

8.2 Greenhouse gas emissions

With no short-term effects on the local environment and little direct consequence to the farm economy, greenhouse gas (GHG) emissions have received little attention until recently. However, concern over climate change and the likelihood of requirements for GHG mitigation has meant that GHG emissions are now a priority for most sectors of the economy.

Dairy farming's GHG footprint

Agriculture was responsible for 16% of Australia's 559 Mt of GHG emissions in 2005 ([AGO 2007b](#)) and is the dominant sector for emissions of methane (CH₄; 60%) and nitrous oxide (N₂O; 85%). Livestock emissions represent 71% of the agricultural sector subtotal, or 11% of national emissions.

Enteric fermentation in the animal gut is responsible for the majority of livestock GHG emissions. According to the Australian Greenhouse Emissions Information System (AGEIS; [AGO 2007a](#)), direct emissions from the dairy industry in 2005 included 7266 kt CO₂-equivalent (CO₂-e) from enteric fermentation, 815 kt CO₂-e from N loss from dung and urine voided to soils, 574 kt CO₂-e from manure management, and a further 100 kt CO₂-e from application of effluent and manure to soil. Additional indirect N₂O emissions are attributed to the dairy industry; further information is provided by the [National Greenhouse Gas Inventory Committee \(2006\)](#) and [Mosier *et al.* \(1998\)](#). Further information on emissions from enteric fermentation is provided by [Hegarty \(2001\)](#) and [Eckard *et al.* \(2002\)](#).

CH₄ and N₂O are emitted during the management of effluent and manure. The 574 kt CO₂-e from the dairy industry in 2005 comprised 26.8 kt of CH₄ and 34.3 t of N₂O with a CO₂-e of 563 and 10.6 kt respectively. CH₄ has a global warming potential 21 times that of CO₂, and N₂O 310 times that of CO₂ ([EPA Victoria 2002](#)). These emissions represent 17% of all livestock manure management and 0.1% of Australia's total GHG emissions.

[Eckard *et al.* \(2002\)](#) developed a decision support framework for the Australian dairy industry and suggested that emissions from effluent ponds contribute <1% to 2% of farm GHG emissions, mostly as enteric CH₄ and N₂O from soils, fertiliser and urine. The contribution from effluent ponds suggested by Eckard is much less than the 7% suggested by AGEIS (or 5% if indirect emissions are included). Some of the difference may be due to the use of empirical emission factors by the National Greenhouse Gas Inventory Committee (2006); for example, the methane productivity of 0.24 m³ CH₄ [kg VS added]⁻¹ is at the upper end of the range suggested in chapter 8.1 '[Production and beneficial use of methane](#)'. [Eckard *et al.* \(2002\)](#) suggested that further research is needed to verify the decision support model under Australian conditions, as the level of uncertainty in modelled emissions may range from 20% to 300%.

Generation of GHGs

GHG emissions must be separated into direct and indirect emissions. Direct emissions arise from sources such as enteric fermentation and manure management. Indirect emissions are caused by the use of electricity. Although this chapter concentrates on minimising direct emissions arising from manure management, it is important to recognise that there are opportunities to minimise indirect emissions through improvements in energy use efficiency in the dairy, and that most environmental authorities now require an energy audit and action plan as part of an application for regulatory approval. Options for improving energy efficiency may include things such as:

- platecoolers and cooling towers to reduce heat load in milk

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- variable-speed drives on milk pumps and vacuum pumps
- energy-efficient lighting
- high coefficient of performance (COP) refrigeration systems.

Further information can be found at

<http://www.cowtime.com.au/EnergyMonitor/index.aspx>

Emissions from the on-site use of delivered gas (LPG, propane, natural gas) are also direct and should be considered as part of the energy management system.

AGEIS suggests that within manure management in the dairy industry, CH₄ is a substantially larger contributor to GHG emissions than N₂O. Although both depend on microbial activity, there are fundamental differences in their modes of formation that must be appreciated before control strategies can be considered.

CH₄ is a product of the anaerobic decomposition occurring in most agricultural effluent treatment ponds (see chapter 2.3 '[Anaerobic, aerobic and facultative ponds](#)'). Under anaerobic conditions, temperature and storage time determine the amount produced (see chapter 8.1 '[Production and beneficial use of methane](#)'). As CH₄ is poorly soluble in water, it is easily lost into the atmosphere.

In contrast, N₂O is not directly produced from compounds primarily present in manure. N₂O is a product of incomplete denitrification: the conversion of nitrate into N₂ under anaerobic conditions. However, raw effluent nitrate concentrations are typically low to negligible (and the nitrification step converting ammonium into nitrate is limited by a lack of oxygen), so anaerobic ponds produce little N₂O. N₂O may also be an intermediary product of nitrification under suboptimal conditions: low oxygen availability, high NH₃ concentrations, low C:N ratios ([Monteny et al. 2001](#)).

Solid manure stockpiles, however, are more likely to undergo uncontrolled nitrification and denitrification resulting in N₂O emissions. Stockpiles have higher concentrations of nitrate as a result of aerobic activity, but when they are poorly composted or periodically saturated by rain, anaerobic conditions can result in denitrification. Incomplete denitrification and emission of N₂O is favoured by low COD-to-NO₃ ratios, low pH and the presence of oxygen ([Shilton 2005](#)).

The National Greenhouse Gas Inventory Committee (2006) has adopted emission factors of 1 g N₂O [kg N]⁻¹ for anaerobic ponds and 20 g N₂O [kg N]⁻¹ for solid storage. Although the accuracy of the assumptions is debateable, the magnitude of difference illustrates that it is important for the total GHG emissions to be considered rather than CH₄ and N₂O in isolation. That is, removing solids from effluent before the anaerobic pond may reduce its CH₄ emissions, but the impact of any increase in N₂O emissions (with its larger global warming potential) must still be considered. System choice must not simply transfer emissions from one component to another for accounting purposes, but rather consider the entire production system.

Ammonia is not a direct GHG but it does have implications for odour, atmospheric N deposition ('acid rain') and eutrophication. Atmospheric deposition of N has been shown to enhance biogenic N₂O formation in Europe, so it can have an indirect impact on GHG emissions. Mosier *et al.* (1998) assumes that 1% of NH₃ emissions are transformed into N₂O. N₂O also contributes to stratospheric ozone depletion.

Direct emissions of CO₂ from manure are not considered to contribute to global warming, as the carbon released originates from the fixation of atmospheric carbon in plant material and cycles over a relatively short period of time ([Pattey et al. 2005](#)).

GHG control strategies within manure management

[Amon et al. \(2006\)](#) compared different manure management strategies. More than 90% of GHG emissions from managing untreated dairy slurry originated from CH₄ produced during storage (80-day retention). Amon *et al.* (2006) therefore concluded that GHG

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abatement measures are most effective if they reduce CH₄ emissions during storage. Covering the storage with straw increased CH₄ and N₂O emissions and resulted in the highest total GHG emissions (Table 1). Treatments involving anaerobic digestion, aeration and solids separation were effective at reducing GHG emissions compared with untreated slurry. GHG emissions from the separated treatment comprised 41.3 kg CO₂-e during storage, 14.8 kg CO₂-e from the composted solids (pile turned seven times in 80 days) and 2.4 kg CO₂-e during reuse.

Table 1. Emissions from variously treated dairy slurry (storage, solids stockpile and reuse).

	NH ₃ (g m ⁻³)	% of un- treated	CH ₄ (g m ⁻³)	% of un- treated	N ₂ O (g m ⁻³)	% of un- treated	Total GHG (kg CO ₂ -e m ⁻³)	% of un- treated
Untreated	227	100	4047	100	23.9	100	92.4	100
Separated ^a	403	178	2363	58	28.6	120	58.5	63
Digested	230	101	1345	33	31.2	130	37.9	41
Straw cover	320	141	4926	122	52.5	220	120	130
Aeration	423	186	1739	43	54.2	227	53.3	58

^a Liquid and solid phases

Similarly, increases in GHG emissions following the application of straw covers to slurry storage were reported by [Berg et al. \(2006\)](#) (lab, pig slurry) and [Cicek et al. \(2004\)](#) (farm, piggery lagoons). Possible reasons for the increases include sinking straw providing an additional C source for methanogens, and that reduced surface mixing maintains optimum anaerobic conditions, both of which result in increased CH₄ emissions. In addition, straw at the interface between N-containing slurry and the atmosphere provides an environment for uncontrolled nitrification and denitrification and N₂O emission. However, conflicting results exist: [Sommer et al. \(2000\)](#) (cattle slurry) and [Lague et al. \(2004\)](#) (piggery lagoon) measured reduced CH₄ emissions following the addition of a straw cover to storages.

Given the uncertainty over possible augmentation of GHG emissions via straw covers, it is fortunate that dairy effluent can be naturally self-crusting and offers the potential for bacterial oxidation of methane without requiring additional carbon. [Petersen et al. \(2005\)](#) demonstrated that oxidation can remove CH₄ under practical storage conditions, and [Petersen and Ambus \(2006\)](#) determined maximum fluxes of ~1 g CH₄ m⁻².day⁻¹ from natural crusts on cattle slurry. Although the CH₄ flux from an uncovered storage was not directly compared by Petersen and Ambus, other researchers have found fluxes from an uncovered storage averaging 28 to 31 g CH₄ m⁻².day⁻¹ ([Sneath et al. 2006](#)) and a maximum of 18 g CH₄ m⁻².day⁻¹ ([Sommer et al. 2000](#)).

Composting of solids separated from the effluent stream before the anaerobic pond appears to offer some reduction in overall GHG emissions, but some research has demonstrated negative results. Separated solids must undergo true aerobic composting to mitigate GHGs. Minimal intervention 'composting' or stockpiling solids without turning is a simple and effective, albeit slow, means of reducing volume and volatile solids. However, it is not a uniformly aerobic process and should not be termed composting; anaerobic conditions do exist, leading to the production of CH₄. [Lopez-Real and Baptista \(1996\)](#) found that forced aeration and turned windrows were effective composting procedures and substantially reduced CH₄ emissions compared with static stockpiles. Therefore, if the separated solids are not composted with due attention to C:N, porosity and moisture content, CH₄ emissions would remain high, and additional N₂O emissions might be produced as a result of incomplete denitrification or nitrification under unfavourable conditions. [Dinuccio et al. \(2008\)](#) demonstrated such a result, finding that the sum of GHG emissions from the liquid and separated solids fraction (with 21% solids in a static stockpile) was 25% higher than that from an untreated control (pig manure).

However, [Pattey et al. \(2005\)](#) found that emissions of CH₄ and N₂O were higher from anaerobic dairy slurry (397 g CO₂-e [kg DM]⁻¹) than from composted dairy manure

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(static pile fitted with two air supply pipes; mostly aerobic; 207 g CO₂-e [kg DM]⁻¹) over a 90-day storage period. Emissions from stockpiled dairy manure solids (partially anaerobic, partially aerobic) fell between the other two treatments at 301 g CO₂-e [kg DM]⁻¹. The contribution of CH₄ decreased and N₂O increased with increasing oxygen availability. Unfortunately, little information on the manure was provided.

[Hao et al. \(2004\)](#) measured GHG emissions from composted beef feedlot manure (with straw bedding). Although emissions (197.5 g CO₂-e [kg DM]⁻¹) were similar to those reported by [Pattey et al. \(2005\)](#), the relative contribution of CH₄ compared to N₂O was significantly different (17% due to CH₄ in [Pattey et al. \(2005\)](#), 95% in [Hao et al. \(2004\)](#)). Although slightly different global warming potentials were used, the reason for the magnitude of the difference is unclear.

Developments in the use of deep-litter dairy housing in intensive operations in colder climates may avoid some CH₄ emissions as a result of not requiring large anaerobic ponds, but may result in increased N₂O emissions from the decomposition of solids under uncontrolled, predominantly aerated conditions ([Monteny et al. 2006](#)). Insufficient evidence is available to draw any conclusions for Australian conditions.

Summary of management options for manure treatment and storage

The following two strategies are the most effective means of reducing GHG emissions from manure:

- **Manure minimisation.** Minimise the volume of manure produced by 'ensuring that the energy requirements of the animals are met from the highest digestibility feed available, fed only at levels required for the desired animal performance' ([Hegarty 2001](#)). The less the amount of VS and N to be decomposed, the less will be emissions of CH₄ and N₂O.
- **Impermeable cover on anaerobic ponds with biogas combustion.** Collection and combustion of CH₄ produced in anaerobic ponds reliably offers the most effective reductions in GHG emissions, as the digester is essentially a closed vessel and only the products of combustion are emitted to the atmosphere. Burning one molecule of CH₄ yields one molecule of CO₂, reducing the global warming potential by a factor of 21. Biogas capture enables the generation of heat or electrical energy with direct economic benefits (see chapter 8.1 '[Production and beneficial use of methane](#)').

Where biogas capture is not an option, the following options are effective (albeit to a lesser degree):

- **Direct application, or minimising retention time.** Direct application avoids the anaerobic storage of effluent and the production of CH₄. However, aside from the likelihood of increased emissions of N₂O from the reuse area, the possible pollution of surface and groundwaters creates more risk than it resolves. There is, however, merit in reducing retention time whenever possible by distributing effluent regularly outside of the storage period.
- **Properly managed composting.** Maintain process parameters within recommended ranges to that ensure aerobic conditions prevail (see chapter 2.9 '[Composting](#)'). Stockpiling solids without frequent turning is not composting.
- **Separation of solids.** If separated solids are composted, solid-liquid separation may reduce overall GHG emissions.
- **Retain crusts on anaerobic ponds.** Crusts provide an environment for bacterial oxidation of methane.

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- **Permeable covers.** Gas-permeable covers have shown mixed results, but where a crust cannot be maintained, they may warrant further research (see chapter 5 '[Odour emissions and control](#)').

GHG control strategies within effluent and manure reuse

[Saggar *et al.* \(2004\)](#) summarise research on N₂O emissions from pasture soils following the application of animal effluent and manures. Emissions vary greatly depending on water-filled pore space and climatic conditions. Reported emissions ranged from <0.1% to over 10% of effluent N applied.

The nature of the effluent applied is also important. [Bhandral *et al.* \(2007\)](#) found that untreated dairy effluent lost a lower percentage of applied N as N₂O than treated effluent (0.7% vs. 2%, autumn application), even though three times as much N was applied in the former (61 vs. 21.8 kg N ha⁻¹). Untreated effluent has a larger proportion of organic N, which will decompose (mineralise) gradually to inorganic N.

[Saggar *et al.* \(2004\)](#) suggest that reuse management practices are likely to affect individual gases differently. For example, direct injection of sludge may reduce NH₃ emissions but increase losses of N₂O depending on C and N levels and moisture status. Although this area is currently the subject of considerable research, strategies that increase the efficiency of N use generally are appropriate for minimising N₂O emissions upon reuse.

Further information on minimising N₂O emissions from animal agriculture is presented by [de Klein and Eckard \(2008\)](#). Best management practices for soils are listed at <http://www.nitrogen.unimelb.edu.au/index.htm>.

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