Swine Manure Storage Covers and Economic Tools to Determine the Payback Period

OVERVIEW:

Most manure from swine is stored in structures that are open to the atmosphere resulting in objectionable odor and gas emissions that have led to nuisance complaints and court actions (Miner 1997). While the U.S. Environmental Protection Agency (USEPA) attempts to define feasible air emission regulations for animal feeding operations, the U.S. Department of Agriculture (USDA) is assisting farmers by funding modified agricultural practices that mitigate air emissions.

In the case of open manure storage structures, aerobic conditions are usually present within the upper few feet and anaerobic conditions dominate in the bottom few feet of storage (MDEQ 2007). Under aerobic conditions, the main gasses produced are carbon dioxide (CO2) and ammonia (NH3) (Reddi 2005). Emissions produced under anaerobic conditions include methane (CH4), volatile organic compounds (VOC), and CO2, with trace amounts of hydrogen sulfide (H2S) and other gasses (USEPA 2001).

Eliminating or reducing gas emissions to open manure storage structures is possible by installation of a cover (Figure 1). An extensive literature review found little information on the cost and comprehensive benefits of installing a manure storage structure cover. This bulletin provides the tools to estimate the economic feasibility of installing a cover, including estimating the savings resulting from reducing nitrogen (N) losses and excluding precipitation. Cover alternatives, capital and maintenance costs, and grant opportunities are also discussed.

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Benefits of Installing a Cover

Potential economic advantages of covering manure storage structures include cost savings from nitrogen retention, precipitation exclusion, biogas production and management, and carbon credits from transforming CH4 to CO2. Environmental benefits include reduction of odor and greenhouse gas emissions and destruction of disease causing microorganisms. Each advantage is discussed in the subsections below.

Nitrogen Retention

The anaerobic conditions of open slurry storage structures result in the loss of nitrogen through NH3 volatilization. This volatilization is very sensitive to the manure slurry pH. Minimal losses are observed with a pH below 6 but rise rapidly with values that exceed 8 (Muck and Steenhuis 1982). Manure pH and slurry pH vary widely and are dependent on the animal's diet (Applegate et al. 2008). Environmental factors that influence NH3 emissions include ambient temperature, wind velocity, and solar radiation (Sommer 1997).

Ammonia (82% nitrogen) is the main source of nitrogen in several types of commercial fertilizers, therefore, it is financially beneficial to prevent its volatilization during storage to maximize the concentration applied to crops. The nitrogen fertilizer market directly correlates to the natural gas market because it is the main input in producing NH3 (USDA 2007). Maximizing NH3 retention also reduces environmental acidification and precipitation deposition that damages ecosystems by causing increased nutrient loading (Petersen et al. 1998).

Figure 1. Example of Covered Lagoon (USEPA 2010)

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Precipitation Exclusion

A manure storage structure cover excludes precipitation and prevents evaporation. Therefore, the volume of liquid in a covered manure storage structure is less than the amount in an uncovered structure if the amount of precipitation is greater than the water loss from the slurry due to evaporation. Decrease in slurry volume due to the exclusion of precipitation results in an increase in the slurry nitrogen concentration and a decrease in labor and diesel fuel consumption when land applying the slurry. With a decrease in equipment use, maintenance costs decrease and life expectancy of the equipment increases. .

Odor Reduction

As the population in rural regions increases, odors from manure storage are becoming a common reason for nuisance complaints. Odors intensify during agitation and pumping of the slurry prior to spreading and under windy weather conditions (Nicolai et al. 2007). A covered storage structure produces less odors as wind no longer passes over the surface of the slurry and, when equipped with a flare to combust the biogas, further reduces objectionable odors and harmful gases such as VOCs, H2S, volatile fatty acids, and NH3 (Bicudo et al. 2004 USEPA 2006).

Biogas Treatment

Biogas produced by anaerobic microorganisms in manure storage structures contains CH4, CO2, and trace amounts of other compounds including H2S. Methane is a greenhouse gas which has 21-23 times more heat trapping capacity than CO2 (USEPA 2006 USDA-NRCS 2007). A net reduction of greenhouse gases results when the biogas is collected and either flared or used for energy because of the conversion of CH4 to CO2 (USDA-NRCS 2007). Destroying CH4 that would have escaped into the atmosphere has value through the carbon credit market. The US does not have a carbon cap and trade program like some other countries, however, several organizations have voluntarily established goals and purchase credits if such goals are not met. Carbon credits are sold on a private exchange and independent verification of the amount of CH4 destroyed by a new practice is required to be eligible to participate.

A covered manure storage structure that maintains an optimized temperature for anaerobic digestion is a digester. The lowest optimal digestion temperature is 95ºF (35oC) (mesophilic conditions). The biogas typically has a CH4 concentration of 60 – 70% and, thus, can be used for the production of heat or electricity (USDA-NRCS 2007). Digesters can be operated without supplemental heat in warmer climates but not in cooler regions where the average ambient temperature is substantially below 95ºF. If the storage structure is not heated in such regions, the quantity of biogas is insufficient for energy use (Miner et al. 2000) and the gas is typically flared or vented to the atmosphere.

Operating a covered manure storage structure as a digester at mesophilic anaerobic temperatures also has several health and environmental advantages such as the destruction of up to 90% of disease causing microorganisms (Miner et al. 2000). Anaerobic conditions also reduce chemical oxygen demand (COD) and volatile solids (VS), a measure of the potential for organic wastes to reduce dissolved oxygen in natural waters (USEPA 2006). Consequently, the land application of digested manure is less likely to have a negative environmental impact.

The conversion of manure to biogas is very dependent on the nature of the manure and the environment and often treatability testing is required to determine the potential that can be produced. The process also requires a substantial investment and specialized training. Consequently, including this information was beyond the scope of this screening tool.

Cover Types & Designs

Covers for manure storage structures are available from numerous sources and vary in permeability, construction material, cost, and lifespan. Details are provided below.

Permeability

Manure storage structure covers are classified as permeable or impermeable. Permeable covers allow gases and precipitation to pass through while impermeable covers do not. The most common permeable covers are floating covers made of straw, geotextiles or naturally forming crust (Bicudo, et al. 2004).

Impermeable covers are fastened to the edge of the storage structure and can rest on top of the slurry surface using floats or can be inflated, providing headspace between the slurry and the cover. Because gases produced under the covers are very corrosive, it is best to install one with a low profile and minimal headspace. Also, when resting on the slurry, volatilization and odors are minimized. However, the biogas that accumulates under the cover must still be removed to prevent explosions. Exhaust fans or gas collection and vent pipes are installed for this purpose. Professional installation is imperative. Impermeable covers do not allow precipitation to penetrate the cover so a system to collect and remove water from the cover surface is required. Precipitation can be removed through a series of perforated collection pipes or trenches created in the cover material and the installation of a sump pump (Bicudo et al. 2004).

Construction Materials

Permeable covers are typically constructed from biological material such as straw, a naturally forming crust on the slurry, or from geotextiles. Covers from biological material, also called biocovers, are the least expensive type to install but are also the least effective in controlling emissions and have the shortest life span. For example a cover of 8 to 12 inches of straw will last only 2 to 6 months depending on weather conditions, depth of application, and uniformity of application. This type of cover is estimated to reduce ammonia emissions by 60% to 90%. Odors are reduced by

90% when the cover is new, but decline to 40% or less over time. H2S emissions are reduced by 70% using straw (Nicolai et al. 2004). Applying a biocover to a structure over 2 acres in size is difficult. Consequently, geotextiles are not recommended for larger structures (Zhao et al. 2008). Natural crusts do not form on all swine slurries however, when one is formed it will be permeable (Bicudo et al. 2004). Fibrous materials in the manure contribute to the formation of a crust, and the presence of these crusts is a function of animal diet and bedding material (Zhao et al. 2008). The slurry in a storage structure can be agitated or pumped with a biocover in place but, if the cover is composed of an organic material added to the surface of the slurry as opposed to a naturally forming crust, the carbon and nutrient content of the slurry will be increased.

Geotextiles used for permeable covers are a cloth-like material made of synthetic components. These covers are anchored to the sides of the storage structure. Geotextile covers are more expensive than biocovers, $0.35 to $1.75 per square foot installed compared to $0.03 per square foot for covers that are mechanically blown onto the surface. The lifespan of geotextile covers 3 to 10 years (Shepherd et al. 2008). This lifespan is lower if the geotextile is not UV protected (Bicudo et al. 2004). A portion of the cover must be removed to agitate or pump the contents of the storage structure and it is still not possible to agitate the contents as vigorously as when there is no cover (Nicolai et al. 2004).

Impermeable covers are complex and expensive compared to permeable covers. Such covers are not designed to be removed and, therefore, must have access points for agitation and pumping. The lifespan of impermeable covers is up to 20 years and their cost is $1.50 to $3.00 per square foot installed (Shepherd et al. 2008). Impermeable covers may be constructed of concrete, wood, or inflatable or floating plastic. Most impermeable covers are constructed of UV stabilized high density polyethylene (HDPE) with a minimum thickness of 20 mil (Nicolai et al. 2004). These covers reduce NH3, odors, and H2S emissions by approximately 95% (Bicudo et al. 2004).

Mechanical Cover Failures

Cover failures occur over time with strain and age of material. Malfunction of geotextile covers are commonly caused from a puncture or crack propagation in an area of high strain (Singbeil 2007). Crack propagation is likely to occur when the flexibility, due to plasticizers in the material, of the membrane is reduced. As the polymer ages, the plasticizer migrates from the geotextile into substances in contact with the membrane and volatilizes when exposed to air. Plasticizer rate loss is a function of the temperature and the polymer it is amended in (Exxon Mobil Corporation 2002).

Covers must be inspected for damage frequently so that small problems can be fixed before turning into large problems that will ultimately lead to the failure of the cover. If a puncture or crack does occur, great care must be taken in repairing as methane that has likely accumulated over the cover is very explosive.

Cover Operation and Maintenance

Manure storage covers require very little operation and maintenance. The only major operation entails water removal. With precipitation, rain water will accumulate. This water must be removed, typically by a float operated sump pump. Care in discharging this water from the pump must be taken as not to cause erosion or localized flooding. Such pumps typically operate based on a float value located in the low point of the cover. No labor is routinely required. Maintenance includes inspections of the water evacuation systems as well as examining the general condition of the cover and vents. If gas collection is practiced, including flaring or energy production, operations and maintenance become very significant and require very specialized safety training.

Economic Tool

An economic screening tool has been developed to aid in evaluating the economic feasibility of installing a manure storage structure cover and typical savings from installing a cover. This tool evaluates the impact of each of the following on the simple payback period, an estimate of the number of years of annual savings needed to pay back capital and operational expenditures.

Each step of the tool is described in the subsections below. A worksheet is then provided to organize and illustrate the calculation of the simple payback period. The payback period is an estimate to enable a decision on the practicality of further consideration of a cover, but should not be sole resource used in making a decision based on economics and other factors.

Net Water Exclusion

If precipitation exceeds evaporation for a given storage period, the increased volume of water results in a reduced slurry nitrogen concentration and increased hauling and spreading costs. A permeable cover eliminates these costs which can be calculated by subtracting the evaporation from the precipitation, as discussed below. .

Precipitation

Annual average precipitation data for numerous weather stations throughout the country is available on the National Climatic Data Center website maintained by the National Oceanic and Atmospheric Administration (NOAA 2008). State and regional data tables and maps of average monthly and annual precipitation are also commonly available. In Michigan, the Michigan State Climatologist's Office (http://climate.geo.msu.edu/index.html) tracks historical data for several weather stations throughout the State.

Evaporation

Evaporation from a free water surface is controlled by the water and air temperatures, solar radiation, the difference between the overlying air and water surface vapor pressures, the wind speed across the surface, and proximity to mountains and large water bodies. For the US, on average, 70% of the precipitation is returned to the atmosphere through evaporation, however this value varies widely based on the before mentioned factors (Bedient and Huber 2002). The water budget, energy budget, and mass transfer methods are the most common evaporation estimation techniques. Each method requires extensive data and analysis. Rough estimates of free water surface evaporation are also made using pan evaporation measurements, which must be adjusted to reflect heat and radiation effects of the pan. The National Weather Service published a map of Annual Free Water Surface Evaporation (Shallow Lake) estimates using pan evaporation measurements during May through October for the period of 1956-1970, Figure 2 (Farnsworth et al. 1982).

Estimating water exclusion on an annual basis in the calculation for water exclusion may result in less water being excluded than actual and, consequently, a reduced economic advantage for installing the cover. This results because manure is typically hauled twice annually, in late spring and early fall, and little evaporation results during the colder weather. During the summer between hauling, the evaporation potential is maximized because of higher temperatures but precipitation is less. Consequently, most of the precipitation and the least amount of precipitation occur at the same time maximizing the amount of water that must be hauled in spring. However, to simplify the analyses, an annual basis is used, which likely results in a longer payback period, or a more conservative estimate of potential savings.

Ammonia Emissions

Retention of ammonia in manure that is then applied at agronomic rates to fertilize crops offsets the purchase of fertilizer. The more ammonia retained within the manure storage structure by preventing emissions, the larger the offset and the smaller the environmental impacts. Determining the potential emissions reduction from the installation of a cover is complex, as discussed below.

Ammonia emission factors from animal feeding operations depend on climate, animal categories, and operational practices (NRC 2003). In 2003, the NRC released a report containing a mass-transfer model to estimate ammonia emissions. However, its use is limited because of the difficulty in determining several needed parameters.

There are numerous references that relate measured ammonia emissions to swine producers. The method of measurement and units vary greatly. Table 1 contains values that can be used to estimate ammonia lost as emissions normalized to the lagoon surface area or animal unit.

One approach to estimate the amount of ammonia retained by covering a manure storage structure is to select the value from Table 1 that best matches conditions on the site-specific farm. However, much variation is observed, which is especially apparent from Arogo et al. 2003. Time periods during which measurements were made and manure stored also varied greatly. Further, NH3 will still escape even from a covered manure storage structure. Bicudo, 2004, reported measured ammonia emissions from multiple structures over multiple years from earthen basins with and without a floating geotextile cover during early spring to mid fall in a climate similar to Michigan. Conservatively, average values with and without the cover were 1.64 and 5.41 g NH3-N/m2/day, respectively. The resulting difference during the approximately 6-month (183 day) period was 3.77 g NH3-N/m2/day (7.71 x 10-4 lb NH3-N/ft2/day). Additionally, by using the value discussed above, the complication of accounting for nitrogen loss during agitation of the manure in the storage structure is minimized as it is assumed that this loss is similar with and without the use of a cover.

Another consideration is the volatility of the nitrogen once applied to the field. Any gains in retaining nitrogen in a storage structure can be lost if not properly applied to the field. If the slurry is simply surface land applied the loss can be over 45%, as compared to less than 5% with a mouldboard plough (Jokela and Meisinger 2011). Consequently, incorporation of the manure slurry into the soil is critical to maximize the benefits of the manure. Guidelines on the best application procedures for site-specific conditions should be strictly followed.

Capital and Operational Costs

To find the capital costs associated with the purchase and installation of a cover, multiple site-specific, comprehensive quotes are needed from vendors for each cover alternative. Costs will depend on the cover style, projected durability of the selected geotextile, expected life, installation technique, and warranty. Quotes can also vary substantially from vender to vender and with time, and quotes may depend on the location of the job, current work load, and agreements with suppliers. Because geotextiles are manufactured from fossil fuels, material prices are highly variable over extended time periods. The cost for a system to remove water from a floating cover must be included, as well as the fan used to create a vacuum for a negative pressure cover when appropriate.

Operational costs include labor for the examination and maintenance of the cover and operation of a pump and blower, if applicable. Costs for the examination and maintenance of the cover are assumed to be low. The primary cost for the sump pump and fan is electricity. To determine this cost, the energy requirements for the pump, its pumping rate given the head loss, and the amount of water that must be removed is considered. A similar approach is used if a fan is required for a negative pressure cover, however, since this type of cover is less common it is not considered in this screening tool.

Grants

Funding received from local, state, and/or federal agencies can offset some of the initial costs of installing a manure storage cover (Table 2). An additional resource published by USEPA (2004) provides information on state and federal resources for farm biogas recovery systems.

Table 1: Summary of Ammonia Volatilization Studies from Uncovered Storage Structures

Location	Manure Storage	Reference
North Carolina	Chamber Method: 1.99 kg NH_3-N/AU/year Micrometeorology Method: 0.87 kg NH_3-N/AU/year	Doorn et al. 2002
Southeastern North Carolina	Average of Manure Storage Structures from 11 Farms • Warm Season: 2.225 g NH_3-N/m^2/day • Cold Season: 0.775 g NH_3-N /m^2/day	Bajwa et al. 2006
Southwestern Minnesota	Multiple Earthen Basins (Nursery and Finishing): 5.41 to 7.40 g NH_3-N/m^2/day	Bicudo et al. 2004
Western Oregon	Raw Storage: 10.33 g NH_3-N/m^2/day	Miner et al. 2003
Southwestern Minnesota	Earthen Basins • Crusted Pit: 8.71 g NH_3-N/m^2/day • Non-Crusted Pit: 10.74 g NH_3-N/m^2/day	Bicudo et al. 2001
Minnesota	• Nursery Earthen Basin Single Cell: 10.32 g NH_3-N/m^2/day • Finishing Earthen Basin Single Cell: 7.83 g NH_3-N/m^2/day • Finishing Earthen Basin Second Cell: 4.53 g NH_3-N/m^2/day • Finishing Concrete Tank: 28,60 g NH_3-N/m^2/day • Finishing Manure Pack: 39.21 g NH_3-N/m^2/day	Gay et al. 2003
Denmark	Crusted Storage Tank: 4.25 g NH_3-N/m^2/day	Sommer et al. 1993
France	Raw Storage: 5.4 g NH_3-N /m^2/day	Loyon et al. 2007
Poland	Solid Manure Heap on Concrete Pad: 15.9 g N/day/LU	Ferm et al. 2005
North Carolina, Illinois, Indiana, Georgia, Missouri	Compilation, in Table Format, from Numerous Authors, Collection Techniques, and Time Periods: 0.03 – 19.9 g NH_3-N /m^2/day	Arogo et al. 2003

Notes: AU: Animal Unit m2: Surface area of the Manure Storage Structure LU: 500 kg of Livestock

Table 2. Federal Funding Opportunities

Agency	Cost Share	Program Name	Requirements
USDA-NRCS	80%/20%	Environmental Quality Incentives Program (EQIP)	Installation of a Flexible Membrane Storage Cover
US Department of Energy	50%/50%	Regional Biomass Energy Program	Implementation of a Biogas Management System
Rural Business-Cooperative Service	N/A	Renewable Energy System and Energy Efficiency Improvements Program	Development of Renewable Energy Systems
USDA - Cooperative State Research, Education and Extension Service	N/A	Sustainable Agriculture Research and Education Program	Adoption of Sustainable Agricultural Practices to Improve Profits, Protect the Environment, and Enhance the Quality of Life

Source: USEPA AgSTAR Program (2008)

Cost Analyses

Table 3 provides a worksheet to estimate the potential simple payback period of a floating cover that does not require a negative pressure (installation and operation of a fan). Calculations are completed on an annual basis although this may result in inaccuracies as discussed in the Water Exclusion section. A biogas flare or energy recovery system is not considered although one can be added using the same analysis structure. However, this would significantly change the analyses because of the complexity of such systems. This table serves as a guide to enable the farmer to decide if further study is warranted and should not be the only tool used in such a decision. Table 4 is a case study using a small swine farm in Michigan. All prices are from 2008 and are site specific and, therefore, should not be used for other analyses.

Important to note is that Tables 3 and 4 do not account for all expenses such as labor costs and unexpected maintenance. An example is the repair of a tear or crack in the cover. Also not accounted for is the value of nuisance avoidance in regard to minimizing odors. Accounting for such cost/benefits is very difficult but the time and associated dollars can be significant.

Conclusion

Impermeable covers allow for a greater retention of ammonia and its associated value when land applied; reduce emissions of greenhouse gasses; and prevent the accumulation of precipitation, reducing the dilution of nutrients and the cost of hauling and land application. The result is the potential for a more sustainable and profitable farm.

The procedure to estimate the simple economic payback period described in this document offers a screening tool to determine the economics of installing a cover over a manure storage structure. However, this is only a screening tool to determine potential feasibility. If results are favorable, a more in depth analyses is needed including obtaining actual quotes to purchase and install a cover and an assessment of the life and maintenance requirements of the entire system. Beneficial CH4 gas management is not considered in this screening tool because of its complexity, specialized operational requirements, and very site-specific required design specification. However, substantial benefits can be realized if the CH4 is destroyed by flaring or used as a renewable energy source. If the installation of such a system is of interest an abundance of guidance is available. The USEPA AgStar website (http://www.epa.gov/agstar/) offers a good starting point. Also, consulting with Extension educators is recommended as well as specialized manure testing at laboratories such as the MSU Anaerobic Digestion Research and Education Center (http://researchgroups.msu.edu/adrec).

Table 3. Simple Payback Period Worksheet

Category	Item	Line Letter	Component	Unit	Operation & Comments
		A	Annual Precipitation	Inches/year	
		B	Annual Evaporation	Inches/year	Use Federal and State Weather Data
		C	Net Annual Precipitation	Inches/year	A – B (0 if negative)
		D	Storage Structure Surface Area	ft^2	Farm Specific
		E	Annual Net Rain Water Volume	ft^3	C * ft/12 inches * D
		F	Annual Net Rain Water Volume	Gallons/year	E * 7.48 gallons/ft^3
	Water Exclusion[1]	G	Annual Cost to Haul Slurry from Storage Structure	$/gallon	Based on Farm Specific Estimate
		H	Cost Savings From Reduced Water Volume	$/year	F * G
		I	Emissions Retained by Cover	lb NH_3-N/ft^2/day	See Table 1 and Associated Discussion[2]
		J	Annual NH_3-N Amount Saved[2]	lb NH_3-N/year	I * 183 days of emissions/ year * D
		K	Nitrogen Cost	$/lb NH_3-N/year	Based on Cost of Commercial Fertilizers
		L	Nitrogen Lost During Application	%	Based on Incorporation Method
	NH_3 Savings	M	Annual Cost Savings from Offsetting Fertilizer Purchase	$/year	J * K *(100-L)/100
Annual Savings	Annual Savings	N		$/year	H + M
		O	Annual Precipitation on Cover	Gallons/year	A * ft/12 inches * D * 7.48 gallons/ft^3
		P	Pump Rating	hp	
		Q	Pumping Rate	gallons/hour	Based on Pump Curve and Head Loss
		R	Time Pump Operates Annually[3]	hour/year	O/Q
		S	Annual Power to Operate Pump	KWh/year	P* R *0.75 Loaded Efficiency * 0.75 kW/hp/0.90 Motor Efficiency
		T	Electricity Cost	$/kWh	Based on Farm Specific Estimate
	Cover Dewatering Pump	U	Annual Pump Electricity Cost	$/year	S * T
Annual Cost[4]	Annual Costs	V		$/year	U
	Cover	W	Cover, Peripheral, and Installation	$	
	Cover Dewatering Pump	X	Pump, Motor, Associated Electrical Equipment, and Installation	$	Obtain Vender Estimates
	Plumbing Associated w/Dewatering Pump	Y	Pipes, Fittings, Discharge Structure, and Installation	$	Supplies (Pipes, Fittings, and Discharge Structure), Installation
	Grant	Z		$	See Table 2
Capital Costs	Capital Costs	AA		$	W + X + Y – Z
	Annual Savings	BB		$/year	N – V (If Negative, 0 Savings and Investment Never Pays for Itself)
Simple Pay Back Period[5]	Pay Back Period			Years	AA / BB

1Cost savings associated with a decrease in hauling supplemental fertilizer to acres where slurry was applied because the increased slurry NH3 level is not considered.

2Careful consideration of the time period manure is stored and/or the measurements were made is required. Values reported in the literature often assume no emissions in the winter.

3Assumes water is pumped from cover before any evaporates.

4Time associated with maintaining the cover and is assumed to be negligible.

5Time value of money and life expectancy of the equipment are not incorporated.

Table 4. Example Estimate for Payback Period for Installing a Manure Storage Cover

Category	Item	Line Letter	Component	Amount	Operation and Comments
		A	Annual Precipitation	36 inches/year	MSU Climate (geo.msu.edu/index.html)
		B	Annual Evaporation	33 inches/year	Figure 2
		C	Net Annual Precipitation	3 inches/year	A – B (0 if negative)
		D	Storage Structure Surface Area	22,500 ft^2	Farm Specific
		E	Annual Net Rain Water Volume	5,625 ft^3	C * ft/12 inches * D
		F	Annual Net Rain Water Volume	42,075 gallons/year	E * 7.48 gallons/ft^3
		G	Annual Cost to Haul Slurry from Storage Structure	$0.098/gallon/ Year	Farm Specific
	Water Exclusion[1]	H	Annual Cost Savings from Reduced Rain Hauling	$4123/year	F * G
		I	Emissions Retained by Cover	7.71 x 10[illegible] lb NH_3-N/ft^2/day	(Bicudo et al. 2004 and Discussion in Text)
		J	Annual NH_3-N Amount Saved[2]	3,175 lb NH_3-N/year	I *183 days of emissions/year * D
		K	Nitrogen Cost	$0.23/lb N/year	Based on Cost of Commercial Fertilizers
		L	Nitrogen Lost During Application	50%	Based on Incorporation Method
	NH_3 Savings	M	Annual Cost Savings from Offset Fertilizer Purchase	$365/year	J * K * (100-L)/100
Annual Savings	Annual Savings	N		$4488/year	H + M
		O	Annual Precipitation on Cover	Gallons/year	A * ft/12 inches * D * 7.48 gallons/ft^3
		P	Pump Rating	1 hp	Farm Specific
		Q	Pumping Rate	4,740 gallons/hour	Pump - Drainage System Specific
		R	Time Pump Operates Annually[3]	107 hour/year	O/Q
		S	Annual Power to Operate Pump	67 KWh/year	P * R * 0.75 Loaded Efficiency * 0.75 kW/hp / 0.90 Motor Efficiency
		T	Electricity Cost	$.09/kWh	Farm Specific
	Cover Dewatering Pump	U	Annual Pump Electricity Cost	$6.00/year	S * T
Annual Cost[4]	Annual Costs	V		$6.00/year	U
	Cover	W	Cover, Peripheral, and Installation	$69,800	Impermeable Membrane by Vender Estimate
	Cover Dewatering Pump	X	Pump, Motor, Associated Electrical Equipment, and Installation	$360	1 hp with Capacity Pump Rated at of 79 gpm (4,740 galllons/hours)
	Plumbing Associated w/Dewatering Pump	Y	Pipes, Fittings, Discharge Structure, and Installation	$1,400	Farm Specific
	Grant	Z		$0	Farm Specific (Table 2)
Capital Costs	Capital Costs	AA		$71,560	W + X + Y – Z
	Annual Savings	BB		$4,482/year	N – V (If Negative, 0 Savings and Investment, Never Pays for Itself)
Simple Pay Back Period[5]	**Pay Back Period**			**16 years**	**AA/BB**

1Cost savings associated with a decrease in hauling supplemental fertilizer to acres where slurry was applied because of increased slurry NH3 level is not considered.

2Careful consideration of the time period manure is stored and/or the measurements were made is required. Values reported in the literature often assume no emissions in the winter.

3 Assumes water is pumped from cover before any evaporates.

4Time associated with maintaining the cover and is assumed to be negligible.

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REFERENCES:

Applegate, T.J, B. Richert, A. Sutton, W. Powers, R. Angel. 2008. Diet and Feed Management Practices Affect Air Quality from Poultry and Swine Operations. Livestock & Poultry Environmental Learning Center Fact Sheet. Available at: http://www.puyallup.wsu.edu/dairy/nutrient-management/default.asp. Accessed February 9, 2010.

Arogo, J., P.W. Westerman, A.J. Heber. 2003. A Review of Ammonia Emissions from Confined Swine Feeding Operations. Transactions of the ASAE. 46(3): 805-817.

Bajwa, K.S., V.P. Aneja, and S.P. Arya. 2006. Measurement and Estimation of Ammonia Emissions from Lagoon-Atmosphere Interface using a Coupled Mass Transfer and Chemical Reactions Model, and an Equilibrium Model. Atmospheric Environment. 40(2): 275-286.

Bedient, P.B, and W.C. Huber. 2002. Hydrology and Floodplain Analysis. Third Ed. Prentice-Hall, Inc., NJ

ISBN 0-13-032222-9.

Bicudo, J.R., D.R. Schmidt, C.L. Tengman, W. Powers, L.D. Jacobson, C.J. Clanton. 2001. Odor and Gas Emissions from a Naturally Crusted Swine Manure Storage. 2001 ASAE Annual International Meeting. July 30 – August 1, 2001, Sacramento, CA.

Bicudo, J.R., D.R Schmidt, and L.D. Jacobson. 2004. Using Covers to Minimize Odor and Gas Emissions from Manure Storages. University of Kentucky-College of Agriculture, Cooperative Extension Service. Available at: http://www.ca.uky.edu/agc/pubs/aen/aen84/aen84.pdf. Accessed October 10, 2008.

Chicago Climate Exchange. 2004. Chapter 9 CCX Exchange Offsets and Exchange Early Action Credits. Available at: www.chicagoclimatex.com/docs/offsets/CCX_Rulebook_Chapter09_OffsetsAndEarlyActionCredits.pdf. Accessed February 2008.

Chicago Climate Exchange. 2008. CCX Agricultural Methane Emission Offsets and Offsets From Renewable Energy. Available at: www.chicagoclimatex.com. Accessed September 17, 2008.

Doorn, M.R.J., D.F. Natschke, S.A. Thorneloe, J. Southerland. 2002. Development of an Emission Factor for Ammonia Emissions form US Swine Farms Based on Field Tests and Application of a Mass Balance Method. Atmospheric Environment. 36(36-37): 5619-5625.

Exxon Mobil Corporation. 2002. Polyethylene Performance Data: Toughness. Available at: www.exxonmobilpp.com/Public_Products/Polyethylene/Polyethylene/Worldwide/Techincal_Information/PerfData/PE_Tech_PerfData_Toughness.asp. Accessed February 26, 2007.

Farnsworth, R.K., E.L Peck, and E.S. Thompson. 1982. Evaporation Atlas for the Contiguous 48 United States, NOAA Technical Report NWS 33, U.S. Dept. of Commerce, Washington, D.C., 26.

Gay, S.W., D.R. Schmidt, C.J. Clanton, K.A. Janni, L.D. Jacobson, S. Weisberg. 2003. Odor, Total Reduced Sulfur, and Ammonia Emissions from Animal Housing Facilities and Manure Storage Units in Minnesota. Applied Engineering in Agriculture. 19(3): 347-360.

Ferm, M., T. Marcinkowski, M. Kieronczyk, S. Pietrzak. 2005. Measurements of Ammonia Emissions from Manure Storing and Spreading Stages in Polish Commercial Farms. Atmospheric Environment. 39(37): 7106-7113.

Joekela, W.E., J.J. Meisinger. 2011. Liquid Manure: Ammonia Loss and Nitrogen. http://www.farmwest.com/index.cfm?method=library.showPage&librarypageid=140. Accessed on August 5, 2011.

Loyon, L., F. Guiziou, F. Beline, P. Peu. 2007. Gaseous Emissions (NH3, N2O, CH4 and CO2) from the Aerobic Treatment of Piggery Slurry – Comparison with a Conventional Storage System. Biosystems Engineering. 97(4): 472-480.

MDEQ. 2007. Alternative Fuels Project Team Final Report. Available at. http://www.michigan.gov/documents/mda/MDA_ADFinalReport_189919_7.pdf. Accessed August 5, 2011.

Miner, J.R. 1997. Nuisance concerns and odor control. Journal of Dairy Science 80(10): 2667-2672.

Miner, J.R., F.J. Humenik, and M.R. Overcash. 2000. Managing Livestock Wastes to Preserve Environmental Quality. Iowa State University Press.

Miner, R.F. Humenik, J. Rice, M. Williams, W. Robarge, D. Rashash, B. Harris, and R. Sheffield. 2003. Evaluation of a Permeable, 5 cm Thick, Polyethylene Foam Lagoon Cover. ASABE. Vol. 46(5): 1421-1429.

Muck, R.E., and T.S. Steenhuis. 1982. Nitrogen Losses from Manure Storages. Agric. Wastes 4(1): 41–54.

Nicolai, R., S. Pohl, and D. Schmidt. 2004. Covers for Manure Storage Units. Available at: http://agbiopubs.sdstate.edu/articles/FS925-D.pdf. Accessed February 1, 2008.

Nicolai, D, D. Schmidt, L. Jacobson. 2007. Odor Rating Systems Estimates Setbacks. Available at: http://nationalhogfarmer.com/mag/farming_development_odorrating_model. Accessed February 9, 2010.

NRC (National Research Council). 2003. Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs. Appendix F: Ammonia Emissions from Manure Storages. Washington, D.C.: The National Academies Press.

NOAA. 2008. National Climatic Data Center. Available at: www.ncdc.noaa.gov/oa/climate/stationlocator.html. Accessed November 24, 2008.

Petersen, S.O., A.M. Lind, and S.G. Sommer. 1998. Nitrogen and Organic Matter Losses during Storage of Cattle and Pig Manure. Journal of Agricultural Science. 130(1): 69-79.

Reddi, N. (editor). 2005. Animal Waste Containment in Lagoons. American Society of Civil Engineers.

Shepherd, T.C., C. Gooch, K. Czymmek. 2008. Covers for Long-Term Dairy Manure Storages Part 1: Odor Control and More. Manure Management Progam. www.manuremanagement.cornell.edu.

Singbeil, A. 2007. Design Engineer, Environmental Containment. asingbeil@bioterre.com, 204-366-6632. Personal communication, February 13, 2007.

Sommer, S.G. B.T. Christensen, N.E. Nielsen, J.K. Schjorring. 1993. Ammonia Volatilization During Storage of Cattle and Pig Slurry: Effect of Surface Cover. Journal of Agricultural Science. 121(1): 63-71.

Sommer, S.G. 1997. Ammonia Volatilization from Farm Tanks Containing Anaerobically Digested Animal Slurry. Atmos. Environ. 31(6):863–868.

USDA. 2007. Impact of Rising Natural Gas Prices on U.S. Ammonia Supply. Available at: www.ers.usda.gov/publications/WRS0702/wrs0702.pdf. Accessed March 18, 2008.

USDA-NASS. 2009. National Agricultural Statistics Service. 2007 Livestock Statistics, Cattle, Hogs and Pigs. Available at: http://usda.mannlib.cornell.edu/MannUsda/viewTaxonomy.do?taxonomyID=16. Accessed February 9, 2010.

USDA-NRCS. 2007. Natural Resources Conservation Service. An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities. Technical Note No. 1. October 2007.

USEPA. 2001. Emissions from Animal Feeding Operations. Available at: www.epa.gov/ttn/chief/ap42/ch09/draft/draftanimalfeed.pdf. Accessed January 10, 2007.

USEPA. 2004. Funding On-Farm Biogas Recovery Systems: A Guide to Federal and State Resources. Available at: www.epa.gov/agstar/pdf/ag_fund_doc.pdf. Accessed January 10, 2007.

USEPA. 2006. Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems. Available at: www.epa.gov/agstar/pdf/biogas%20recovery%20systems_screenres.pdf. Accessed January 12, 2007.

USEPA. 2010. Anaerobic Digesters. Available at: http://www.epa.gov/agstar/anaerobic/ad101/anaerobic-digesters.html. Accessed March 4, 2011.

Zhao, L., J.N. Rausch and T.L. Combs. 2008. Overview of Odor Control for Manure Storage Facilities. The Ohio State University Extension Agriculture and Natural Resources Fact Sheet. AEX-738-08.

ACKNOWLEDGEMENTS:

This bulletin was prepared by Steven Safferman based on a senior design project conducted by Daniel Sparks, Terrelle L. Smolinski, and Sara J. Gerstacker, as part of their Biosystems Engineering degree, Michigan State University. Contact information for Steven Safferman follows: Michigan State University, Department of Biosystems and Agricultural Engineering, 212 Farrall Hall, East Lansing, MI 48824 Phone: 517-432-0812 email: safferma@msu.edu.

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