Cornell University

Dairy Manure Storage & Greenhouse Gas Mitigation Opportunities

Information Sheet #2

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Information Sheet #2 – OVERVIEW

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Fast Facts

- **Trends**: Due to increasing farm size and water quality requirements, more farms are storing manure in order to apply valuable nutrients to cropland during the growing season.
- **An imperative to act:** Stored manure is often anaerobic (low oxygen) and produces methane, a greenhouse gas (GHG) that is 34 times more potent than carbon dioxide (CO_2) over 100 years (86 times more potent over 20 years). If methane is combusted it greatly reduces farm GHG emissions.
- **A concern for implementation:** Stored manure also produces N_2O (a potent GHG 298 times more potent than CO_2) and other gases such as hydrogen sulfide (H_2S) that can impact health.
- **An opportunity for proactive change:** Many carbon-trading programs recognize methane destruction; methane can also be used to generate useable energy on and off farms.

Introduction

Society increasingly expects agriculture to produce food in a manner that maintains environmental quality. In the past, daily spreading of manure, with the potential to contaminate surface waters, was common particularly during fall or winter when crops are not growing and frozen ground increases surface runoff of nutrients to streams (Williams et al., 2011, Wightman & Woodbury 2016). To address water quality, manure is stored in a solid stack (less often) or in a liquid storage facility (more often) for many months so manure can be spread on dates closer to when crops can take up the nutrients, reducing the potential for pollution of surface and groundwater. However, these improvements for water quality may have drawbacks when considering greenhouse gas (GHG) emissions (Gooch, 2005a).

Environmental Concerns

Methane (CH_4) and nitrous oxide (N_2O) are potent GHG and should be considered when evaluating manure management. For more general information about GHG in agriculture, see Information Sheet #1. Dairy manure is about 90% moisture and 10% solids (ASABE, 2006), with a portion of those solids being carbon compounds called volatile solids (VS), and also various nitrogen (N) compounds. Some of the VS are precursors for CH_4 and some of the nitrogen compounds are precursors for N_2O. More anaerobic (low oxygen) manure management conditions, as found in liquid storage, cause more CH_4 production. More aerobic (high oxygen) manure management conditions, such as daily spreading or composted solids, prevent CH_4 production. The opposite pattern is true for N_2O: when manure-N is stored more anaerobically, N will not convert to N_2O (and has great benefit for reducing synthetic N fertilizer needs during spring planting); when manure-N is stored under aerobic conditions (e.g. composted solids), more N_2O is released. These two gases are important because CH_4 is 34 times more potent as a GHG than CO_2 while N_2O is 298 times more potent over

100 years. This is potency is referred to as the Global Warming Potential or GWP; see Information Sheet #1. To note, there is significantly more VS than N in the manure, so while N_2O is a more potent GHG than CH_4, there is significantly greater potential to produce more CH_4. Besides GHG, other emissions including ammonia, hydrogen sulfide, and other odor causing compounds are often released from manure storage. In high concentrations these toxic gases can cause damage and even death to humans and other animals.

Summary Of Regulations Of GHG Emissions

Policies and regulations, such as Concentrated Animal Feeding Operation (CAFO) permitting, Total Maximum Daily Load (TMDL) requirements for certain watersheds, and other watershed protection efforts throughout NYS, have led to more storage capacity on farms to facilitate better management of manure for water quality. There are no regulations of GHG emissions from agriculture in NYS.

Goal

This Information Sheet is intended to help dairy farmers and their advisors navigate meaningful methods for reducing GHG emissions from manure management systems. Three major opportunities are summarized below.

Summary Of Potential GHG Reduction Practices From Manure

Description of Strategy	Opportunities	Considerations
Optimized animal feed	• Reduce nitrogen in animal feed to reduce N_2O emissions from manure storage. • Improve diet efficiency to reduce total inputs, reduce VS in the manure, and potentially reduce the enteric emissions of CH_4 from the cow. Other benefits: Feed efficiency saves money.	• Requires animal diet planning and testing of diet and manure.
Manure storage with cover and flare for methane destruction	• Methane capture with a cover + combustion with a flare reduces the GWP of CH_4 from 34 to 1. • Documented and verified CH_4 destruction can qualify for carbon credits. • State and federal agencies offer competitive funding for manure cover and flare systems. Other benefits: Manure covers exclude rain reducing storage size. Excluding rainfall can reduce hauling costs. A cover prevents rainfall from causing overflow of storages. Covers can control storage odor and improve neighbor relations.	• Covers + flares cost money, require labor & maintenance. • Covers last ~10-20 years and will need to be replaced. • Carbon markets are not mature. • CH_4 is a highly flammable gas requiring new safety considerations. • Storing manure can produce hydrogen sulfide (H_2S), a deadly gas. • Manure solid/liquid separation is required.
Anaerobic Digestion System (ADS) methane destruction + energy generation	• Methane capture and combustion for generating electricity reduces the GWP of methane from 34 to 1. • AD can be used to generate heat and power on farm, reducing fossil fuel emissions. • Grants are available for ADS-electricity • AD may qualify for carbon credits and/or renewable energy credits if documented and verified. Other benefits: ADS can control odors from storage and spreading, reduce electric costs, and improve neighbor relations.	• ADS intentionally produce additional methane, which if not properly combusted in an engine, boiler, or flare can cause increased farm GHG emissions. • AD systems are expensive to construct and require regular maintenance. • CH_4 is a highly flammable gas requiring new safety considerations. • Storing manure can produce hydrogen sulfide (H_2S), a deadly gas. H_2S can also corrode equipment; corrosion is reduced by proper design. • Capital costs may not be recouped from sale of electricity.

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Information Sheet #2 – IN DEPTH

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Target Audience: Educators and technicians helping dairy farmers manage stored manure
Target Greenhouse Gases (GHG): Methane (CH_4) and nitrous oxide (N_2O)
Questions by Educator to help in Farmer Planning

- What type and number of animals do you manage (e.g. 20% heifers, 80% milking)?
- Does your farm store manure?
  - If no,
    - How do you currently manage your manure?
    - Are you experiencing any issues with your manure management practices?
    - What are your near and long term manure management goals?
    - Are you interested in exploring GHG mitigation options?
  - If yes,
    - How many months of storage capacity?
    - What kind of storage (e.g. solid under a roof, liquid in earthen containment)?
    - Are you experiencing any issues with your manure management practices?
    - What are your near and long term manure management goals?
- Are you interested in exploring GHG mitigation options?

GHG Emissions From Manure

Different manure storage systems have different amounts of available oxygen that impact the potential for greenhouse gas (GHG) production. When a storage unit has no free oxygen (anaerobic, such as stored liquid manure), CH_4 is produced (Kebreab et al., 2006). These anaerobic systems reduce N_2O emissions. In contrast, high oxygen (aerobic) systems inhibit CH_4 production but have increased N_2O emissions. Both CH_4 and N_20 are GHG.

Over 100 years, CH_4 is 34 times as potent as carbon dioxide (CO_2); over 20 years CH_4 is 86 times as potent as CO_2 (IPCC, 2013) making it an even more important target for near-term GHG mitigation efforts (Shoemaker et al., 2013). As N_2O is 298 times as potent as CO_2 (over 100 years, IPCC, 2013), both CH_4 and N_2O must be considered when evaluating the GHG emissions from a change in manure management systems.

Emissions of CH_4 and N_2O from manure storage depend on the storage conditions of the N and volatile solid (VS) content in the manure. Conditions that promote CH_4 emissions include the mass of VS, storage time, and temperature (Dong et al., 2006, Hashimoto et al., 1981). Table 1 below illustrates how a change away from daily spread to more anaerobic storage systems has more than doubled farm GHG despite a decrease in total animal number and increase in milk productivity.

Table 1. Effect of manure management strategy on total greenhouse gas (GHG) emissions in NYS.*

	Daily spread†	Solids	Liquids‡	Total	
1992					
Percentage waste management system (%)	80.6	3.6	15.8		
	Mg CO_2e yr^{-1}				% GHG
N_2O direct	0	11,427	49,572	60,999	8.7
N_2O Volatilization indirect§	50,736	6,171	25,778	82,684	11.8
N_2O Runoff indirect¶	0	0	521	521	0.1
CH_4#	52,016	18,745	487,907	558,668	79.5
1992 TOTAL	102,752	36,342	563,777	**702,872**	
2012					
Percentage waste management system (%)	42.6	10.7	46.6		
	Mg CO_2e yr^{-1}				% GHG
N_2O direct	0	28,641	124,251	152,892	9.9
N_2O Volatilization indirect§	22,709	15,466	64,610	102,786	6.6
N_2O Runoff indirect¶	0	0	1,305	1305	0.1
CH_4#	23,282	46,982	1,222,913	1,293,178	83.4
2012 TOTAL	45,992	91,090	1,413,078	**1,550,160**	

* From Wightman and Woodbury 2016
†In 1992 there were 721,286 milking cows, and 81% of manure was daily spread. In 2012 there were 610,712 milking cows and 48% of manure was daily spread (Wightman & Woodbury 2016).
‡Using USEPA methane conversion factor values for daily spread, solids, and liquid–slurry.
§N_2O Volatilization indirect refers to N that volatilized from the point source and redeposited at a remote location and subsequently converted to N_2O (not including emission on land application).
¶N_2O Runoff indirect refers to N that has run off from the point source to a remote location and subsequently converted to N_2O (not including emission on land application).

The data in Table 1 indicate several important considerations about GHG emissions for manure management. First, roughly 80% of manure management emissions come from CH_4 and 20% from N_2O. Second, there are three different mechanisms by which manure N can become N_2O (directly emitted and indirectly emitted through leaching and volatilization and re-deposition). Third, there has been a change in practice away from daily spread (81% of manure was daily spread in 1992 compared to 43% of manure daily spread in 2012).

Table 2 indicates how changes in practice have impacted GHG per unit milk.

Table 2. Effects of changes in manure management on methane emissions in NYS (1992–2012).*

	No. animal units	Milk produced	Methane produced†	
		Mg	Mg CO_2e yr^{-1}	Mg CO_2e Mg $milk^{-1}$
1992 herd total	1,414,436	5,246,878	558,668	0.11
2012 herd total	1,197,601	5,988,260	1,293,178	0.22
2012 herd with 1992 WMS‡	1,197,601	5,988,260	473,023	0.08

* From Wightman and Woodbury 2016

†Using only USEPA methane conversion factors for daily spread, liquid–slurry, and solid manure.

‡Manure from the 2012 cow population is managed by the 1992 waste management system (WMS), which was predominantly daily spread.

The data in Table 2 indicate that even though the 1992 NY dairy herd was larger (milking cows plus replacement heifers), the 1992 manure management produced half the CH_4 per unit milk of the smaller 2012 herd (Wightman & Woodbury, 2016). However, if the 2012 herd used the 1992 manure management practices, it would have produced less total GHG emission as well as less GHG per unit milk. This result indicates that milk production efficiency practices have reduced the amount of manure per unit milk, thus reducing the GHG precursors that could have been converted to CH_4 and N_2O.

Managing GHG from Volatile Solids (VS) And Nitrogen (N) by Manure Management System

Different manure storage systems allocate the VS and N differently between the liquid and solid portions of the manure as shown for separation examples in Table 3.

Table 3. Solid-Liquid separation impact on volume, VS, & N.

Separator Type	Screen size mm	Fraction liquid % original mass	Vs in liquid %	N in liquid % total N	Author
Screw press	0.80	82%	44%	79%	Rico et al., 2011
Belt press	0.30	88%	48%	n/a	Sutaryo et al., 2013
Screw press	0.50	n/a	44%	78%	Chastain 2009
Screw press	0.75	77%	32%	77%	Gooch et al., 2005b
Roller separator	n/a	78%	54%	76%	Gooch et al., 2005b
AVERAGE		81%	45%	77%	

These data show three things. First, they illustrate that manure is mostly liquid (separated with screw press, belt press, or roller separator). Second, the N partitions relatively equally between the liquid and solid portions of the manure. Third, the VS also partitions relatively equally between the liquid and solid portions, but favoring the solid portions on a mass basis. This partitioning is important when selecting a manure management system. The various effects that manure management practices have on CH_4 and N_2O production are summarized in Table 4.

Table 4. How manure management practices impact production of N_2O and CH_4

Practice	Oxygen condition	Manure component	Portion of GHG precursor	N to N_2O	VS to CH_4
Daily spread	Aerobic	Liquid+Solids	100% N and 100% VS	HIGH	~none
Separated Solids ‡	Mostly Aerobic	Solids Only	~25% N and ~50% VS	HIGH	LOW
Separated Liquids ‡	Anaerobic	Liquids Only	~75% N and ~50% VS	LOW	HIGH
Liq/Slurry	Anaerobic	Liquids+Solids	100% N and 100% VS	LOW	HIGH*
Liq/Slurry (ADS)	Anaerobic	Liquids+Solids	100% N and 100% VS	LOW	Very HIGH*

‡ Solids only and liquids only should be 'combined' when thinking about total GHG potential.

* The VS in lignin solids is generally more difficult to convert into CH_4. However, an anaerobic digester facilitates the conversion of the VS by controlling the temperature and retention time. This is beneficial in AD energy generating systems because it creates more CH_4 gas for increased energy production.

Table 4 lists common manure management practices based on oxygen levels within the management practice starting with the highest N_2O emissions (most aerobic or high oxygen systems) at the top and the highest CH_4 production at the bottom (anaerobic or low oxygen systems). It also illustrates how these manure management practices partition their GHG precursors (VS and N) and the likelihood of these GHG precursors to be converted to CH_4 or N_2O. Generally, aerobic systems produce the most N_2O, anaerobic systems produce the most CH_4.

Summary Of Conceptual Strategies For Managing Manure GHG

Conditions that may reduce GHG precursors in manure storage.

- Increasing the feed efficiency (reduces amount of manure per unit milk), thus reducing VS and N precursors available in the manure to be converted to CH_4 and N_2O emissions.
- Considering the amount of other wastes (bedding, imported food waste) placed in the storage that add additional N and VS precursors available for conversion to N_2O and CH_4 on farm.

Conditions that may reduce the formation of GHG.

- Maintaining the manure-N in anaerobic conditions can help store the N (reduce N to N_2O conversion) until field application during the growing season so the plants absorb it (thus reducing purchase of synthetic N).
- Separating manure solids retains the majority of N in the liquid portion that if stored anaerobically, produce relatively little N_2O, keeping the N for spring field application. Separation also removes ~50% of the VS to the more aerobic solid storage thus reducing potential CH_4 emissions. It is estimated that separation may reduce overall GHG emissions by 20% but is difficult to quantify the total CH_4+N_2O benefit of separation on a variety of farms and practices (Jayasundara et al., 2016).
- As warm temperatures increase the biological conversion of VS to CH_4, reducing the amount of manure and/or storage time of manure during warmer seasons can reduce the CH_4 emitted.

Conditions that may destroy CH_4.

- Methane can be metabolized in the manure crust by bacteria. However, manure crust conditions also increase the N_2O emissions; a recent review indicates that the GHG mitigation potential of a crust can be variable. (Jayasundara et al, 2016).
- Methane can be captured and combusted (by a flare, boiler, or engine) to CO_2 and water vapor, thus significantly reducing the GWP of CH_4 from manure storage. This CH_4 destruction can be measured and be eligible for carbon credits. CH_4 combustion for energy can displace fossil fuel emission.

Mitigation Opportunity 1: Optimizing Animal Feed

Improved diet can mitigate emissions in four ways. 1) It can reduce enteric emissions (not assessed here because it is not a manure management strategy). 2) Maximal feed utilization results in less VS in the manure per unit milk, thus reducing the CH_4 precursors per unit milk. To note, Table 2 above illustrates that NY dairy farmers have been increasing milk production efficiency. 3) If diet is monitored so no excess N is fed, there will be less N in manure available to be potentially turned into N_2O. 4) This feed efficiency can also reduce emissions from producing the extra feed (upstream GHG emissions from fertilizing, harvesting, transporting grain etc.). By reducing the N and VS available in the manure and increasing the milk production efficiency, the farm is reducing the quantity of N and VS available to potentially be converted to N_2O and CH_4 in the manure management systems.

Mitigation Opportunity 2: Separate Manure (Solid Storage + Liquid Storage With Cover & Flare)

SOLID portion (N_2O and CH_4 production)

The solid portion, because it is generally more aerobic, has low CH_4 emission despite storing ~50% of the VS. In contrast, while only ¼ of the N precursors end up in the solid portion, the fluctuating aerobic/anaerobic condition of the solid manure has the capacity to cause a significant increase in N_2O emissions compared to N stored in anaerobic liquid/slurry storage. A recent review indicates aerated composting in warm summer months is preferable to a stockpile for GHG (Jayasundara et al., 2016) but may not be preferable for N-retention.

LIQUID portion (N_2O and CH_4 production)

Anaerobic liquid storage of manure N is effective in keeping N from converting to N_2O (for liquid/slurry or separated liquids) as well as retaining N for spring field application. As shown in Table 3, separation retains most of the manure-N in the liquid portion. While liquid storage keeps N_2O emissions low, the anaerobic conditions of liquid storage make manure CH_4 emissions a significant source of farm GHG during warm months. Farms could spread the liquid frequently in the summer thus minimizing anaerobic storage during warm temperatures favorable for converting VS to CH_4. If frequent summer spreading of the liquids is unrealistic, farms may consider placing a cover on their liquid manure storage to capture the methane and convert the methane to carbon dioxide by flaring it. Additionally, covers prevents extreme weather-event induced overflows, reduces rainwater collection to reduce hauling costs, enhances the N retention in the manure, and reduces odors from liquid manure storage. This has been done on farms in NYS (Wightman & Woodbury 2016). Figure 1 is an image of an existing cover in NY followed by a review of information from three farms that have storage equipped with a cover and flare.

Figure 1. Manure cover on New York dairy farm, photo courtesy of Fessenden Dairy

A pilot project performed by Environmental Credit Corp (ECC) placed covers (1.5 mm thick high-density polyethylene) and flares on three existing NY dairy farm manure storage units from 2008-2009. The storage units contained only separated liquids; farm size ranged from 1,265 – 1,710 animal units (AU) (Subler, 2011). Animal populations were tracked and used to estimate volatile solid outputs. Biogas flow was continuously measured and recorded, and methane concentration readings were taken quarterly. Overall, flaring was 80% effective in burning the combustible components in the biogas; in the winter months the flare rarely operated (Table 5).

Table 5. Monthly biogas data averaged across 3 covered manure storage units on dairy farms in New York during 12 consecutive months between 2010 and 2011.

	m^3 biogas	% CH_4†	AFE ‡
Jan	5,859	34%	0.2
Feb	3,129	34%	0.0
Mar	4,432	34%	0.2
Apr	5,839	47%	0.0
May	5,738	47%	0.3
Jun	14,183	47%	0.8
Jul	30,585	65%	1.0
Aug	34,291	65%	1.0
Sep	33,265	65%	1.0
Oct	30,793	52%	0.9
Nov	11,841	52%	0.6
Dec	3,615	52%	0.1
TOTAL	183,568	57%	0.8

‡AFE – annual flare effectiveness is a measure of the percentage of methane produced and effectively destroyed by flaring on an annual basis. Note, most methane is produced in the summer when the flare is the most effective.

† % methane in biogas (measurements taken quarterly)

The data in Table 5 illustrate several things. First, liquid-only storage on farm produces a lot of biogas (averaging 57% CH_4 concentration). Second, most CH_4 is produced in the warm summer months. Third, when the CH_4 concentration is low in the biogas, the flare is less effective, because there is less CH_4 to combust and the flares were not designed for low methane concentrations. Fourth, since most gas is produced in the summer months with high CH_4 concentrations, the flare can be 80-90% effective at destroying the annual CH_4 emissions. Note, these are actual covers and flares from trials implemented; the CH_4 destruction could be improved with increased capital investment and management.

Table 6. Estimated costs for manure storage unit covers with a 10-year* lifespan†.

Budget Category	**Large Cover:1000-Milking Cows#** **USD**	**Medium Cover: 550-Milking Cows#** **USD**
Equipment	$221,081	$121,595
Personnel	$25,399	$25,399
Travel	$3,136	$3,136
Supplies	$890	$890
Contractual	$20,947	$20,947
Other	$14,545	$14,545
SubTotal	$285,999	$186,513
Separator	$46,613	$46,613
Cover Disposal	$34,503	$18,977
Rain water (savings/10yr) ‡	-$62,031	-$34,117
Interest (10 yrs at 4.5%)	$74,337	$53,115
Total Cost	**$379,422**	**$271,100**
cost per milking cow/yr	$37.94	$49.29
cost per Mg CO_2e	$9.63	$12.51

† Wightman & Woodbury, 2016.

‡Note, rainwater saving is estimated to be $0.02/gallon for transport to field. We do not give a savings from N-storage as that would occur with or without the cover.

Milking cow (plus manure from 0.5 associated replacement heifers/milking cow)

*While cover manufacturers predict a 20-year life-span, we have chosen 10 years to conservatively estimate cost.

In Table 6, costs for covering a 550-cow and 1000-cow storage with a flare would range between $270,000 and $380,000. Note, the values are modified from data collected on five farms that installed manure covers with flares in NYS in 2008-2009. To make this system break even, the price paid per Mg CO_2e would need to be in the $10-$13 range. To learn more about retrofitting existing storage units for covers, or planning to build a new storage unit, please see Information Sheet #3. Alternatively, one might consider installing an anaerobic digester system (ADS, see below and Information Sheet #3) to destroy CH_4 while also producing energy.

Mitigation Opportunity 3: Liquid/Slurry Anaerobic Digestion For Energy Generation

Anaerobic digestion can be passive, as in the case for the liquid storage of manure (described above) or it can be active when a farm installs an Anaerobic Digester System (ADS) – an example of an active ADS located on a NYS dairy farm is shown in Figure 2. Currently, there are 26 operating digesters in NYS with about 1,500 candidate farms for ADS.

Figure 2. Vertical digester vessel and biogas utilization building on a 100-cow tiestall farm in NYS.

An ADS actively produces methane from a portion of the VS in manure. Well-designed systems are optimized to produce CH_4 by providing adequate retention time, uniform heating to target level, and in some cases agitation. Methane production can be increased substantially by adding VS from other sources such as food waste. From an electric generation standpoint, more methane means more energy to run the engine-generator set and/or boiler. However, if there is a leak in the system, it can also mean increased overall farm GHG emissions because more CH_4 can be produced. Increased retention time can also increase total CH_4 produced while also reducing CH_4 emissions from ADS effluent storage. To note, for every kWh produced with an ADS, a farm is displacing 0.24 kg CO_2e from grid-based emissions (EIA, 2014). Note, most of the GHG mitigation benefit will come from destroying the high GWP of CH_4 and not from displacing fossil-based electricity.

Table 7. Sample costs from Swiss Valley Farm, a NY dairy farm (Boerman et al, 2014)

Farm Name	Swiss Valley
Number of Milking Cows	900
Loading Rate (gal)	30,000
Percent Food Waste	0%
Retention Time (days)	30
Digester Construction	$500,000
Digester Heating System	$200,600
Gas Mixing System	$44,250
Building and Plumbing	$106,500
Electrical Generator Set	$350,000
Solid Separation Building	$135,000
Engineering/Administrative	$355,000
Total Cost	**$1,691,350+**

+This cost was offset by a NYSERDA grant and a federal tax credit.

Figure 3. A view of the Swiss Valley Farm Anaerobic Digester System

ADS may contribute to farm sustainability in other ways by making a farm energy-self-sufficient if electric prices fluctuate. Farms will have to calculate how well the energy savings from generating electricity on-farm fit with the larger farm management plan and significant cost of constructing and operating an ADS. To learn about installing an ADS, see Information Sheet #3)

Important safety note: Methane is highly combustible under certain conditions. Additionally stored manure can produce a dense gas called hydrogen sulfide (H_2S) that is deadly. Careful management of these gases is required to maintain safety.

Vocabulary

Aerobic: Having oxygen in the system (for example in the case of manure management, an actively mixed compost aerates the solids). See also Anaerobic.

Anaerobic: Lacking free oxygen in the system (like liquid manure storage that is not aerated). See also Aerobic.

Anaerobic Digester Systems (ADS): engineered systems that regulate temperature, pH, and retention time to promote a synergistic relationship between bacteria, including methanogens, to produce more methane from manure with the intention of producing renewable energy from the biogas.

Greenhouse Gas (GHG): Any gas that causes atmospheric warming by absorbing infrared radiation in the atmosphere (common greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)).

Global Warming Potential (GWP): The potency of a gas to contribute to global warming is referred to as a Global Warming Potential (GWP). The common unit is referred to as a carbon dioxide equivalent or CO_2e. Methane and nitrous oxide are 34 and 298 times more potent than CO_2, respectively, over a 100-year period. To convert tons of methane to CO_2e, simply multiply by 34. To convert tons Nitrous Oxide to CO_2e multiply by 298.

Methane (CH_4): A potent greenhouse gas that has a Global Warming Potential (GWP) of 34 on 100-year time scale. It is formed in a variety of ways (cow rumen, liquid manure storage, wetlands, rice fields, etc.). When combusted, methane is oxidized to CO_2, a much less potent GHG.

Methanogen: bacteria that thrive in anaerobic conditions and produce methane.

Nitrogen (N): an element essential to plant and animal growth. Nitrogen is found in many forms on the farm, including nitrate, ammonia, nitrous oxide (N_2O), and other N-species.

Nitrous oxide (N_2O): A potent greenhouse gas that has a global warming potential (GWP) of 298 on 100-year time scale (meaning that it is 298 times more potent than CO_2 as a GHG). It is produced when N is present in wet agricultural fields or more aerobic manure storage systems (and inhibited in anaerobic conditions).

Volatile Solids (VS): are a more biologically available form of carbon that methanogens can convert to methane.

Resources And Tools

To learn more about opportunities to reduce GHG emissions, see other information sheets in this series:

Tier II Worksheets Identifying Farm & Forest GHG Opportunities

Information Sheet	**Topic**
IS#1	Intro to Farm & Forest GHG
IS#2	Dairy Manure Storage
IS#3	Planning for Quantitative Methane Capture and Destruction from Liquid Dairy Manure Storage
IS#4	Energy Efficiency
IS#5	Nitrogen Fertilizer Management
IS#6	Soil Carbon Management
IS#7	Forest Management

AEM Technical	Water Quality BMPs
Tools	http://www.nys-soilandwater.org/aem/techtools.html

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