How Much Gas Do Beef or Dairy Cattle Produce?

Author, *Zifei Liu, Ph.D., Biological and Agricultural Engineering; Kansas State University*

Which gases are of interest and why?

The beef and dairy industries emit gases to the atmosphere from animal feed digestion (enteric fermentation) and manure decomposition. Some of the gases have been labeled greenhouse gases. Greenhouse gases in the atmosphere delay heat on the Earth's surface from being lost to space, contributing to climate change.

The U.S. Environmental Protection Agency (EPA) estimates that enteric fermentation and manure management in livestock production are responsible for 2.2 percent and 1.1 percent of the total human-induced greenhouse gas emissions in the United States respectively. Beef and dairy cattle are considered the major contributors within the various livestock species. In 2012, beef and dairy cattle accounted for 71 percent and 25 percent of the total emissions from enteric fermentation respectively, and 15 percent and 46.7 percent of the total emissions from manure management, respectively (EPA, 2014). The greenhouse gas from enteric fermentation is mainly methane (CH_4), while the greenhouse gases from manure management include CH_4 and nitrous oxide (N_2O). The carbon dioxide (CO_2) generated by animal breathing is considered biogenic and so is often excluded or deferred in accounting of total greenhouse gas emissions.

Ammonia (NH_3) emissions from animal manure are receiving attention because of the effect they have on ecosystems and air quality concerns. Deposition of NH_3 can lead to over-enrichment of nutrients and cause eutrophication of surface waters. Ammonia reacts with other gases in the atmosphere to form fine particulates, which affect visibility and cause health concerns. The largest source of human-induced NH_3 emissions in the United States is livestock agriculture, accounting for 71 percent (EPA, 2004a). The EPA estimated total NH_3 emissions from livestock operations were 2.42 million tons in 2002, in which beef and dairy cattle accounted for 27 percent and 23 percent, respectively (EPA, 2004b).

Dairy cattle.

In addition to environmental concerns, NH_3 emissions represent losses of nutrients and inefficient conversion of feed nitrogen into animal product. CH_4 emissions represent losses of energy and inefficient use of feed energy (Figure 1).

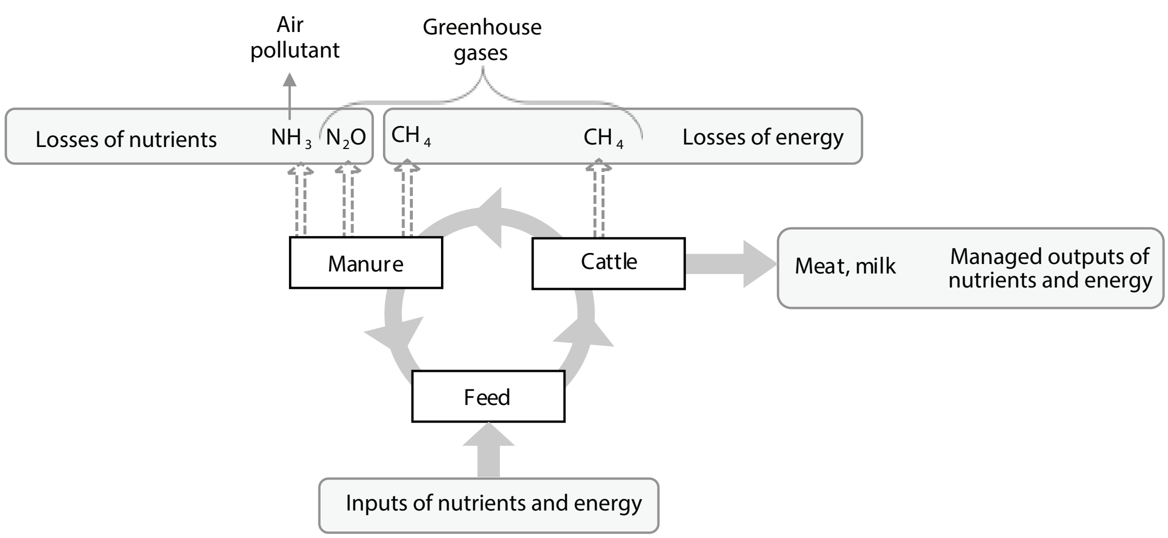

Figure 1. Gas emissions represent losses of nutrients and energy from cattle operation.

Methane

On-farm CH_4 emissions are mainly from enteric fermentation and manure management, with enteric CH_4 accounting for about 75 percent (EPA, 2014). The International Panel on Climate Change (IPCC) presented guidelines for estimating CH_4 emissions from both sources (IPCC, 2006). The enteric CH_4 emission factors can be estimated based on the gross energy intake by individual animals and the CH_4 conversion factor (an estimate of CH_4 loss per unit of feed). The manure management CH_4 emission factor depends on the quality and quantity of the excreted volatile solid (VS) and how it is managed (Table 1).

Enteric CH_4 emissions are produced by ruminants as a result of microbial breakdown of carbohydrates in the rumen. Typical rumen gases include 66 percent CO_2 and 27 percent CH_4 (Sniffen and Herdt, 1991). The quantity of CH_4 produced depends on the type of digestive tract, age, and weight of the animal, as well as the quality and quantity of the feed consumed. Generally, the higher the feed intake, the higher the CH_4 emission, though emission also is affected by the composition of the diet. Using highly digestible feed results in lower feed intake and lower emissions. The gross energy intake (GE) can be converted to dry matter intake (DMI), after dividing by the energy density of the feed, and using a default value of 18.45 MJ/kg of dry matter. The typical daily DMI is 2 to 3 percent of the body weight of the animals. In high-producing milk cows, daily DMI may exceed 4 percent of body weight (IPCC, 2006). The quantity of gross energy converted to CH_4 also is critical in determining emissions. Substantial research is aimed at improving estimates of the enteric CH_4 conversion factor (Ym) for different livestock and feed combinations. The EPA (2014) calculated national enteric CH_4 emission factors for beef and dairy cattle by animal type using the IPCC methods, and the results for 2012 are presented in Table 2.

Manure management CH_4 emissions are produced from decomposition of manure under anaerobic conditions during storage and treatment. How much manure management CH_4 is produced depends on the amount of manure and the portion of the manure that decomposes anaerobically. Liquid manure systems (e.g., lagoons, tanks) tend to have anaerobic conditions, and produce more CH_4 as compared to dry manure systems (e.g., stacks, piles). Higher CH_4 emissions also are associated with higher temperatures and longer retention times of the storage unit. The EPA (2014) calculated national manure management CH_4 emissions for beef and dairy cattle based on manure distribution data among waste management systems, and the results for 2012 are presented in Table 3. Due to the increasing use of liquid manure systems, the national CH_4 emissions from manure management in dairy industries increased from 1990 to 2012, although the population of dairy cattle was relatively stable (EPA, 2014).

Table 1. Equations for estimating emission factors for enteric fermentation and manure management (adapted from IPCC, 2006)

Equations	Key variables
$EF_e = GE \cdot Y_m / 55.65 = (NE/DE) \cdot Y_m / 55.65$ In which, EF_e = enteric CH_4 emission factor, kg CH_4 /head/year. GE = gross energy intake, MJ/head/year. Y_m = enteric CH_4 conversion factor, percentage of gross energy in feed converted to CH_4. NE = summed net energy requirements, MJ/head/year. DE = digestibility of feed, percentage of GE intake digestible. The factor 55.65 MJ/kg CH_4 is the energy content of CH_4.	• NE includes net energy required by the animal for maintenance, growth, activity, pregnancy, lactation, work, etc.), and depends on type and weight of the animal. • DE can affect gross energy intake; typical DE in the U.S. was 66.7% for dairy cows and 82.5% for feedlot cattle in 2012 (EPA, 2014). • Y_m depends on several interacting feed and animal factors; default values of Y_m provided by IPCC (2006) are 3.0±1.0% for feedlot cattle that are fed diets contains 90% or more concentrates, and 6.5±1.0% for dairy cows and cattle that are primarily fed low-quality crop residues and byproducts.
$EF_m = VS \cdot 365 \cdot B_0 \cdot MCF \cdot 0.67$ In which, EF_m = manure management CH_4 emission factor, kg CH_4/head/year. VS = daily excreted volatile solid, kg/head/day. B_0 = maximum methane producing capacity of manure, m^3/kg of VS. MCF = manure management CH_4 conversion factor, percentage of VS actually converted to CH_4 compared to B_0. The factor 0.67 kg/m^3 is conversion factor of m^3 CH_4 to kg CH_4.	• VS can be estimated based on feed intake and digestibility; typical VS in the U.S. is 5.4 and 2.4 kg/head/day for dairy cow and other cattle respectively. • B_0 varies by species and diet; typical B_0 in U.S. is 0.24 and 0.19 m^3/kg of VS for dairy cow and other cattle respectively. • MCF depends on manure management system, temperature, and retention time of the storage unit; MCF for liquid manure systems is much larger than that for dry manure systems (e.g. 50 to 80% for anaerobic lagoon vs. 2 to 5% for dry manure, solid storage).

Table 2. National enteric CH_4 emission factors for beef and dairy cattle for 2012 (kg CH_4/head/year).

	Calves	Cows	Replacements 7 to 11 months	Replacements 12 to 23 months	Bulls	Steer Stockers	Heifer Stockers	Feedlot Cattle
Dairy	12	143	46	69	–	–	–	–
Beef	11	95	60	70	98	58	60	46

Note: To convert to a daily emission factor, the yearly emission factor can be divided by 365. Data from EPA (2014).

Table 3. National manure management CH_4 emissions for beef and dairy cattle for 2012.

	Population (1,000 head)	Total manure management emissions (Gg)	Average manure management emission factor (kg CH_4/head/year)
Dairy	13,816	1,291	93
Beef	81,443	128	1.6

Note: Data are from EPA (2014).

Table 4. Estimated NH_3 emission factors for beef and dairy cattle in recent studies.

Source area	Cattle type	Emission factor (kg NH_3 /head/year)	References
Open lot pens	Beef steers and heifers, 275-550 kg	19.3	Todd et al., 2006
Dry lot	Beef and heifers	11.4	EPA, 2004b
Free stall barns	Dairy	1.8–20.6	NAEMS, 2010
Simulated tie-stall	Dairy	11.0	Liu et al., 2012

Ammonia

Ammonia is produced as a by-product of the microbial decomposition of organic nitrogen (N) compounds in manure. For dairy cows, 25 to 35 percent of the N they consume is secreted in milk (Liu et al., 2012). For beef cattle, only 14 percent of the N they consume is retained by the animal (Cole and Todd, 2009). Almost all the remaining N is excreted in urine and feces.

Estimated N excretion rates in the United States are 0.44 and 0.31 kg N per day per 1,000 kg animal mass for dairy cattle and other cattle respectively (IPCC, 2006). The N in the urine is mainly in the form of urea, which can rapidly be converted to NH_3 when in contact with the urease enzyme in feces. Higher pH and temperature favor this enzymatic conversion and increase NH_3 emissions. Ammonia emissions are sensitive to urinary urea levels, which increase as protein increases beyond dietary requirements.

The total N volatilization from manure (primarily in the form of NH_3) ranges from 5 percent to 80 percent of manure N, depending on different manure management systems (IPCC, 2006). It was estimated that annual NH_3 loss from an open lot cattle feed yard was about 50 percent of fed N. Summer emissions are about twice as great as in the winter (Todd et al., 2006). Results of some recent studies on NH_3 emission factors for beef and dairy cattle are presented in Table 4.

Nitrous oxide

Though most of the N loss from manure is in the form of NH_3, a small part of the N loss is in the form of N_2O and mono-nitrogen oxides (NO_x). Direct N_2O emissions occur via combined nitrification and denitrification of N contained in manure. Oxidized forms of N are first formed through nitrification with a sufficient supply of oxygen. They are transformed to N_2O through denitrification in an anaerobic environment.

For uncovered anaerobic lagoon or liquid/slurry, direct N_2O emissions are negligible, while N loss as direct N_2O is estimated to be 2 percent, 0.5 percent, and 0.5 percent of manure N for dry lots (including feedlots), solid storage, and liquid/slurry with crust cover, respectively (EPA, 2009). Indirect N_2O emissions result from other forms of N loss from manure. About 1 percent of N loss in the forms of NH_3 and NO_x can be counted as indirect N_2O emissions. Total (direct and indirect) N_2O emissions in 2012 were estimated to be 1.4 and 0.3 kg N_2O/head/year for dairy and beef cattle respectively (EPA, 2014).

Implications

Air emissions from industries are subject to reporting requirements under the Emergency Planning and Community Right-to-Know Act (EPCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act

(CERCLA). In the past, efforts to regulate air emissions from agricultural sources were confounded by a lack of information, and the reporting requirement for livestock operations is generally not enforced. On January 2009, the EPA finalized a rule providing an exemption to small farms (confining fewer than 700 dairy cows or 1,000 other cattle) for reporting requirements under CERCLA. The exemption created by the new rule does not affect the EPA's authority to respond to citizen complaints or requests for assistance from state or local government agencies to investigate releases of hazardous substances from farms. The new rule requires only large animal feeding operations to report air emissions as directed by EPCRA. The reportable quantity for NH_3 is 100 lb/day. There will be increasing liability for not complying with EPCRA. Based on currently available data, the farm sizes that may trigger the need for a farm to report NH_3 emissions under EPCRA are estimated to be 800 to 9,200 head for dairy and 860 to 1,450 head for beef.

On April 10, 2009, EPA published proposed mandatory greenhouse gas reporting rules to regulate greenhouse gas emissions. Manure management systems for livestock manure with combined CH_4 and N_2O emissions in amounts equivalent to 25,000 metric tons of CO_2 equivalent unit or more per year are required to report under this rule. The animal population threshold level below which facilities are not required to report emissions is 3,200 head for dairy and 29,300 head for beef (EPA, 2009). Enteric emissions are not covered under the current reporting requirement.

There is continuing pressure on the industry to reduce greenhouse gas and NH_3 emissions. The dairy industry has announced a long-term goal of reducing greenhouse gas emissions by 25 percent by 2020 (Innovation Center for U.S. Dairy, 2010). The reductions may be a combination of reduced emissions per head and reduced population of cattle. Nutritional principles and manure management practices can be used to develop strategies to reduce emissions. For more information, see other publications by the author at *www.ksre.ksu.edu/bookstore.*

References

Cole, N.A. and R.W. Todd. 2009. *Nitrogen and phosphorus balance of beef cattle feedyards.* Texas animal manure management issues conference program. September 29-30, 2009. Round Rock, Texas.

EPA, 2004a. "Estimating ammonia emissions from anthropogenic nonagricultural sources." *www.epa.gov/ttnchie1/eiip/techreport/volume03/eiip_areasourcesnh3.pdf*

EPA. 2004b. "National emission inventory – ammonia emissions from animal husbandry operations." *www.epa.gov/ttnchie1/ap42/ch09/related/nh3inventorydraft_jan2004.pdf*

EPA. 2009. "Final Rule: Mandatory Reporting of Greenhouse Gases." *www.epa.gov/ghgreporting/documents/pdf/2009/GHG-MRR-FinalRule.pdf*

EPA. 2014. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2012.* U.S. Environmental Protection Agency. *www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf*

Innovation Center for U.S. Dairy. 2010. *U.S. Dairy Sustainability Commitment Progress Report.*

IPCC. 2006. *Guidelines for national greenhouse gas inventories, Vol. 4: Agricultural, forestry and other land use.* Intergovernmental Panel on Climate Change.

Liu, Z., et al. 2012. "Gas emissions from dairy cows fed typical diets of Midwest, South and West regions of the United States." *J. Environ. Qual.* 41(4):1228-1227.

NAEMS. 2010. Summary reports of the *National Air Emissions Monitoring Study*. Available at *www.epa.gov/airquality/agmonitoring/data.html*

Sniffen, C.J. and H. H. Herdt. 1991. *The Veterinary Clinics of North America: Food Animal Practice, Vol 7, No 2.* Philadelphia, PA: W. B. Saunders Company.

Todd, R.W. 2006. "Ammonia Emissions from Open Lot Beef Cattle Feedyards on the Southern High Plains." *www.epa.gov/ttnchie1/conference/ei16/session5/todd.pdf*

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

MF3185 April 2015

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, John D. Floros, Director.