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# Greenhouse Gas and Ammonia Emissions from Dairy Manure Management Systems

## Introduction

Manure produced from dairy animals can improve or maintain soil health and provide valuable nutrients for crop production when applied to the land. On average, a 1,400-pound lactating dairy cow produces nearly 54,000 pounds of manure each year, containing approximately 360 pounds of nitrogen, 40 pounds of phosphorus and 260 pounds of potassium, in addition to a number of plant-essential secondary macro- and micronutrients (Aguirre-Villegas et al. 2015). Using average 2016 nutrient prices for nitrogen, phosphorus and potassium, and assuming 80% plant availability for phosphorus and potassium and 50% for nitrogen (Laboski and Peters 2012), the annual nutrient value of manure produced by a single dairy cow is estimated at approximately \$160. While manure provides some value, it also costs money to manage. If you assume a \$0.02 per gallon hauling cost, the yearly manure produced by one dairy cow requires \$130 to take to the field. It is therefore critical to understand the many aspects of manure management systems to reduce costs and environmental impacts while taking advantage of manure's value.

Manure handling and application can pose several environmental challenges when manure constituents are lost to air and water. Animals that are confined to a barn or limited land area require additional manure handling processes compared to animals in grazing systems. This includes manure collection, handling and land application. Manure handling is a significant economic and labor challenge to many dairy farms, as handling costs can reach up to \$300 per cow annually (Bentley et al. 2016). In addition to economic constraints, manure management systems are often regulated by local, state and federal conservation and natural resource agencies to reduce environmental impacts.

Manure management system designs are highly variable, ranging from very few components to complex systems with numerous processing and storage steps. An effective manure handling system not only meets the current needs of an individual facility but also considers farm expansion plans. To maximize nutrient use efficiency while reducing environmental concerns, manure management planning should minimize nutrient losses and ensure a sufficient land base to balance manure nutrient applications with the agronomic needs of growing crops. While we are actively working to design manure systems to reduce impacts on water resources, more attention is needed to consider preprocessing and management practices that reduce greenhouse gas (GHG) and ammonia emissions.

Manure management represents the second largest source of GHG emissions on a dairy farm, after enteric fermentation (methane emitted directly from the animal). Methane and nitrous oxide are the most potent greenhouse gases emitted from manure management, as they have 28 and 264 times greater global warming potential than carbon dioxide, respectively (Myhre et al. 2013). Dairy manure methane emissions are particularly important, as they are responsible for 7% of global and 8% of U.S. agricultural methane emissions, respectively (USEPA 2012; USEPA 2016).

In addition to GHG emissions, up to 70% of the nitrogen excreted by the animal through manure and urine can be volatilized as ammonia. Animal-derived ammonia can travel long distances in the air and eventually redeposit in waterbodies and natural terrestrial systems. Moreover, this ammonia can further transform to nitrous oxide (Hristov et al. 2002) or particulate matter, negatively impacting air quality.

## Manure Management Systems

The processes and practices adopted for manure management systems vary significantly by farm and depend on key factors such as manure type, farm size, operation and layout. For example, small farms often handle solid manure, whereas larger operations handle mostly liquid or slurry manure (Aguirre-Villegas and Larson 2017). The most common processes involved in manure handling can be separated into collection, processing, storage and land application (Figure 1). Some farms may only employ collection and land-application systems, while others may also integrate processing and storage into their manure management systems.

Manure management systems start with collecting and aggregating the manure at a centralized point. Manure collection strategies can be as varied as the types of management systems themselves. Manure is often collected manually with skid steers, via gravity through slotted floors, with flush systems using recycled manure liquids to wash manure to a collection point or by mechanical systems, such as an alley scraper or gutter cleaner.

Automatic collection with alley scrapers can reduce labor, time and energy needs as compared to skid-steer collection (Aguirre-Villegas and Larson 2017), but alley scrapers are more susceptible to freezing in the winter and may require increased maintenance in facilities using sand bedding. Slotted floors often require less labor as manure is collected by gravity, but the under-barn manure storage can lead to gas and odor issues, particularly when agitating and emptying the manure. Flush systems are very effective in cleaning barn alleys, but they are also more expensive than other collection systems, require large pumps and low-solids liquid manure for flushing and may freeze in winter. Regardless of the method, the collection system must be compatible with other manure system components on a dairy operation and must meet the operational needs of the facility.

After collection, manure is transported by gravity or mechanical systems to processing, storage or land-application systems. Manure processing is more common at large facilities, particularly at those large enough to require permitting, which includes farms that have more than 1,000 animal units (1 animal unit = 1,000 pounds). These farms are more able to justify the technological investments. Some of the most common manure processing technologies include:

- **Sand separation** – separating sand bedding collected with the manure stream to recycle sand and reduce input

costs, while avoiding issues with equipment wear and clogging.

- **Solid-liquid separation** – dividing manure into multiple solid and liquid streams to facilitate handling and optimize nutrient application to croplands.
- **Composting** – aerobic microbial decomposition of manure, where manure is often combined with other organic residues to optimize the composting process. Composting reduces manure volume, kills pathogens, reduces weed seeds and produces a more stable humic material, all of which have added benefits when land-applied.
- **Anaerobic digestion** – anaerobic microbial decomposition of organic material. During digestion, biogas containing methane is produced and collected for use as an energy source, generally for electricity or heat. Digestion also reduces pathogens and odors contained within manure.

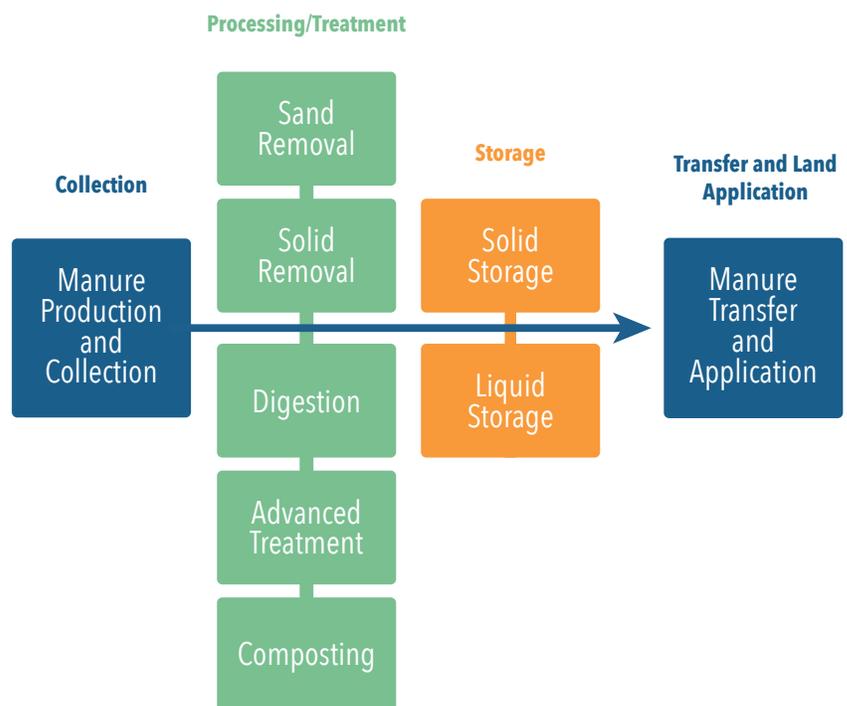


Figure 1. Manure-handling system components.

Following collection or processing, manure is either transported to storage or directly land-applied. Manure storage provides flexibility in the timing of manure applications, which can reduce labor requirements, reduce water quality impacts, and allow for application of nutrients during periods when the crop needs them. Unlike direct land application after collection, stored manure can be applied when environmental conditions are suitable for reducing nutrient losses via runoff and/or leaching, which avoids water quality impacts. This

includes avoiding manure applications during or near rain events or on frozen ground. The ability to apply manure closer to crop uptake periods also reduces nutrient losses to air and water systems.

There are many manure storage designs. Currently the most common system is a storage basin or pit designed simply to hold manure for a given period. Storage systems can include under-barn pits, above-ground tanks and pads and excavated storages, using one of a number of different liners. There are other storage systems that are designed to contain and provide limited manure treatment, such as aerobic and anaerobic lagoons. While these lagoons can provide some additional treatment past simple storage, they generally require increased space and cost.

Regardless of the manure storage system selected, the design must meet local, state and federal regulations. There are numerous standards and engineering guidelines for siting and designing manure storages. These include a thorough site investigation to identify environmentally sensitive areas, residences and wells to reduce or eliminate negative impacts. As with any manure system component, storage design must be compatible with other system components for the system to function as designed.

While manure storage provides critical flexibility in timing of applications, it also requires additional labor and management, including regular maintenance and coordination of manure handling and transport. An additional step prior to land application is the agitation of liquid and slurry manure to resuspend any settled solids prior to pumping and removal. In addition, stored manure is more susceptible to gas and odor emissions leading to diminished air quality.

Land application is the final component of most manure management systems. Manure is typically transported from the farmstead to the field using tractors, tankers, box spreaders, semi trucks and/or pumps. Solid manure is usually handled with tractors or skid-steer loaders and surface-applied to fields using a tractor and box spreader. Manure is typically incorporated into the soil within 48 hours of land application. Slurry and liquid manures are often land-applied via irrigation, surface applicators or injection equipment.

Irrigation systems typically use pumps to transport manure directly to the field, but they frequently have the most significant gaseous nitrogen losses compared to other land-application systems. Irrigated manure is not incorporated via tillage and is dependent on natural manure infiltration into the soil to reduce ammonia volatilization losses.

Surface application and injection equipment use pumps and drag hose lines or tankers to transport manure from the storage facility to the field. Surface applications of manure result

in varying degrees of nitrogen loss, depending on inherent soil properties, as well as the amount of time manure is left on the soil surface before natural or mechanized incorporation. Manure injection, where manure is directly incorporated into the soil, is the most effective application method in reducing gaseous nitrogen losses and odor.

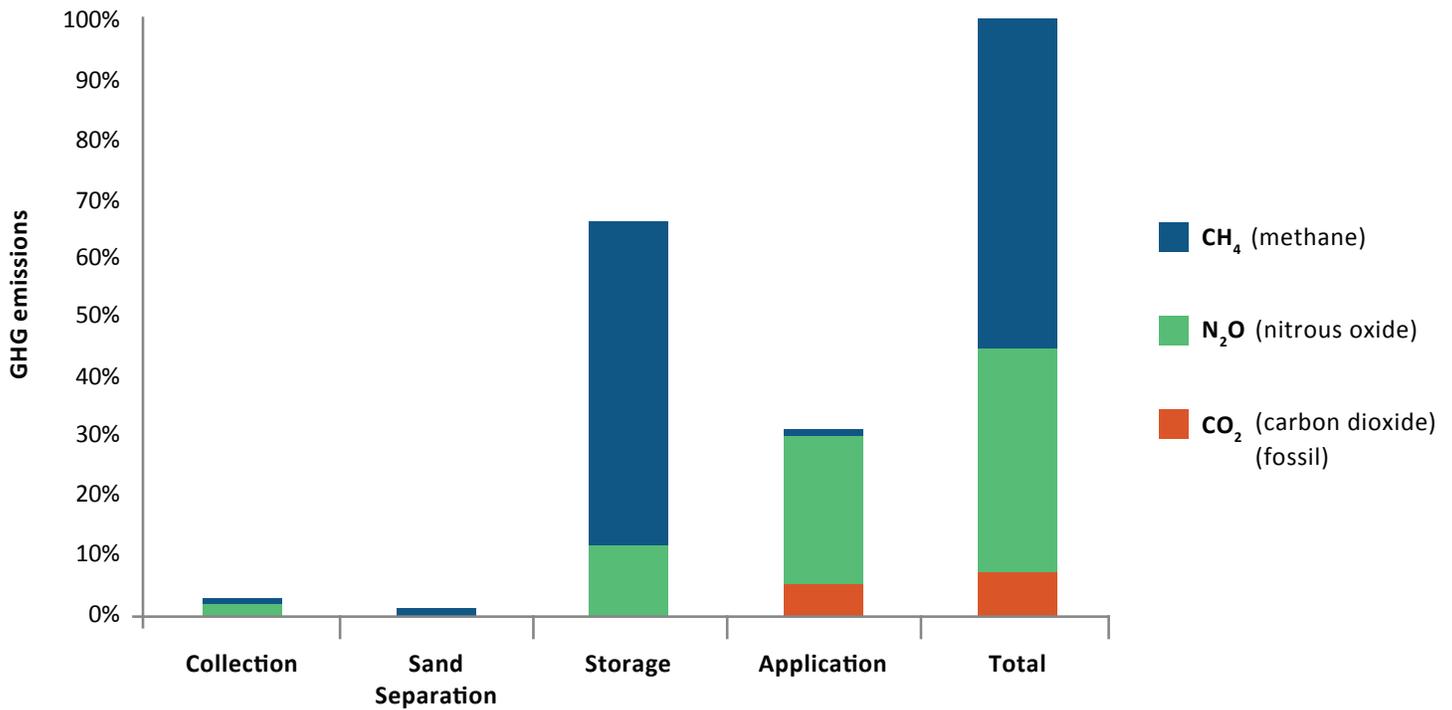
## **GHG Emissions from Manure Management Systems**

GHG emissions produced from manure management systems result both from the combustion of fossil energy required to operate the equipment and from the microbial decomposition of the manure itself. GHG emissions related to energy consumption are primarily carbon dioxide, while GHG emissions from manure include carbon dioxide, methane and nitrous oxide. Carbon dioxide emitted directly from manure is typically not included in the total GHG emissions, as it is assumed the carbon contained within carbon dioxide was previously captured from the atmosphere by the crops included in the dairy diet. The release of carbon (in the form of carbon dioxide) from the manure, therefore, is assumed to be a natural part of the carbon cycle.

As shown in Figure 2, methane (CH<sub>4</sub>) accounts for most GHG emissions from manure management systems, with nearly 98% of methane loss occurring during storage. Long-term storage of liquid and slurry manure provides the ideal conditions for methane-producing microorganisms to grow and reproduce. While methane emissions from manure storage are significant, manure storage structures are critical in reducing potential negative impacts on water quality by increasing the flexibility of when manure is land-applied. While it would be unwise to eliminate manure storage systems from dairy operations, it is important to manage these systems to reduce methane emissions. In a simple system, the manure storage area could be covered, capturing the methane, which could then be burned to produce carbon dioxide—a less potent GHG (Myhre et al. 2013).

By using an anaerobic digester, GHG emissions from manure management can be reduced by more than 50% (Aguirre-Villegas, Larson, and Reinemann 2015). This loss can be further reduced if electricity used on-farm is replaced with energy produced from the captured methane. Unfortunately, when manure is digested there can be an increase in ammonia emissions, but these losses can be reduced by using a cover to limit manure's exposure to wind and by injecting the manure into the soil when land-applied.

Other strategies to reduce methane emissions from manure include solid-liquid separation and composting. After solid-liquid separation, some of the degradable carbon follows the manure solid stream, reducing the potential to emit methane during liquid storage. As composting is an aerobic process, it minimizes methane emissions from manure. However,



**Figure 2.** Form and source of GHG emissions from various manure management system operations: skid-steer collection, sand separation, storage with agitation and surface land application. (from Aguirre-Villegas, Larson, and Reinemann 2014).

composting can create the necessary conditions to promote ammonia and nitrous oxide emissions (Amon et al. 2006). Nitrous oxide emissions occur primarily during land application of manure (Figure 2), as microbial populations in the soil utilize the manure nitrogen sources. One strategy to reduce nitrous oxide emissions during land application is to time manure applications to avoid wet soil conditions and precipitation thereby avoiding the conditions favorable for nitrous oxide production (Montes et al. 2013). Another strategy is to apply manure when it is needed by a crop, thereby facilitating the opportunity for nitrogen uptake by the plant and reducing soil nitrogen concentrations. Leguminous cover crops can increase plant nitrogen uptake, and once in the plant, conversion of nitrogen compounds to nitrous oxide is limited (Montes et al. 2013).

Carbon dioxide emissions from machinery are primarily associated with land application, as machinery uses fossil fuels (gas, diesel and oil) to operate. These emissions can be reduced by adopting practices that increase the energy efficiency of manure handling, including using pumps instead of tankers to transport manure during application.

### Ammonia Emissions from Manure Management Systems

Ammonia emissions from manure are also important as they can travel long distances and contaminate water streams or transform into nitrous oxide or particulate matter, further contributing to climate change. Ammonia that is lost in

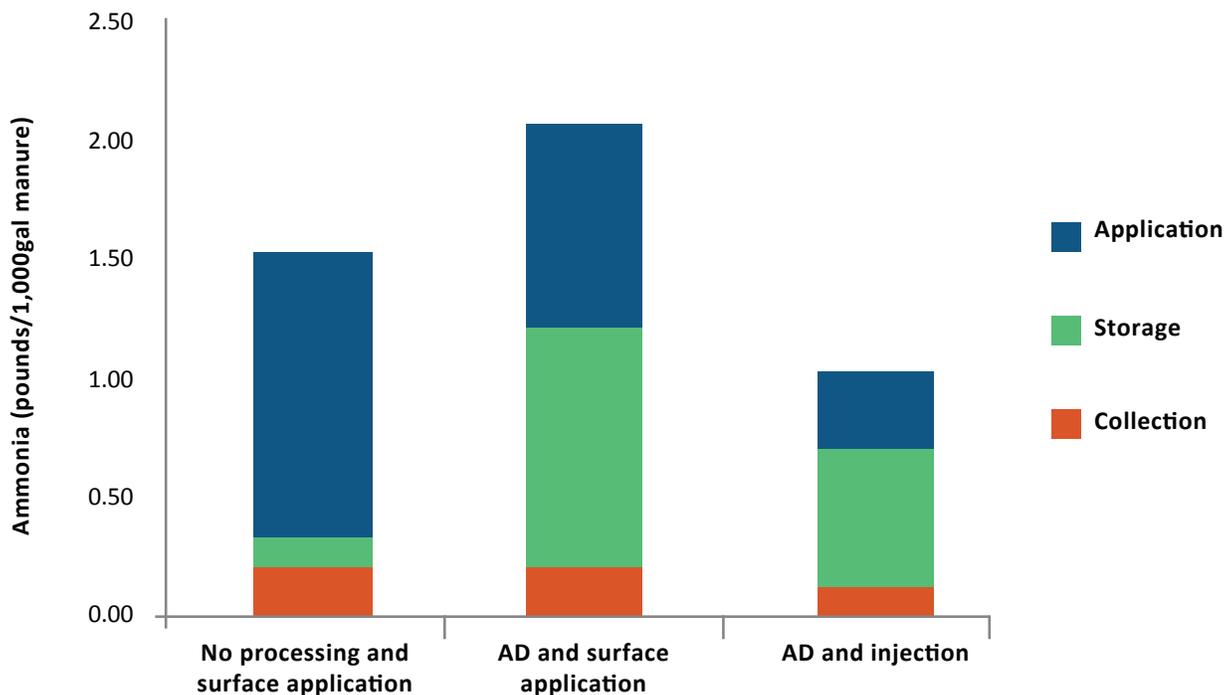
emissions reduces the concentration of plant-available nitrogen within the manure and its economic value as a fertilizer. Depending on the adopted manure management strategies, the majority of ammonia emissions are from storage or land applications (Figure 3).

Ammonia emissions from manure management systems can be reduced by more than 70% by covering storage systems and by injecting manure instead of surface applying (Hristov et al. 2011). Alternatively, allowing a natural crust to form on top of the manure storage can reduce ammonia emissions (Figure 3). These practices minimize the exposure of the nitrogen contained in manure to wind and heat, factors that facilitate nitrogen loss in the form of ammonia. On the downside, injection of manure might increase nitrous oxide emissions compared to surface applications (Montes et al. 2013).

Since a majority of ammonia emissions usually occur within the first hours after manure excretion, reducing the time that manure remains on the barn floor can also reduce nitrogen loss. Additionally, segregating manure and urine to reduce the contact of enzymes in the feces with the urea in urine can reduce ammonia losses (Ndegwa et al. 2008). However, this is not practical in most farm situations.

### Summary

Manure management systems vary significantly by farm but can include collection, processing, storage and land



**Figure 3.** Contribution of ammonia emissions from manure handling steps from three types of dairy operations: 1) No manure processing, long-term storage with surface crust formation and surface land application; 2) Anaerobic digestion (AD), long-term storage with no surface crust formation and surface land application; and 3) AD, long-term storage with no surface crust formation and manure injection (from Aguirre-Villegas, Larson, and Reinemann (2014); and Aguirre-Villegas, Larson, and Reinemann (2015)).

application. Manure storage and processing can alter manure characteristics and management strategies that can decrease negative impacts. While manure collection and land application are a part of most farms' manure systems, manure storage and processing are more common on larger farms that can afford the investments. Manure storage provides flexibility in the timing of manure applications, which is critical for water quality issues but may increase farm ammonia and GHG emissions and in particular methane emissions. Management practices such as manure covers are available to reduce this impact. While processing systems are more economically feasible at larger facilities, low-cost processing such as composting or solids-settling can be integrated with a low initial investment to reduce impacts on smaller facilities. GHG emissions can be cut in half if processing via anaerobic digestion is adopted. However, this may not be economically feasible. Selecting the most appropriate land-application method (e.g., irrigation, surface application or injection) can aid in reducing GHG and ammonia emissions and potential runoff while conserving nutrients for crop uptake. Manure injection or incorporation is an effective practice to reduce ammonia emissions from land application.

## References

Aguirre-Villegas, Horacio A., and Rebecca A. Larson. "2017. Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools."

*Journal of Cleaner Production* 143: 169–79. doi:10.1016/j.jclepro.2016.12.133

Aguirre-Villegas, Horacio A., Rebecca A. Larson, and Douglas J. Reinemann. 2014. "From waste-to-worth: Energy, emissions, and nutrient implications of manure processing pathways." *Biofuels, Bioproducts and Biorefining* 8: 770–93. doi:10.1002/bbb.1496

Aguirre-Villegas, Horacio A., Rebecca A. Larson, and Douglas J. Reinemann. 2015. "Effects of management and co-digestion on life cycle emissions and energy from anaerobic digestion." *Greenhouse Gases: Science and Technology* 5: 603–21. doi:10.1002/ghg.1506

Aguirre-Villegas, Horacio A., Thaís H. Passos-Fonseca, Douglas J. Reinemann, Louis E. Armentano, Michel A. Wattiaux, Victor E. Cabrera, John M. Norman, and Rebecca A. Larson. 2015. "Green cheese: Partial life cycle assessment of greenhouse gas emissions and energy intensity of integrated dairy production and bioenergy systems." *Journal of Dairy Science* 98: 1571–92. doi:10.3168/jds.2014-8850

Amon, B., V. Kryvoruchko, T. Amon, and S. Zechmeister-Boltenstern. 2016. "Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment." *Agriculture, Ecosystems & Environment* 112: 153–62. doi:10.1016/j.agee.2005.08.030

Bentley, Jenn, Leo L. Timms, Larry F. Tranel, Greg Brenneman, and Kris Kohl. 2016. "Economics of dairy manure management in Iowa." Iowa State University. [http://lib.dr.iastate.edu/ans\\_air/vol662/iss1/36/](http://lib.dr.iastate.edu/ans_air/vol662/iss1/36/)

Hristov, Alexander N., Mark Hanigan, Noel A. Cole, Richard W. Todd, Tim A. McAllister, Pius M. Ndegwa, and Alan Rotz. 2011. "Review: Ammonia emissions from dairy farms and beef feedlots." *Canadian Journal of Animal Science* 91: 1–35. doi:10.4141/cjas10034

Hristov, Alexander N., Shah Zaman, Mike Vander Pol, Pius Ndegwa, Larry Campbell, and Steven Silva. 2002. "Nitrogen losses from dairy manure estimated through nitrogen mass balance and chemical markers." *Journal of Environmental Quality* 38: 2438–48. doi:10.2134/jeq2009.0057

Laboski, Carrie A.M., and John B. Peters. 2012. "Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin (A2890)." University of Wisconsin-Extension. <https://learningstore.uwex.edu/Nutrient-Application-Guidelines-for-Field-Vegetable-and-Fruit-Crops-in-Wisconsin-P185.aspx>

Montes, Felipe, Robert Meinen, Curtis J. Dell, Alan Rotz, Alexander N. Hristov, Joonpyo Oh, G. Waghorn, Pierre J. Gerber, Benjamin Henderson, Harinder P. Makkar, and Joost Dijkstra. 2013. "Special topics—Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of animal management mitigation options." *Journal of Animal Science* 91: 5070–94. doi:10.2527/jas2013-6584

Myhre, Gunnar, Drew Shindell, Francois-Marie Bréon, William Collins, Jan Fuglestedt, Jianping Huang, Dorothy Koch, Jean-François Lamarque, David Lee, Blanca Mendoza, Teruyuki Naka-jima, Alan Robock, Graeme Stephens, Toshihiko Takemura, and Hua Zhang. 2013. "2013: Anthropogenic and natural radiative forcing supplementary material." *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Thomas F Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda MB Tignor, Simon K Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline M Midgley. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf)

Ndegwa, Pius M., Alex N. Hristov, Jactone Arogo, and Ronald E. Sheffield. 2008. "A review of ammonia emission mitigation techniques for concentrated animal feeding operations." *Biosystems Engineering* 100: 453–69. doi:10.1016/j.biosystemseng.2008.05.010

United States Environmental Protection Agency (USEPA). 2012. Global anthropogenic non-CO<sub>2</sub> greenhouse gas emissions: 1990–2030. Washington, DC: USEPA Climate Change Division, [https://www3.epa.gov/climatechange/Downloads/EPAactivities/EPA\\_Global\\_NonCO2\\_Projections\\_Dec2012.pdf](https://www3.epa.gov/climatechange/Downloads/EPAactivities/EPA_Global_NonCO2_Projections_Dec2012.pdf)

United States Environmental Protection Agency (USEPA). 2016. Inventory of U.S. greenhouse gas emissions and Sinks: 1990–2014. Washington, DC: USEPA. <https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html>

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