Cornell University

Planning for Quantitative Methane Capture & Destruction from Liquid Dairy Manure Storage

Information Sheet #3

Peter Wright, Curt Gooch, Jenifer Wightman & Peter Woodbury
Soil and Crop Sciences Section, School of Integrative Plant Science
Department of Biological & Environmental Engineering
College of Agriculture and Life Sciences, Cornell University

Cornell University

Planning for Quantitative Methane Capture & Destruction from Liquid Dairy Manure Storage

Information Sheet #3 – OVERVIEW

Peter Wright, Curt Gooch, Jenifer Wightman & Peter Woodbury
Soil and Crop Sciences Section, School of Integrative Plant Science
Department of Biological & Environmental Engineering
College of Agriculture and Life Sciences, Cornell University

Fast Facts

- **Trends**: Liquid manure storage is a commonly implemented and recognized Best Management Practice (BMP) for addressing water quality concerns.
- **Challenge:** Liquid manure storages are a major contributor of dairy farm-based GHG. Stored liquid dairy manure produces methane (CH_4) a greenhouse gas (GHG). Stored solid manure may produce nitrous oxide (N_2O) a more potent GHG (See Information Sheet #1). Reducing the greenhouse gas emissions from dairy products is an important sustainability goal.
- **Management concerns:** Long-term manure storage produces GHG as well as other gases such as hydrogen sulfide (H_2S) that can present significant neighbor relations concerns as well as health and safety issues.
- **Opportunities:** With whole farm planning, farms can take steps to reduce manure-storage GHG emissions that may have other financial, social, and ecological benefits.

Introduction

Manure storage provides farms with an important capacity to recycle valuable nutrients to the land for future crop uptake and productivity. To reduce a farm's impact on water quality, manure is often stored in a liquid storage facility (earthen manure storage pond or a manure storage structure) or as a solid stack for many months. Properly sized storage can facilitate spreading manure on dates closer to when crops can take up nutrients, reducing the potential for pollution of surface and groundwater, reducing the need to purchase fertilizer, and reducing the damage to crop fields from compaction. However, as discussed in Information Sheet #2, manure storage can significantly increase farm greenhouse gas (GHG) emissions.

Manure Storage GHG Emissions

Different manure storage systems have different amounts of available oxygen that impact the potential for GHG production. When a storage unit has no free oxygen (anaerobic, such as stored liquid manure), CH_4 is produced. These anaerobic systems reduce N_2O emissions. In contrast, high oxygen (aerobic) systems inhibit CH_4 production but have increased N_2O emissions (See Information Sheet #2). 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

Farms operating with a Concentrated Animal Feeding Operation (CAFO) permit are required to follow a Comprehensive Nutrient Management Plan (CNMP) that requires the capacity to store manure during certain higher-risk weather and field conditions. CAFO-permitted farms that install BMPs that involve manure storage and manure transfer (including liquid/solid separation, covered storage with gas collection and flares, and anaerobic digestion systems) require a licensed professional engineer to design since they impact the health and safety of the public. All farms are also obligated by New York State Department of Environmental Conservation (NYS DEC) Water Quality Standards to have no discharge that will cause a substantial visible contrast in the receiving waters. Specific watersheds providing drinking water discourage manure spreading during adverse weather. There are no regulations of GHG emissions from agriculture at this time, however, there are regional regulations on GHG emissions from the electric power sector and voluntary opportunities to participate in carbon trading from methane destruction by farms.

Goal

This Information Sheet is intended to help farms that are interested in installing quantifiable GHG mitigation infrastructure by modifying an existing liquid manure storage or when installing a new liquid manure storage (e.g. cover & flare system or anaerobic digestion system).

Summary Of Quantifiable GHG Mitigation Practices For Dairy Manure Storage +

Description of Strategy	Opportunities	Considerations
Impermeable cover on liquid manure storage unit with flare	• Storage volume/duration is increased by excluding rainwater and solids. • Odor during storage is controlled. • Nutrients are retained. • Reduces CH_4 emissions if effectively captured and combusted.	• Requires solid separation and cover installation. • Requires flare and water management. • Variable Cost (~$375,000 for 1000 cow farm). State and federal agencies may have cost-share programs for cover and flare projects.
Anaerobic Digestion System (ADS) with energy generation	• Renewable energy is produced. • Odor and pathogens are reduced. • Nutrients are retained. • Reduces CH_4 emission if effectively captured and combusted plus displaces fossil fuel energy needs and associated GHG emissions. • Can add food waste to increase energy production.	• ADS produce additional methane, which if not properly captured & combusted (by engine generator, boiler, or flare) could lead to greater GHG emissions than passive manure storage. • Management of system needed. • May consider installing a cover for effluent storage (to capture additional gas and exclude rainwater) • Capital costs may not be recouped from sale of electricity. • Variable Costs (~$1,500,000 for 1000 cow farm). NYSERDA may have grant opportunities and there may be Federal Tax Incentives.

[+]These practices have been selected because they are measurable and quantifiable methods to mitigate a large portion of GHG emissions associated with manure management. These GHG mitigation strategies may qualify for state and federal cost-share programs, grants, and tax incentives as well as carbon-trading income. Verification for carbon credits may be both difficult and expensive.

Cornell University

Planning for Quantitative Methane Capture & Destruction from Liquid Dairy Manure Storage

Information Sheet #3 – IN DEPTH

Peter Wright, Curt Gooch, Jenifer Wightman & Peter Woodbury
Soil and Crop Sciences Section, School of Integrative Plant Science
Department of Biological & Environmental Engineering
College of Agriculture and Life Sciences, Cornell University

Target Audience

This information sheet targets educators and technicians dairy farmers to plan manure cover+flare or Anaerobic Digestion Systems (ADS) to quantitatively mitigate greenhouse gases (GHG).

Target Greenhouse Gases (GHG): Methane (CH_4) and nitrous oxide (N_2O)

Background Questions By Educator To Help In Farm Planning

- Does your farm store manure?
  - If no, are you interested in installing liquid storage in the future?
  - If yes, what kind of storage facilities do you have?
- Are you experiencing any issues with your current manure management practices?
- What are your near and long term manure management goals for:
  - manure separation (for management, bedding, selling compost)?
  - odor control?
  - partitioning manure nutrients (e.g., into separate N and P products)?
  - energy production?
  - greenhouse gas emissions?

Background Information On GHG Emissions From Manure

Manure contains volatile solids (VS), which are organic carbon compounds and various nitrogen (N) compounds. Depending on the oxygen levels in the manure, the VS can be formed into CH_4 and the nitrogen compounds can be formed into N_2O. These two greenhouse gases are important because CH_4 is 34 times more potent than CO_2 and N_2O is 298 times more potent than CO_2 over 100 years, potency is also referred to as Global Warming Potential (GWP) (see Information Sheet #1). Anaerobic (low oxygen) manure management conditions, as found in liquid storage, cause more CH_4 production but reduce N_2O emission. (To learn more, see Information Sheet #2). Aerobic manure management promotes N_2O production but inhibits CH_4 production. This Information sheet focuses on two meaningful and quantifiably verifiable methods of CH_4 destruction from anaerobic liquid storage while considering effects on N_2O production from a whole-farm perspective.

Introduction

The capability to store manure reduces or eliminates the need to collect, remove, and spread manure on a daily basis. In past years, with less concern for nutrient losses and when livestock operations were smaller, daily spreading or very short-term storage with frequent hauling was a common system. However many manure management systems evolved from solid/semisolid systems to liquid systems. Comprehensive Nutrient Management Plans (CNMP) recycle the stored nutrients to grow crops while limiting losses to the environment. The primary reason to store manure is to protect water quality by allowing the producer to land apply the manure at a time that is compatible with the climatic and cropping characteristics of the land receiving the manure (during the growing season). This limits losses to both ground and surface water. To learn more about how to protect water quality with storage systems, see "Manure and Fertilizer Storage" in Resources and Tools, below.

Compared to daily spread, liquid manure storage has led to more GHG emissions, primarily from CH_4 but also N_2O. Estimates of CH_4 and N_2O emissions from storage vary depending on the type and condition of the storage (length of storage, type of manure, composition of manure, oxygen levels, pH, temperature, etc). Because CH_4 and N_2O are 34 and 298 times more potent greenhouse gases than CO_2, it is important to pay attention to the conditions that create these GHG (see Information Sheet #2). Fortunately, these two gases have characteristics that allow us to manage their impact on climate. One can reduce impacts from storage by monitoring feed to minimize N in the diet and maximize feed efficiency (to reduce N and VS in the manure), reduce storage time during warm summer months (to reduce conditions favorable for CH_4 production), or allow a crust to form on slurries (to increase conditions for methane-consuming bacteria to thrive and metabolize a fraction of the CH_4). While these methods may reduce GHG emissions, liquid manure storage has doubled GHG emission from NY dairy farms over recent decades primarily due to CH_4 production (Wightman & Woodbury 2016). Fortunately, the anaerobic condition of the liquid manure storage prevents N from being converted into N_2O and if covered, the CH_4 can be captured and flared (see Information Sheet #2) thus destroying the global warming potential (GWP) of the methane.

If methane is captured and flared, the methane is converted to carbon dioxide and water vapor:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

The resulting CO_2 and water return to the atmosphere from which it was recently extracted by the process of photosynthesis in crops that produced the animal feed. Returning CO_2 and H_2O has no net GHG impact but the higher GHG impact of the CH_4 is avoided through combustion (by combusting CH_4, one is negating its GWP of 34 and there is no net gain in CO_2 equivalents or CO_2e, see Information Sheet #1).

There are two quantifiable methods to capture and flare CH_4 from an anaerobic liquid storage. The first is to install a cover to capture the passively produced CH_4 gas and combust it with a flare. The second is an anaerobic digestion system (ADS) specifically designed to actively produce CH_4 from the manure for combustion in a boiler or engine-generator for heat or electricity.

If the methane can be collected, combusted, and converted to carbon dioxide the impact of long-term liquid manure storages on dairy farm GHG can be mitigated while still providing water quality benefits. Covers & flare systems can address additional issues including controlling odors from the storage, reducing ammonia losses, excluding precipitation and solids so less storage volume is needed thus reducing the volume of liquids to be transported to fields, as well as preventing unanticipated volume additions from extreme weather events. ADS reduce both the odors in storage and when spread, reduce pathogens, convert nutrients to a more available and quantifiable form, and reduce the oxygen demand of the manure.

Solid separation prior to storage is highly recommended for covered manure storage units since separated liquids will not require agitation to avoid settled solid build up. Preventing solid build up in a covered storage is an operation and maintenance priority. Agitation under a cover is difficult unless the storage is specifically designed to be agitated with agitation ports. Separated liquids and digested effluent can also be more easily pumped to the field.

Solid separation is not necessary prior to ADS as including all the VS from the manure (and from additional imported materials such as food waste) will maximize the potential energy produced from the farm. Besides destroying the methane, combustion of CH_4 in a boiler or engine-generator set displaces the GHG emissions from traditional fossil-based energy sources. To achieve the most GHG reduction, leaks in the system and emissions from the effluent storage should be controlled. Solid separation after digestion will limit the CH_4 emissions from the effluent storage.

Safety

Manure storages and their appurtenances create additional safety issues on the farm. Manure storages should be fenced to prevent inadvertent access by people and to keep animals out. Warning signs should be posted and rescue equipment (ladders, floats, and rope) should be provided. Access to enclosed spaces should be limited until complete ventilation has been verified by gas detection equipment. Mechanical equipment (solid separators) and combustion equipment (flares, boilers, and engine generators) should be shielded to limit exposure to moving parts, high temperature, and electric shock. Access to floating manure covers should be limited. See "Anaerobic Digesters and Biogas Safety" in Resources and Tools, below.

Mitigation Opportunity 1: Solid/Liquid Separation With Cover & Flare.

Separation of manure liquids and solids for water quality and GHG mitigation require installing infrastructure including: separation, solid storage, liquid storage, and field transport components.

Step	H_2O benefit	GHG benefit	Other benefits
Solid/Liquid Separation	Partitions ~3/4 N to the liquid portion for application to field closer to the growing season.	Anaerobically stored liquids reduce N_2O production. Aerobically stored solids reduce CH_4 production.	Separated liquids can be pumped to the field. Solids can be sold or used for bedding or soil amendment.
Cover for Solid Storage	Prevents rain from eroding the pile and contaminating ground and surface water.	Prevents excess moisture in the pile thus reducing the CH_4 production and enhancing composting.	Lower moisture content solids are better for bedding, transport, and sales.
Cover for Liquid Storage and Flare	Excludes rainwater, thus preventing normal and extreme precipitation events from impacting the volume.	If combined with a flare, the CH_4 can be combusted and significantly reduce manure GHG emissions.	Reduces odor from storage. Increases storage capacity. Retains N.
Field Transport	Excluded rainwater reduces the number of trips to the field and associated compaction of soil.	Reduced trips to the field or pumping time which reduces tractor/engine fossil fuel emissions.	Reduced trips to the field will reduce time, labor and equipment expenses.

Separation

Typical screw-press manure solid separators can remove about 20% of the mass of dairy manure into a 70% moisture content component. Depending on the technology, screen size, flocculants, throughput, initial condition of the manure and management, the volatile solids (VS) roughly split between the liquid and solid portion. However, roughly ¾ of the N remains in the liquid portion (see Table 3 in Information Sheet #2).

<u>Planning considerations for Solid/Liquid Separated Manure System</u>: Leave space between the manure collection system and the liquid manure storage so a separation system can be added. This can be as little as a valve and bypass to pump the unseparated manure to a building holding the separator above an area for the separated solid to collect. Solids can be dropped directly into a truck or if there is room, moved by conveyors and stored. The returning liquid and overflow from the separator will have to be piped back to the storage and collection tank respectively. Manure systems with a direct push-off into a storage will require some major retrofitting to collect the manure for separation. Farms may consider an additional storage for unseparated manure for times when the separation system is not functioning.

<u>Advantages of Separation</u>: The reduced solids in the liquid storage make that storage easier to manage. The increased moisture content of the liquid portion increases the efficiency of pumps, reduces plugging in pipes, reduces solid build up in the bottom of the storage, and makes it easier to agitate. Pumping manure both into and out of the storage unit becomes easier. Pipe and pump systems for draghose applications are more efficient. The mass that is removed means that the storage itself will either hold about 20% more or can be built 20% smaller for the same time period as if all the manure were included.

Considerations of Separation: Maintenance is required to keep the solid separator performing as desired.

Cost of Separation: Costs for separation equipment can vary. Capital costs for a screw press system to handle 500-800 cows is ~$50,000 with the building and plumbing averaging another $50,000. The operation and maintenance costs include daily monitoring of the equipment, replacing the screens and augers as they wear and cleanup of spills as they occur.

Management of Solids

The solids that are separated can be used as bedding in well ventilated dairy barns. The amount of separated solids may meet the bedding needs of a freestall dairy with some to spare. Manure solids can be used on the farm as a soil amendment delivering not only nutrients but also organic matter in a transportable form with less moisture. The solids can also be composted and sold.

Composting may be an integral part of a solid manure storage system. With bedding or solid addition and the appropriate site all the manure may be composted in open windrows or piles. The cost of the additional carbon source needs to be considered. More sophisticated compost facilities under a roof may also be part of a manure storage/treatment system. Well-aerated and covered compost during warm summer months may reduce overall GHG emissions (low CH_4 emissions, but potentially higher N_2O emissions), but may reduce N-content (Jayasundara et al., 2016).

Roof for solids: Composted or not, solid manure storage facilities may be roofed to eliminate the effects of rainfall. Leachate or runoff from the solid storage needs to be contained and treated. Solid manure storage facilities usually have a concrete bottom and may have concrete walls to confine the solids and provide a "push" wall for stacking and loading of the solids. If uncovered, plan for a vegetated treatment area downstream of the composting pad.

Cost of Roof: Although a roof adds additional cost, the benefits of not having to collect and manage runoff, not adding moisture to the solid manure, and ease of solids handling during inclement weather may offset the additional cost. However, if additional amendment is needed to reduce the moisture content sufficiently for solid handling both the cost of this material and the cost of increased area to cover and cost to move the additional mass needs to be considered.

Advantages: Advantages in handling and storing manure as a solid may include less odor (bacterial action producing odorous compounds is reduced at lower moisture contents), less runoff potential, relatively high nutrient retention and less risk of a catastrophic failure.

General considerations: Disadvantages may include more labor in manure collection and handling (mechanical vs. hydraulic handling), as well as runoff management from uncovered storage areas. Separation requires two manure/wastewater processes on the farm that add both cost and complexity. Limited mixing of a compost system to minimize N_2O emissions may limit the marketability of the compost as it may not be homogeneous enough for a consistent product. Composted bedded packs will have high N_2O emissions while bedded packs will have high CH_4 GHG emissions. Many farms that used the solids for cow bedding have experienced udder health and milk quality challenges.

Planning considerations: Plan for both the solid manure system and for any liquid or waste water generated on the farm. Determine if any additional amendments are needed and their availability. Contact Cornell Cooperative Extension, the USDA-Natural Resources Conservation Service (NRCS) office, your Soil and Water Conservation District, or a qualified professional for design assistance in developing a solid manure storage system.

Summary of Impact of Covered or Uncovered Solids on Water and GHG: Covered stacks will not become saturated with rain, thus reducing anaerobic conditions that are favorable to CH_4 production. Stacks that are actively turned and therefore more aerobic, will significantly reduce the methane emitted from a solid storage but increase N_2O emission. Uncovered (exposed to rain) and unturned stacks will be wetter and thus more anaerobic and produce more methane. Uncovered stacks may also affect water quality during rain events depending on site and storage conditions.

Management of Liquids: Cover & Flare

A method to reduce the GHG and odor being emitted from open manure storage facilities is to contain the odors and gases using an impermeable cover. By covering a manure storage facility, the release of hydrogen sulfide, methane, and other volatile organic compounds from the liquid to the gas phase can be greatly reduced. Covers create reduced air movement over the manure surface, and liquid turbulence is minimized. Combined with a flare, boiler, or other biogas utilization system, a cover will capture and combust the methane thus reducing GHG emissions.

Licensed Professional: New York State CAFO regulations as well as State and federal cost-share programs require a New York State licensed professional engineer to design the cover and flare system. Design/build systems generally include engineering/technical service fees within the overall cost of the system. These would only then require a New York professional engineer's review and approval ranging from $500 to $5,000 depending on the scope of the work. For custom designed systems, the engineering/technical services cost may range from $12,000 to $25,000 with costs depending on project specifics.

Cover Systems: There are a wide variety of storage cover options with most systems manufactured, designed, and installed in a turnkey operation by one company or companies vertically integrated so they are familiar with the materials, methods, design concerns and implementation of the specific product. Typically covers are appropriate for separated liquids so liquids can be pumped in and out and there is little solid buildup on the bottom.

The gas collection and flare system needs to be sized for a maximum biogas production rate and for a minimum biogas production rate. Quantification of the maximum flow rate is difficult to calculate and, based on information currently available at this time, may be best estimated by the following equation from Intergovernmental Panel on Climate Change (IPCC, 2006):

$$E_{CH4} = VS \times B_0 \times 0.67 \times (MCF/100)$$

where

E_{CH4} = CH_4 emissions (kg CH_4/cow-day)

VS = Total volatile solids in manure (kg/cow-day)
=[7.7 kg/cow-day (average for high producing NY dairy cows)]

B_0 = Maximum CH_4 producing capacity for manure (m^3 CH_4/kg VS)
= [0.24 m^3 CH_4/kg VS (for dairy cow manure)]

0.67 = Conversion factor of m^3 CH_4 to kg CH_4

MCF = CH_4 conversion factor for the manure management system (%)
= [17% for cold winter conditions]
= [80% for extremely hot summer condition – for max value calculation only.]

The maximum CH_4 production per cow can be estimated by using a hot-summer-high Methane Conversion Factor (MCF) of 80% (~99 kg CH_4/cow-day; the upper limit for engineering purposes only). CH_4 production may be very limited during cold winter storage. Flare function during these times may require some storage or additional fuel if combustion is to continue. Additional consideration must be made if there is a substantial percentage of carbon dioxide in the resulting biogas (up to 70% of the volume). During periods when biogas flows are below the minimum or above the maximum needed for proper combustion, methane will be released. The cover and gas handling system must have a safety relief valve designed for emissions that exceed the design capacity. Specific manure and storage characteristics and temperature variables will result in varying biogas production rates that are difficult to calculate and, based on information currently available at this time, might best be addressed after the system has been in place and operated for a time.

References are given to the NRCS-NY 366 Anaerobic Digester Controlled Temperature Standard; and although this Standard does not directly apply to covered manure storages, it can be used as a guide for the biogas collection and handling components associated with covered long-term manure storages in New York State. This includes the requirement for a gas meter, auto-ignition system powered by a battery/solar or direct connection to electrical services, and flame arrestor.

Covers last 10-20 years and are generally not opened during this time. If you are interested in actively managing CH_4 from unseparated slurry or producing maximal energy on farm from biogas, consider an Anaerobic Digester System (ADS, in Mitigation #2, below).

Flares: To achieve GHG mitigation, accumulated gas must be collected and combusted. During summer and fall, gas can usually be combusted with a flare, during cooler temperatures in the winter and spring before the manure has a chance to warm sufficiently for active biological conversion of VS to CH_4, the cover system will not likely produce sufficient quality or quantity of gas to be flared easily. The choice of a flare needs to be considered carefully. Open flares work best in low wind conditions and when the quality and quantity of gas are within a limited range. Combustion can only occur in the proper range of fuel to air mix. During high methane production some flares will not work as the fuel mixture is too rich to burn (not enough oxygen where the spark is applied). During low methane production the fuel mix may be too lean. High winds can also dilute the fuel mixture and blow out a flare. Open flares are only estimated to combust 50% of the methane delivered. Enclosed flares with multiple spark locations would ensure more combustion (estimates of 90% combustion are often used). Enclosed flares have a higher capital cost, but their enclosed design is less affected by the wind and more likely to stay lit during lower biogas flow rates. As a general guide, an enclosed flare is 1.5 to 2 times more expensive than an open flare of the same capacity. Design engineers, whose farm clients are looking to monetize carbon credits associated with covered manure storages, should talk with carbon credit aggregators/verifiers to make sure flares qualify with Climate Action Reserve standards. Without a flare, with a poorly operating flare, or a dysfunctional flare, the GHG mitigation potential of CH_4 conversion to CO_2 is lost. Because of the seasonal variation in the Northeast it is unlikely that the emissions collected can be economically used for supplementary heat and power by integrating a boiler or engine-generator set.

Meters: Two basic types of commercially available meters are recommended for use to measure the total volume of gas produced**.** These are mechanical meters and thermal mass flow meters. Mechanical meters measure gas flow rates directly and may need temperature and pressure sensors to more accurately measure gas production. These meters require periodic maintenance due to their mechanical nature. Thermal mass flow meters are generally temperature and pressure compensated thus providing the most accurate measurements. For both types of meters, total gas production is measured and since biogas is not pure methane, samples of the biogas need to be taken to determine the estimated methane produced over time. Systems should include ports for biogas samples to be obtained. Design engineers, whose farm clients are looking to monetize carbon credits associated with covered manure storages, should talk with carbon credit aggregators/verifiers to make sure selected meters qualify with Climate Action Reserve standards.

Although gas meters and sampling will determine the methane produced, the flare function must be verified to show that the methane was combusted, converting methane to carbon dioxide.

Temperature sensors and recording devices on the flare show when the flare is operating. The flame temperature can be used to predict the combustion products.

<u>Advantage (Avoided Precipitation</u>)<u>:</u> Precipitation excluded by the cover increases capacity for manure storage and reduces hauling. By excluding precipitation, the cover reduces the total storage needed or increases the storage period for an existing manure storage. There is energy, labor, and cost savings in not having to haul the precipitation water mixed in with the manure. There would also be a reduction in the potential for water pollution as less mass would have to be spread and the spreading times could be delayed from the precipitation event. Periods of wet conditions can be more easily managed if the additional precipitation does not increase the manure level in the storage. Not being forced to spread manure during higher-risk weather and field conditions is an important advantage. The total impact of rainwater avoidance depends upon the surface area of the storage system, whether adjacent areas contribute runoff to the storage, and the net annual precipitation (rainfall-evaporation) of the specific site. Annual avoidance can range from 300,000-700,000 gallons per acre of surface area in NY. The risk of overtopping in extreme events would be eliminated.

<u>Advantage (Reduced GHG, odor, and N emissions):</u> Impermeable covers combined with a combustion mechanism reduce GHG emissions and odor emissions from the storage, and may reduce nitrogen loss to the atmosphere. With a properly operating flare, the methane is destroyed with significant reduction of farm GHG emissions.

<u>Advantage (Saved or Earned Income</u><u>)</u>. Reduced rainwater hauling costs, increased storage capacity, increased retention of nitrogen, and the potential to earn carbon credits for destroyed methane are all benefits of covered and flared storages. Additionally, there are grants available specifically for capturing and flaring methane from manure storage – see "Past Granting Opportunities" below to identify potential sources.

<u>General Considerations:</u> To achieve both the full GHG benefit as well as the protection from precipitation it is important that leaks in the cover are minimized and the flare has high operation efficiency. Gas escaping from access ports, connections, and pipes will allow the GHG (and odor) to escape. Maintaining the cover so the precipitation remains uncontaminated from the manure is critical if the water on the surface of the cover is to be discharged as clean water. Sophisticated floats and weights need to be installed to keep the cover in place during high wind events and snow loads. The cover must also be designed to stay functional when the manure storage is empty as well as when full. Due to safety concerns rigid covers that allow an air space under the cover need to be air tight under all operating pressures to prevent the potential of oxygen and fuel mixing in the air space within the combustible range.

<u>Cost:</u> A cost-benefit analysis is an important part of evaluating whether to install a cover. This analysis needs to consider the lost opportunity cost of capital, depreciation, maintenance, repairs, and end of life cover disposal costs. Maintenance and repair costs vary depending upon the cover material chosen and are typically covered by the installer or an associated service provider. For remote locations, a one-time repair cost can be as high as $5,000. The "Cover Cost Calculator" (see below in Resources and Tools Section) allows for the estimation of on-farm savings based on rainwater avoidance and specific manure handling costs.

A properly designed and maintained impermeable cover is expected to have an operational life of 20 years. Impermeable cover cost is in part correlated with petroleum price, with recent estimates for installed cost ranging from $1.50 to $3 per square foot with an additional cost for the gas handling equipment; highly technical cover installations may increase the cost to $5 per square foot. Rigid or structurally supported covers are more costly than floating covers. At the end of the cover's useful life, it will need to be removed and properly disposed of, representing an additional cost for the system ranging at this time from $0.50 to $0.75 per square foot.

The cost of gas handling will depend on the system chosen, applicable regulations, and carbon credit market requirements. A basic open gas flare can be implemented for $15,000 to $25,000. A more complex, high efficiency enclosed flare, to ensure that complete combustion occurs in both high and low methane production, may have a capital cost exceeding $150,000.

Site Planning: The type of manure storage will depend on a number of factors and require a relatively high degree of planning and preliminary investigation to determine if an earthen manure storage pond or a fabricated manure storage structure will need to be installed. See the AEM worksheet and information Sheet: "Manure and Fertilizer Storage" in Resources and Tools, below.

Space availability on the farmstead needs to be considered as there should be room for the solid and liquid storages, the solid separation system, manure transfer components, the flare, and a stable outlet for the clean water pumped from the cover. Most impermeable covers are not designed to be removed for storage pump-out or solids removal. Special considerations for slurry removal and handling are required, and manure solid-liquid separation with storage of liquid effluent is recommended. The flare needs to be located where it will not create a fire hazard and where inadvertent un-combusted gases will not create a hazard.

Fabricated manure storage structures have the least surface area. Consider the surface area of the storage and the ability to install a manure cover. The smaller the surface area, the less precipitation will be collected, and the less square feet of cover material required resulting in lowering the cost of a manure cover. Manure storage structures with vertical sides have less surface area but floating covers need to be functional when both empty and when full. Rigid covers add an additional load to the vertical walls that then need to be designed to support that load.

The best designs generally incorporate permanent access points for agitation and pumping. Producers may want to consider including permanent access points in any new manure storage designs if they think a cover may be installed in the future. Covers need to be sealed at the edges to prevent gas escape. Covers on an earthen storage use a trench to anchor and seal the cover on the edges. The covers need to have a system to keep the cover material tight enough to prevent flapping from the wind so they won't fail by fatigue. This is typically done with a system of weights and floats incorporated into the cover design. Most impermeable covers are designed and installed in a turnkey operation involving the manufacturer, the engineer, and trained technicians to install the cover properly. Appurtenances where manure enters and exits, the gas is collected, or for other purposes need to be designed into the cover to keep it gas tight. At concrete fixtures a strip that the cover can be heat welded to is embedded as the concrete is installed. Consult a design professional if you are considering covered manure storage.

Summary: separated solid-liquid systems with Covers & Flares.

Soil+Water Benefits: Covered manure storage reduces potential for water pollution and provides more flexibility in spreading times. Not being forced to spread manure during wet field conditions is an important advantage in reducing soil compaction. Major storms exceeding the 25-year, 24-hour event would also not impact a covered-liquid or covered-solid manure storage. The risk of overtopping a covered liquid storage from a precipitation event would be virtually eliminated.

GHG+Other Benefits: Impermeable covers combined with a biogas collection and combustion mechanism reduce GHG, odor emissions, and may reduce nitrogen loss to the atmosphere. Covers can also provide further operational benefits that can help offset higher capital costs. With a well-operating flare, the methane is destroyed with significant reduction of GHG emissions. Another advantage is the potential to sell carbon credits (CO_2e) if methane is captured, destroyed, and verified (meters + temperature sensors).

Mitigation Opportunity 2: Liquid/Slurry Anaerobic Digestion For Energy Production

Anaerobic digestion systems (ADS) are designed and managed to optimize the bacterial decomposition of organic matter under controlled conditions. Unlike passive anaerobic digestion in covered or uncovered liquid manure storage, ADS actively produces and captures CH_4 in biogas that is then combusted to generate electricity and/or run a boiler on farm. An ADS system can address methane production from manure storage (by combusting the CH_4 and reducing its global warming impact) and by displacing fossil fuel (that might have been used to generate electricity or heat). If well operated, an ADS is a very proactive system to mitigate GHG emissions, improve farm energy-self-sufficiency, reduce odors from manure, and set the stage for additional manure treatment practices. However, ADS systems can be quite expensive to build and operate and not all ADS are designed and managed to maximize CH_4 destruction.

Plug Flow

One common anaerobic reactor used for the treatment of manure is the plug-flow reactor. In this system, dairy manure slurry is added to one end of a long container, pushing the effluent out the other end and into a storage facility. Effluent solids may be separated from the liquid, stored as a solid for soil amendment or used for bedding (see Separation section above). Separating digestate solids may reduce CH_4 production in the effluent storage that is especially important if there is a short retention period in the ADS.

Complete-Mix

Another type of anaerobic digester is the complete-mix digester. Agitators are in place to fully mix any inputs within the whole digestion vessel exposing the whole bacteria population to the new substrate feed. This digester type allows the addition of other organic material often with accompanying tipping fees adding to the energy production and income. The added nutrients need to be included in the CNMP for the farm. Any additional VS from the outside organic material may impact the GHG emissions of the system.

GHG impacts: ADS that generate electricity from the biogas replace fossil fuel energy generation in addition to reducing GHG emissions from existing manure storages (and future storages mandated by regulation). Considerable methane, approximately 20% of what is produced in the digester itself, may be emitted from the stored effluent of the anaerobic digester. Some digesters are designed to reduce odors and operate with a limited retention time and do not maximize methane production. ADS are often economically designed based on the value of the CH_4 produced without considering the GHG impact of CH_4 released from the effluent in storage. The effluent from the digester contains the bacterial community and often the temperature to continue CH_4 production from the remaining VS. This production may not be high enough to economically support capture and control with a low value for the additional methane produced. Effluent solids may be separated from the liquid, stored as a solid for soil amendment or used for bedding. Solid separation at this stage also reduces the VS remaining in the storage so continued CH_4 emissions are reduced. See Solid Separation, above. To obtain the full benefit of anaerobic digesters in GHG mitigation the ADS can be designed with a longer retention time to maximize CH_4 conversion and capture within the system or effluent storage would also need to be covered and the gas collected and combusted by the biogas utilization system as described in Mitigation Method Opportunity No. 1 (see above).

Advantages: Farm-based anaerobic digestion systems are beneficial by producing renewable energy, increasing the potential for off farm sales of by-products, recycling of nutrients, and improving water and air quality. Digested manure can be stored and recycled to the farm's land base as fertilizer for crops with far less odorous emissions; less odor allows a farmer to be more flexible in dealing with how manure is stored and how and when it is recycled to crop fields. Nutrients are not only conserved but a portion of both the phosphorous and nitrogen is converted to a more plant available form to make fertilizer applications more efficient. ADS provides for the opportunity through stabilization of the effluent and additional heat to further process manure to partition the nutrients for more efficient application of fertilizer to the farm's land and, potentially, the sale of fertilizer nutrients to other farms or sectors.

If the ADS controls the leaks and recovers biogas from the effluent storage it may reduce the CH_4 emissions from manure storage by 90% while also displacing fossil fuel by utilizing the renewable energy. Biogas can be used to generate electricity, heat water, dry materials such as grain and cow bedding, or for a number of other potential alternative uses including: liquid fossil fuel replacement on vehicles, powering fuel cells, running cooling systems, or cleaned and compressed and added to natural gas pipelines. Besides reducing on-farm purchased energy costs for electricity and/or heat, the digester may facilitate other enterprises such as digested manure solids sale as compost or bedding, excess electricity sales, or co-digestion of food waste for a tipping fee. Both renewable energy and carbon credits are potential revenue sources.

General Considerations: Managing the complex and expensive ADS system requires a dedicated management effort that may be difficult to integrate with competing tasks and time-management needed to run the farm. There is the potential to emit excess CH_4 if leaks are not properly controlled, the engine generator, boiler, or flare are not efficient, and/or if the effluent storage continues to produce uncontained CH_4. These issues can all be compounded if off site organics are added to the system. The current price paid for exported electricity is low, reducing the motivation to produce and capture the maximum amount of methane for electric generation.

Cost: The costs and benefits of anaerobic digestion are quite complex. Capital costs of turnkey ADS vary but can range from $4,000 to $5,500 per kW of generation capacity. Operating costs have been estimated at $0.02 to $0.03 per kWh or more for systems with more features. Much of the capital investment is considered lost capital by lenders.

Planning Considerations: Careful calculations need to be made when planning for ADS because it is an expensive and complex system. Examine the manure and wastewater stream to determine any disadvantages from extra solids, contaminants, or dilution. If the successful operation of the ADS depends on tipping fees for outside organics, determine the reliability of these sources. If electricity is to be sold, the utility should be consulted to determine how/if the distribution lines to the farm can handle it. Remember the mass of manure will decline only slightly so the rest of the storage, treatment, and application system needs to continue to operate. Utilization of extra heat energy should be considered. Consult a design professional if you are considering an Anaerobic Digestion System. There are a number of design firms working on ADS; chose one with a good track record.

Summary of Anaerobic Digestion Systems (ADS).

Water+Soil Benefits: ADS reduces potential for water pollution and provides more flexibility in spreading times. Being able to spread manure during warmer weather to growing crops and near neighbors is an important advantage. This added flexibility can be used for optimum nutrient placement and reduced soil compaction. Pathogen reduction created by the anaerobic digestion is another important water quality advantage. The homogenous conditioning of the effluent allows greater possible advanced treatments to be installed for additional nutrient partitioning and mass reduction.

GHG+Other Benefits: properly designed and optimized, ADS reduce GHG, odor emissions from storage and spreading, and provide a more quantifiable nutrient source for efficient application. ADS can also provide further operational benefits that can help offset higher capital costs. With an efficient engine and/or boiler, not only is methane destroyed with significant reduction of GHG emissions but fossil fuel use is avoided by the energy produced. Another advantage is the potential to sell renewable energy and carbon credits (CO_2e) if methane is captured, destroyed, and verified (meters + temperature sensors).

Past Granting Opportunities

The NY **Dairy Acceleration Program** is designed to enhance profitability and environmental stewardship of New York dairy farms. Funding for eligible projects may be used for organization of financial records and benchmarking, creation of strategic business plans, design of new or remodeled production facilities, development or updates of Comprehensive Nutrient Management Plans (CNMPs) and design of Best Management Practice Systems (BMPs) identified in the farm CNMP.

Basic program eligibility:

- Must be a dairy cattle farm shipping milk (heifer farms can apply for planning funds).
- Must have complete financial records for business planning.
- Must have a current CNMP if applying for funds to design BMPs.
- Preference is given to farms with under 300 cows, but funds to support BMP System designs are available for farms up to 700 cows.

For more information see http://prodairy.cals.cornell.edu/dairy-acceleration and contact: Caroline Potter, PRO-DAIRY (315)-683-9268 or dap@cornell.edu

NYS Agricultural Nonpoint Source Abatement & Control Grant Program (AgNPS) assists farmers in preventing water pollution from agricultural activities by providing technical assistance and financial incentives. County Soil & Water Conservation Districts apply for the competitive grants on behalf of farmers and coordinate funded conservation projects. Grants can cost-share up to 75% of project costs or more if farmers contribute in the following two areas:

1. Planning- funds awarded to conduct environmental planning
2. Implementation- funds awarded to construct or apply management practices

The New York State Soil & Water Conservation Committee and the Department of Agriculture & Markets coordinate the statewide program and award funds provided by the NYS Environmental Protection Fund on an annual basis.

See www.nys-soilandwater.org/aem/nonpoint.html and contact your local SWCD

NYS Climate Resilient Farming Program (CRF) provides competitive funding to help farmers reduce the impact of agriculture on climate change (mitigation) and increase the resiliency of New York State farms in the face of a changing climate (adaptation). The CRF Program is administered similarly to the NYS AgNPS Program, in that funds are from the Environmental Protection Fund, are administered by NYS Department of Agriculture & Markets and the NYS Soil and Water Conservation Committee, and are sponsored locally by Soil and Water Conservation Districts.

See www.nys-soilandwater.org/programs/crf.html and contact your local SWCD.

The **Environmental Quality Incentives Program** (EQIP available in every state) is a voluntary conservation program that helps agricultural producers in a manner that promotes agricultural production and environmental quality as compatible goals. Through EQIP, agricultural producers receive financial and technical assistance to implement structural and BMPs that optimize environmental benefits on working agricultural land. Incentives and priorities vary depending on location. You can sign up anytime. For information contact your local NRCS office or visit: www.nrcs.usda.gov/wps/portal/nrcs/main/ny/programs/financial/eqip/.

NYSERDA has had support for qualifying anaerobic digestion systems in the past. New ones may be available at: www.nyserda.ny.gov/Funding-Opportunities/Current-Funding-Opportunities

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), and 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 in 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 & Tools

- PRO-DAIRY Covered Manure Storage Cost Calculator: http://www.manuremanagement.cornell.edu/Pages/Assessment_Tools/Covered_Storage_Calculator.html
- Covers for Long-Term Dairy Manure Storages Part 1: Odor Control and More http://www.manuremanagement.cornell.edu/Pages/General_Docs/Fact_Sheets/A_Covers_Factsheet_1_updated_11_2005.pdf
- Covers for Long-Term Dairy Manure Storages Part 2: Estimating Your Farm's Annual Cost and Benefit http://www.manuremanagement.cornell.edu/ .
- Dairy Gas Emissions Model: http://www.ars.usda.gov/Main/docs.htm?docid=21345
- NRCS Standards: Anaerobic Digester Controlled Temperature Standard NY366 Manure Storage Facilities NY313, Roofs and Covers NY367, Waste Separation Facility NY632. https://efotg.sc.egov.usda.gov/
- Manure and Fertilizer Storage: http://www.nys-soilandwater.org/aem/techtools.html
- Anaerobic Digesters and Biogas Safety: http://articles.extension.org/pages/30311/anaerobic-digesters-and-biogas-safety .

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

References

Covers for Long-Term Dairy Manure Storages Part 2: Estimating Your Farm's Annual Cost and Benefit Updated Nov. 2015 Dairy Environmental Systems Program http://www.manuremanagement.cornell.edu/ .

Intergovernmental Panel on Climate Change (IPPC) Tier 2 method from the 2006 IPCC Guidelines for National GHG Inventories, Volume 4, Chapter 10.

Jayasundara, S., J.A.D. R.N. Appuhamy, E. Kebreab, and C. Wagner-Riddle. 2016. Methane and nitrous oxide emissions from Canadian dairy farms and mitigation options: An updated review, Canadian Journal of Animal Science. 96:306-331.

Livestock and Poultry Environmental Stewardship Curriculum Lessons Chapter 43 Emission Control Strategies for Manure Storage Facilities by Larry Jacobson, University of Minnesota; Jeff Lorimor, Iowa State University; Jose Bicudo, University of Kentucky; and David Schmidt, University of Minnesota http://articles.extension.org/pages/8964/livestock-and-poultry-environmental-stewardship-curriculum-lessons

Manure Storage Covers Curriculum Materials http://articles.extension.org/pages/61433/manure-storage-covers-curriculum-materials

Quantifying GHG fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory USDA Technical Bulletin 1939 7/2014.

Shephard, T., C.A. Gooch, & K.J. Czymmek. 2015. Covers for Long-Term Dairy Manure Storages Part 1: Odor Control and More. http://www.manuremanagement.cornell.edu/Pages/General_Docs/Fact_Sheets/A_Covers_Factsheet_1_updated_11_2005.pdf

Shephard, T., C.A. Gooch, K.J. Czymmek, Karszes, J., 2015. Covers for Long-Term Dairy Manure Storages Part 2: Estimating Your Farm's Annual Cost and Benefit. www.manuremanagement.cornell.edu

Westenbroek, P.A. & J. Martin. 2012. Anaerobic Digesters and Biogas Safety. http://articles.extension.org/pages/30311/anaerobic-digesters-and-biogas-safety .

Wightman, J.W., P.B. Woodbury. 2016. New York Dairy Manure Management Greenhouse Gas Emissions and Mitigation Costs (1992-2022). J. Environ. Qual. 45:266-275. doi:10.2134/jeq2014.06.0269

Credits & Acknowledgments

Authors, Peter Wright, Curt Gooch, Jenifer Wightman, and Peter Woodbury

Contact Info pew2@cornell.edu, cag26@cornell.edu, jw93@cornell.edu, pbw1@cornell.edu

Date: Last updated 2017

Funders: This work was supported in part by the USDA National Institute of Food & Agriculture Project Hatch Project 223995 and 1004302, PRO-DAIRY program, and by the NYS Soil and Water Conservation Committee's Climate Resilient Farming program.

Collaborators: Cornell Institute for Climate Change and Agriculture (D. Grantham) and NYS Department of Agriculture & Markets (G. Spitzer, G. Albrecht, B. Steinmuller).

This and other Info Sheets available at: http://blogs.cornell.edu/woodbury/