5 kg)	4.8	4.0	0.41	0.83
Swine – Grow-finish (70 kg)	56	45	4.7	0.80
	kg/day – animal (d-a)			
Gest. Sow (200 kg)	0.50	0.45	0.032	0.90
Lact. Sow (192 kg)	1.2	1.0	0.085	0.83
Boar (200 kg)	0.38	0.34	0.028	0.89

Beef cattle

Volatile solids are calculated only for beef cattle and are called organic matter (OM). Equation 5 and 6 predict organic matter (or volatile solids) excretion:

$$\mathbf{OM_{E} = [DMI*(1-ASH/100]*(1-OMD) +17*(0.06*BW_{AVG})} \qquad \textbf{Equation 5}$$

$$\mathbf{OM_{E\text{-}T} = n^{n}{}_{x=1}\ [DMI_{x} * DOF_{x} *(1-ASH_{x}/100)]*(1-OMD_{x}/100) + n^{n}{}_{x=1} DOF_{x}*17*(0.06* BW_{AVG})} \qquad \textbf{Equation 6}$$

where:

OM_E is the organic matter (or volatile solids) excretion per animal per day (g of organic matter / day / animal)

DMI is the dry matter intake (g DM / day)

ASH is the ash concentration of total ration (% of DMI)

OMD is the organic matter digestibility of total ration (% of OMI)

BW_{AVG} is the average live body weight for the feeding period (kg)

OM_{E-T} is the total organic matter (or volatile solids) excretion per finished animal (g of organic matter / finished animal)

DOF is the days on feed for individual ration (days)

x is a ration number

n is the Total number of rations fed

Dairy Cattle

For dairies, VS is obtained from the VS/TS ratio calculated from data provided by ASABE (2005). Table 3 presents TS, VS, VS/TS ratio for ASABE (2005), ASAE (1988) and DAIRY-BAL (QPIF 2004b). ASABE (2005) provides equations to estimate TS, called actual faecal dry matter and urine dry matter (DM_E).

Table 3: Fresh Manure Production for Dairies from ASABE and DAIRY-BAL

Waste variable	ASABE (2005)		ASAE (1988)	DAIRY-BAL - Darling Downs	
	Lact. Cow	Dry Cow	per 600 kg live animal	Lact. Cow	Dry Cow
	(kg/day/animal)		(kg/day/animal)	(kg/day/animal)	
TS	8.9	4.9	7.2	5.2	4.8
VS	7.5	4.2	6.0	4.3	3.9
N	0.45	0.23	0.31	0.26	0.20
VS/TS	0.84	0.86	0.83	0.82	0.81

Equation 7 to 9 shows DM_E calculated regression for lactating cow from different US data sets. There is no clear guidance given on which is the most appropriate method to use. Other models are available for heifers and dry cows.

$$DM_E = (DMI \times 0.350) + 1.017 \qquad \textbf{Equation 7}$$

$$DM_E = (Milk \times 0.135) + (BW \times 0.004) + (DIM \times 0.004) + (MTP \times 118.370) - 2.456 \qquad \textbf{Equation 8}$$

$$DM_E = (Milk \times 0.096) + 5.073 \qquad \textbf{Equation 9}$$

Where:

DM_E is the dry matter (solids) excretion per animal per day (kg / animal / day)

DMI is the dry matter intake (kg dry feed / animal / day)

Milk is the milk production (kg of milk / animal /day)

BW is the average live body weight (kg)

DIM is the days in milk (days)

MTP is the milk true protein (g / g milk / day)

Pigs

Pig VS are calculated from the VS/TS ratio data provided by ASABE (2005). Table 4 presents TS, VS, VS/TS ratio for ASABE (2005) and ASAE (1988). ASABE (2005) also estimates TS as total dry matter excretion per finished animal (DM_{E-T}) in Equation 10, which applies to grower-finish pigs.

Table 4: Fresh Manure Data for Piggeries from ASABE (2005) and ASAE (1988)

Waste variable	ASABE (2005) Swine-Nursery Pig (12.5 kg)	ASABE (2005) Swine - Grower-finish (70 kg)	ASAE (1988)
Waste units	kg / finished animal	kg / finished animal	kg / 1000 kg animal mass / day
TS	4.8	56	11.0
VS	4	45	8.5
N	0.41	4.7	0.52
VS/TS	0.83	0.80	0.77

$$DM_{E-T} = [C_{DM} * FI_G * (100 - DMD) / 10{,}000] + [0.025 * DOF_G * (20 * BW_{AVG} + 2{,}100)] \qquad \textbf{Equation 10}$$

Where: DM_{E-T} is the Total Dry Matter Excretion per finished animal (g/finished animal)

C_{DM} is the Dry Matter Concentration of diet (%)

FI_G is the Feed intake per finished animal (grow – finish phase) (g/finished animal)

DMD is the Dry matter digestibility of the total ration (%)

DOF_G is the Days on feed to finished animal (grow – finish phase) (days)

BW_{AVG} is the average of initial and final body weight (kg)

Manure Models to Estimate Greenhouse Gas Emissions (IPCC)

The previous sections have described manure estimation models that were derived to provide design data for waste treatment facilities at intensive livestock enterprises. Somewhat independently, manure estimation models were developed to provide the basis for prediction of greenhouse gas emissions from intensive livestock facilities.

The estimation of VS excretion rate using the IPCC (2006) method is based on energy intake, digestibility and ash content. The VS excretion rate is estimated for all livestock species as (Equation 11).

$$VS = [GE * (1 - (DE\% / 100) + (UE * GE)] * [(1 - ASH) / 18.45] \qquad \textbf{Equation 11}$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, (kg VS/day)

GE = gross energy intake, (MJ/day)

DE% = digestibility of the feed in percent (e.g.60%)

(UE * GE) = urinary energy expressed as fraction GE. Typically, 0.04 GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). If country-specific data are available, it is preferable to use these.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (country specific data recommended)

18.45 = conversion factor for dietary GE per kg of dry matter (MJ/kg). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

To undertake a national greenhouse gas inventory, each country should estimate gross energy (GE) intake and its fractional digestibility (DE) as appropriate to that production system.

For cattle, GE and DE are given in equations in IPCC (2006). Feedlot cattle fed with over 90% concentrate diet have a digestibility ranging from 75 to 85%.

For swine, IPCC (2006) state country specific data are required to estimate feed intake, with feed digestibility of swine varies with class:

Mature Swine –confinement: 70-80% DE%

Growing Swine – confinement: 80-90% DE%

Methods for calculating gross energy (GE) are provided in Appendix A.

Manure Prediction Models Currently used in Australia

BEEF-BAL

BEEF-BAL (QPIF 2004a) is spreadsheet model that is used to predict the amount of solids (total and volatile) and nutrients (nitrogen, phosphorus and potassium) excreted by feedlot cattle based on the improved model of DMD approximation of manure production (DMDAMP - van Sliedregt et al. 2000) and mass balance principles (Watts et al. 1994). The model requires data on herd size, diet, quantity fed and waste. This model also accounts for associative effects that occur in ruminants as a result of the nature and compositions of individual ingredients, as well as the digestive processes that occur when feeds are mixed together that affect the digestibility of feed consumed by ruminants. This model was first developed in the mid 1990’s and has been modified and refined since then according to various case studies and consulting needs.

This model is not often used by the industry because it requires intensive data on the animal’s diet. It has not yet developed to a commercial standard for the general use by the public. Queensland Primary Industries and Fisheries (QPIF) provide it for free to researchers and consultants on the understanding that they are provided on an "as-is" basis. QPIF advises that it should be used with caution and professional judgement should be exercised in drawing conclusions from the model outputs. The version used in this study was Version 9.1_TI.

DAIRY-BAL

DAIRY-BAL (QPIF 2004b) was developed by DEEDI's intensive livestock environmental management engineers and scientists. It is available as a stand-alone spreadsheet and has also been incorporated in the Dairying Better n' Better CD which is a Knowledge Based Decision Support System (KBDSS) developed through the Dairying Better n' Better project. The CD is a web-style information manual for subtropical dairy farms, providing guidance for more profitable and environmentally sustainable farm management, focusing on better practices for irrigation, fertiliser, soil and effluent management. This prediction of solids excretion uses the DMDAMP model. The total solids excreted are calculated using Equation 1, the fixed solids with Equation 2 and the volatile solids with Equation 4. DAIRY-BAL uses a library of dry matter digestibility, ash and nutrient contents for all the pasture, crop, hay, silage and supplementary feed ingredients (McGahan et al. 2001b). The version used in this study was Version 3.4.

PIG-BAL

PIG-BAL (QPIF 2004c) predicts effluent output using DMDAMP theory. PIG-BAL also predicts the amount of nutrients (nitrogen, phosphorus and potassium) produced based on mass balance principles (as with ash production). TS, FS and VS are calculated with following Equation 12 to 14.

TS = (Feed intake x DM% of feed x (100-DMD% of feed) + (Feed wasted x DM% of feed)   Equation 12

Ash = (Feed intake x DM% of feed x Ash% of feed) – (LW gain * Ash content of pig)   Equation 13

VS = TS Production – Ash Production   Equation 14

The DMDAMP and mass balance approaches for predicting the amount of manure have been validated experimentally at a commercial 2500-sow piggery (McGahan and Casey 1998, McGahan et al. 2001a). All inputs (pigs, feed, fresh drinking water, fresh flushing water) and outputs (pigs, mortalities and manure) were measured on the grower/finisher section of the piggery.

The National Environmental Guidelines for Piggeries (NEGP) (Australian Pork Limited 2004) has tabulated values for TS, VS, nitrogen, phosphorus and potassium production for various pig classes (Table 5). These values were developed using the PIG-BAL model incorporating DMDAMP with typical Australian diets and waste feed estimates. The version used in this study was Version 3 TI.

Table 5: Predicted solids and nutrient output for each class of pig - NEGP

Pig Class	TS (kg/yr)	VS (kg/yr)	Ash (kg/yr)	N (kg/yr)	P (kg/yr)	K (kg/yr)
Gilts	197	162	35	12.0	4.6	4.0
Boars	186	151	35	15.0	5.3	3.8
Gestating Sows	186	151	35	13.9	5.2	3.7
Lactating Sows	310	215	95	27.1	8.8	9.8
Suckers	11.2	11.0	0.2	2.3	0.4	0.1
Sow + Litter	422	325	97	50	13	11
Weaner pigs	54	47	7	3.9	1.1	1.1
Grower pigs	108	90	18	9.2	3.0	2.4
Finisher pigs	181	149	32	15.8	5.1	4.1

Manure Models to Estimate Greenhouse Gas Emissions (DCC)

The Department of Climate Change (DCC) (formerly Australian Greenhouse Office (AGO)) undertakes national greenhouse gas inventories for Australia. For livestock manure management systems, the method used provides specific volatile solids (VS) rates according to livestock population (DCC 2007). The VS prediction equations use dry matter intake and dry matter digestibility data developed to calculate enteric methane production. The equation and guidelines for VS estimation for beef cattle feedlots, dairy and pigs are given in this section. The DCC method draws heavily on van Sliedregt et al. (2000) and McGahan and Casey (1998).

Beef Cattle in Feedlots

For beef cattle feedlots, VS are estimated with Equation 15 using dry matter intake, digestibility and ash content. Table 6 gives the feed intakes for feedlot cattle that are assumed from NGGI (DCC 2007) calculations.

$$\mathbf{VS = I \times (I - DMD) \times (1 - A)} \qquad \textbf{Equation 15}$$

where:

I = dry matter intake (Table 6), kg/day

DMD = digestibility expressed as a fraction (assumed to be 80%)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

Table 6: Feedlot cattle intake (I) (kg DM/day) (DCC 2007)

Feedlot Cattle Class/ Average time in Feed	1990-1995	1996+
Domestic/ 75 days	7.20	9.8
Export/ 140 days	8.47	11.7
Japan ox/ 250 days	11.50	11.0

Dairy cattle

For dairies, VS are estimated using the same equation as for beef cattle (Equation 15) with dry matter intake, digestibility and ash content.

Where

I = dry matter intake (Equation 16), kg/day

DMD = digestibility expressed as a fraction (Table 7)

A = ash content expressed as a fraction (assumed to be 8% of faecal DM)

The feed intake of non-lactating cows is calculated from liveweight and liveweight gain data. Additional intake for milk production (MI) is included for lactating cattle.

$$\mathbf{I = (1.185 + 0.0045W - 0.0000026W^2 + 0.315LWG)^2 \times MR + MI} \qquad \textbf{Equation 16}$$

Where:

W = weight (Table 8), kg

LWG = liveweight gain (Table 9), kg/day

MR = increase in metabolic rate when producing milk (SCA 1990), 1.1 for milking and house cows and 1 for all other cases.

Table 7: Dairy cattle - dry matter digestibility of feed intake (%) (DCC 2007)

State	Milking Cows (%)	Heifers >1 yr (%)	Heifers <1 yr (%)	House Cows – Milk and Dry (%)	Dairy Bulls >1 yr (%)	Dairy Bulls <1 yr (%)
NSW/ ACT	75	75	75	75	75	75
Tasmania						
Spring	75	75	75	75	75	75
Summer	65	65	65	65	65	65
Autumn	65	65	65	65	65	65
Winter	75	75	75	75	75	75
Western Australia	75	75	75	75	75	75
South Australia	75	75	75	75	75	75
Victoria	78	78	78	78	78	78
Queensland	70	65	65	60	65	65
Northern Territory	75	75	75	75	75	75

Table 8: Dairy cattle –liveweight (kg) (DCC 2007)

State	Milking Cows	Heifers >1 yr	Heifers <1 yr	House Cows – Milk and Dry	Dairy Bulls >1 yr	Dairy Bulls <1 yr
NSW/ ACT	550	425	240	450	650	300
Tasmania	500	350	220	400	600	250
Western Australia	550	350	180	450	550	250
South Australia	550	450	260	500	500	350
Victoria	550	450	250	450	600	250
Queensland	580	400	150	500	650	200
Northern Territory	500	350	220	400	550	250

Table 9: Dairy cattle –liveweight gain (kg/day) (DCC 2007)

State	Milking Cows	Heifers >1 yr	Heifers < 1 yr	House Cows – Milk and Dry	Dairy Bulls >1 yr	Dairy Bulls <1 yr
NSW/ ACT	0.04	0.6	0.6	0.04	0.2	0.9
Tasmania	0.04	0.5	0.8	0.04	0.1	1
Western Australia	0.06	0.8	0.8	0.06	0.1	1
South Australia	0.06	0.5	0.8	0.06	0.1	1
Victoria	0.04	0.5	0.6	0.04	0.1	1
Queensland	0.06	0.7	0.7	0.06	0.1	0.7
Northern Territory	0.06	0.5	0.8	0.06	0.1	1

Note: These data from the Standing Committee on Agriculture (SCA 1990) and there have been substantial changes in the way dairy cattle are fed since this data was collated.

Pigs

For pigs, the volatile solids production (kg VS/head/day) entering the manure management system is given in Table 10 (DCC 2007).

Table 10: Pigs – volatile solids (kg/head/day) entering manure management system (DCC 2007)

Year	Volatile Solids (kg VS/head/day)			
	Boars	Gilts-intended for breeding	Breeding sow	Other pigs
1990	0.38	0.40	0.47	0.22
1991	0.38	0.42	0.47	0.23
1992	0.38	0.43	0.47	0.23
1993	0.39	0.44	0.48	0.24
1994	0.39	0.46	0.48	0.24
1995	0.39	0.47	0.48	0.25
1996	0.39	0.48	0.48	0.26
1997	0.39	0.50	0.49	0.26
1998	0.39	0.51	0.49	0.27
1999	0.39	0.52	0.49	0.28
2000 +	0.39	0.54	0.49	0.28

Summary of Current Australian Methods Used

In PIG-BAL, DAIRY-BAL and BEEF-BAL, the waste details are presented in the DMDAMP and nutrient balance analysis sheets. The TS, VS, ash and nutrient component of the manure is presented for different classes of animal. The National Environmental Guidelines for Piggeries (NEGP) also uses the same DMDAMP and mass balance theory to predict waste output for different classes of pig.

In DCC (2007) models for high density of animals in feedlots, VS production is estimated using intake and dry matter digestibility data developed to calculate enteric methane production. For pigs, the VS production for each state and different pig classes is given in a table in the appendix. This table was generated with predicted outputs from the PIG-BAL model.

In ASABE (2005) standards, organic matter is estimated with an equation for beef cattle only and VS/TS ratios are also provided. For pigs and dairy cows, TS are estimated from empirical equations and VS is calculated with standard VS/TS ratios. ASAE (1988) provides tables to determine VS/TS ratio for pigs, dairy cows and beef cattle based on live animal mass.

In IPCC (2006), the VS excretion rate calculation is a necessary step to estimate a CH_4 emissions factor from the type of manure management. The VS excretion rate equation is given based on gross energy intake, digestibility, urinary energy and ash content.

Case Study Sites

To test the predictive methods for estimating TS, VS and N production, a series of case studies were conducted. These case studies scenarios were chosen based on actual measured data of TS, VS and N from all or part of a production system. To provide estimates of TS, VS and N production using predictive models and methods, data was required on the production systems. This data collection included herd structure, individual diet ingredients, amount of each ingredient fed, liveweight in and out, and mortalities.

Dairy Sites

No dairy case study was able to be reported on due to the lack of measured data on manure production for Australian dairies. At the beginning of the project, it was claimed by a member of the M2M technical committee that data would become available by the end of this project. After consultation with Dairy Australia and researchers in both Queensland and Victoria, no actual measured data on manure production from a dairy was uncovered. It is believed that there is data that will be potentially available within the next 12 months from Department of Primary Industries Victoria researchers at Ellenbank. If this data collection proceeds, it is important that all feed intake and diet specifications are collected to validate the waste estimation model DAIRY-BAL.

Feedlot Sites

No beef cattle feedlot case study was able to be conducted because of the non-availability of actual measured manure production from a feedlot. The difficulty with measuring manure production from a feedlot is that manure is deposited on an outdoor pad and undergoes decomposition before it is harvested from the pad (generally between 6 and 20 weeks). Further decomposition occurs when the manure is harvested and stockpiled and/or windrow composted. To address this issue, a research project has begun under the Methane to Markets research program of RIRDC (Project No. PRJ-004377 - Quantification of feedlot manure output for BEEF-BAL model upgrade). It is proposed that this project will provide measured feedlot manure production data for comparison against predicted manure output from the BEEF-BAL model. Total solids, volatile solids and moisture content will be measured and losses calculated from feedlot manure under current management practices. This project aims to improve the quality of BEEF-BAL outputs by validating the DMDAMP section of the model.

Piggery Sites

Using PIG-BAL, all the calculations for the predictive models and methods were calculated, including diet dry matter, diet dry matter digestibility, feed intake in terms of N, P, K and ash, and liveweight gain. The PIG-BAL model is the only method that requires feed wastage as an input. For all case study piggeries no information was able to be provided on feed wastage, so the “standard” values provided in the PIG-BAL model were used (Table 11) to provide estimates of waste output using PIG-BAL. A sensitivity analysis was also conducted by varying the feed wastage by ±50% from the standard values.

Table 11: Feed wastage values used in PIG-BAL to predict TS and VS production for different pig classes

Pig Class	Standard Feed Wastage (%)	Standard Feed Wastage x 1.5 (%)	Standard Feed Wastage x 0.5 (%)
Gilt	10	15	5
Boars	5	7.5	2.5
Gestating Sows	5	7.5	2.5
Lactating Sows	5	7.5	2.5
Nursery	20	30	10
Weaner pigs	15	22.5	7.5
Grower pigs	10	15	5
Finisher pigs	10	15	5

As Barth (1985a) stated in the publication of his DAMP method, feed waste, avoidable and unavoidable is a very significant contribution to total manure properties. He estimated that feed waste of 5% can increase manure TS by as much as 40%. To illustrate this, a typical pig diet has a dry matter digestibility of 85%, meaning that for every kg of feed dry matter consumed, 0.15 kg of TS is excreted in the manure (base on the DMDAMP methodology). If, for every kg of dry matter consumed, another 10% (0.1 kg) is wasted and will go directly into the effluent system. Thus, the feed wastage component of the effluent will make up 40% (0.1/0.25) of the TS in the effluent.

Three piggeries were used as case studies, with the size of the piggeries and waste output calculated in terms of the number of standard pig units (SPU). SPU are estimated from the relative amount of VS that each class of pig produces, with one SPU representing an average size grower pig (McGahan and Casey 1997a, McGahan and Casey 1997b). The SPU conversion table in the National Environmental Guidelines for Piggeries (Australian Pork Limited 2004) was used to convert the size of each piggery into number of SPU. The piggeries used in the case studies were classed as small (< 2000 SPU), medium (2000 – 10,000 SPU) and large (>10,000 SPU).

Site 1 – Piggery A

Overview

Piggery A is a medium sized conventional farrow-to-finish piggery in southern Queensland. The piggery is a family operated business, with feed milling conducted on-farm. Skerman et al. (2008) undertook measurements at this site which they refer to as the Dalby piggery.

Herd Details

Herd details were provided and calculated as an average for an entire year (Table 12).

Table 12: Pig numbers, SPU conversions and average static mass of pigs for case study 1 (piggery A).

Pig Class	Number pigs	Number SPU	Static Mass (kg)
Nursery	599	60	2,815
Weaners	964	482	15,665
Growers	949	949	37,723
Finishers	1,508	2,413	116,870
Gestating Sows	394	630	73,875
Lactating Sows	119	298	22,313
Boars	20	32	4,000
Gilts	38	68	4,940
Total	4,591	4,932	278,201

Feed Details

Typical diets used in the piggery over a year were provided. The diets were sorghum based for the grower and finisher pigs, barley based for the dry sows and boars, with a mixture of sorghum, barley and wheat for the remainder of the pigs.

The predicted overall dry matter of all diets combined from PIG-BAL was 89.2%. The predicted overall dry matter digestibility of all feed going into the piggery was 84.7%. Total feed offered is 2,937 t/yr, with total dry matter of 2,620 t/yr, total ash of 111.9 t/yr and total nitrogen of 73.2 t/yr. Overall feed wastage was estimated to be 9.4%. A sensitivity analysis was conducted on feed wastage by varying it between ±50%, giving estimated overall feed wastage varying between 14.2% and 4.7%.

Effluent Collection and Sampling

Skerman et al. (2008) collected effluent samples from the entire flushing event from each shed at the piggery on several occasions over a 14 month period. Effluent was collected during the flush event by pumping almost continuously from the effluent flush channels into a 200 L sample drum using a Davey D15A submersible sump pump capable of handling 20 mm solids. This sample drum was then thoroughly agitated with a paddle stirrer and a 1 L sub-sample was collected and placed in a 25 L drum. It took approximately 5 minutes to fill the 200 L drum. The drum was then quickly emptied and the process repeated until the flush event from the shed was complete. At the end of the flush event the 25 L drum was generally full. This drum was then thoroughly mixed with a paddle stirrer and a 1 L sub-sample was taken from the centre of the drum for analysis.

The collected samples were transported back to the DEEDI laboratory in Toowoomba for testing. A minimum of three x 50 mL replicate sub-samples were then decanted into ceramic crucibles for determination of TS, ash and VS. Further chemical analysis of the samples was conducted by the Toowoomba Regional Council Mt Kynoch Treatment Plant laboratory

Site 2 – Piggery B

Overview

Piggery B is a small sized conventional grower-finisher piggery located in southern Queensland. The piggery receives weaner pigs from a breeder herd approximately 60 km away. The weaner pigs are housed in a single shed as a batch until they are 10 weeks of age. The weaner section of the piggery has its own effluent collection system. The pigs are transferred to the grower-finisher section of the piggery at 10 weeks of age, where they remain until finish (approximately 24 weeks). Feed is supplied by a commercial feed mill. Skerman et al. (2008) undertook measurements at this site which they refer to as the DEEDI Wacol piggery.

Herd Details

Herd details were provided and calculated as an average for the grower-finisher section of the piggery (Table 13).

Table 13: Pig numbers, SPU conversions and average static mass of pigs for case study 2 (piggery B).

Pig Class	Number pigs	Number SPU	Static Mass (kg)
Growers	500	500	19,875
Finishers	500	800	38,750
Total	1,000	1,300	58,625

Feed Details

Typical diets used in the piggery over a year were provided by the commercial feedmill providing the feed to the piggery. The diets were sorghum/maize with some wheat for the grower pigs, with predominantly sorghum and some maize and barley for the finisher pigs.

The predicted overall dry matter of the diets from PIG-BAL was 89.2%. The predicted overall dry matter digestibility of all feed going into the piggery was 86.2%. Total feed intake is 815 t/yr, with total dry matter of 721 t/yr, total ash of 35.1 t/yr and total nitrogen of 20.4 t/yr. Overall feed wastage was estimated to be 10.0%. A sensitivity analysis was conducted on feed wastage by varying it between ±50%, giving estimated overall feed wastage varying between 15.0% and 5.0%.

Effluent Collection and Sampling

Skerman et al. (2008) collected effluent samples 18 times over a 9 month period from a 52,000 L concrete tank that was agitated and was able to store two days of flushed waste from the piggery (40,000 L). Each sampling event from the sump involved the collection of samples over 6 sampling cycles spread evenly throughout the 35 minute sump pump-out cycle. These samples were either collected with a hand-held sampling pump or using the same pump described for Piggery A. Separate samples were also collected from a 10,000 L polythene tank that was also receiving a representative sample of effluent from the sump for a separate experiment. Additional samples of recycled effluent used for flushing were also collected. The collected samples were transported back to the DEEDI laboratory in Toowoomba for testing as per Piggery A.

Site 3 – Piggery C

Overview

Piggery C is a large conventional grower-finisher piggery located in south eastern Australia. The piggery receives weaner pigs from a breeder herd and the pigs remain on site to finisher age. The piggery operates with stationary rundown screens that remove a percentage of the solids from the waste stream before it enters the effluent treatment system. Feed is provided by a commercial mill off-farm.

Herd Details

Herd details were provided and calculated for a one month period (June 30 2008 – July 28 2008). The piggery is divided into four sections, with seven separate diets: nursery (starter and nursery diets), weaner (weaner and porker diets), grower (grower diet) and finisher (finisher diet with and without Paylean). Table 14 has the average number of pigs and average static mass of pigs on each diet for the month of July 2008. The pigs on the finisher diets (with and without Paylean®) were combined.

Table 14: Pig numbers, SPU conversions and average static mass of pigs for case study 3 (piggery C).

Pig Class	Number pigs	Number SPU	Static Mass (kg)
Starter	1,248	125	8,421
Nursery	3,743	1,497	37,430
Weaner	3,500	1,750	61,250
Porker	3,507	2,455	105,195
Grower	6,386	7,025	319,300
Finisher	8,184	13,094	662,864
Total	26,568	25,946	1,194,460

Feed Details

Diets used in the piggery for the trial period (July 2008) were provided by the operator. The diets were predominantly wheat based for the starter, nursery and weaner pigs, with a mixture of sorghum, wheat and barley for the porker, grower and finisher pigs.

Paylean® was used in half of the finisher diet, which represents approximately 25% of the total feed offered during the trial period. Paylean® is a feed additive that is designed to direct nutrient deposition into lean muscle and away from fat deposition. Research trials have shown that Paylean® increases the rate of weight gain, improves feed efficiency and increases carcass leanness in finisher pigs. This ‘associative’ effect that Paylean® has in improving feed efficiency was not taken into account in the estimations of waste production using the PIG-BAL model and hence predicted feed digestibility is likely to be underestimated and hence waste production is likely to be overestimated.

The predicted overall dry matter of the diets from PIG-BAL was 89.6%. The predicted overall dry matter digestibility of all feed going into the piggery was 84.6%. Total feed intake is 13,703 t/yr, with total dry matter of 12,305 t/yr, total ash of 722 t/yr and total nitrogen of 365 t/yr. Overall feed wastage was estimated to be 10.4%. A sensitivity analysis was conducted on feed wastage by varying it between ±50%, giving estimated overall feed wastage varying between 15.6% and 5.2%.

Waste Pre-treatment

Details were provided by the operator on the amount of solids removed from the waste stream over a 55 day period around the time of the test period – July 2008. The number of truckloads of screenings was totalled, along with the mass of a sub-sample of truckloads. Three samples of screenings were also collected and sent for laboratory analysis to determine TS and VS content of the material. From this data it was estimated that the screenings has a TS and VS concentration of 16.8% and 14.5% respectively. From the operator data provided and the laboratory analysis it is estimated that the screens remove 3181 kg/d of TS and 2751 kg/d of VS.

Effluent Collection and Sampling

Birchall (2009) provides a description of the effluent collection and sampling regime at the piggery. Effluent from all the sheds is collected in a central sump that is agitated with a paddle-type stirrer. Effluent sampling occurred continuously during each 24 hr period over 7 days via an automatic sampling station (paddle switch, cycling timer, Onga 421 open-impeller pump, and 750 L uninsulated tank). The sampling pump was designed to run for 30 seconds in each 4 minute period. Each 24 hr composite was agitated before sub-samples were collected and refrigerated until the end of the 7 day event. Effluent in the sump was pumped through a 100 mm Siemens Sitrans Magflo electromagnetic flow meter to measure daily flows. Effluent samples were analysed for TS, VS, Chemical Oxygen Demand (COD), COD soluble, Total Kjeldahl Nitrogen (TKN), Ammonia, Volatile Fatty Acids (VFA).

Comparison – Model and Method Prediction versus Actual

For the three piggery case studies, the model and method predictions of TS, VS and N were compared against actual measured data provided by others: Mr Alan Skerman (Department of Primary Industries and Fisheries – DEEDI) and Mr Scott Birchall (Coomes Consulting Pty Ltd). The models and methods used to compare predicted versus actual are PIG-BAL, National Environmental Guidelines for Piggeries (NEGP), ASAE (1988), DCC and the IPCC methods and models. The DCC method and the IPCC method only predict VS production.

Site 1 – Piggery A

Table 15 provides the predicted VS and TS production for case study 1 (piggery A) using the PIG-BAL, NEGP, ASABE (2005), ASAE (1988), DCC and IPCC methods and models versus the actual measured data provided by the DEEDI. A sensitivity analysis is also shown for PIG-BAL, with feed wastage varied between ±50% of the “standard” values provided in PIGBAL.

Table 15: Estimates of VS and TS production versus measured output for case study 1 (piggery A).

Method	VS (kg/d)	TS (kg/d)	VS (t/yr)	TS (t/yr)	VS (kg/SPU/yr)	TS (kg/SPU/yr)	VS:TS Ratio
PIG-BAL	1,548	1,795	565	656	115	133	0.86
PIG-BAL (+50% feed wastage)	1,925	2,193	703	800	143	162	0.88
PIG-BAL (-50% feed wastage)	1,213	1,440	443	526	90	107	0.84
NEGP	1,249	1,521	456	555	92	113	0.82
ASABE (2005)	1,415	1,721	517	629	105	127	0.82
ASAE (1988)	2,365	3,060	864	1,118	175	227	0.77
DCC	1,405	-	513	-	104	-	-
IPCC	1,236	-	451		92	-	-
Measured Data	1,613	1,859	589	679	119	138	0.87

Table 16 provides the N production for case study 1 (piggery A) using the PIG-BAL, NEGP, ASABE (2005) and ASAE (1988) methods and models versus the actual measured data provided by the DEEDI.

Table 16: Estimates of N production versus measured output for case study 1 (piggery A).

Method	N (kg/d)	N (t/yr)	N (kg/SPU/yr)
PIG-BAL	147	53.7	10.9
PIG-BAL (after shed losses)*	135	49.4	10.0
NEGP	129	47.2	9.6
ASABE (2005)	139	50.6	10.3
ASAE (1988)	145	52.8	10.7
Measured Data	NA	NA	NA

* After shed losses of nitrogen due to volatilisation of 8% are taken into account.

Site 2 – Piggery B

Table 17 provides the predicted VS and TS production for case study 2 (piggery B) using the PIG-BAL, NEGP, ASABE (2005), ASAE (1988), DCC and IPCC methods and models versus the actual measured data provided by the DEEDI. A sensitivity analysis is also shown for PIG-BAL, with feed wastage varied between ±50% of the “standard” values provided in PIGBAL.

Table 17: Estimates of VS and TS production versus measured output for case study 2 (piggery B).

Method	VS (kg/d)	TS (kg/d)	VS (t/yr)	TS (t/yr)	VS (kg/SPU/yr)	TS (kg/SPU/yr)	VS:TS Ratio
PIG-BAL	398	474	145	173	112	133	0.84
PIG-BAL (+50% feed wastage)	509	592	186	216	143	166	0.86
PIG-BAL (-50% feed wastage)	302	372	110	136	86	105	0.81
NEGP	327	396	120	145	92	111	0.83
ASABE (2005)	375	467	137	170	105	131	0.80
ASAE (1988)	498	645	182	236	140	181	0.77
DCC	280	-	102	-	79	-	-
IPCC	311	-	114	-	87	-	-
Measured Data	294	342	107	125	82	96	0.86

Table 18 provides the N production for case study 2 (piggery B) using the PIG-BAL, NEGP, ASABE (2005) and ASAE (1988) methods and models versus the actual measured data provided by the DEEDI.

Table 18: Estimates of N production versus measured output for case study 2 (piggery B).

Method	N (kg/d)	N (t/yr)	N (kg/SPU/yr)
PIG-BAL	36	13.2	10.2
PIG-BAL (after shed losses)*	33	12.2	9.4
NEGP	34	12.5	9.6
ASABE (2005)	39	14.3	11.0
ASAE (1988)	30	11.1	8.6
Measured Data	NA	NA	NA

* After shed losses of nitrogen due to volatilisation of 8% are taken into account.

Site 3 – Piggery C

Table 19 provides the predicted VS and TS production for Case Study 3 (Piggery C) using the PIG-BAL, NEGP, ASABE (2005), ASAE (1988), DCC and IPCC methods and models. These predictions are based on actual excretions, before screen removal.

Table 20 provides predicted VS and TS production for Case Study 3 (Piggery C) for the various methods and models versus the actual measured data provided by Birchall (2009) after the estimated screen removal of 2751 kg/d of VS and 3181 kg/d of TS. A sensitivity analysis is also shown for PIG-BAL, with feed wastage varied between ±50% of the "standard" values provided in PIGBAL.

Table 19: Estimates of VS and TS production for Case Study 3 (Piggery C)

Method	VS (kg/d)	TS (kg/d)	VS (t/yr)	TS (t/yr)	VS (kg/SPU/yr)	TS (kg/SPU/yr)	VS:TS Ratio
PIG-BAL	7,269	8,698	2,655	3,177	102	122	0.84
NEGP	6,708	8,052	2,450	2,941	94	113	0.83
ASABE (2005)	7,722	9,568	2,821	3,495	109	135	0.81
ASAE (1988)	10,153	13,139	3,708	4,799	143	185	0.77
DCC	7,439	-	2,717	-	105	-	-
IPCC	5,807	-	2,121	-	82	-	-

Table 20: Estimates of VS and TS production versus measured output for case study 3 (piggery C) after estimated screen removal.

Method	VS (kg/d)	TS (kg/d)	VS (t/yr)	TS (t/yr)	Percent VS Removal	Percent TS Removal
PIG-BAL	4,518	5,517	1,650	2,015	37.8	36.6
PIG-BAL (+50% feed wastage)	6,455	7,554	2,358	2,759	30.0	29.5
PIG-BAL (-50% feed wastage)	2,696	3,673	985	1,342	50.5	46.4
NEGP	3,957	4,871	1,445	1,779	41.0	39.5
ASABE (2005)	4,971	6,387	1,816	2,333	35.6	33.2
ASAE (1988)	7,402	9,958	2,704	3,637	27.1	24.2
DCC	4,688	-	1,712	-	37.0	-
IPCC	3,056	-	1,116	-	47.4	-
Measured Data	4,483	6,473	1,637	2,364	Not measured	Not measured

Table 21 provides the nitrogen production estimations for Case Study 3 (Piggery C) using the PIG-BAL, NEGP, ASABE (2005) and ASAE (1988) methods and models. No analysis was conducted on N removal with the stationary rundown screens, thus no estimates are provided on N production for this piggery after screening for the various models. Nitrogen was however measured in the waste stream.

Table 21: Estimates of N production versus measured output for case study 3 (piggery C).

Method	N (kg/d)	N (t/yr)	N (kg/SPU/yr)
PIG-BAL	547	200	7.7
PIG-BAL (after shed losses)*	504	184	7.1
NEGP	688	251	9.7
ASABE (2005)	805	294	11.3
ASAE (1988)	621	227	8.7
Measured Data**	679	248	9.5

* After shed losses of nitrogen due to volatilisation of 8% are taken into account.

** Measured in waste stream by Birchall (2009).

Summary of Model Predictions

Table 22 provides the percentage difference in VS production for estimates versus measured data for the three case study piggeries. The predicted VS production uses the PIG-BAL, NEGP, ASABE (2005), ASAE (1988), DCC and IPCC methods and models, while the measured data was provided by DEEDI Queensland (Skerman et al. 2008) and Coomes Consulting Pty Ltd (Birchall 2009).

Table 22: Percent difference in VS produced for predicted versus measured data for the piggeries

Method	Site 1 – Piggery A	Site 2 – Piggery B	Site 3 – Piggery C
PIG-BAL	-4	35	1
PIG-BAL (+50% feed wastage)	19	73	44
PIG-BAL (-50% feed wastage)	-25	3	-40
NEGP	-23	11	-12
ASABE (2005)	-12	28	11
ASAE (1988)	47	69	65
DCC	-13	-5	5
IPCC	-23	6	-32

Table 23 provides the percentage difference in TS production for estimates versus measured data for the three case study piggeries. The predicted TS production uses the PIG-BAL, NEGP, ASABE (2005) and ASAE (1988) methods and models, while the measured data was provided by DEEDI Queensland and Coomes Consulting Pty Ltd.

Table 23: Percentage difference in TS production for predicted versus measured data for the piggeries

Method	Site 1 – Piggery A	Site 2 – Piggery B	Site 3 – Piggery C
PIG-BAL	-3	39	-15
PIG-BAL (+50% feed wastage)	18	73	17
PIG-BAL (-50% feed wastage)	-23	9	-43
NEGP	-18	16	-25
ASABE (2005)	-7	37	-1
ASAE (1988)	65	89	54

Table 24 provides the percentage difference in nitrogen production for estimates versus measured data for one the case study piggeries. The predicted nitrogen production uses the PIG-BAL, NEGP, ASABE (2005) and ASAE (1988) methods and models, while the measured data was provided by Coomes Consulting Pty Ltd. No measured data for nitrogen production was provided for Piggery A and Piggery B.

Table 24: Percentage difference in N produced for predicted versus measured data for two piggeries

Method	Site 3 – Piggery C
PIG-BAL	-19%
PIG-BAL (after shed losses)*	-26%
NEGP	1%
ASABE (2005)	19%
ASAE (1988)	-9%

Site 1 – Piggery A

The PIG-BAL prediction of VS and TS is 4% and 3% respectively less than the measured data provided by DEEDI Queensland. The next closest method was the ASABE (2005) standard, with VS and TS prediction 12% and 7% respectively less than the measured data provided. Both the NEGP and the IPCC method underestimated VS production by 23%. The DCC method underestimated VS production by 13%. The ASAE (1988) standard, which estimates manure production based on animal mass was the least effective, with an over-prediction of VS of 47% and TS of 65%.

Varying the amount of feed wastage in Pig-BAL by ±50% from the “standard” values results in predictions of VS and TS being within 20 – 25% of the measured data.

No measured data was provided on nitrogen production for the piggery. The predicted nitrogen production from PIG-BAL was 147 kg/d, with the variation between models less than that for TS and VS, where the range was 129 kg/d (NEGP) to 145 kg/d (ASAE 1988).

Piggery A was able to supply detailed performance, feed usage and feed analysis data for all classes of pig at the piggery over an entire year of production. A detailed sampling strategy was also employed by DEEDI, where effluent from each of the sheds on the farm was sub-sampled from the flush drains during an entire flush event to provide a representative composite sample of effluent. No actual measured effluent production data was provided for the piggery, only a total volume of flush water used (37.2 L/pig/day). Therefore, the volume of effluent generated and hence the amount of TS and VS produced will be greater for the measured data than if the actual manure (urine and faeces) volume, cleaning (hosing) water and spilt drinking water are included.

The additional effluent is estimated to approximately 2.0 L/pig/day based on calculations from Wiedemann et al. (2009) on drinking water usage and subsequent outputs of water from a conventional flushing farrow to finish piggery during a Life Cycle Assessment study of two piggery supply chains. If this additional liquid was added, it would subsequently increase the measured amount of TS and VS by approximately 5%. With this increase, the measured VS and TS production of manure would be within 10% of the predicted data using PIG-BAL.

Site 2 – Piggery B

The PIG-BAL prediction of VS and TS is 35% and 39% respectively more than the measured data provided by DEEDI Queensland. The closest methods for predicting VS production were the AGO method (5% less) and the IPCC method (6% greater). The NEGP predicted VS and TS 11% and 16% respectively more than the measured data provided. Again the ASAE (1988) standard was the least effective, with an over-prediction of VS of 69% and TS of 89%.

Varying the amount of feed wastage in Pig-BAL by +50% from the “standard” values results in predictions of VS and TS being 73% higher than the measured data. Varying the amount of feed wastage in PIG-BAL by -50% from the “standard” values results in predictions of VS and TS being 3% and 9% higher respectively than the measured data.

No measured data was provided on nitrogen production for the piggery. The predicted nitrogen production from PIG-BAL was 36 kg/d, with the variation between models less than that for TS and VS, where the range was 30 kg/d (ASAE 1988) to 39 kg/d (ASABE 2005).

Piggery A was able to supply typical production data for the piggery (500 growers and 500 finishers). The amount of feed purchased over a one year period, with the typical diets also provided.

A detailed sampling strategy was also employed by DEEDI, where effluent from the sheds flows into a central sump before being pumped into the effluent treatment system. The effluent is mixed in the sump and sub-sampled to provide a representative composite sample of effluent. No actual measured effluent production data was provided for the piggery, only a total volume of flush water used (20 L/pig/d). Therefore the volume of effluent generated and hence the amount of TS and VS produced would be greater for the measured data than if the actual manure (urine and faeces) volume, cleaning (hosing) water and spilt drinking water are included.

The additional effluent is estimated to approximately 2.2 L/pig/day based on calculations from Wiedemann et al. (2009) on drinking water usage and subsequent outputs of water from a conventional flushing grower piggery during a Life Cycle Assessment study of two piggery supply chains. If this additional liquid was added, it would subsequently increase the measured amount of TS and VS produced by approximately 11%. With this increase, the measured VS and TS production of manure would be within 25% of the predicted data using PIG-BAL.

Site 3 – Piggery 3

The PIG-BAL prediction of VS is only 1% more than the measured data provided by Coomes Consulting. The next closest method was the AGO method, with VS 5% greater than the measured data provided. The prediction from the NEGP (12% less) and the ASABE (2005) standard (11% more) were also relatively close to the predicted data. The IPCC method was less effective at predicting manure production for this piggery (32% less). Again the old ASAE (1988) standard, which basis manure production on animal mass was the least effective at predicting VS production, with an over-prediction of 65%.

The PIG-BAL estimation of TS is not as close to the measured data, with a prediction of 15% less than the measured data provided by DEEDI Queensland. The ASABE (2005) standard was however, within 1% of the measured data. Again the ASAE (1988) standard was the least effective at predicting TS production, with an over-prediction 54%.

Varying the amount of feed wastage in PIG-BAL by +50% from the “standard” values results in predictions of VS and TS being 44% and 17% higher respectively than the measured data. Varying the amount of feed wastage in PIG-BAL by -50% from the “standard” values results in predictions of VS and TS being about 40% lower than the measured data.

The PIG-BAL prediction of nitrogen production is 19% less than the measured data. The NEGP proved to have the closest prediction (1% more), with the ASABE (2005) standard over-predicting N production by 19%.

Piggery C was able to supply very detailed performance, feed usage and feed analysis data for all classes of pig at the piggery for a month during the time the measured effluent samples were collected. A detailed sampling strategy was also employed by Birchall (2009), where effluent was automatically sub-sampled from the effluent after screening and effluent volumes were also able to be accurately measured.

This piggery did however screen the effluent after it left the sheds, prior to entering the waste treatment system. This made predicting the amount of VS, TS and N produced by the piggery more difficult. Sub-samples of screenings were collected and analysed, along with the amount of screenings removed, however not all the screened solids were able to be weighed, with a representative truck mass obtained from three truck loads out of 76 averaged for the month. The variation in the three weighed truckloads was 6%.

Since the completion of this study Coomes Consulting Pty Ltd has conducted further effluent production studies at this piggery with the solids removal screens removed. Birchall (2009) reports VS production with the screens turned off to be 7,280 kg/d, which is within 0.1% of the measured data.

Conversion Factors for Manure to Methane

To determine the methane production from manure, it is necessary to convert VS content to methane generation. This is done by applying the B_o factor and the MCF factor.

B_o Factor

B_o is the maximum methane-producing capacity for manure produced by an animal and has the units of m^3 CH_4/kg VS (IPCC 2006). B_o varies with animal type (via differences in digestive capacity) and feed type.

IPCC (2006) provides typical B_o values for different livestock species and locations. Table 25 shows IPCC values for B_o for pigs, dairy cattle and beef cattle in Australia (Oceania).

Table 25: Maximum methane-producing capacity of the manure (B_o) - Oceania (IPCC 2006)

Animal	B_o m^3 CH_4/ kg VS
Swine	0.45
Dairy cattle	0.24
Non-dairy cattle	0.17

Moller et al. (2004) note that "methane productivity" from manure can be measured in terms of volatile solids (VS) destroyed, VS loaded, volume, or animal production. Methane productivity measured in terms of VS destroyed (m^3 CH_4/kg VS_{DES}) corresponds to the **theoretical methane yield** (B_u) if there is complete degradation of all organic components of the manure. The theoretical methane potential can be calculated from Bushwell's formula. Methane productivity in terms of VS loaded (m^3 CH_4/kg VS_{load}) as residence time approaches infinity is referred to as the **ultimate methane yield** (B_o). The **ultimate methane yield** will always be lower than the **theoretical methane yield** because a fraction of the substrate is used to synthesize bacterial mass, a fraction of the organic material will be lost in the effluent, and lignin-containing compounds will only be degraded to a limited degree (Moller et al. 2004). Inhibition of the biological process by inhibitors such as ammonia and volatile fatty acids (VFA) is another factor contributing to the actual methane yield being lower than the potential yield which would be obtained if inhibition was not present. It has been observed that both the ultimate methane yield (B_o) and the volumetric methane production (L CH_4/ m^3 manure) of manure from different origins can be very variable. Moller et al. (2004) notes that the **ultimate methane yield** (m^3 CH_4/kg VS) is affected by various factors, including:

- species, breed and growth stage of the animals.
- feed.
- amount and type of bedding material.
- degradation processes during pre-storage.

This discussion about the definition of B_o by Moller et al. (2004) highlights the lack of clear definitions in this area. Most researchers assume that B_o refers to fresh manure directly from the animal prior to any breakdown and without additions from bedding and wasted feed. This is a parameter that is intrinsic to the animal and independent of the housing and feeding system. However, the discussion by Moller et al. (2004) suggests that B_o takes into account housing and feeding systems. This has clear implications for actual methane yield predictions from a manure treatment system depending on the MCF applied.

B_o is determined by anaerobically digesting a sample of manure and measuring the methane yield. However, Vedrenne et al. (2008) point out that there is no standard methodology for the determination of B_o and different researchers have used different methodologies. The variations in methodology include:

- Incubation temperature (varies from 35°C to 55°C).
- Source and amount of inoculums added.
- Timing and amount of mixing of the sample.
- Amount of dilution of the sample.
- Incubation time (50 to 157 days).

Not surprisingly, both Vedrenne et al. (2008) and Karim et al. (2005) have found that variation of any of these parameters affects maximum methane yield. Hence, apart from variations between species and feed type, B_o data will vary depending on experimental protocol and should be evaluated with a knowledge of the experimental procedures adopted.

For example, ICF Consulting (1999) provides B_o values for beef, dairy and swine for various diets as collated from a range of researchers (see Table 26). This table shows the variability of the data.

Table 27 presents data from a recent experiment in France with a maximum and minimum B_o value for swine and dairy cattle slurry (Vedrenne et al. 2008). The swine value from France is lower than the value from IPCC, perhaps because they include a slurry component. For dairy cattle, the IPCC value is about the average of the French values.

Amon et al. (2004) determined B_o for dairy cattle manures where the feed and milk yield varied. They found a range of B_o from 0.132 to 0.166 m^3 CH_4/kg VS. They concluded that lignin in the manure reduced the specific methane yield. The higher the feeding intensity and the milk yield, the greater was the reduction in methane yield through an increase in lignin content.

Moller et al. (2004) determined both **theoretical methane yield** and **ultimate methane yield (B_o)** for pigs and dairy cattle. The theoretical methane productivity is higher in pig (0.516 m^3 CH_4/kg VS) and sow (0.530 m^3 CH_4/kg VS) manure than in dairy cattle manure (0.469 m^3 CH_4/kg VS), while the ultimate methane yield in terms of VS is considerably higher in pig (0.356 m^3 CH_4/kg VS) and sow manure (0.275 m^3 CH_4/kg VS) than in dairy cattle manure (0.148 m^3 CH_4/kg VS).

Table 26: Maximum CH_4-Producing Capacity for U.S. Livestock Manure (ICF Consulting 1999)

Animal Type	Diet	Converted B_o (m^3CH_4/kg VS)	References cited
Beef	7% corn silage, 87.6% corn	0.29	(Hashimoto et al. 1981)
	Corn-based high energy	0.33	(Hashimoto et al. 1981)
	91.5% corn silage, 0% corn	0.17	(Hashimoto et al. 1981)
		0.23	(Hill 1984)
		0.33	(Chen et al. 1980)
Dairy	58-68% silage	0.24	(Morris 1976)
	72% roughage	0.17	(Bryant et al. 1976)
		0.14	(Hill 1984)
	Roughage, poor quality	0.10	(Chen et al. 1988)
Swine	Barley-based ration	0.36	(Summers and Bousfield 1980)
	Corn-based high energy	0.48	(Hashimoto 1984)
		0.32	(Hill 1984)
	Corn-based high energy	0.52	(Kroeker et al. 1979)
	Corn-based high energy	0.48	(Stevens and Schulte 1979)
	Corn-based high energy	0.47	(Chen 1983)
	Corn-based high energy	0.44	(Iannotti et al. 1979)
	Corn-based high energy	0.45	(Fischer et al. 1975)

Table 27: Measured maximum methane-producing capacity of the manure (Bo) (Vedrenne et al. 2008)

Slurry	Bo	
	Min	Max
Swine	0.244	0.343
Dairy cattle	0.204	0.296

Table 28 summarises the reported range of B_o for pigs, dairy cattle and beef cattle compared to the default value used in the Australian NGGI methods (DCC 2007). It can be seen that range of reported values varies by at least twofold for each species. Clearly, it is difficult to choose an appropriate value at this time, yet it has a profound effect on the prediction of maximum potential methane yield from manure.

Table 28: Reported range of Bo for pigs, dairy cattle and beef cattle

Species	B_o (m^3 CH_4/ kg VS)		
	lower value	upper value	DCC default
Pigs	0.24	0.52	0.45
Dairy cattle	0.10	0.30	0.24
Beef cattle	0.17	0.33	0.17

No papers providing B_o data measured in Australia have been found. At the moment, there is no Australia specific value of B_o and this information would be essential to provide more accurate estimation of methane production for piggeries, beef feedlots and dairies under Australian conditions.

MCF Factor

MCF is methane conversion factor (MCF) that reflects the portion of B_o that is achieved (IPCC 2006). The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF. Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. These manure management conditions can have high MCFs, of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1%. DCC (2007) recommends the use of 90% as the MCF for lagoons at piggeries.

Conclusions

For Piggery A, the PIG-BAL model, with “standard” feed wastage rates supplied was able to closely predict (within 5%) the actual amount of TS and VS produced when compared to measured data. No other predictive methods and models were able to predict the amount of solids produced. This piggery was also able to supply detailed production data, feed usage and actual feed ingredients for the piggery over a 12 month period to enable accurate inputs to the PIG-BAL model. This piggery also had a rigorous sampling strategy to provide average solids concentrations. The volumes of effluent and hence the amount of solids produced is likely to be underestimated if the true volume of effluent produced that includes spilt drinking water, manure volume (urine and faeces) and cleaning water are added to the flush water. It is estimated that the additional effluent produced from these sources would increase the amount of effluent by approximately 5% and hence the predicted VS and TS production is within 10% of the measured data.

For Piggery B, the PIG-BAL model with “standard” feed wastage rates supplied provided a poor estimation of both VS and TS production. This is likely due to two reasons. Firstly, the actual volume of effluent produced was not measured (only flushing water) and the additional effluent produced would have increased the amount of VS and TS actually produced by around 11%. Also, the feed usage data provided by this piggery appeared to be high, with an average finisher pig (20 weeks) using 2.6 kg/d. A figure of around 2.2 – 2.3 kg/d would appear to be more realistic for pigs of this age. This increased feed usage would have the effect of over-estimating solids (VS and TS) production. Interestingly the DCC method, which is based on standard tables closely matched (within 5%) the measured data. This is likely due to the DCC method tabulated values supplied being generated with PIG-BAL, using more realistic feed usage rates.

For Piggery C, the PIG-BAL model, using “standard” feed wastage rates supplied was able to closely predict the actual amount of VS produced (within 1%) when compared to measured data. This piggery was also able to supply detailed production data, feed usage and actual feed ingredients for the piggery over a 1 month period while a detailed parallel effluent sampling was conducted. This piggery also had the most rigorous testing regime to obtain effluent concentrations. Total volumes of effluent produced were also measured, not just estimates based on flushing volumes. The prediction of TS for Piggery C using the PIG-BAL model was less accurate, with an under-prediction of 15% compared to the measured data. There is no clear explanation for this, except for the issue that the piggery was screening solids prior to the effluent being sampled and the amount of solids removed during screening had to be partially estimated. Since the data for this projected was collated further testing has taken place at the piggery with the screens inactivated. Sampling at this piggery has shown that VS production has increased by approximately 35%, the same amount that was estimated to be removed in this study.

Overall it can be concluded that the PIG-BAL model can provide a good estimate of VS production and hence potential methane production as it allows “real data” to be input on production details, diet ingredients fed and amount of feed used. However, the input value of percent feed wastage used in PIG-BAL was shown to have a large impact on the predicted values of VS and TS production. For the three case study piggeries, modifying the “standard” feed wastage values in PIG-BAL by ±50% resulted in variations of VS production from between 21 and 40%, with TS varying between 20 and 34%. This highlights the importance of being able to accurately estimate feed wastage.

A possible improvement to the PIG-BAL model is to remove the feed wastage percentage as an input and make feed conversion ratio (FCR) an input variable. Guidance could be provided to the user on typical high, medium and low FCR for different herd structures (e.g farrow-to-finish, farrow-to-wean, weaner, grower-finisher etc) for different housing types (e.g. conventional flushing, flushing and environmentally controlled, deep litter). Feed ingested and feed wastage could then theoretically back-calculated by reviewing and including feed required for maintenance and activity. This would reduce the number of inputs required by the user. This type of change may also warrant the investigation changing the model to an energy balance model similar to that adopted by IPCC.

Other predictive methods are also potentially useful for predicting manure production provided they are based on up-to-date feed digestibility/energy availability and feed intake data. Methods that use standard text book values (such as the old ASAE (1988) standard) are very poor at predicting manure production.

Recommendations

From this study the following recommendations can be made:

1. Collect effluent production data from an intensive dairy system so that comparisons can be made against predictions from the DAIRY-BAL model and the other methods and models in this report. The dairy industry is likely to offer more potential for harvested energy from manure as it continues to expand.

2. Collect manure production and decomposition data from beef cattle feedlots so that comparisons can be made against predictions from the BEEF-BAL model and the other methods and models in this report. The feedlot industry is a very large producer of organic waste and potentially offers the greatest potential for harvesting energy from the intensive animal industries.

3. Ensure further studies that measure manure production from piggery systems also collect production and feed data to enable further validation of the PIG-BAL model. This should also involved controlled experiments using metabolic cage experiments. The case studies piggeries investigated in this report that had both good production and feed data, as well as reliable effluent concentration and volume data showed that modern predictive models and methods that use feed usage and digestibility (such as PIG-BAL) can give reliable estimates of VS production.

4. Ensure that the balance models that are commonly used in Australia for estimating manure production (PIG-BAL and BEEF-BAL) are kept up-to-date with the latest digestibility and nutrient content of feed ingredients that are an important input to these models. It would also be useful to investigate the updating of these models with energy balance predictive methods, as this information is more readily available in the Australian literature than dry matter digestibility values for individual feed ingredients.

5. Develop methane potential (B_o) standards and analysis data for Australia conditions.

References

AFRC 1996, *Energy and Protein Requirements of Ruminants,* G Alderman (ed.), An advisory manual prepared by AFRC Technical Committee on Responses to Nutrients, CAB International, Wallingford, U.K

Amon, T, Kryvoruchko, V and Amon, B 2004, 'Methane production from maize, grassland and animal manures through anaerobic digestion', in *Sustainable Organic Waste Management for Environmental Protection and Food Safety II*, pp. 175-182.

APHA 1989, *Fixed and Volatile Solids Ignited at 550°C* (APHA 2540E), Standard Methods for the Examination of Water and Waste water, 17th edn, American Public Health Association New York, USA.

ASABE 2005, *Manure production and characteristics* (ASAE D384.2), American Society of Agricultural and Biological Engineers, St. Joseph, USA.

ASAE 1988, *Manure production and characteristics* (ASAE D384.1), American Society of Agricultural Engineers, St. Joseph, MI, USA.

ASTM 2008, *D 2974-07a - Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils* (PA 19428-2959), ASTM International, West Conshohocken.

Australian Pork Limited 2004, *National Environmental Guidelines for Piggeries,* APL (APL), August 2004, Deakin, A.C.T.

Bamualim, A and Kartiarso 1985, 'Nutrition of draught animals with special reference to Indonesia', in *Draught Animal Power for Production*, JW Copland (ed.), Proceedings Series No. 10, Australian Centre for International Agricultural Research (ACIAR), Canberra.

Barth, CL 1985a, 'Livestock waste characterization - a new approach', in *Proceedings of the 5th International Symposium on Agricultural Wastes*, St Joseph, MI, USA, sponsered by Agricultural Waste Utilization and Management, American Society of Agricultural Engineers pp. 286-294.

Barth, CL 1985b, 'The Rational Design Standard for anaerobic livestock waste lagoons', in *Proceedings of the 5th International Symposium on Agricultural Wastes*, St Joseph, MI, USA, sponsered by Agricultural Waste Utilization and Management, American Society of Agricultural Engineers, pp. 638-647.

Barth, CL and Kroes, J 1985, 'Livestock waste lagoon sludge characterization', in *Agricultural Waste Utilization and Management: proceedings of the 5th International Symposium on Agricultural Wastes*, St Joseph, MI. USA, American Society of Agricultural Engineers, pp. 660-671.

Birchall, S 2009, *Biogas Production by Covered Lagoons - Performance Data from Bears Lagoon Piggery,* Rural Industries Research and Development Corporation, RIRDC Project No PRJ-002705, October 2009, Barton, A.C.T.

Bryant, MP, Varel, VH, Frobish, RA and Isaacson, HR 1976, in, HG Schlegel (ed.), Seminar on Microbial Energy Conversion. E. Goltz KG. Gottingen, Germany, 347 pp.

Chen, TH, Day, DL and Steinberg, MP 1988, 'Methane production from fresh versus dry dairy manure', *Biological Wastes,* vol. 24, no. 4, pp. 297-306.

Chen, YR 1983, 'Kinetic analysis of anaerobic digestion of pig manure and its design implications', *Agricultural Wastes*, vol. 8, no. 2, pp. 65-81.

Chen, YR, Varel, VH and Hashimoto, AG 1980, 'Effect of temperature on methane fermentation kinetics of beef-cattle manure', *Biotechnology and Bioengineering Symposium*, vol. 10, pp. 325-339.

Clanton, CJ, Gilbertson, CB, Schulte, DD and Peo, ER 1988, 'Model for Predicting the Effect of Nitrogen Intake, Body Mass and Dietary Calcium and Phosphorus on Manure Nitrogen Content', *Transactions of the ASAE*, vol. 31, no. 1, pp. 208-214.

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 >.

Dumas, A, Dijkstra, J and France, J 2008, 'Mathematical modelling in animal nutrition: a centenary review', *The Journal of Agricultural Science*, vol. 146, no. 2, pp. 123-142, viewed 2008, < http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1816684&fulltextType=RA&fileId=S0021859608007703 >.

Erickson, GE, Auvermann, B, Eigenberg, RA, Greene, LW, Klopfenstein, T and Koelsch, R 2003, 'Proposed Beef Cattle Manure Excretion and Characteristics for ASAE', in *Proceedings of the Ninth International Animal, Agricultural and Food Processing Wastes Symposium*, RT Burns (ed.), Research Triangle Park, North Carolina USA, ASAE Publication Number 701P1203 pp. 269-276.

Fischer, JR, Seivers, DM and Fulhage, DC 1975, 'Anaerobic digestion in swine wastes', in *Energy, Agriculture and Waste Management: Proceedings of the 1975 Cornell Agricultural Waste Management Conference*, WJ Jewell (ed.), Ann Arbor, Michigan, Ann Arbor Science Publishers Inc., pp. 307-316.

Fulhage, CD 2003, 'Proposed Revision of ASAE D384.1 for Representative Values of “As-Excreted” Manure Production', in *Proceedings of the Ninth International Animal, Agricultural and Food Processing Wastes Symposium*, RT Burns (ed.), Research Triangle Park, North Carolina USA, ASAE Publication Number 701P1203, pp. 257-262.

GHD Pty Ltd 2008, *Assessment of Methane Capture and Use from the Intensive Livestock Industry*, RIRDC Project No PRJ-000875, Rural Industries Research and Development Corporation, RIRDC Publication No 08/025, June 2008, Barton, A.C.T.

Gibbs, MJ and Johnson, DE 1993, 'Livestock Emissions', in *International Methane Emissions*, US Environmental Protection Agency, Climate Change Division, Washington, D.C., U.S.A.

Hashimoto, AG 1984, 'Methane from swine manure: effect of temperature and influent substrate concentration on kinetic parameter (K)', *Agricultural Wastes*, vol. 9, no. 4, pp. 299-308.

Hashimoto, AG, Varel, VH and Chen, YR 1981, 'Ultimate methane yield from beef cattle manure: effect of temperature, ration constituents, antibiotics and manure age', *Agricultural Wastes*, vol. 3, no. 4, pp. 241-256.

Hill, DT 1984, 'Methane productivity of the major animal waste types', *Transactions of the ASAE*, vol. 27, no. 2, pp. 530-534.

Iannotti, EL, Porter, JH, Fischer, JR and Sievers, DM 1979, 'Changes in swine manure during anaerobic digestion', *Developments in Industrial Microbiology*, vol. 20, pp. 519-529.

ICF Consulting 1999, *Chapter 7 - Greenhouse Gas Emissions from Manure Management*, vol VIII, Prepared for Greenhouse Gas Committee, Emission Inventory Improvement Program, US EPA, August 1999, < www.epa.gov/ttn/chief/old/eiip/vol08/ch07/viii07_oct1999 >.

IPCC 2006, *IPCC Guidelines for National Greenhouse Gas Inventories*, HS Eggleston, L Buendia, K Miwa, T Ngara and K Tanabe (eds.), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.

Jurgen, MH 1988, *Animal Feeding and Nutrition*, Sixth Edn, Kendall/Hunt Publishing Company, Dubuque, Iowa, U.S.A.

Karim, K, Hoffmann, R, Klasson, T and Al-Dahhan, MH 2005, 'Anaerobic digestion of animal waste: Waste strength versus impact of mixing', *Bioresource Technology*, vol. 96, no. 16, pp. 1771-1781.

Kroeker, EJ, Schulte, DD, Sparling, AB and Lapp, HM 1979, 'Anaerobic Treatment Process Stability', *Journal of Water Pollution Control Federation*, vol. 51, no. 4, pp. 718-727.

Maynard, LA 1953, 'Editorial Review: Total Digestible Nutrients as a Measure of Feed Energy', *The Journal of Nutrition*, pp. 15-21, viewed 28 November 2009, < www.jn.nutrition.org >.

McGahan, EJ and Casey, KD 1997a, 'Defining the Size of a Pig Production Unit by its Waste Production (Standard Pig Units)', in *Proceedings of Queensland Pig Science Seminar, Queensland Pig Consultancy Group*, Gatton, Qld., pp. 46.

McGahan, EJ and Casey, KD 1997b, 'A New Unit for Defining the Size of a Pig Enterprise for Environmental Management Purposes', in *Proceedings of Manipulating Pig Production V*, Canberra, sponsered by Australasian Pig Science Association, pp. 298.

McGahan, EJ and Casey, KD 1998, 'Use of a modified version of the DAMP model to define the size of pig production enterprises (standard pig units)', in *In Proceedings of ASAE Meeting*, St Joseph, MI, USA, Paper No.984126

McGahan, EJ, Casey, KD, Duperouzel, D and Smits, RJ 2000, 'Validation of Waste Estimation Theory for Intensive Pig Production Systems', in *Proceedings of the Eighth International Symposium on Animal, Agricultural and Food Processing Wastes*, Des Moines, Iowa, pp. 96-102.

McGahan, EJ, Duperouzel, D and Casey, KD 2001a, *Validation of AUSPIG and PIGBAL models for Predicting Effluent Output and Reducing Feed Wastage (DPI Component)*, Project BMI 17/1349, Amended Final Report (March 2001). Pig R&D Corporation, Canberra, ACT.

McGahan, EJ and van Sliedregt, H 2000, 'The Effect of Diet on Waste Output from Piggeries', Paper presented to the *Second National Pig Environment Conference* Gatton, Qld., 29-30 June 2000.

McGahan, EJ, van Sliedregt, H, Skerman, AS, Dunlop, M and Redding, MR 2001b, *Draft DairyBal Version 1.0 - A Nutrient and Effluent Mass Balance Spreadsheet for Dairy Farms*, Report prepared for the Department of Primary Industries, FSA Environmental, Toowoomba, Qld.

Moller, HB, Sommera, SG and Ahring, BK 2004, 'Methane productivity of manure, straw and solid fractions of manure', *Biomass and Bioenergy*, vol. 26, no. 5, pp. 485-495.

Morris, GR 1976, 'Anaerobic fermentation of animal wastes: a kinetic and empirical design fermentation', M.S. thesis, Cornell University.

MWPS 1985, *Livestock Waste Facilities Handbook No. 18*, 2nd Edn, MidWest Plan Service, Iowa State University, Ames, Iowa.

MWPS 2000, *Manure Characteristics*, MWPS-18 Section 1. MidWest Plan Service, Iowa St. University, Ames, IA.

National Research Council 1996, *Nutrient Requirements of Beef Cattle*, Update 2000, Seventh Revised Edn, Subcommittee on Beef Cattle Nutrition, Committee on Animal Nutrition, National Research Council, Washington.

National Research Council 1998, *Nutrient Requirements of Swine*, Tenth Revised Edn, Subcommittee on Swine Nutrition, Committee on Animal Nutrition, National Research Council, Washington.

National Research Council 2001, *Nutrient Requirements of Dairy Cattle*, Seventh Revised Edn, Subcommittee on Dairy Cattle Nutrition, Committee on Animal Nutrition, National Research Council, Washington.

Nolan, J, Godwin, I and Hegarty, R 2000, *ANUT 221: Animal Metabolism, Digestion and Nutrition*, 2nd Edn, School of Rural Science and Agriculture, University of New England, Armidale, N.S.W.

QPIF 2004a, *BEEFBAL - a nutrient mass balance model for beef cattle feedlots*, Department of Employment, Economic Development and Innovation, Queensland Primary Industries and Fisheries, < http://www2.dpi.qld.gov.au/environment/1240.html > accessed October 2009.

QPIF 2004b, *DAIRYBAL - a whole of farm nutrient and water mass balance spreadsheet*, Department of Employment, Economic Development and Innovation, Queensland Primary Industries and Fisheries, < http://www2.dpi.qld.gov.au/environment/1334.html > accessed October 2009, originally developed by McGahan, EJ, Skerman, AG, van Sliedregt, H, Dunlop, MW and Redding, MR.

QPIF 2004c, *PIGBAL - a nutrient mass balance model for intensive piggeries*, A Skerman (ed.), Department of Employment, Economic Development and Innovation, Queensland Primary Industries and Fisheries, viewed October 2009, < http://www2.dpi.qld.gov.au/environment/1531.html >.

RIRDC 2009, *RIRDC Completed Projects in 2008 - 2009 and Research in Progress as at June 2009*, Australian Methane to Markets in Agriculture, Rural Industries Research and Development Corporation, RIRDC Publication No. 09/118, viewed 2 November 2009, < https://rirdc.infoservices.com.au/items/09-118 >.

SCA 1990, *Feeding Standards for Australian Livestock, Ruminants*, JL Corbett (ed.), Standing Committee on Agriculture, Ruminant Sub-committee, CSIRO Publications, East Melbourne, Australia.

Sinclair, SE 1997, *Effects of Ration Modification on Production and Characteristics of Manure from Feedlot Cattle - (1) Phosphorus Levels*, Report to the Cattle and Beef Industry CRC Sub-Program 6 - Feedlot Waste Management, Queensland Department of Primary Industries, Brisbane, Qld.

Skerman, A, Collman, G, Duperouzel, D, Sohn, J, Atzeni, M and Kelly, A 2008, *Improved piggery effluent management systems incorporating highly loaded primary ponds*, Final report to Australian Pork Limited (APL), Project 2108, Department of Primary Industries and Fisheries (DEEDI), Toowoomba, Qld.

Stevens, MA and Schulte, DD 1979, 'Low Temperature Anaerobic Digestion of Swine Manure', *Journal of the Environmental Engineering Division*, vol. 105, no. 1, pp. 33-42.

Summers, R and Bousfield, S 1980, 'Detailed study of piggery-waste anaerobic digestion', *Agricultural Wastes*, vol. 2, no. 1, pp. 61-78.

van Sliedregt, H, Casey, KD and McGahan, EJ 2001, 'Cleaner Production: Waste Characterisation and Minimisation', in *Proceedings of Production and Environmental Monitoring Workshop* University of New England, Armidale, NSW, Paper No. PEM009,.

van Sliedregt, H, McGahan, EJ and Casey, KD 2000, *Predicting Waste Production from Feedlot Cattle*, Unpublished Confidential Report prepared for Cattle and Beef CRC (Meat Quality) Sub-program 6 - Feedlot Waste Management, DPI Intensive Livestock Environmental Management Services, August 2000, Toowoomba, Qld.

Vedrenne, F, Beline, F, Dabert, P and Bernet, N 2008, 'The effect of incubation conditions on the laboratory measurement of the methane producing capacity of livestock measurement wastes', *Bioresource Technology*, vol. 99, pp. 146-155.

Watts, PJ, Gardner, EA, Tucker, RW and Casey, KD 1994, 'Mass-balance approach to design of nutrient management systems at cattle feedlots', in *Great Plains Animal Waste Conference on Confined Animal Production and Water Quality*, Denver, Colorado, GPAC Publication 151, pp. 27-33.

Watts, PJ, Gardner, EA, Tucker, RW, Moody, PW and Gilbert, M 1992, 'Phosphorus Balance for Cattle Feedlots', in *Conference on Engineering in Agriculture*, Albury, NSW, Institutution of Engineers Australia, Publication No. 92/11, pp. 153-158.

Wiedemann, SG, McGahan, EJ, Grist, S and Grant, T 2009, *Environmental Assessment of Two Pork Suppy Chains using Life Cycle Assessment*, Final Report, RIRDC Project No .... RIRDC and APL, Rural Industries Research and Development Corporation, RIRDC Publication No 09/ .... August 2009.

Appendix A – Methods for Calculating Gross Energy

Gross energy GE calculation

GE is the summation of the net energy requirements and the energy availability characteristics of the feeds. IPCC (2006) considered Equation A1 to be a good practice for calculating GE requirement for cattle, buffalo and sheep using the results of equations for energy requirement.

$$GE = \{[((NE_m + NE_a + NE_l + NE_{work} + NE_p)/ REM) + (NE_g /REG)]/ (DE\%/100)\} \qquad \textbf{Equation A1}$$

where:

GE = gross energy, (MJ/day)

NE_m = net energy required for animal maintenance, (MJ/day)

NE_a = net energy for animal activity, (MJ/day)

NE_l = net energy for lactation, (MJ/day)

NE_{work} = net energy for work, (MJ/day)

NE_p = net energy required for pregnancy, (MJ/day)

REM = ration of net energy available in a diet for maintenance to digestible energy consumed, (MJ/day)

NE_g = net energy needed for growth, (MJ/day)

REG = ratio of net energy available for growth in a diet to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy, (MJ/day)

Net energy for animal maintenance

The net energy for animal maintenance, Equation A2, is the amount of energy needed to keep the animal in equilibrium where body energy is neither gained nor lost (Jurgen 1988).

$$NE_m = Cf_i * (Weight)^{0.75} \qquad \textbf{Equation A2}$$

Where:

NE_m = net energy required for animal maintenance, (MJ/day)

Cf_i = a coefficient which varies for each animal category as shown in Table 29, (MJ/day/kg)

Weight = live-weight of animal, (kg)

Table 29: Coefficient for calculating net energy for maintenance (NE_M) (IPCC 2006)

Animal category	Cf_i (MJ/d/kg)	Comments
Cattle (non-lactating cows)	0.322	
Cattle (lactating cows)	0.386	This value is 20% higher for maintenance during lactation
Cattle (bulls)	0.37	This value is 15% higher for maintenance of intact males

Mean winter temperature will affect the net energy for maintenance. The coefficient, $Cf_{i,}$ must be adjusted with Equation A3 (IPCC 2006).

$$Cf_i\,(in\_cold) = Cf_i + 0.0048 \times (20 - {}^\circ C) \qquad \textbf{Equation A3}$$

Where:

Cf_i = a coefficient which varies for each animal category (Coefficient for calculating NE_m), MJ/day/kg

°C = mean daily temperature during the winter season

Net energy for animal activity

The net energy for activity, Equation A4, is the energy needed to obtain their food, water and shelter; it is based on the feeding situation. It is calculated as a fraction of the net energy for maintenance.

$$NE_a = C_a \times NE_m \qquad \textbf{Equation A4}$$

Where:

NE_a = net energy for animal activity, (MJ/day)

C_a = coefficient corresponding to animal’s feeding situation (Table 30)

NE_m = net energy required by the animal for maintenance, (MJ/day)

Table 30: Activity coefficient corresponding to animal’s feeding situation (IPCC 2006)

Situation	Definition	C_a
Cattle (unit for C_a is dimensionless)		
Stall	Animal are confined to a small area (i.e., tethered, pen, barn) with the result that they expend very little or no energy to acquire feed	0.00
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed	0.17
Grazing large areas	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed	0.36
Source: National Research Council (1996) and AFRC (1996) cited in IPCC (2006)		

Net energy for lactation

The net energy for lactation, Equation A5, is expressed as a function of the amount of milk produced and its fat content expressed as a percentage (National Research Council (2001) cited in IPCC (2006)).

$$NE_l = Milk \times (1.47 + 0.40 \times Fat) \qquad \textbf{Equation A5}$$

Where:

NE_l = net energy for lactation, (MJ/day)

Milk = amount of milk produced, (kg of milk/day)

Fat = fat content of milk, (% by weight)

Net energy for work

The net energy for work estimate the energy required for draft power for cattle (Equation A6). Bamualim and Kartiarso (1985) cited by IPCC (2006)) show that about 10% of day's NE_m requirements are required per hour for typical draft power work for animals.

$$NE_{work} = 0.10 \times NE_m \times Hours \qquad \textbf{Equation A6}$$

where:

NE_{work} = net energy for work, (MJ/day)

NE_m = net energy required by the animal for maintenance, (MJ/day)

Hours = number of hours of draft power work per day

Net energy required for pregnancy

The energy for pregnancy for cattle is the total energy requirement for a 281-day gestation period averaged over an entire year. Equation A7 calculated it as a fraction of the net energy for maintenance.

$$NE_p = C_{pregnancy} \times NE_m \qquad \textbf{Equation A7}$$

Where:

NE_p = net energy required for pregnancy, (MJ/day)

$C_{pregnancy}$ = pregnancy coefficient (0.10)

NE_m = net energy required by the animal for maintenance, (MJ/day)

Ratio of net energy available in a diet for maintenance to digestible energy consumed

The ratio of net energy available in a diet for maintenance to digestible energy consumed (REM) is predicted using Equation A8 (Gibbs and Johnson (1993) cited in IPCC (2006)).

$$\mathbf{REM = \{1.123 - (4.092 x10^{-3} \text{ x } DE\ \%) + [1.126 x10^{-5} \text{ x } (DE\%)^2] – (25.4/DE\%)\}} \qquad \textbf{Equation A8}$$

Where:

REM = ration of net energy available in a diet for maintenance to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy

Net energy needed for growth

The net energy needed for growth, Equation A9, is based on National Research Council (1996) cited in IPCC (2006).

$$\mathbf{NE_g = 220.02 \text{ x } (BW/(C \text{ x } MW))^{0.75} \text{ x } WG^{1.097}} \qquad \textbf{Equation A9}$$

Where:

NE_g = net energy needed for growth, (MJ/day)

BW = the average live body weight (BW) of the animals in the population, (kg)

C = a coefficient with a value of 0.8 for female, 1.0 for castrates and 1.2 for bulls

MW = the mature live body weight of an adult female in moderate body conditions, (kg)

WG = the average daily weight gain of the animals in the population, (kg/day)

Ratio of net energy available for growth in a diet to digestible energy consumed

The ratio of the net energy available for growth available in a diet to digestible energy consumed (REG) is estimated by Equation A10 (Gibbs and Johnson (1993) cited in IPCC (2006)).

$$\mathbf{REG = \{1.164 – (5.160 x10^{-3} \text{ x } DE\ \%) + [1.308 \text{ x } 10^{-5} \text{ x } (DE\%)^2] – (37.4/DE\ \%)\}} \qquad \textbf{Equation A10}$$

Where:

REG = ratio of net energy available for growth in a diet to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy, (MJ/day)

NRC method for estimation of GE

National Research Council (NRC) provides methods for estimating nutrient requirements for pigs(National Research Council 1998), beef cattle (National Research Council 1996)and dairy cattle (National Research Council 2001). Maintenance, pregnancy, lactation and growth energies are reported in tables according to the diet for beef cattle and dairies.

Alternate method for estimation of GE

The gross energy of the diet is calculated from the chemical composition. The energy value of crude protein, crude fat and carbohydrate is given as 24, 39 and 185 MJ/kg respectively. The calculated gross energy intake is given in Equation A11 (Nolan et al. 2000):

$$\mathbf{GE = 24 \times CP + 39 \times FAT + 18 \times CAR} \qquad \textbf{Equation 22}$$

where:

GE = gross energy intake, (MJ/day)

CP = crude protein intake, (kg/day)

FAT = fat intake, (kg/day)

CAR = carbohydrate intake, (kg/day.)

The crude protein content is calculated from the nitrogen content of the diet multiplied by 6.25 (Equation 23). The fat intake is assumed to be 2%. The carbohydrate intake is the balance of the fat and carbohydrate components.

$$\mathbf{CP = N \times 6.25} \qquad \textbf{Equation 23}$$

where:

N = Nitrogen intake (kg/day)

Estimates of Manure Production from Animals for Methane Generation

by Mr Eugene J McGahan, Miss Claudiane Ouellet-Plamondon and Dr Peter J Watts

Publication No. 10/151

The increased costs of energy and the potential greater prices paid for renewable energy is making methane capture from animal manures more economically feasible. With a better understanding of the manure production rates and the economically feasible size of these industries, a greater uptake of the existing technology to recover energy from these intensive animal industries will occur.

This project aimed to provide independent estimations of waste production using available methods and models.

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.

Most RIRDC publications can be viewed and purchased at our website:

www.rirdc.gov.au

Contact RIRDC:
Level 2
15 National Circuit
Barton ACT 2600

PO Box 4776
Kingston ACT 2604

Ph: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au
web: www.rirdc.gov.au
Bookshop: 1300 634 313

RIRDC Innovation for rural Australia